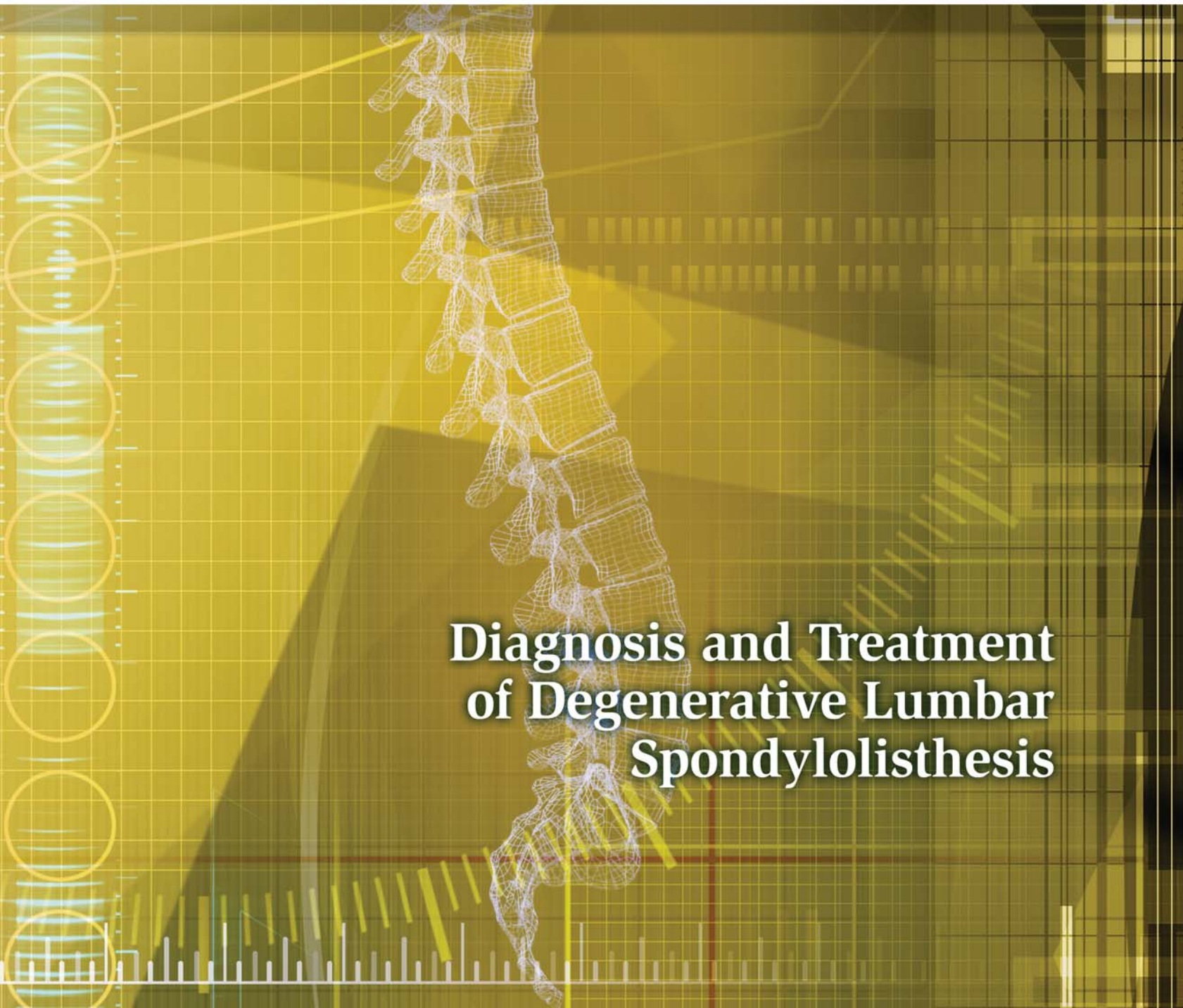
North American Spine Society

2014
Revised

Evidence-Based Clinical Guidelines for Multidisciplinary Spine Care



Diagnosis and Treatment of Degenerative Lumbar Spondylolisthesis

Evidence-Based Clinical Guidelines for Multidisciplinary Spine Care

Diagnosis and Treatment of Degenerative Lumbar Spondylolisthesis 2nd Edition

NASS Evidence-Based Clinical Guidelines Committee

Paul Matz, MD
Committee Co-Chair and Surgical Treatment Section Chair

R.J. Meagher, MD
Diagnosis/Imaging Section Chair

Tim Lamer, MD
Medical/Interventional Section Chair

William Tontz Jr, MD
Surgical Treatment and Value Section Chair

Thiru M. Annaswamy, MD
R. Carter Cassidy, MD
Charles H. Cho, MD, MBA
Paul Dougherty, DC

John E. Easa, MD
Dennis E. Enix, DC, MBA
Bryan A. Gunnoe, MD
Jack Jallo, MD, PhD, FACS

Terrence D. Julien, MD
Matthew B. Maserati, MD
Robert C. Nucci, MD
John E. O'Toole, MD, MS

Jonathan N. Sembrano, MD
Alan T. Villavicencio, MD
Jens-Peter Witt, MD

North American Spine Society
Clinical Guidelines for Multidisciplinary Spine Care
Diagnosis and Treatment of Degenerative Lumbar Spondylolisthesis

7075 Veterans Boulevard
Burr Ridge, IL 60527 USA
630.230.3600
www.spine.org

ISBN 1-929988-36-2

Financial Statement

This clinical guideline was developed and funded in its entirety by the North American Spine Society (NASS). All participating authors have disclosed potential conflicts of interest consistent with NASS' disclosure policy. Disclosures are listed below:

Paul G. Matz, Co-Chair:	Speaking and/or teaching arrangements: AO Spine North America (Financial, Honoraria for Faculty at AO Advance Concepts Courses and AO Aging Bone Symposium); Board of Directors: AO Spine North America Executive Committee (Nonfinancial, Remuneration for Travel to AONASEC meeting). (1/29/13)
Thiru M. Annaswamy:	Board of Directors: Association of Academic Physiatrists (AAP) (Nonfinancial, No remuneration. I am on the board of trustees of AAP); Grants: Innovative Neurotronics (Level D, Research Grant from Sponsor for INSTRIDE study on Foot drop in stroke), NSF (0, Subcontract award for research on developing a virtual reality based tele-rehabilitation system. PI: Dr. Prabhakaran, UT Dallas), Health & Human Services-Via University of Washington; BOLD-LESS study (Level C, Subcontract award for research on use of steroids in lumbar epidural steroid injections in lumbar spinal stenosis; the LESS study. PI: Dr. Friedly, U. of Washington, Seattle); Other: AAPMR (Nonfinancial, Committee Chair of the Evidence Committee at AAPMR). (1/31/13)
R. Carter Cassidy:	Relationships Outside the One Year Requirement: Synthes USA (Upcoming Committee Meeting [Evidence Based Guidelines Committee], 12/2010, Speaking and/or Teaching Arrangement, Level A). (1/30/13)
Charles H. Cho:	Other Office: American Society of Spine Radiology (Nonfinancial, Executive Committee (March 2012 - February 2013). (1/29/13)
Paul Dougherty:	Nothing to disclose. (1/29/13)
John E. Easa:	Stock Ownership: Janus Biotherapeutics (Level E, 3, Janus Biotherapeutics is an auto-immunity company, Paid directly to institution/employer). (1/29/13)
Dennis E. Enix:	Research Support (Investigator Salary): Logan College (Level D of my salary amount is paid from HRSA Chiropractic Demonstration Projects Grant number 1R18HP15125-01-00., Paid directly to institution/employer), Standard Process (Level C of my salary amount is paid from a grant from the Standard Process Company., Paid directly to institution/employer); Grants: HRSA (Level D of my salary amount is paid from HRSA Chiropractic Demonstration Projects Grant number 1R18HP15125-01-00., Paid directly to institution/employer). (1/31/13)
Bryan A. Gunnoe:	Nothing to disclose. (2/1/13)
Jack Jallo:	Nothing to disclose. (1/31/13)
Terrence D. Julien:	Consulting: Stryker Spine (Both, Consulting for product lines), Biomet Spine (Both, Consulting for product lines); Speaking and/or teaching arrangements: Stryker Spine (Both, Teach hands-on cadaveric and didactic lectures for MIS procedures), Globus Medical (Both, Teach hands-on cadaveric and didactic lectures for MIS procedures). (1/30/13)
Tim Lamer:	Board of Directors: American Academy of Pain Medicine (Nonfinancial). (2/1/13)
Matthew B. Maserati:	Nothing to disclose. (2/8/13)
R.J. Meagher:	Nothing to disclose. (1/29/13)
Robert C. Nucci:	Nothing to disclose. (1/30/13)
John E. O'Toole:	Royalties: Globus Medical Inc. (Level A); Consulting: Globus Medical Inc. (Level B), Pioneer Surgical (Level B). (1/9/13)
Jonathan N. Sembrano:	Board of Directors: Society of Lateral Access Surgeons (SOLAS) (Nonfinancial), Philippine Minnesota Medical Association (PMMA) (Nonfinancial), University of the Philippines Alumni of Minnesota (UPAM) (Nonfinancial); Research Support (Staff/Materials): NuVasive (0, Study site for a multicenter RCT of XLIF vs. MIS TLIF for degenerative spondylolisthesis. Approved January 2010. Enrollment just ended 12/31/12. Nine patients enrolled from our site. Patients will be followed for two years postop. Study sponsor compensates for study coordinator efforts, but not for the investigator, Paid directly to institution/employer). (1/31/13)
William L. Tontz, Jr.:	Stock Ownership: Phygen (1, 6, Physician owned implant company involved in development and distribution of spinal implants, Paid directly to institution/employer); Other Office: Board of Managers (Financial, Paid Level B dollars for board of manager term from 2009-2010). (1/31/13)
Alan T. Villavicencio:	Stock Ownership: Lanx (Level I, 2, Founder); Board of Directors: Justin Parker Neurological Institute (Nonfinancial, Not for profit); Other Office: Boulder Neurosurgical Associates, LLC (Nonfinancial, managing partner); Research Support (Investigator Salary): Profibrix, Medtronic (Level F, Paid directly to institution/employer). (2/5/13)
Jens-Peter Witt:	Relationships Outside the One Year Requirement: Aesculap (Upcoming Committee Meeting [Evidence-based Guideline Committee], 12/2008, Speaking and/or Teaching Arrangement). (2/1/13)

Range Key:

Level A. $100 to $1,000
Level B. $1,001 to $10,000
Level C. $10,001 to $25,000
Level D. $25,001 to $50,000
Level E. $50,001 to $100,000
Level F. $100,001 to $500,000
Level G. $500,001 to $1M
Level H. $1,000,001 to $2.5M
Level I. Greater than $2.5M

Comments

Comments regarding the guideline may be submitted to the North American Spine Society and will be considered in development of future revisions of the work.

Table of Contents

A technical report, including the literature search parameters and evidentiary tables developed by the authors, can be accessed at https://www.spine.org/Documents/ResearchClinicalCare/Guidelines/DegenerativeSpondylolisthesisTechReport.pdf

I. Introduction

Objective

The objective of the North American Spine Society (NASS) *Clinical Guideline for the Diagnosis and Treatment of Degenerative Lumbar Spondylolisthesis* is to provide evidence-based recommendations to address key clinical questions surrounding the diagnosis and treatment of degenerative lumbar spondylolisthesis. The guideline is intended to update the original guideline on this topic, published in 2008. This guideline is based upon a systematic review of the evidence and reflects contemporary treatment concepts for symptomatic degenerative lumbar spondylolisthesis as reflected in the highest quality clinical literature available on this subject as of May 2013. The goals of the guideline recommendations are to assist in delivering optimum, efficacious treatment and functional recovery from this spinal disorder.

Scope, Purpose and Intended User

This document was developed by the North American Spine Society Evidence-based Guideline Development Committee as an educational tool to assist practitioners who treat patients with degenerative lumbar spondylolisthesis. The goal is to provide a tool that assists practitioners in improving the quality and efficiency of care delivered to these patients. The NASS *Clinical Guideline for the Diagnosis and Treatment of Degenerative Lumbar Spondylolisthesis* provides a definition of this disorder, outlines a reasonable evaluation of patients suspected to have degenerative lumbar spondylolisthesis and outlines treatment options for adult patients with this diagnosis.

THIS GUIDELINE DOES NOT REPRESENT A "STANDARD OF CARE," nor is it intended as a fixed treatment protocol. It is anticipated that there will be patients who will require less or more treatment than the average. It is also acknowledged that in atypical cases, treatment falling outside this guideline will sometimes be necessary. This guideline should not be seen as prescribing the type, frequency or duration of intervention. Treatment should be based on the individual patient's need and doctor's professional judgment. This document is designed to function as a guideline and should not be used as the sole reason for denial of treatment and services. This guideline is not intended to expand or restrict a health care provider's scope of practice or to supersede applicable ethical standards or provisions of law.

Patient Population

The patient population for this guideline encompasses adults (18 years or older) with a chief complaint of low back pain and/or lower extremity symptoms related to spinal stenosis and degenerative lumbar spondylolisthesis. In general, the nature of the pain and associated patient characteristics (eg, age) are more typical of a diagnosis of spinal stenosis with degenerative lumbar spondylolisthesis than discogenic low back pain, lumbar sprain/strain, or mechanical low back pain with degenerative spondylolisthesis.

II. Guideline Development Methodology

Through objective evaluation of the evidence and transparency in the process of making recommendations, it is NASS' goal to develop evidence-based clinical practice guidelines for the diagnosis and treatment of adult patients with various spinal conditions. These guidelines are developed for educational purposes to assist practitioners in their clinical decision-making processes. It is anticipated that where evidence is very strong in support of recommendations, these recommendations will be operationalized into performance measures.

Multidisciplinary Collaboration

With the goal of ensuring the best possible care for adult patients suffering with spinal disorders, NASS is committed to multidisciplinary involvement in the process of guideline and performance measure development. To this end, NASS has ensured that representatives from both operative and non-operative, medical, interventional and surgical spine specialties have participated in the development and review of NASS guidelines. To ensure broad-based representation, NASS welcomes input from other societies and specialties.

Evidence Analysis Training of All NASS Guideline Developers

All Evidence-Based Guideline Development Committee Members have completed NASS' Fundamentals of Evidence-Based Medicine Training. Members have the option to attend a one-day course or complete training via an online program. In conjunction with Qwogo Inc., a University of Alberta affiliated enterprise, NASS offers an online training program geared toward educating guideline developers about evidence analysis and guideline development. All participants in guideline development for NASS have completed the live or online training prior to participating in the guideline development program at NASS. Both trainings include a series of readings and exercises, or interactivities, to prepare guideline developers for systematically evaluating literature and developing evidence-based guidelines. The live course takes approximately 8-9 hours to complete and the online course takes approximately 15-30 hours to complete. Participants are awarded CME credit upon completion of the course.

Disclosure of Potential Conflicts of Interest

All participants involved in guideline development have disclosed potential conflicts of interest to their colleagues in accordance with NASS' Disclosure Policy for committee members (https://www.spine.org/Documents/WhoWeAre/DisclosurePolicy.pdf) and their potential conflicts have been documented in this guideline. NASS does not restrict involvement in guidelines based on conflicts as long as members provide full disclosure. Individuals with a conflict relevant to the subject matter were asked to recuse themselves from deliberation. Participants have been asked to update their disclosures regularly throughout the guideline development process.

Levels of Evidence and Grades of Recommendation

NASS has adopted standardized levels of evidence *(Appendix B)* and grades of recommendation *(Appendix C)* to assist practitioners in easily understanding the strength of the evidence and recommendations within the guidelines. The levels of evidence range from Level I (high quality randomized controlled trial) to Level V (expert consensus). Grades of recommendation indicate the strength of the recommendations made in the guideline based on the quality of the literature.

Grades of Recommendation:

A: Good evidence (Level I studies with consistent findings) for or against recommending intervention.

B: Fair evidence (Level II or III studies with consistent findings) for or against recommending intervention.

C: Poor quality evidence (Level IV or V studies) for or against recommending intervention.

I: Insufficient or conflicting evidence not allowing a recommendation for or against intervention.

Levels of evidence have very specific criteria and are assigned to studies prior to developing recommendations. Recommendations are then graded based upon the level of evidence. To better understand how levels of evidence inform the grades of recommendation and the standard nomenclature used within the recommendations see Appendix D.

Guideline recommendations are written utilizing a standard language that indicates the strength of the recommendation. "A" recommendations indicate a test or intervention is "recommended"; "B" recommendations "suggest" a test or intervention and "C" recommendations indicate a test or intervention "may be considered" or "is an option." "I" or "Insufficient Evidence" statements clearly indicate that "there is insufficient evidence to make a recommendation for or against" a test or intervention. Work group consensus statements clearly state that "in the absence of reliable evidence, it is the work group's opinion that" a test or intervention may be appropriate.

The levels of evidence and grades of recommendation implemented in this guideline have also been adopted by the Journal of Bone and Joint Surgery, the American Academy of Orthopaedic Surgeons, Clinical Orthopaedics and Related Research, the journal Spine and the Pediatric Orthopaedic Society of North America.

In evaluating studies as to levels of evidence for this guideline, the study design was interpreted as establishing only a potential level of evidence. As an example, a therapeutic study designed as a randomized controlled trial would be considered a potential Level I study. The study would then be further analyzed as to how well the study design was implemented and significant shortcomings in the execution of the study would be used to downgrade the levels of evidence for the study's conclusions. In the example cited previously, reasons to downgrade the results of a potential Level I randomized controlled trial to a Level II study would include, among other possibilities: an underpowered study (patient sample too small, variance too high), inadequate

randomization or masking of the group assignments and lack of validated outcome measures.

In addition, a number of studies were reviewed several times in answering different questions within this guideline. How a given question was asked might influence how a study was evaluated and interpreted as to its level of evidence in answering that particular question. For example, a randomized controlled trial reviewed to evaluate the differences between the outcomes of surgically treated versus untreated patients with lumbar disc herniation with radiculopathy might be a well designed and implemented Level I therapeutic study. This same study, however, might be classified as providing Level II prognostic evidence if the data for the untreated controls were extracted and evaluated prognostically.

Guideline Development Process

Step 1: Identification of Clinical Questions

The clinical questions from the original guideline, published in 2008, are included in this guideline update. Since 2008, an additional section addressing value in spine care has been added. Trained guideline participants were asked to submit a list of new additional clinical questions that the guideline should address in addition to the questions included in the original guideline. The lists of new questions were compiled into a master list, which was then circulated to each member with a request that they independently rank the questions in order of importance for consideration in the guideline. The questions from the previous guideline and most highly ranked new questions, as determined by the participants, served to focus the guideline.

Step 2: Identification of Work Groups

Multidisciplinary teams were assigned to work groups and assigned specific clinical questions to address. Because NASS is comprised of surgical, medical and interventional specialists, it is imperative to the guideline development process that a cross-section of NASS membership is represented on the work group. This also helps to ensure that the potential for inadvertent biases in evaluating the literature and formulating recommendations is minimized.

Step 3: Identification of Search Terms and Parameters

One of the most crucial elements of evidence analysis is the comprehensive literature search. Thorough assessment of the literature is the basis for the review of existing evidence and the formulation of evidence-based recommendations. In order to ensure a thorough literature search, NASS has instituted a Literature Search Protocol (Appendix E) which has been followed to identify literature for evaluation in guideline development. In keeping with the Literature Search Protocol, work group members have identified appropriate search terms and parameters to direct the literature search. Specific search strategies, including search terms, parameters and databases searched, are documented in the technical report that accompanies this guideline.

Step 4: Completion of the Literature Search

Once each work group identified search terms/parameters, the literature search was implemented by a medical/research librarian at InfoNOW at the University of Minnesota, consistent with the Literature Search Protocol. Following these protocols ensures that NASS recommendations (1) are based on a thorough review of relevant literature; (2) are truly based on a uniform, comprehensive search strategy; and (3) represent the current best research evidence available. NASS maintains a search history in Endnote, for future use or reference.

Step 5: Review of Search Results/Identification of Literature to Review

Work group members reviewed all abstracts yielded from the literature search and identified the literature they will review in order to address the clinical questions, in accordance with the Literature Search Protocol. Members have identified the best research evidence available to answer the targeted clinical questions. That is, if Level I, II and or III literature is available to answer specific questions, the work group was not required to review Level IV or V studies.

Step 6: Evidence Analysis

Members have independently developed evidentiary tables summarizing study conclusions, identifying strengths and weaknesses and assigning levels of evidence. In order to systematically control for potential biases, at least two work group members have reviewed each article selected and independently assigned levels of evidence to the literature using the NASS levels of evidence. Any discrepancies in scoring have been addressed by two or more reviewers. Final ratings are completed at a final meeting of all section workgroup members including the section chair and the guideline chair. The consensus level (the level upon which two-thirds of reviewers were in agreement) was then assigned to the article.

As a final step in the evidence analysis process, members have identified and documented gaps in the evidence to educate guideline readers about where evidence is lacking and help guide further needed research by NASS and other societies.

Step 7: Formulation of Evidence-Based Recommendations and Incorporation of Expert Consensus

Work groups held web-conferences and face-to-face meetings to discuss the evidence-based answers to the clinical questions, the grades of recommendations and the incorporation of expert consensus. Work group members incorporated evidence findings from the original guideline in the guideline update. Where there was no new evidence, the work group re-reviewed the original literature and recommendation statements to ensure agreement with original findings. When new literature was found, work group members included existing evidence when updating recommendations statements.

Expert consensus was incorporated only where Level I-IV evidence is insufficient and the work group has deemed that a recommendation is warranted. Transparency in the incorporation of consensus is crucial, and all consensus-based recommendations made in this guideline very clearly indicate that Level I-IV evidence is insufficient to support a recommendation and that the recommendation is based only on expert consensus.

Consensus Development Process

Voting on guideline recommendations was conducted using a modification of the nominal group technique in which each work group member independently and anonymously ranked a recommendation on a scale ranging from 1 ("extremely inappropriate") to 9 ("extremely appropriate"). Consensus was obtained when at least 80% of work group members ranked the recommendation as 7, 8 or 9. When the 80% threshold was not attained, up to three rounds of discussion and voting were held to resolve disagreements. If disagreements were not resolved after these rounds, no recommendation was adopted.

After the recommendations were established, work group members developed the guideline content, addressing the literature supporting the recommendations.

Step 8: Submission of the Draft Guidelines for Review/ Comment

Guidelines were submitted to the full Evidence-Based Guideline Development Committee and the Research Council for review and comment. Revisions to recommendations were considered for incorporation only when substantiated by a preponderance of appropriate level evidence.

Step 9: Submission for Board Approval

Once any evidence-based revisions were incorporated, the drafts were prepared for NASS Board review and approval. Edits and revisions to recommendations and any other content were considered for incorporation only when substantiated by a preponderance of appropriate level evidence.

Step 10: Submission for Publication and National Guideline Clearinghouse (NGC) Inclusion

Following NASS Board approval, the guidelines have been slated for publication and submitted for inclusion in the National Guidelines Clearinghouse (NGC). No revisions were made after submission to NGC, but comments have been and will be saved for the next iteration.

Step 11: Review and Revision Process

The guideline recommendations will be reviewed every three to five years by an EBM-trained multidisciplinary team and revised as appropriate based on a thorough review and assessment of relevant literature published since the development of this version of the guideline.

Use of Acronyms

Throughout the guideline, readers will see many acronyms with which they may not be familiar. A glossary of acronyms is available in Appendix A.

Nomenclature for Medical/Interventional Treatment

Throughout the guideline, readers will see that what has traditionally been referred to as "nonoperative," "nonsurgical" or "conservative" care is now referred to as "medical/interventional care." The term medical/interventional is meant to encompass pharmacological treatment, physical therapy, exercise therapy, manipulative therapy, modalities, various types of external stimulators and injections.

III. Recommendation Summary

Comparison of 2008 and Current Guideline Recommendations

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation **See reccomendation sections for supporting text*
Definition and Natural History		
What is the best working definition of degenerative lumbar spondylolisthesis?	An acquired anterior displacement of one vertebra over the subjacent vertebra, associated with degenerative changes, without an associated disruption or defect in the vertebral ring. **Workgroup Consensus Statement**	Maintained.
What is the natural history of degenerative lumbar spondylolisthesis?	The majority of patients with symptomatic degenerative lumbar spondylolisthesis and an absence of neurologic deficits will do well with conservative care. Patients who present with sensory changes, muscle weakness or cauda equina syndrome, are more likely to develop progressive functional decline without surgery. Progression of slip correlates with jobs that require repetitive anterior flexion of the spine. Slip progression is less likely to occur when the disc has lost over 80% of its native height and intervertebral osteophytes have formed. Progression of clinical symptoms does not correlate with progression of the slip.	Not addressed in guideline update. The literature to address natural history is limited and efforts to develop recommendations are often unsuccessful. Therefore, natural history questions have been eliminated from this guideline.
Diagnosis and Imaging		
What are the most appropriate historical and physical examination findings consistent with the diagnosis of degenerative lumbar spondylolisthesis?	Obtaining an accurate history and physical examination is essential to the formulation of the appropriate clinical questions to guide the physician in developing a plan for the treatment of patients with degenerative lumbar spondylolisthesis. **Work Group Consensus Statement** In older patients presenting with radiculopathy and neurogenic intermittent claudication, with or without back pain, a diagnosis of degenerative lumbar spondylolisthesis should be considered. **Grade of Recommendation: B**	In the absence of evidence to address this question, it is the work group's opinion that obtaining an accurate history and physical examination is important for the diagnosis and treatment of patients with degenerative lumbar spondylolisthesis. Formulating appropriate clinical questions is essential to obtaining an accurate history that can be used in developing a treatment plan for patients. **Work Group Consensus Statement** In patients with imaging evidence of degenerative lumbar spondylolisthesis, the following clinical characteristics have been reported: asymptomatic with only occasional back pain; chronic low back pain with or without radicular symptoms and with or without positional variance; radicular symptoms with or without neurologic deficit, with or without back pain; and intermittent neurogenic claudication. Study summaries are provided as background support to help further define the clinical characteristics that may be associated with a diagnosis of degenerative lumbar spondylolisthesis.

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation **See reccomendation sections for supporting text*
What are the most appropriate diagnostic tests for degenerative lumbar spondylolisthesis?	The most appropriate, noninvasive test for detecting degenerative lumbar spondylolisthesis is the lateral radiograph. **Grade of Recommendation: B** The most appropriate, noninvasive test for imaging the stenosis accompanying degenerative lumbar spondylolisthesis is the MRI. **Work Group Consensus Statement** Plain myelography or CT myelography are useful studies to assess spinal stenosis in patients with degenerative lumbar spondylolisthesis. **Grade of Recommendation: B** CT is a useful noninvasive study in patients who have a contraindication to MRI, for whom MRI findings are inconclusive or for whom there is a poor correlation between symptoms and MRI findings, and in whom CT myelogram is deemed inappropriate. **Work Group Consensus Statement**	The lateral radiograph is the most appropriate, noninvasive test for detecting degenerative lumbar spondylolisthesis. **Grade of Recommendation: B (Suggested)** In the absence of reliable evidence, it is the work group's opinion that the lateral radiograph should be obtained in the standing position whenever possible. **Work Group Consensus Statement** The most appropriate, noninvasive test for imaging stenosis accompanying degenerative lumbar spondylolisthesis is MRI. **Work Group Consensus Statement** Facet joint effusion greater than 1.5mm on supine MRI may be suggestive of the presence of degenerative lumbar spondylolisthesis. Further evaluation for the presence of degenerative lumbar spondylolisthesis should be considered, including using plain standing radiographs. **Grade of Recommendation: B** There is insufficient evidence to make a recommendation for or against the utility of the upright seated MRI in the diagnosis of degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)** There is insufficient evidence to make a recommendation for or against the use of axial loaded MRI to evaluate the dural sac cross sectional area in patients with degenerative lumbar spondylolisthesis and spinal stenosis. **Grade of Recommendation: I (Insufficient Evidence)** Plain myelography or CT myelography are useful studies to assess spinal stenosis in patients with degenerative lumbar spondylolisthesis especially in those who have contraindications to MRI. **Grade of Recommendation: B (Suggested)** In patients with degenerative lumbar spondylolisthesis with associated spinal stenosis for whom MRI is either contraindicated or inconclusive, CT myelography is the most appropriate test to confirm the presence of anatomic narrowing of the spinal canal or the presence of nerve root impingement. **Work Group Consensus Statement** In patients with degenerative spondylolisthesis with associated spinal stenosis for whom MRI and CT myelography are contraindicated, inconclusive or inappropriate, CT is suggested as the most appropriate test to confirm the presence of anatomic narrowing of the spinal canal or the presence of nerve room impingement. **Work Group Consensus Statement**

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation *See reccomendation sections for supporting text
What are the most appropriate diagnostic or physical exam tests consistent with the diagnosis of fixed versus dynamic deformity?	Not addressed	There is insufficient evidence to make a recommendation on the most appropriate diagnostic or physical exam test consistent with fixed or dynamic deformity in degenerative lumbar spondylolisthesis patients due to the lack of uniform reference standards which define instability. There is no universally accepted standard to diagnose fixed versus dynamic spondylolisthesis. To evaluate instability, many studies employ the use of lateral flexion extension radiographs, which may be done in the standing or recumbent position; however, there is wide variation in the definition of instability. To assist readers, the definitions for instability (when provided) in degenerative spondylolisthesis patients, are bolded below. **Grade of Recommendation: I (Insufficient Evidence)**
Is dynamic MRI and/or dynamic CT myelography imaging (including standing imaging, imaging with axial loading) helpful in the diagnostic testing for degenerative lumbar spondylolisthesis?	Not addressed	There is insufficient evidence to make a recommendation for or against the utility of dynamic MRI and dynamic CT myelography in the diagnosis of degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)**
Outcome Measures for Medical/Interventional and Surgical Treatment		
What are the appropriate outcome measures for the treatment of degenerative lumbar spondylolisthesis?	TheZurich Claudication Questionnaire (ZCQ)/Swiss Spinal Stenosis Questionnaire (SSS), Oswestry Disability Index (ODI), Likert Five-Point Pain Scale and 36-Item Short Form Health Survey (SF-36) are appropriate measures for assessing treatment of degenerative lumbar spondylolisthesis. **Grade of Recommendation: A** The Japanese Orthopedic Association (JOA) Score and the calculated Recovery Rate may be useful in assessing outcome in degenerative lumbar spondylolisthesis. **Grade of Recommendation: B** The Shuttle Walking Test (SWT), Oxford Claudication Score (OCS), Low Back Pain Bothersome Index and Stenosis Bothersome Index are potential outcome measures in studying degenerative lumbar spondylolisthesis. Grade of **Recommendation: I (Insufficient Evidence)**	An updated literature search was not conducted. For more information on appropriate outcome measures for degenerative lumbar spondylolisthesis, the North American Spine Society has a publication entitled *Compendium of Outcome Instruments for Assessment and Research of Spinal Disorders*. To purchase a copy of the Compendium, visit https://webportal.spine.org/Purchase/ProductDetail.aspx?Product_code=68cdd1f4-c4ac-db11-95b2-001143edb1c1. For additional information about the Compendium, please contact the NASS Research Department at nassresearch@spine.org.

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation **See reccomendation sections for supporting text*
Medical and Interventional Treatment		
• Do medical/ interventional treatments improve outcomes in the treatment of degenerative lumbar spondylolisthesis compared to the natural history of the disease? • What is the role of pharmacological treatment in the management of degenerative lumbar spondylolisthesis? • What is the role of physical therapy/ exercise in the treatment of degenerative lumbar spondylolisthesis? •What is the role of manipulation in the treatment of degenerative lumbar spondylolisthesis? •What is the role of ancillary treatments such as bracing, traction, electrical stimulation and transcutaneous electrical stimulation (TENS) in the treatment of degenerative lumbar spondylolisthesis? •What is the long-term result of medical/ interventional management of degenerative lumbar spondylolisthesis? • What is the role of injections for the treatment of degenerative lumbar spondylolisthesis?	A systematic review of the literature yielded no studies to adequately address any of the medical/interventional treatment questions posed. Medical/interventional treatment for degenerative lumbar spondylolisthesis, when the radicular symptoms of stenosis predominate, most logically should be similar to treatment for symptomatic degenerative lumbar spinal stenosis. **Work Group Consensus Statement**	Not addressed in guideline update; the literature to address natural history is limited and efforts to develop recommendations are often unsuccessful. Therefore, natural history questions have been eliminated from this guideline. Maintained. An updated systematic review of the literature yielded no studies to adequately address any of the medical/interventional treatment questions posed **(except for injections).** There is insufficient evidence to make a recommendation for or against the use of injections for the treatment of degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)** Maintained. Medical/interventional treatment for degenerative lumbar spondylolisthesis, when the radicular symptoms of stenosis predominate, most logically should be similar to treatment for symptomatic degenerative lumbar spinal stenosis. **Work Group Consensus Statement**
Surgical Treatment		
Do surgical treatments improve outcomes in the treatment of degenerative lumbar spondylolisthesis compared to the natural history of the disease?	Surgery is recommended for treatment of patients with symptomatic spinal stenosis associated with low grade degenerative spondylolisthesis whose symptoms have been refractory to a trial of medical/ interventional treatment. **Grade of Recommendation: B**	Not addressed in guideline update; the literature to address natural history is limited and efforts to develop recommendations are often unsuccessful. Therefore, natural history questions have been eliminated from this guideline.

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation *See reccomendation sections for supporting text
Does surgical decompression alone improve surgical outcomes in the treatment of degenerative lumbar spondylolisthesis compared to medical/interventional treatment alone or the natural history of the disease?	Direct surgical decompression is recommended for treatment of patients with symptomatic spinal stenosis associated with low grade degenerative lumbar spondylolisthesis whose symptoms have been recalcitrant to a trial of medical/interventional treatment. **Grade of Recommendation: I (Insufficient Evidence)** Indirect surgical decompression is recommended for treatment of patients with symptomatic spinal stenosis associated with low grade degenerative lumbar spondylolisthesis whose symptoms have been recalcitrant to a trial of medical/interventional treatment. **Grade of Recommendation: I (Insufficient Evidence)**	Direct surgical decompression may be considered for the treatment of patients with symptomatic spinal stenosis associated with low grade degenerative lumbar spondylolisthesis whose symptoms have been recalcitrant to a trial of medical/interventional treatment. **Grade of Recommendation: C** There is insufficient evidence to make a recommendation for or against the use of indirect surgical decompression for the treatment of patients with symptomatic spinal stenosis associated with low grade degenerative lumbar spondylolisthesis whose symptoms have been recalcitrant to a trial of medical/interventional treatment. **Grade of Recommendation: I (Insufficient Evidence)**
Does the addition of lumbar fusion, with or without instrumentation, to surgical decompression improve surgical outcomes in the treatment of degenerative lumbar spondylolisthesis compared to treatment by decompression alone?	Surgical decompression with fusion is recommended for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis to improve clinical outcomes compared with decompression alone. **Grade of Recommendation: B**	Surgical decompression with fusion is suggested for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis to improve clinical outcomes compared with decompression alone. **Grade of Recommendation: B** For symptomatic single level degenerative spondylolisthesis that is low-grade (<20%) and without lateral foraminal stenosis, decompression alone with preservation of midline structures provides equivalent outcomes when compared to surgical decompression with fusion. **Grade of Recommendation: B (Suggested)**
Does the addition of lumbar fusion, with or without instrumentation, to surgical decompression improve surgical outcomes in the treatment of degenerative lumbar spondylolisthesis compared to medical/interventional treatment alone?	Not addressed	Surgical decompression with fusion, with or without instrumentation, is suggested to improve the functional outcomes of single-level degenerative spondylolisthesis compared to medical/interventional treatment alone. **Grade of Recommendation: B** There is insufficient evidence to make a recommendation for or against efficacy of surgical decompression with fusion, with or without instrumentation, for treatment of multi-level degenerative lumbar spondylolisthesis compared to medical/interventional treatment alone. **Grade of Recommendation: I (Insufficient Evidence)**
Does the addition of instrumentation to decompression and fusion for degenerative lumbar spondylolisthesis improve surgical outcomes compared with decompression and fusion alone?	The addition of instrumentation is recommended to improve fusion rates in patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. **Grade of Recommendation: B** The addition of instrumentation is not recommended to improve clinical outcomes for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. **Grade of Recommendation: B**	The addition of instrumentation is suggested to improve fusion rates in patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. **Grade of Recommendation: B** The addition of instrumentation is not suggested to improve clinical outcomes for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. **Grade of Recommendation: B**

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation **See reccomendation sections for supporting text*
How do outcomes of decompression with posterolateral fusion compare with those for 360° fusion in the treatment of degenerative lumbar spondylolisthesis?	Because of the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question.	There is insufficient evidence to make a recommendation for or against the use of either decompression with posterolateral fusion or 360° fusion in the surgical treatment of patients with degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)**
Does 360° fusion with decompression lead to better outcomes versus 360° fusion without decompression for treatment of degenerative lumbar spondylolisthesis?	Not addressed	No evidence was found to address this question. Due to the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question.
Do flexible fusions improve outcomes in the treatment of degenerative lumbar spondylolisthesis compared to nonoperative treatment?	Not addressed	No evidence was found to address this question. Due to the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question.
Does the use of interspinous spacers in the treatment of degenerative lumbar spondylolisthesis improve outcomes compared to nonoperative treatment?	Not addressed	There is insufficient and conflicting evidence to make a recommendation for or against the efficacy of interspinous spacers versus medical/interventional treatment in the management of degenerative lumbar spondylolisthesis patients. **Grade of Recommendation: I (Insufficient Evidence)**
What is the role of reduction (deliberate attempt to reduce via surgical technique) with fusion in the treatment of degenerative lumbar spondylolisthesis?	Reduction with fusion and internal fixation of patients with low grade degenerative lumbar spondylolisthesis is not recommended to improve clinical outcomes. **Grade of Recommendation: I (Insufficient Evidence)**	There is insufficient evidence to make a recommendation for or against the use of reduction with fusion in the treatment of degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)**
For patients undergoing posterolateral fusion, does the use of autogenous bone graft improve surgical outcomes compared to those fused with bone graft substitutes?	Not addressed	Due to the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question. There is insufficient evidence to make a recommendation for or against the use of autogenous bone graft or bone graft substitutes in patients undergoing posterolateral fusion for the surgical treatment of degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence**)
Do minimally invasive surgical treatments improve outcomes in the treatment of degenerative lumbar spondylolisthesis compared to: a. conventional open decompression (laminectomy)? b. conventional (open) lumbar decompression and fusion, with or without instrumentation?	Not addressed	No evidence was found to assess the efficacy of minimally invasive surgical techniques versus open decompression alone in the surgical treatment of degenerative lumbar spondylolisthesis. While both minimally invasive techniques and open decompression and fusion, with or without instrumentation, demonstrate significantly improved clinical outcomes for the surgical treatment of degenerative lumbar spondylolisthesis, there is conflicting evidence which technique leads to better outcomes. **Grade of Recommendation: I (Insufficient/ Conflicting Evidence)**

Clinical Question	2008 Guideline Recommendation	Current Guideline Reccomendation *See reccomendation sections for supporting text
What is the long-term result (four+ years) of surgical management of degenerative lumbar spondylolisthesis?	Decompression and fusion is recommended as a means to provide satisfactory long-term results for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. **Grade of Recommendation: C**	Decompression and fusion may be considered as a means to provide satisfactory long-term results for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. **Grade of Recommendation: C**
Which patient-specific characteristics influence outcomes (and prognosis) in the treatment (surgical or any) of degenerative lumbar spondylolisthesis?	Not addressed	There is insufficient evidence to make a recommendation for or against the influence of a nonorganic pain drawing on the outcomes/prognosis of treatments for patients with degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)** There is insufficient evidence to make a recommendation regarding the influence of age and three or more comorbidities on the outcomes of patients undergoing treatment for degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)** There is insufficient evidence to make a recommendation regarding the influence of symptom duration on the treatment outcomes of patients with degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)** There is insufficient evidence to make a recommendation regarding the influence of obesity (BMI >30) and its impact on treatment outcomes in patients with degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)**
What is the effect of postsurgical rehabilitation including exercise, spinal mobilization/manipulation or psychosocial interventions on outcomes in the management of degenerative lumbar spondylolisthesis (compared to patients who do not undergo postsurgical rehabilitation)?	Not addressed	There was no evidence found to address this question. Due to the paucity of evidence, a recommendation cannot be made regarding the effect of postsurgical rehabilitation the outcomes of patients undergoing surgical treatment for degenerative lumbar spondylolisthesis.
Value of Spine Care		
What is the cost-effectiveness of the surgical treatment of degenerative lumbar spondylolisthesis compared to nonoperative management (consider with and without fusion separately)?	Not addressed	There was no evidence found to address this question. Due to the paucity of evidence, a recommendation cannot be made regarding the cost-effectiveness of surgical treatment compared to nonoperative treatment for the management of patients with degenerative lumbar spondylolisthesis.
What is the cost-effectiveness of minimal access-based surgical treatments of degenerative lumbar spondylolisthesis compared to traditional open surgical treatments?	Not addressed	There is insufficient evidence to make a recommendation for or against the cost-effectiveness of minimal access-based surgical treatments compared to traditional open surgical treatments for degenerative lumbar spondylolisthesis. **Grade of Recommendation: I (Insufficient Evidence)**

IV. Definition of Degenerative Lumbar Spondylolisthesis

Original Guideline Question:

What is the best working definition of degenerative lumbar spondylolisthesis?

An acquired anterior displacement of one vertebra over the subjacent vertebra, associated with degenerative changes, without an associated disruption or defect in the vertebral ring. *Maintained from original guideline*

Work Group Consensus Statement

The literature search revealed several reports that describe variants of degenerative spondylolisthesis in which the degree of anterior displacement is measurably affected by the posture and position of the patient. These observations on position dependent deformities may have significant implications for the pathophysiology and natural history of degenerative spondylolisthesis; however, no longitudinal studies have yet addressed this issue.

Degenerative spondylolisthesis is an anatomic finding. The clinical symptoms of degenerative spondylolisthesis, however, are varied. Patients with degenerative lumbar spondylolisthesis can be asymptomatic. They can also present with back pain, or with neurogenic claudication and/or radicular pain, with or without axial back pain. Therefore, the work group agreed upon this anatomic definition, but also evaluated the relevant literature inclusive of the variations of clinical presentation.

V. Recommendations for Diagnosis and Treatment of Degenerative Lumbar Spondylolisthesis

A. Diagnosis and Imaging

Original Guideline Question:

What are the most appropriate historical and physical examination findings consistent with the diagnosis of degenerative lumbar spondylolisthesis?

In the absence of evidence to address this question, it is the work group's opinion that obtaining an accurate history and physical examination is important for the diagnosis and treatment of patients with degenerative lumbar spondylolisthesis. Formulating appropriate clinical questions is essential to obtaining an accurate history that can be used in developing a treatment plan for patients. *Maintained from original guideline with minor word modifications*

Work Group Consensus Statement

In patients with imaging evidence of degenerative lumbar spondylolisthesis, the following clinical characteristics have been reported: asymptomatic with only occasional back pain; chronic low back pain with or without radicular symptoms and with or without positional variance; radicular symptoms with or without neurologic deficit, with or without back pain; and intermittent neurogenic claudication. The summaries below are provided as background support to help further define the clinical characteristics that may be associated with a diagnosis of degenerative lumbar spondylolisthesis.

Studies obtained from updated literature search:

Chen et al[1] conducted an age- and sex-matched case-control study to identify the predisposing factors of degenerative lumbar spondylolisthesis. A total of 66 women, aged 45 to 64 years, with a first time lumbar spondylolisthesis diagnosis were compared to 66 controls. A physiatrist confirmed the grade of the anterior displacement of the lumbar spine according to Neuman's classification and assessed the anthropometric parameters from the lateral view of L-spine radiograph and KUB, which included angles of the lumbar and sacral spine. In the case group, most parameters, including disc height, body height, and angles tended to be lower than those in the control group, whereas the length of the transverse process of L5 (TPL), the width of the transverse process of L5 (TPW) and TP-AREA were higher than the control group. The differences in disc height, lumbar index, sacral inclination angle, sacral horizontal angle and transverse processes between the two groups were statistically significant ($p<0.05$). Using multivariate logistic regression analysis, this study suggests that antero-inferior disc height and lumbar index are independent variables of predisposing factors of degenerative lumbar spondylolisthesis.

Pearson et al[2] conducted a retrospective analysis of data from the Spine Patient Outcomes Trial (SPORT) to compare baseline characteristics and the surgical and nonoperative outcomes between degenerative spondylolisthesis and spinal stenosis patients. The degenerative spondylolisthesis cohort included 601 patients and the spinal stenosis cohort included 634 patients. Primary outcome measures included the SF-36 bodily pain, physical function scores and the Oswestry Disability Index (ODI). Comparison of baseline characteristics between the degenerative spondylolisthesis and spinal stenosis groups revealed statistically significant differences. The degenerative spondylo-

listhesis group included a higher proportion of women (69% vs 39%, p<0.001) and was about 18 months older (66.1 vs 64.6 years, p<0.021) than the spinal stenosis group. Fewer degenerative spondyolisthesis patients reported heart (20% vs 26%, p<0.021) or bowel (7% vs 14%, p<0.001) problems compared to spinal stenosis patients, while more reported depression (16% vs. 11%, p<0.009). There were no significant differences on any of the primary (SF-36 BP, PF or ODI) or secondary (Stenosis Bothersome Index or Low Back Pain) outcome measures at baseline between the 2 diagnostic groups. In addition, degenerative spondylolisthesis patients were found to have similar levels of disability when compared to spinal stenosis patients. This study suggests that degenerative spondylolisthesis patients tended to be female, older, with more depression and similar levels of disability, but less heart and bowel problems when compared to spinal stenosis patients.

Studies included in original guideline:

Cauchioux et al[3] described a study in which the diagnostic evaluation of 26 patients with degenerative spondylolisthesis included plain radiographs and myelography. The study included 26 patients with nerve root compression secondary to degenerative slip, with 80% reporting back pain, 46% reporting primary chronic sciatica and 54% reporting primary neurogenic claudication. Sciatica tended to occur in older patients and neurogenic claudication in younger subjects. In critique of this study, this is a characterization of a subset of patients with degenerative lumbar spondylolisthesis referred for evaluation of neurological symptoms. These data offer background for the neurological symptoms associated with degenerative lumbar spondylolisthesis.

Fitzgerald et al[4] conducted a study of 43 patients with symptomatic spondylolisthesis which examined various parameters. It is unclear if the patients represented a consecutive or nonconsecutive series. In addition to a description of plain radiographic findings of the spine, as well as concomitant hip arthritis, the authors provided a detailed description of the presentation (symptom) pattern of the patients. In summary, they found that 34 patients had back pain without leg pain and signs of nerve root compression, 5 cases with leg pain with or without back pain with signs of nerve root compression and four cases in which patients reported neurogenic claudication. As a diagnostic history and physical examination study, the study presents a spectrum of symptoms and signs in patients with degenerative lumbar spondylolisthesis.

Matsunaga et al[5] conducted a prospective observational study to determine the clinical course of nonsurgically managed patients with degenerative spondylolisthesis as well as the indications for surgery. A total of 145 nonsurgically managed patients with degenerative spondylolisthesis were examined annually for a minimum of 10 years. Lumbar rheumatism, with or without pain in the lower extremities was a common complaint at initial examination. Conservative treatment for these patients consisted of brace wearing, use of antiiflammatory drugs and/or lumbar exercises. Twenty-nine (83%) of the 35 patients who had neurological symptoms, such as intermittent claudication or vesicorectal disorder, at initial examination and refused surgical treatment experienced neurological deterioration.

Postacchini et al[6] performed a retrospective study which reported on the clinical features of 77 patients with degenerative lumbar spondylolisthesis. Within these patients, 18% reported chronic low back pain as the only symptom; 12% had lower extremity symptoms felt to be nonvertebral in origin (eg, hip arthritis) and reported no low back pain; 47% had radicular symptoms and low back pain; and 23% reported only radicular symptoms. Radiculopathy presented as pain alone, pain and sensory symptoms or pain and sensorimotor changes. Lasegue test was negative in almost all cases. The most common neurological signs were absent ankle jerks, weak extensor hallucis longus (EHL), weak anterior tibialis or loss of knee jerk reflex. The authors reviewed five clinical patterns and three radiographic patterns as defined by Fitzgerald and MacNab. Clinical patterns included the following:

1. no symptoms, occasional back pain;
2. chronic low back pain with no radicular symptoms;
3. radicular symptoms with no root compression, with or without back pain;
4. radicular symptoms with neurologic deficit; or
5. intermittent claudication.

Radiological findings included slight central stenosis, lateral root canal stenosis or combined central and root canal stenosis. The authors concluded that degenerative lumbar spondylolisthesis is not always symptomatic. Patients may complain of low back pain, but the etiology is uncertain. Patients largely complain of radicular symptoms or intermittent claudication, which is secondary to an associated stenosis.

Rosenberg et al[7] conducted a retrospective study which characterized symptoms in 200 consecutive patients with degenerative lumbar spondylolisthesis. Back, buttock or thigh pain were the principal complaints in a large majority of patients. Of the 200 patients, 61 had leg symptoms. Some patients described gait abnormalities. Seven patients had sacral nerve root symptoms. Acute radiculopathy occurred in 19 instances and a disc herniation was confirmed on myelography. Symptoms included aching, pulling, weakness, heaviness, numbness or burning. Lower extremity symptoms could be unilateral, bilateral or alternating. Neurogenic claudication was uncommon. Examination of the patients demonstrated that many were supple and able to touch toes, 10% had back spasms and 42% had neurologic deficits, primarily L5 with decreased sensation in the lateral thigh or inability to walk on heels. Atrophy occurred occasionally and 20% had altered deep tendon reflexes.

Vogt et al[8] described a retrospective, cross-sectional study of 788 women greater than 65 years of age enrolled in the Study of Osteoporotic Fractures. The presence of olisthesis (degenerative spondylolisthesis and retrodisplacement) was defined as greater than 3mm of translational change. Of the women enrolled in the study, 29% had anterior olisthesis (degenerative spondylolisthesis) and 14% had retrolisthesis. Ninety percent of degenerative spondylolisthesis and 88% of retrolisthesis occurred at one level. Prevalence was not associated with smoking status, diabetes or oophorectomy. Unlike retrolisthesis, degenerative spondylolisthesis was not associated with back pain. This study suggests that degenerative spondylolisthesis is relatively common in elderly Caucasian women and does not correlate with back pain.

Future Directions For Research

The work group identified the following potential studies that would generate meaningful evidence to assist in identifying the most appropriate historical and physical examination findings consistent with the diagnosis of degenerative lumbar spondylolisthesis:

Recommendation #1:

Sufficiently-powered observational studies evaluating the predictive value of physical examination tests in diagnosing degenerative lumbar spondylolisthesis.

Recommendation #2:

Large multicenter registry database studies are needed to better understand the importance of certain patient characteristics or clinical presentation associated with the diagnosis of degenerative lumbar spondylolisthesis.

References

1. Chen, I.R, & Wei, TS. Disc height and lumbar index as independent predictors of degenerative spondylolisthesis in middle-aged women with low back pain. Spine. 2009 Jun 1;34(13):1402-1409.
2. Pearson A, Blood E, Lurie J, Tosteson, T, Abdu WA, Hillibrand A, Weinstein J Degenerative spondylolisthesis versus spinal stenosis: does a slip matter? Comparison of baseline characteristics and outcomes (SPORT). Spine. 2010 Feb 1;35(3):298-305.
3. Cauchoix J, Benoist M, Chassaing V. Degenerative spondylolisthesis. Clin Orthop Relat Res. 1976(115):122-129.
4. Fitzgerald JA, Newman PH. Degenerative spondylolisthesis. J Bone Joint Surg Br. 1976 May;58(2):184-192.
5. Matsunaga S, Ijiri K, Hayashi K Nonsurgically managed patients with degenerative spondylolisthesis: a 10- to 18-year follow-up study. J Neurosurg. 2000;93(Suppl):194–198.
6. Postacchini F, Perugia D. Degenerative lumbar spondylolisthesis. Part I: Etiology, pathogenesis, pathomorphology, and clinical features. Ital J Orthop Traumatol. 1991;17(2):165-173.
7. Rosenberg NJ. Degenerative spondylolisthesis. Predisposing factors. J Bone Joint Surg Am. 1975;57(4):467-474.
8. Vogt MT, Rubin D, Valentin RS, et al. Lumbar olisthesis and lower back symptoms in elderly white women. The Study of Osteoporotic Fractures. Spine. 1998;23(23):2640-2647.

Bibliography from updated literature search

1. Bartynski WS, Petropoulou KA. The MR imaging features and clinical correlates in low back pain-related syndromes. Magnetic Reson Imaging Clinics N Am. 2007 May;15(2), 137-154.
2. Bolesta M J, Winslow L, Gill K. A comparison of film and computer workstation measurements of degenerative spondylolisthesis: intraobserver and interobserver reliability. Spine. 2010;35(13):1300-1303.
3. Cansever T, Civelek E, Sencer A, Karasu A, Turantan I. Intermittent priapism in degenerative lumbar spinal stenosis: Case report. Turk Neurosurg. 2007;17(4):260-263.
4. Carrino JA, Lurie JD, Tosteson ANA, Tosteson TD, Carragee EJ, Kaiser J, Herzog R. Lumbar spine: Reliability of MR imaging findings. Radiology. 2009;250(1):161-170.
5. Chad DA Lumbar Spinal Stenosis. Neurol Clin. 2007;25(2):407-418.
6. Chaput C, Padon D, Rush J, Lenehan E, Rahm M. The significance of increased fluid signal on magnetic resonance imaging in lumbar facets in relationship to degenerative spondylolisthesis. Spine. 2007;32(17):1883-1887.
7. Chen IR, Wei TS. Disc height and lumbar index as independent predictors of degenerative spondylolisthesis in middle-aged women with low back pain. Spine. 2009;34(13), 1402-1409.
8. Elhawary Y, Azzazi A. Dynamic stabilization using X-stop vs. trans-pedicular screw fixation in the treatment of lumbar canal stenosis: Comparative study of the clinical outcome. Spine J. 2010;10(9)Supplement, S130.
9. Ferreiro Perez A, Garcia Isidro M, Ayerbe E, Castedo J, Jinkins JR. Evaluation of intervertebral disc herniation and hypermobile intersegmental instability in symptomatic adult patients undergoing recumbent and upright MRI of the cervical or lumbosacral spines. Eur J Radiol. 2007;62(3):444-448.
10. Gilbert JW, Wheeler GR, Kreft MP, Upadhyay SP, Storey BB, Spitalieri JR, Gibbs RA. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-631.
11. Glassman, SD, Carreon LY, Djurasovic M, Dimar JR, Johnson JR, Puno RM, Campbell MJ. Lumbar fusion outcomes stratified by specific diagnostic indication. Spine J. 2009(1):13-21.
12. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. Surgical technique. JBone Joint Surg Am. 2008;90(Suppl 2 Pt 1):145-152.
13. Huang KY, Lin RM, Lee YL, Li JD. Factors affecting disability and physical function in degenerative lumbar spondylolisthesis of L4-5: evaluation with axially loaded MRI. Eur Spine J. 2009;18(12):1851-1857.
14. Huang TY, Lee KS, Tsai TH, Su YF, Hwang SL. Posterior epidural migration of sequestrated lumbar disc fragments into the bilateral facet joints: Case report. Neurosurgery. 2011;69(5): E1148-E1151.
15. Hussain NS, Hanscom D, Oskouian RJ. Chyloretroperitoneum following anterior spinal surgery. J Neurosurg Spine. 2012;17(5):415-421.
16. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17(3):327-335.
17. Karabekir HS, Atar EK, Yaycioglu S, Yildizhan A. Comparison of unilateral posterior lumbar interbody fusion and bilateral posterior interbody fusion with simple discectomy at degenerative disc herniations. Neurosciences., 2008;13(3):248-252.
18. Korovessis P, Repantis T, Zacharatos S, Zafiropoulos A. Does Wallis implant reduce adjacent segment degeneration above lumbosacral instrumented fusion? Eur Spine J. 2009:18(6):830-840.
19. Lamberg T, Remes V, Helenius I, Schlenzka D, Seitsalo S, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. J Bone Joint Surg Am. 2007;89(3):512-518.
20. Lindley EM, McCullough MA, Burger EL, Brown CW, Patel VV. Complications of axial lumbar interbody fusion: Clinical article. J Neurosurg Spine. 2011;15(3): 273-279.
21. Lindley EM, Sherman B, Ohnmeiss D, Zigler J, Kasow D, Janssen M, Patel VV. The positive predictive value of provocative discography in artificial disc replacement. Spine J. 2010; SUPPL. (1), 68S-69S.
22. Ly JQ. Systematic Approach to Interpretation of the Lumbar Spine MR Imaging Examination. Magnetic Reson Imaging Clin N Am. 2007;15(2):155-166.
23. Manchikanti L, Cash KA, McManus CD, Pampati V, Abdi S. Preliminary results of a randomized, equivalence trial of fluoroscopic caudal epidural injections in managing chronic low back pain: Part 4--Spinal stenosis. Pain Physician. 2008;11(6):833-848.

24. Martin BI, Mirza SK, Franklin GM, Lurie JD, MacKenzie TA, Deyo RA. Hospital and surgeon variation in complications and repeat surgery following incident lumbar fusion for common degenerative diagnoses. Health Serv Res. 2013 Feb;48(1):1-25.
25. Maus, T Imaging the Back Pain Patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-766.
26. Ozawa H, Kanno H, Koizumi Y, Morozumi N, Aizawa T, Kusakabe T, Itoi E. Dynamic changes in the dural Sac cross-sectional area on axial loaded MR imaging: Is there a difference between degenerative spondylolisthesis and spinal stenosis? Am J Neuroradiol. 2012;33(6), 1191-1197.
27. Roy C, Chatterjee N. Does the diagnosis of spondylolisthesis matter? Pain Physician. 2012 May-June;15(3)E353. Chatterjee, Nilay [added].
28. Skowronski J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. Ortop Traumatol Rehabil. 2007;9(2):149-155.
29. Tanaka M, Shimizu H, Yato Y, Asazuma T, Nemoto K. Acute pyogenic discitis in a degenerative intervertebral disc in an adult. 2010 Aug 4;3:77-80.
30. Wang J, Yang X. Age-related changes in the orientation of lumbar facet joints. Spine. 2009;34(17:E596-598.
31. Watters WC 3rd, Bono CM, Gilbert TJ, Kreiner DS, Mazanec DJ, Shaffer WO, et al. An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2009;9(7):609-614.
32. Yee A J, Yoo JU, Marsolais EB, Carlson G, Poe-Kochert C, Bohlman HH, Emery SE. Use of a postoperative lumbar corset after lumbar spinal arthrodesis for degenerative conditions of the spine. A prospective randomized trial. J Bone Joint Surg Am. 2008;90(10):2062-2068.

Original Guideline Question:

What are the most appropriate diagnostic tests for degenerative lumbar spondylolisthesis?

The lateral radiograph is the most appropriate, noninvasive test for detecting degenerative lumbar spondylolisthesis. *Maintained from original guideline with minor word modifications*

Grade of Recommendation: B (Suggested)

In the absence of reliable evidence, it is the work group's opinion that the lateral radiograph should be obtained in the standing position whenever possible. *New consensus statement*

Work Group Consensus Statement

Study obtained from updated literature search:

Cabraja et al[1] analyzed the images of 100 symptomatic patients with low-grade spondylolisthesis who underwent surgical fusion to test the hypothesis that in symptomatic patients, imaging in the standing and recumbent position that is done as part of the routine diagnostics with CT and radiography reveals a higher sagittal translation (ST) and sagittal rotation (SR) compared to lumbar flexion-extension radiographs in the standing position. To determine the ST and SR in the standing and recumbent position, the authors compared the images taken in the recumbent position in the CT with images taken in the standing position during the routine plain radiography. ST and SR were measured on the dynamic radiographs by subtraction from flexion to extension; on the plain radiographs (standing position) and on the CT (recumbent supine position) by subtraction from plain standing position and supine recumbent position, respectively. Results indicated that the absolute values of measurement of ST differed significantly (p=0.001) with 2.3 ± 1.5 mm in standing flexion-extension radiograph and 4.0 ± 2.0 mm in the standing and recumbent radiograph. The analysis of the relative value showed an ST of 5.9 ± 3.9% in standing flexion-extension radiograph and 7.8 ± 5.4% in standing and recumbent radiograph and also differed significantly (p = 0.008). The vertebral anterior translation was highest during flexion and lowest during recumbent supine position. The measurement of ST in the recumbent supine position showed an absolute value of 4.6 ± 2.5 mm and differed significantly from ST in the standing flexion-extension position (p = 0.001) and standing and recumbent position (p = 0.045). The analysis of the relative value showed an ST of 9.2 ± 5.7% in radiography in the flexion and recumbent spine position. This differed significantly from standing flexion-extension (p = 0.0062), but did not reach the level of significance when comparing the relative values with the standing and recumbent position (p = 0.062). The measurement of SR revealed no significant differences between standing flexion-extension, standing and recumbent position and flexion in a recumbent position; however there was at least a trend that standing flexion-extension evokes a greater SR than standing and recumbent position (p = 0.051). The authors concluded that in symptomatic patients with a low-grade spondylolisthesis,

radiography in the standing and recumbent position evokes a greater ST than the standing flexion-extension radiograph in most patients. In critique, it is unclear if these patients were consecutive and there was no subgroup analysis separating the results of the 17 patients with isthmic spondylolisthesis patients. This study offers Level III diagnostic evidence that for evaluation of ST in symptomatic patients with degenerative spondylolisthesis, imaging in the standing and recumbent position appears to be more suitable than flexion-extension, while a pathological SR is better identified in flexion-extension radiographs in the standing position.

Studies included in original guideline:

Brown et al[2] reported findings from a retrospective study of patients with degenerative spondylolisthesis, which examined a number of different parameters, including diagnostic features on plain radiographs. These patients were selected from a review of 2,348 consecutive charts of patients with low back pain; 132 (5.6%) had radiographic evidence of degenerative spondylolisthesis. Of patients included in the study, 88 were female and 44 were male. The average age was 63.5 years for the female group and 65.2 years for the male group. Seventy-eight percent had back pain with proximal leg referral lasting between one week and 40 years; 17% had instability symptoms (eg, catch in the back, tiredness in back, inability to walk one hour, limitation of forward bend, inability to lift weights, back pain with coughing or sneezing, significant back pain with twisting). In critique, this study does not present peer-reviewed data. There was no comparison of diagnostic tests. As the study was performed in the early 1980s, the primary radiographic modality was plain radiographs. These data offer Level III diagnostic evidence that plain radiographs are a useful test for identifying patients with degenerative spondylolisthesis.

Cauchioux et al[3] conducted a diagnostic evaluation on 26 patients with degenerative spondylolisthesis using plain radiographs and myelography. The study included 26 patients with nerve root compression secondary to degenerative slip, with 80% reporting back pain, 46% reporting chronic sciatica and 54% reporting neurogenic claudication. Sciatica tended to occur in the older patient and neurogenic claudication in the younger subjects. Myelography was performed in 17 patients to detect nerve root/cauda equina compression. Although not supported by statistical analysis, the authors claimed that lateral recess stenosis was "most important." In critique of this study, the authors did not state whether patients were consecutively selected; thus, it was assumed that they were nonconsecutive patients. The study did not include comparison of diagnostic modalities. Admittedly, in the mid to late 1970s, plain radiograph and myelography were the most advanced imaging methods available. By default, they would have been considered gold standard diagnostic tests for degenerative spondylolisthesis and spinal stenosis. These data offer Level III diagnostic evidence that plain radiographs and myelography are useful diagnostic tests for this disorder.

Fitzgerald et al[4] described a study of 43 patients with symptomatic spondylolisthesis. It is unclear if the patients represented a consecutive or nonconsecutive series. In addition to a description of plain radiographic findings of the spine, as well as concomitant hip arthritis, the authors provided a detailed description of the presentation (symptom) pattern of the patients. In summary, they found that 34 patients had back pain without leg pain and signs of nerve root compression, 5 cases with leg pain with or without back pain with signs of nerve root compression and four cases in which patients reported neurogenic claudication. As a diagnostic study, the primary imaging method was plain radiographs; however, plain myelography was also performed in 7 of the 9 patients with neurological symptoms. In critique of this study, one must presume that the patients were not consecutively enrolled. The only two imaging methods used were plain radiographs and myelography, which were not uniformly performed in all patients. This study provides Level III diagnostic evidence that plain radiographs and myelography are useful modalities with which to diagnose and evaluate degenerative spondylolisthesis in the lumbar spine.

Kanayama et al[5] conducted a case series of 19 patients with symptomatic degenerative lumbar spondylolisthesis who were candidates for instrumented lumbar arthrodesis and decompression. Patients were assessed according to radiographic parameters including disc angle, range of motion (ROM), percent slip, percent posterior height, which were then compared with distraction stiffness in the operating room. The authors concluded that disc angle in flexion and ROM were highly correlated with distraction stiffness. Patients with segmental kyphosis with flexion showed lower stiffness compared to those with lordosis in flexion. In critique of this study, it assessed an intraoperative and nonvalidated test. The clinical application of such a test remains unknown. Although the study presents potential Level II diagnostic evidence, the authors failed to mention whether the patients were consecutively assigned, thus the study was downgraded to Level III evidence. The study provides Level III diagnostic evidence that standing flexion and extension radiographs are predictive of instability.

Postacchini et al[6] described a study of 77 patients with degenerative spondylolisthesis in which flexion-extension radiographs, CT and/or MRI, and myelography were obtained. The various findings were reported. Dynamic radiographs "showed hypermobility of L4 in approximately half of the cases." Myelography revealed neural structure compression in the spinal canal in all cases in which it was performed. (Note: myelography may have only been performed if patients had neurologic symptoms.) CT was useful for assessing the facet joint. MRI, CT and myelography were useful in identifying stenosis in patients with neurological symptoms. In critique, the diagnostic studies were applied inconsistently across patients. Not all patients received all studies, preventing comparison between diagnostic modalities. This article presented comprehensive descriptions of the findings with each of the diagnostic modalities. These data offer Level III diagnostic evidence of the utility of dynamic radiographs, CT, MRI and myelography for evaluation of degenerative spondylolisthesis.

The most appropriate, noninvasive test for imaging the stenosis accompanying degenerative lumbar spondylolisthesis is MRI. *Maintained from original guideline*

Work Group Consensus Statement

Based on NASS' Clinical Guideline for Diagnosis and Treatment of Degenerative Lumbar Spinal Stenosis (2011)[7], MRI is suggested as the most appropriate, noninvasive test to confirm the presence of anatomic narrowing of the spinal canal or the presence of nerve root impingement in patients with history and physical examination findings consistent with degenerative lumbar spinal stenosis (Grade B Recommendation). This Work Group Consensus has been made with the understanding that the symptoms of degenerative lumbar spondylolisthesis are related to the presence of anatomic narrowing or nerve root impingement, which are similar to imaging findings in lumbar spinal stenosis.

Facet joint effusion greater than 1.5mm on supine MRI may be suggestive of the presence of degenerative lumbar spondylolisthesis. Further evaluation for the presence of degenerative lumbar spondylolisthesis should be considered, including using plain standing radiographs. *New recommendation statement*

Grade of Recommendation: B

Studies obtained from updated literature search:
In a retrospective radiographic review, Chaput et al[8] evaluated the association between facet joint effusion seen on MRI and spondylolisthesis seen on standing lateral flexion-extension (SLFE) radiographs in patients with degenerative spondylolisthesis. A total of 193 patients were studied, including 139 without degenerative spondylolisthesis and 54 with degenerative spondylolisthesis. Degenerative spondylolisthesis was considered present if anterior translation of L4 on L5 was >5% on SLFE films. When reviewing radiographic indicators for degenerative spondylolisthesis, degenerative spondylolisthesis patients were more likely to have synovial cysts ($p<0.0001$), higher osteoarthritis grade ($p<0.0001$) and larger effusions ($p< 0.0001$) compared to nondiseased patients. After adjusting for age and osteoarthritis grade, every 1mm increase in effusion increased the odds of having degenerative spondylolisthesis by 5.6 fold (OR=5.6). An effusion > 1.5mm was not found in the negative degenerative spondylolisthesis group. Using facet effusion as the only variable in univariate logistic regression, the probability of having spondylolisthesis when 1mm effusion was present on MRI was 29.6%, 60.3% when 2mm of effusion was present and 84.6% when 3mm of effusion was present. This study provides Level II diagnostic evidence that an effusion >1.5 mm is predictive of degenerative spondylolisthesis and the increasing size of the effusion may be correlated to the increased probability of degenerative spondylolisthesis.

In a prospective diagnostic study, Caterini et al[9] analyzed supine weight-bearing flexion–extension lumbosacral radiographs and lumbosacral MRI for 52 patients with low back pain and/or radiculopathy to determine the incidence of increased fluid in the lumbar facet joints seen on the supine axial T2 MRI and to evaluate whether this finding is correlated with radiographic evidence of lumbar instability. The patients had a mean age of 64.7 years. Results indicated that in 12 patients (23.1%) in the series, radiographic signs of degenerative lumbar spondylolisthesis were present, and in 10 of these 12, the degenerative spondylolisthesis was not evident on the sagittal MRI; in 8 cases out of 12, degenerative spondylolisthesis was present at L4–L5, and in the remaining 4 cases at L3–L4. Among these 12 patients with radiographic signs of degenerative spondylolisthesis, the MRI showed exaggerated fluid in the facet joints at the corresponding level in 8 patients (66%). Facet joint effusion was evident on MRI (range 1.5–3mm) in 7 patients (13.4%), but no radiographic signs of corresponding lumbar instability were found. Althogether, 15 patients (28.8%) presented with increased lumbar facet joint fluid on the axial T2 MRI. According to their conclusions, the authors observed a statistical correlation between increased fluid in the lumbar facet joints on the supine axial T2 MRI and degenerative spondylolisthesis seen on standing lateral flexion–extension lumbosacral radiographs. In critique of this study, the investigators did not incorporate a blinded evaluation, there was no control group of asymptomatic patients, and statistical analysis comparing patients with degenerative spondylolisthesis and increased facet fluid to those without degenerative spondylolisthesis and increased facet fluid was not performed. This potential Level II study has been downgraded to level III due to these limitations. This study provides Level III diagnostic evidence that increased facet fluid as seen on MRI may be associated with degenerative spondylolisthesis.

There is insufficient evidence to make a recommendation for or against the utility of the upright seated MRI in the diagnosis of degenerative lumbar spondylolisthesis. *New recommendation statement*

Grade of Recommendation: I (Insufficient Evidence)

Study obtained from updated literature search:
Ferreiro-Perez et al[10] evaluated the differences in imaging findings between recumbent and upright-sitting MRI of the cervical and lumbosacral spine. A total of 89 patients were included in the analysis, including 45 lumbosacral spine patients and 44 cervical spine patients. When determining pathology, degenerative spondylolisthesis was seen in 13 patients, including 11 anterior and 2 posterior. Anterior spondylolisthesis was only seen on the upright-sitting examination in 4 patients (31%). Anterior spondylolisthesis was comparatively greater in degree on the upright-seated study in 7 patients (54%). Posterior spondylolisthesis was comparatively greater in degree on the recumbent examination in 2 patients (15%). The authors suggest that the upright-seated MRI was found to be superior to recumbent MRI. In critique of this study, the sample size was small, it was unclear which patients received which type of MRI and statistical analysis of results was not performed. Due to these limitations, this potential Level III study has been downgraded to a Level IV. This study provides Level IV diagnostic evidence that upright-seated MRI may be superior to recumbent MRI of the spine in cases of anterior spondylolisthesis. The seated upright MRI may make an-

terior spondylolisthesis more visible when compared to supine MRI.

There is insufficient evidence to make a recommendation for or against the use of axial loaded MRI to evaluate the dural sac cross sectional area in patients with degenerative lumbar spondylolisthesis and spinal stenosis. *New recommendation statement*

Grade of Recommendation: I (Insufficient Evidence)

Study obtained from updated literature search:

Ozawa et al[11] compared the dural sac cross sectional area (DCSA) in patients with degenerative spondylolisthesis versus patients with spinal stenosis (without degenerative spondylolisthesis) on axially loaded MR imaging. All patients had neurogenic intermittent claudication and leg pain or numbness and associated neurologic signs. Lumbar spinal canal narrowing was radiographically confirmed on cross-sectional imaging in all patients. For the comparative analysis in this study, the patients with >3mm spondylolisthesis were assigned to the degenerative spondylolisthesis group, while the other patients were assigned to the spinal stenosis group. A total of 88 patients were included in the study, including 40 with degenerative spondylolisthesis patients. All patients received MR imaging. After conventional MR imaging, axial loading was applied by using an external commercially available nonmagnetic compression device. The DCSA was measured from the L2-3 to L5-S1 on the axial image. The measurement was performed three times and the mean value was calculated and used for analysis in this study. Results indicated that a >15-mm^2 change in the DCSA was found in 8 patients (16.7%) in the spinal stenosis group and 25 patients (62.5%) in the degenerative spondylolisthesis group. In the degenerative spondylolisthesis group, patients with a >15-mm^2 change had a significantly larger DCSA on conventional MR imaging (58 ± 26 mm^2) than those with a <15 mm^2 change (41 ± 18 mm^2) (p=0.028), while the axial loaded MR imaging showed no significant difference between the patients with a >15 and a <15-mm^2 change in the DCSA (p =0.897). The authors conclude that DCSA in patients with degenerative spondylolisthesis is more likely to be decreased by axial loading than in those with spinal stenosis. Axial loaded MRI may be a more useful tool for the assessment of spinal canal narrowing in patients with degenerative spondylolisthesis than those with spinal stenosis without spondylolisthesis. In critique, use of a 15mm^2 criterion as significant change in DCSA is not a universally accepted diagnostic standard; therefore, this study has been downgraded from Level II to III. This study provides Level III diagnostic evidence that axially loaded MRI may reveal more severe stenosis in patients with degenerative spondylolisthesis than might be apparent on conventional MRI.

Plain myelography or CT myelography are useful studies to assess spinal stenosis in patients with degenerative lumbar spondylolisthesis especially in those who have contraindications to MRI. *Maintained from original guideline*

Grade of Recommendation: B (Suggested)

Studies included in original guideline:

Cauchioux et al[3] conducted a diagnostic evaluation of 26 patients with degenerative spondylolisthesis which included plain radiographs and myelography. Specifically, the authors stated that they made the diagnosis based on the "presence of a slip of one vertebra on the vertebra below in the absence of a defect of the pars interarticularis." The study included 26 patients with nerve root compression secondary to degenerative slip, with 80% reporting back pain, 46% reporting chronic sciatica and 54% reporting neurogenic claudication. Sciatica tended to occur in the older patient and neurogenic claudication in the younger subject. Myelography was performed in 17 patients to detect nerve root/cauda equina compression. Although not supported by statistical analysis, the authors claimed that lateral recess stenosis was "most important." In critique of this study, the authors did not state whether patients were consecutively selected, thus it was assumed that they were nonconsecutive patients. There was no comparison of diagnostic modalities. Admittedly, in the mid- to late-1970s, plain radiographs and myelography were the most advanced imaging methods available. By default, they would have been considered gold standard diagnostic tests for degenerative spondylolisthesis and spinal stenosis. These data offer Level III diagnostic evidence that plain radiographs and myelography are useful diagnostic tests for this disorder.

Fitzgerald et al[4] described a study of 43 patients with symptomatic spondylolisthesis. It is unclear if the patients represented a consecutive or nonconsecutive series. In addition to a description of plain radiographic findings of the spine, as well as concomitant hip arthritis, the authors provided a detailed description of the presentation (symptom) pattern of the patients. In summary, they found that 34 patients had back pain without leg pain and signs of nerve root compression, five cases with leg pain with or without back pain with signs of nerve root compression, and four cases in which patients reported neurogenic claudication. As a diagnostic study, the primary imaging method was plain radiographs. However, plain myelography was also performed in 7 of the 9 patients with neurological symptoms. In critique of this study, one must presume that the patients were not consecutively enrolled. The only 2 imaging methods used were plain radiographs and myelography, which were not uniformly performed in all patients. This study provides Level III diagnostic evidence that plain radiographs and myelography are useful modalities with which to diagnose and evaluate degenerative spondylolisthesis in the lumbar spine.

Postacchini et al[6] described a study of 77 patients with degenerative spondylolisthesis in which flexion-extension radiographs, CT and/or MRI, and myelography were obtained. The various findings were reported. Dynamic radiographs "showed

hypermobility of L4 in approximately half of the cases." Myelography revealed neural structure compression in the spinal canal in all cases in which it was performed. (Note: myelography may have only been performed if patients had neurologic symptoms.) CT was useful for assessing the facet joint. MRI, CT and myelography were useful in identifying stenosis in patients with neurological symptoms. In critique, the diagnostic studies were applied inconsistently across patients. Not all patients received all studies, preventing comparison between diagnostic modalities. This article presented comprehensive descriptions of the findings with each of the diagnostic modalities. These data offer Level III diagnostic evidence of the utility of dynamic radiographs, CT, MRI and myelography for evaluation of degenerative spondylolisthesis.

Rosenberg et al[12] conducted a retrospective study which characterized 200 consecutive patients with degenerative lumbar spondylolisthesis. This cohort contained a subgroup of 39 patients with severe unremitting symptoms; 29 underwent myelography and showed an hourglass constriction of the dura at the level of slippage. Seven patients also had a protrusion. Surgical findings included absence of epidural fat, pale pulseless dura and decreased capacity of the spinal canal. In critique of this study, data were collected retrospectively and tests were not uniformly applied across patients. However, from the diagnostic perspective, this small subgroup of 29 patients provides a consecutive series of patients that was retrospectively analyzed. These subgroup data provide Level II diagnostic evidence that myelography is useful in identifying stenosis in patients with degenerative spondylolisthesis and neurological symptoms.

Satomi et al[13] reported findings from a retrospective case series of patients with degenerative spondylolisthesis who were evaluated with CT myelography in order to plan the optimal surgical procedure. CT myelograms were compared with plain radiographic myelograms to evaluate the sites of dural compression. Patients who underwent anterior lumbar interbody fusion (ALIF) were included in Group A. Patients were selected for the posterior decompression group (Group B) if their imaging showed displacement at 2 or more discs, had CT myelographic findings indicating lateral stenosis or were deemed inappropriate candidates for ALIF due to age. Group A consisted of 27 patients; discography was performed in 22. Based on the novel CT myelogram classification used in the study, 38% of these patients had stage 3 stenotic changes. Group B consisted of 14 patients, 5 of whom underwent fusion. Of these patients, 4 reported back pain; neurogenic intermittent claudication was more severe in Group B. Discography was performed in 2 patients. Based on myelogram classification used in the study, 62% of these patients had stage 3 stenotic changes. Stenosis over two disc space levels was present in 92% of these patients. The authors concluded that information on CT myelography was useful for identifying pathologic processes and for planning surgery. In critique of this study, the authors did not evaluate a list of diagnostic criteria a priori. The authors failed to indicate whether patients were selected consecutively. These data offer Level III diagnostic evidence that CT myelography is a useful imaging study for this disorder.

In patients with degenerative lumbar spondylolisthesis with associated spinal stenosis for whom MRI is either contraindicated or inconclusive, CT myelography is suggested as the most appropriate test to confirm the presence of anatomic narrowing of the spinal canal or the presence of nerve root impingement.

New Consensus Statement

Work Group Consensus Statement

In patients with degenerative spondylolisthesis with associated spinal stenosis for whom MRI and CT myelography are contraindicated, inconclusive or inappropriate, CT is suggested as the most appropriate test to confirm the presence of anatomic narrowing of the spinal canal or the presence of nerve room impingement.

New Consensus Statement

Work Group Consensus Statement

Based on NASS' *Clinical Guideline for Diagnosis and Treatment of Degenerative Lumbar Spinal Stenosis* (2011)[7], CT was demonstrated to be an effective diagnostic tool to detect degenerative lumbar spinal stenosis. As many patients included in the review had degenerative spondylolisthesis, it is logical to conclude that CT would be useful in this group as well. However, only one disease-specific study was found, necessitating reference to the NASS *Clinical Guideline on Lumbar Spinal Stenosis* to support this consensus statement.

Study included in original guideline:

Rothman et al[14] conducted a retrospective review of the CT findings of 150 patients with degenerative spondylolisthesis. The authors described the pathological findings, which included canal stenosis, facet overgrowth, joint-capsule hypertrophy, ligamentum flavum enlargement and gas within the facet joints. All patients were examined on GE 8800 CT scanners using axial scans of 5mm-thick sections at every 3mm spacing (2mm overlap), with sagittal and coronal reformats. The authors found only 19% had subluxation greater than 6mm. Severe facet degeneration with marked hypertrophy, erosive changes or gas within an irregular joint was noted in 91 patients. Severe canal stenosis was detected in 15 patients due to narrowing of the central canal secondary to a combination of subluxation, facet bony overgrowth, joint-capsule hypertrophy, ligamentous hypertrophy, bulging and end plate osteophyte formation. Foraminal stenosis was observed in 38 patients. Anterior soft tissue bulge/herniation of greater than 5mm was present in only three patients. The authors concluded that CT is useful in evaluating the severity of stenosis in patients with symptomatic degenerative spondylolisthesis. Stenosis is frequently secondary to soft tissue changes and facet hypertrophy, and does not always correlate with the

severity of slip. In critique, this was a study of nonconsecutive patients, radiological findings were not correlated with clinical signs or symptoms, and no gold standard was employed. The data offers Level IV diagnostic evidence that CT is a useful modality in the diagnosis of stenosis in patients with degenerative spondylolisthesis.

Future Directions for Research

The work group recommends prospective, appropriately powered studies to better assess the utility of supine recumbent, axial loaded and positional MRI in the detection and evaluation of stenosis in the setting of degenerative lumbar spondylolisthesis.

References

1. Cabraja M, Mohamed E, Koeppen D, Kroppenstedt S. The analysis of segmental mobility with different lumbar radiographs in symptomatic patients with a spondylolisthesis. Eur Spine J. 2012 Feb;21(2):256-61.
2. Brown MD, Lockwood JM. Degenerative spondylolisthesis. Instr Course Lect. 1983;32:162-169.
3. Cauchoix J, Benoist M, Chassaing V. Degenerative spondylolisthesis. Clin Orthop Relat Res. Mar-Apr 1976(115):122-129.
4. Fitzgerald JA, Newman PH. Degenerative spondylolisthesis. J Bone Joint Surg Br. May 1976;58(2):184-192.
5. Kanayama M, Hashimoto T, Shigenobu K, Oha F, Ishida T, Yamane S. Intraoperative biomechanical assessment of lumbar spinal instability: validation of radiographic parameters indicating anterior column support in lumbar spinal fusion. Spine. Oct 15 2003;28(20):2368-2372.
6. Postacchini F, Perugia D. Degenerative lumbar spondylolisthesis. Part I: Etiology, pathogenesis, pathomorphology, and clinical features. Ital J Orthop Traumatol. Jun 1991;17(2):165-173.
7. North American Spine Society. Diagnosis and Treatment of Degenerative Lumbar Spinal Stenosis: Evidence-Based Clinical Guidelines for Multidisciplinary Spine Care. 2011. Burr Ridge, IL. Available at: https://www.spine.org/Documents/ResearchClinicalCare/Guidelines/LumbarStenosis.pdf
8. Chaput C, Padon D, Rush J, Lenehan E, Rahm M. The significance of increased fluid signal on magnetic resonance imaging in lumbar facets in relationship to degenerative spondylolisthesis. Spine 2007;32(17):1883-1887.
9. Caterini R, Mancini F, Bisicchia S, Maglione P, Farsetti P. The correlation between exaggerated fluid in lumbar facet joints and degenerative spondylolisthesis: prospective study of 52 patients. J Orthop Traumatol. 2011 Jun;12(2):87-91.
10. Ferreiro Perez A, Garcia Isidro M, Ayerbe E, Castedo J, Jinkins JR. Evaluation of intervertebral disc herniation and hypermobile intersegmental instability in symptomatic adult patients undergoing recumbent and upright MRI of the cervical or lumbosacral spines. Eur J Radiol. 2007;62(3):444-448.
11. Ozawa H, Kanno H, Koizumi Y, Morozumi N, Aizawa T, Kusakabe T, Itoi E. Dynamic changes in the dural sac cross-sectional area on axial loaded MR imaging: is there a difference between degenerative spondylolisthesis and spinal stenosis? AJNR Am J Neuroradiol. 2012;33(6):1191-1197.
12. Rosenberg NJ. Degenerative spondylolisthesis. Predisposing factors. J Bone Joint Surg Am. Jun 1975;57(4):467-474.
13. Satomi K, Hirabayashi K, Toyama Y, Fujimura Y. A clinical study of degenerative spondylolisthesis. Radiographic analysis and choice of treatment. Spine. Nov 1992;17(11):1329-1336.
14. Rothman SL, Glenn WV, Jr., Kerber CW. Multiplanar CT in the evaluation of degenerative spondylolisthesis. A review of 150 cases. Comput Radiol. Jul-Aug 1985;9(4):223-232.

Bibliography from updated literature search

1. Bagheri MH, Hosseini MM, Foroughi AA Pseudolisthesis secondary to small L5. Eur J Radiol. 2011;80(3):802-804.
2. Been E, Li L, Hunter DJ, Kalichman L. Geometry of the vertebral bodies and the intervertebral discs in lumbar segments adjacent to spondylolysis and spondylolisthesis: Pilot study. Eur Spine J. 2011;20(7):1159-1165.
3. Boden SD. Spinescope. Semin Spine Surg. 2011;23(2):151-156.
4. Bolesta MJ, Winslow L, Gill K. A comparison of film and computer workstation measurements of degenerative spondylolisthesis: intraobserver and interobserver reliability. Spine. 2010;35(13):1300-1303.
5. Bourassa-Moreau E, Mac-Thiong JM, Labelle H. Redefining the technique for the radiologic measurement of slip in spondylolisthesis. Spine. 2010;35(14):1401-1405.
6. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD. SF-6D values stratified by specific diagnostic indication. Spine. 2012;37(13):E804-E808.
7. Carrino JA, Lurie JD, Tosteson ANA, Tosteson TD, Carragee EJ, Kaiser J, Herzog R. Lumbar spine: Reliability of MR imaging findings. Radiology. 2009;250(1):161-170.
8. Chen IR, Wei TS. Disc height and lumbar index as independent predictors of degenerative spondylolisthesis in middle-aged women with low back pain. Spine. 2009;34(13): 1402-1409.
9. Don AS, Robertson PA. Facet joint orientation in spondylolysis and isthmic spondylolisthesis. J Spinal Disord Tech. 2008;21(2), 112-115.
10. Hasegawa K, Kitahara K, Hara T, Takano K, Shimoda H, Homma T. Evaluation of lumbar segmental instability in degenerative diseases by using a new intraoperative measurement system. J Neurosur Spine. 2008;8(3):255-262.
11. Hasegawa K, Shimoda H, Kitahara K, Sasaki K, Homma T. What are the reliable radiological indicators of lumbar segmental instability? J Bone Joint Surg Br. 2011 May;93(5):650-657.
12. Huang KY, Lin RM, Lee YL., Li JD. Factors affecting disability and physical function in degenerative lumbar spondylolisthesis of L4-5: evaluation with axially loaded MRI. Eur Spine J. 2009;18(12):1851-1857.
13. Kalpakcioglu B, Altinbilek T, Senel K. Determination of spondylolisthesis in low back pain by clinical evaluation. J Back Musculoskelet Rehabil. 2009;22(1):27-32.
14. Kang CH, Shin MJ, Kim SM, Lee SH, Lee CS. MRI of paraspinal muscles in lumbar degenerative kyphosis patients and control patients with chronic low back pain. Clin Radiol. 2007;62(5):479-486.
15. Kim KS, Chin DK, Park JY. Herniated nucleus pulposus in isthmic spondylolisthesis: Higher incidence of foraminal and extraforaminal types. Acta Neurochir. 2009;151(11):1445-1450.
16. Lee JY, Hohl JB, Fedorka CJ, Devin C, Brodke DS, Branch Jr, CLJ, Vaccaro AR. Surgeons agree to disagree on surgical options for degenerative conditions of the cervical and lumbar spine. Spine. 2011;36(3):E203-E212.
17. Mariconda M, Galasso O, Imbimbo L, Lotti G, Milano C. Relationship between alterations of the lumbar spine, visualized with magnetic resonance imaging, and occupational variables. Eur Spine J. 2007;16(2):255-266.
18. Maus T. Imaging the Back Pain Patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-766.

19. Pearson A, Blood E, Lurie J, Tosteson T, Abdu WA, Hillibrand A, Weinstein J. Degenerative spondylolisthesis versus spinal stenosis: does a slip matter? Comparison of baseline characteristics and outcomes (SPORT). Spine. 2010;35(3):298-305.
20. Watters WC 3rd, Bono CM, Gilbert TJ, Kreiner DS, Mazanec DJ, Shaffer WO, et al. An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2009;9(7):609-614.
21. Yao Q, Wang S, Shin JH, Li G, Wood KB. Lumbar facet joint motion in patients with degenerative spondylolisthesis. J Spinal Disord Tech. 2013;26(1):E19-E27.

New Guideline Question:

What are the most appropriate diagnostic or physical exam tests consistent with the diagnosis of fixed versus dynamic deformity?

There is insufficient evidence to make a recommendation on the most appropriate diagnostic or physical exam test consistent with fixed or dynamic deformity in degenerative lumbar spondylolisthesis patients due to the lack of uniform reference standards which define instability.

There is no universally accepted standard to diagnose fixed versus dynamic spondylolisthesis. To evaluate instability, many studies employ the use of lateral flexion extension radiographs, which may be done in the standing or recumbent position; however, there is wide variation in the definition of instability. To assist the readers, the definitions for instability (when provided) in degenerative spondylolisthesis patients, are bolded below.

Grade of Recommendation: I (Insufficient Evidence)

In a prospective diagnostic study, Caterini et al[1] analyzed supine weight-bearing flexion–extension lumbosacral radiographs and lumbosacral MRI for 52 patients with low back pain and/or radiculopathy to determine the incidence of increased fluid in the lumbar facet joints seen on the supine axial T2 MRI and to evaluate whether this finding is correlated with radiographic evidence of lumbar instability. The patients had a mean age of 64.7 years. **Degenerative spondylolisthesis was considered positive when the vertebral slippage was greater than 4.5 mm or greater than 15% of the width of the vertebral body on flexion x-rays.** In 12 patients (23.1%) in the series, radiographic signs of degenerative lumbar spondylolisthesis were present, and in 10 of these 12, the degenerative spondylolisthesis was not evident on the sagittal MRI. In 8 cases out of 12, degenerative spondylolisthesis was present at L4–L5, and in the remaining 4 cases at L3–L4. Among these 12 patients with radiographic signs of degenerative spondylolisthesis, the MRI showed exaggerated fluid in the facet joints at the corresponding level in 8 patients (66%). Facet joint effusion was evident on MRI (range 1.5–3mm) in 7 patients (13.4%), but no radiographic signs of corresponding lumbar instability were found. Altogether, 15 patients (28.8%) presented with increased lumbar facet joint fluid on the axial T2 MRI. The authors observed a statistical correlation between increased fluid in the lumbar facet joints on the supine axial T2 MRI and degenerative spondylolisthesis seen on standing lateral flexion–extension lumbosacral radiographs. In critique of this study, the investigators did not incorporate a blinded evaluation, there was no control group of asymptomatic patients and statistical analysis comparing patients with degenerative spondylolisthesis and increased facet fluid to those without degenerative spondylolisthesis and increased facet fluid was not performed. This potential Level II study has been downgraded to III due to these limitations. This study provides level III diagnostic evidence that increased facet fluid may be associated with degenerative spondylolisthesis on lateral plain films even when not evident on MRI.

In a retrospective radiographic review, Chaput et al[2] evaluated the association between facet joint effusion found on MRI and spondylolisthesis found on standing lateral flexion-extension (SLFE) radiographs in patients with degenerative

spondylolisthesis. A total of 193 patients were studied, including 139 without degenerative spondylolisthesis and 54 with degenerative spondylolisthesis. **Degenerative spondylolisthesis was considered present if anterior translation of L4 on L5 was >5% on SLFE films.** When reviewing radiographic indicators for degenerative spondylolisthesis, it was found that degenerative spondylolisthesis patients were more likely to have synovial cysts ($p<0.0001$), higher osteoarthritis grade ($p<0.0001$) and larger effusions ($p< 0.0001$) compared to nondiseased patients. After adjusting for age and osteoarthritis grade, every 1mm increase in effusion increased the odds of having degenerative spondylolisthesis by 5.6 fold (OR=5.6). An effusion > 1.5mm was not found in the negative degenerative spondylolisthesis group, and the authors suggest that an effusion > 1.5mm is highly predictive of degenerative spondylolisthesis. Using facet effusion as the only variable in univariate logistic regression, the probability of having spondylolisthesis when 1mm effusion was present on MRI was 29.6%, 60.3% when 2mm of effusion was present and 84.6% when 3mm of effusion was present. This study provides Level II diagnostic evidence that there is a probability of progressive spondylolisthesis with increasing facet joint effusion size, even if spondylolisthesis is not evident on supine MRI. MRI findings of large facet effusion and synovial cysts are suggestive of degenerative spondylolisthesis.

Hammouri et al[3] conducted a retrospective radiographic review to assess use of lateral dynamic flexion-extension radiographs in the initial evaluation of patients with degenerative lumbar deformities. Anteroposterior and lateral lumbar radiographs were taken with the patients in their natural posture. Flexion and extension lumbar films were taken by asking the patient to achieve his or her maximum effort at flexion and extension in the standing position. **The measurement of spondylolisthesis was made by determining the relative AP distance between the posterior borders of adjacent vertebral bodies. A minimum measurement of 2mm was used to achieve this definition.** In review of the spondylolisthesis patients, 67 (20%) patients had anterolisthesis and 46 (13%) had retrolisthesis, including 54% at L4-5 and 31% at L5-S1. Only 2 out of 342 patients had new findings on flexion/extension not visible on anteroposterior and lateral lumbar radiographs. Fifteen patients had change in degree of listhesis with flexion/extension/ anteroposterior/lateral lumbar radiograph, without any change in their Meyerding grade. This study provides Level II diagnostic evidence that standing lateral extension films are not indicated in patients who do not demonstrate a degenerative spondylolisthesis on standing radiograph.

Cho et al[4] assessed the correlatation between the degree of L4–5 spondylolisthesis on plain flexion-extension radiographs and the corresponding amount of L4–5 facet fluid visible on MR images. Only patients diagnosed with L4–5 degenerative spondylolisthesis (DS) and who had both lumbosacral flexion-extension radiographs and MR images available for review were eligible for this study. The authors did not provide a specific definition for a positive diagnosis of degenerative spondylolisthesis. Dynamic motion index (DMI) was measured using the lateral lumbosacral plain radiograph and calculated as the percentage of the degree of anterior slippage seen on flexion versus that seen on extension. Axial T2-weighted MR images of the L4–5 facet joints were analyzed for the amount of facet fluid using the image showing the widest portion of the facets. The facet fluid index was calculated from the ratio of the sum of the amounts of facet fluid found in the right plus left facets over the sum of the average widths of the right plus left facet joints. Facet fluid was noted on MR images in 29 of 54 patients (53.7%) with a mean DMI of 6.349 ± 2.726. Patients without facet fluid on MR imaging had a mean DMI of 1.542 ± 0.820. The difference between the mean DMI's of patients with and without facet fluid on MR imaging was statistically significant ($p < 0.001$). In the patients who exhibited facet fluid on MRI, there was a positive linear association between the facet fluid index and DMI (Pearson correlation coefficient 0.560, $p < 0.01$). In the subgroup of 29 patients with L4–5 DS and facet fluid on MR images, flexion-extension plain radiographs showed anterolisthesis in 10 (34.5%) patients, but corresponding MR images did not show anterolisthesis. The authors conclude that there is a linear correlation between the degree of segmental motion seen on flexion-extension plain radiography in patients with DS at L4–5 and the amount of L4–5 facet fluid on MR images. If L4–5 facet fluid is seen on MR images in DS patients, a corresponding anterolisthesis on weight-bearing flexion-extension lateral radiographs should also been seen. In critique of this study, it is unclear whether the patients included were consecutive. This study provides Level III diagnostic evidence that when facet fluid is present, the use of weight-bearing flexion-extension plain radiography will prevent the clinician from missing the anterior slippage caused by a hypermobile segment of the lumbar spine not visualized on a supine MR image.

D'Andrea et al[5] evaluated the use of the supine-prone position in performing dynamic x-ray examination in patients with low grade spondylolisthesis. **Segmental lumbar instability was defined as translation movement exceeding 3 mm from flexion to extension and supine to prone.** A total of 75 patients had a standard lateral x-ray films in the supine position, and then in the prone position. At supine-prone examination, the authors observed 46 patients with grade I spondylolisthesis versus only 32 positive cases at standard dynamic examination, 29 versus 24 grade I-II spondylolisthesis, and the 19 negative results, prior observed, disappeared. Nineteen patients had new diagnosis of spondylolisthesis, 19 had higher grade of spondylolisthesis and 56 had no change in diagnosis. In critique, it is unclear whether the patients were consecutive and how many patients had a diagnosis of degenerative spondylolisthesis. This study provides Level III diagnostic evidence that using the supine-prone position for performing a dynamic x-ray examination is simple, safe and economically effective in diagnosis lumbar spinal instability in patients with degenerative spondylolisthesis.

In a retrospective radiographic study, Lattig et al[6] evaluated whether facet joint effusion seen on supine MRI was an indicator of increased abnormal motion in patients with degenerative spondylolisthesis and rotational translation. The sample included 160 patients with degenerative spondylolisthesis and varying degrees of narrowing of the spinal canal who had undergone decompression only or decompression with instrumented fusion. All patients had preoperative upright x-ray films in AP and lateral views and supine MRI. A cut off value of >3% was arbitrarily chosen to represent the threshold for a real difference.

The imaging studies were assessed for the following parameters: percent of slippage, absolute value of facet joint effusion, facet angles, degree of facet degeneration and spinal canal central narrowing, disc height, presence of facet cysts and the presence of rotational translation in the AP x-ray study. Results indicated that both mean and maximum facet joint effusion were significantly greater ($p = 0.0001$) in the group with >3% MRI–x-ray slip difference than in the <3% group. In the group with <3% MRI–x-ray slip difference, there was a significantly lower proportion of facet joint cysts ($p = 0.045$) and a lower mean facet joint angle ($p = 0.04$) compared to the group with >3% slip difference. According to findings, the extent of effusion correlated significantly with the relative slippage difference between standing and supine positions ($r = 0.64$, $p<0.001$). The extent of the left/right difference in effusion was also found to be associated with the presence of rotational translation (RT 1.31 ± 0.8mm vs. no-RT 0.23 ± 0.17mm, $p<0.0001$). The authors suggest that in degenerative spondylolisthesis, facet joint effusion on MRI and reduction in slip between standing x-ray and supine MRI should be used in surgical decision making. This study provides Level III diagnostic evidence that there is a significant correlation between the extent of effusion of the facet joints on MRI and the difference in the degree of slippage between the standing and lying positions in patients with degenerative spondylolisthesis.

Ozawa et al[7] compared the dural sac cross sectional area (DCSA) in patients with degenerative spondylolisthesis and spinal stenosis on axially loaded MR imaging. All patients had neurogenic intermittent claudication and leg pain or numbness with associated neurologic signs and had radiographically confirmed lumbar spinal canal narrowing on cross-sectional imaging. **For the comparative analysis in this study, the patients with >3mm spondylolisthesis were assigned to the degenerative spondylolisthesis group, while the other patients were assigned to the spinal stenosis group.** A total of 88 patients were included in the study, including 40 with degenerative spondylolisthesis patients. All patients received MR imaging. After conventional MR imaging, axial loading was applied by using an external commercially available nonmagnetic compression device. The DCSA was measured from the L2/3 to L5/S1 on the axial image. The measurement was performed three times and the mean value was calculated and used for analysis in this study. Results indicated that a >15mm^2 change in the DCSA was found in 8 patients (16.7%) in the spinal stenosis group and 25 patients (62.5%) in the degenerative spondylolisthesis group. In the degenerative spondylolisthesis group, patients with a >15mm^2 change had a significantly larger DCSA on conventional MR imaging (58 ± 26 mm^2) than those with a <15mm^2 change (41 ± 18 mm^2) ($p=0.028$), while the axial loaded MR imaging showed no significant difference between the patients with a >15 and a <15mm^2 change in the DCSA ($p=0.897$). The authors conclude that DCSA in patients with degenerative spondylolisthesis is more likely to be decreased by axial loading than in those with spinal stenosis and that axial loaded MRI may be a more useful tool to provide valuable imaging findings for the assessment of spinal canal narrowing in patients with degenerative spondylolisthesis than those with spinal stenosis. In critique, use of a 15mm^2 criterion as significant change in DCSA is not a universally accepted diagnostic standard; therefore, this study has been downgraded from Level II to III. This study provides Level III diagnostic evidence that axially loaded MRI may reveal more severe stenosis in patients with degenerative spondylolisthesis than might be apparent on conventional MRI.

Tokuhashi et al[8] analyzed the utility of the treadmill provocation test in evaluating clinical lumbar instability. A total of 82 patients were included in the study, including 18 degenerative spondylolisthesis patients, 17 herniated lumbar disc patients, 10 isthmic spondylolisthesis patients and 37 canal stenosis patients. The treadmill exercise began at a speed of 0.6 mile/hr and gradually accelerated up to 1.8 mile/hr at different rates depending on the patient's age and symptoms. The symptoms elicited by the treadmill exercise, such as low-back pain, pain of the lower extremities and intermittent claudication, were analyzed and divided into groups. The 0 group had no symptoms after 10 minutes; the 1+ group reproduced symptoms after treadmill exercise with the same distances of walking that formally elicited symptoms on a flat road; the 2+ group reproduced symptoms after far less exercise; and the 3+ group were unusually and severely induced symptoms that had not occurred when the patient was walking on a flat road. The authors utilized radiographs to compare the symptoms after treadmill exercise to the segmental abnormality of the lumbar spine on radiographs. Results indicated that symptoms were elicited at a relatively higher rate in patients with degenerative spondylolisthesis. The dynamic abnormality of segmental movement was evaluated as translational movement over 3mm anteriorly or posteriorly, or abnormal tilting movement on the flexion-extension radiograph. Patients with instability/movement on flexion-extension radiograph did not correlate with treadmill provocation. The reproduction rates of symptoms after treadmill exercise were more affected in the clinical symptomatic instability than in the findings of abnormal structure or movement on the radiograph. In critique, this study had a small sample size, it is unclear whether the patients were consecutive **and it's important to note that this study is evaluating clinical instability, not radiographic instability.** This study provides Level III diagnostic evidence that the treadmill provocation test can be useful in evaluating the lumbar spine.

Ferreiro-Perez et al[9] evaluated the differences in imaging findings between recumbent and upright-sitting MRI of the cervical and lumbosacral spine. A total of 89 patients were included in the analysis including, 45 lumbosacral spine patients and 44 cervical spine patients. When determining pathology, degenerative spondylolisthesis was seen in 13 patients, including 11 anterior and 2 posterior; however, the authors' definition of degenerative spondylolisthesis was not provided. Anterior spondylolisthesis was only seen on the upright-sitting examination in 4 patients (31%). Anterior spondylolisthesis was comparatively greater in degree on the upright-seated study in 7 patients (54%). Posterior spondylolisthesis was comparatively greater in degree on the recumbent examination in 2 patients (15%). The authors suggest that the upright-seated MRI was found to be superior to recumbent MRI. In critique of this study, the sample size was small, it was unclear which patients received which type of MRI, and statistical analysis of results was not performed. Due to these limitations, this potential Level III study has been downgraded to a Level IV. This study provides Level IV diagnostic evidence that upright-seated MRI may be superior to recumbent MRI of

the spine in cases of anterior spondylolisthesis. The seated upright MRI may make anterior spondylolisthesis more visible when compared to supine MRI; however, the significance of this finding is unclear.

Friberg et al[10] conducted a radiographic analysis to study the dynamic behavior of the lumbar spine segments when subject to traction and compression. A total of 117 patients were included in the study; however, only 7 patients had the diagnosis of degenerative spondylolisthesis. Patients were examined for segmental translatory instability using a new method in which lateral spot radiographs of the lumbosacral spine were taken during axial traction and compression. Axial compression of the spine was brought about by positioning the patient to stand erect with a sac filled with 20kg of sand. The lumbar spine was subjected to gravitational traction by patients suspended from a horizontal bar. The compressive force consisted of the weight of the entire torso, compressive preloads, and the extra load of 20kg. During the evaluation, every patient could carry the 20kg load without difficulty during the radiographic tests, but one female patient was unable to hang from the bar because of a stiff and painful shoulder. As a sign of instability, distinct movement was found in patient with degenerative spondylolisthesis of L4. **The mean amount of malalignment was 8mm (SD-1.3mm). The mean amount of translatory movement at the spondylolisthetic level, measured on traction-compression radiography, was 6.2mm (SD=1.7mm).** In critique, the degenerative spondylolisthesis sample size was small, there was no clear comparison with a control group and the gold standard of lateral flexion-extension x-ray films were not used. This potential Level III study provides Level IV diagnostic evidence that traction-compression radiography of the lumbar spine can be used to assess for translational instability.

McGregor et al[11] conducted a radiographic study to investigate patterns of intervertebral mobility (using flexion-extension positions in open MRI) in subjects with spondylolisthesis to determine the level of spinal instability. In this case-control study, 29 patients, including 15 with a diagnosis of isthmic spondylolisthesis and 14 with a diagnosis of degenerative spondylolisthesis, were enrolled and compared with a preexisting database of 12 patients with no history of back pain (controls). The motion characteristics of these patients in flexed and extended positions were investigated using open MRI of known precision. In all of the subjects, the level of resting pain, grade of slip, and level of defect were evaluated. No mobility differences of angular or translatory motion were found between the spondylolisthesis (degenerative or isthmic) group and asymptomatic controls. It is unclear how patients were recruited to this study and whether there was consecutive enrollment. The authors concluded that there is no evidence to support that subjects with spondylolisthesis will have an unstable spine. This study provides Level IV diagnostic evidence that the presence of degenerative spondylolisthesis does not lead to hypermobility. Additionally, this study suggests that dynamic MRI may not be able to differentiate between dynamic and fixed deformity.

In a case-control study, Oishi et al[12] assessed which factors determined whether the involved disc levels were restabilized (from initial assessment to the time of surgery) or remained unstable at the time of operation in 195 consecutive Japanese patients with degenerative lumbar spondylolisthesis. Patients who had received laminectomy with or without fusion for progressed degenerative spondylolisthesis, defined as slip percentage >10% at lateral flexion position with spinal canal stenosis, were included in the study. **Sagittal plane unstable motion was defined according to the criteria that translatory displacement was > 4mm (translatory hypermobility) or rotatory displacement was >10° (rotatory hypermobility).** The following 9 parameters were investigated retrospectively as the candidate factors to determine whether the affected segments were restabilized or not at the time of operation: age, sex, BMI, disc level, grade of disc degeneration, grade of disc spur formation, facet effusion size, length of facet spur formation and angle between facets. Radiographic measurements were taken by x-ray, CT and MRI. Multiple regression analysis for all candidate factors (except for sex and disc level) indicated that translatory displacement significantly correlated with facet effusion size positively ($p < 0.001$), and that rotatory displacement significantly correlated with facet effusion size positively ($p < 0.001$) and with age ($p = -0.042$) and grade of disc degeneration ($p = -0.033$) negatively. Logistic regression analysis for all candidate factors demonstrated that increased facet effusion size (OR 1.656, 95% CI 1.182–2.321) was the only independent factor for the presence of unstable motion at the time of operation. This study provides Level IV diagnostic evidence that facet effusion size is correlated to translational instability (translator displacement >4mm).

Future Directions For Research

The work group identified the following potential studies that would generate meaningful evidence to assist in defining the most appropriate diagnostic or physical exam tests consistent with the diagnosis of fixed versus dynamic deformity in patients with degenerative lumbar spondylolisthesis:

Recommendation #1:

Future studies are needed to establish a consistent, universally agreed upon reference standard for instability with a confirmed validated clinical relevance.

Recommendation #2:

The diagnosis of instability needs to be further validated by correlation with symptom severity, prognosis and response to treatment.

References

1. Caterini R, Mancini F, Bisicchia S, Maglione P, Farsetti P. The correlation between exaggerated fluid in lumbar facet joints and degenerative spondylolisthesis: Prospective study of 52 patients. J Orthop Traumatol. 2011;12(2):87-91.
2. Chaput C, Padon D, Rush J, Lenehan E, Rahm M. The significance of increased fluid signal on magnetic resonance imaging in lumbar facets in relationship to degenerative spondylolisthesis. Spine. 2007;32(17):1883-1887.
3. Hammouri QM, Haims AH, Simpson AK, Alqaqa A, Grauer JN. The utility of dynamic flexion-extension radiographs in the initial evaluation of the degenerative lumbar spine. Spine. 2007;32(21):2361-2364.
4. Cho BY, Murovic JA, Park J. Imaging correlation of the degree of degenerative L4-5 spondylolisthesis with the corresponding amount of facet fluid: Clinical article. J Neurosurg Spine. 2009;11(5): 614-619.

5. D'Andrea G, Ferrante L, Dinia L, Caroli E, Orlando ER. "Supine-prone" dynamic X-ray examination: new method to evaluate low-grade lumbar spondylolisthesis. J Spinal Disord Tech. 2005;18(1):80-83.
6. Lattig F, Fekete TF, Grob D, Kleinstück FS, Jeszenszky D, Mannion AF Lumbar facet joint effusion in MRI: A sign of instability in degenerative spondylolisthesis? Eur Spine J. 2012;21(2):276-281.
7. Ozawa H, Kanno H, Koizumi Y, Morozumi N, Aizawa T, Kusakabe T, Itoi E. Dynamic changes in the dural sac cross-sectional area on axial loaded MR imaging: is there a difference between degenerative spondylolisthesis and spinal stenosis? AJNR Am J Neuroradiol. 2012;33(6):1191-1197.
8. Tokuhashi Y, Matsuzaki H, Sano S. Evaluation of clinical lumbar instability using the treadmill. Spine. 1993;18(15):2321-2324.
9. Ferreiro Perez A, Garcia Isidro M, Ayerbe E, Castedo J, Jinkins JR. Evaluation of intervertebral disc herniation and hypermobile intersegmental instability in symptomatic adult patients undergoing recumbent and upright MRI of the cervical or lumbosacral spines. Eur J Radiol. 2007;62(3):444-448.
10. Friberg O. Lumbar instability: A dynamic approach by traction-compression radiography. Spine. 1987;12(2):119-129.
11. McGregor AH, Anderton L, Gedroyc WMW, Johnson J, Hughes SPF. The use of interventional open MRI to assess the kinematics of the lumbar spine in patients with spondylolisthesis. Spine. 2001;27(14):1582-1586.
12. Oishi Y, Murase M, Hayashi Y, Ogawa T, Hamawaki JI. Smaller facet effusion in association with restabilization at the time of operation in Japanese patients with lumbar degenerative spondylolisthesis: Clinical article. J Neurosurg Spine. 2010;12(1):88-95.

Bibliography

1. Acosta FL Jr, Thompson TL, Campbell S, Weinstein PR, Ames CP. Use of intraoperative isocentric C-arm 3D fluoroscopy for sextant percutaneous pedicle screw placement: Case report and review of the literature. Spine J. 2005;5(3):339-343.
2. Adachi K, Futami T, Ebihara A, Yamaya T, Kasai N, Nakazawa T, Imura T. Spinal canal enlargement procedure by restorative laminoplasty for the treatment of lumbar canal stenosis. Spine J. 2003;3(6):471-478.
3. Aiki H, Ohwada O, Kobayashi H, Hayakawa M, Kawaguchi S, Takebayashi T, Yamashita T. Adjacent segment stenosis after lumbar fusion requiring second operation. J Orthop Sci. 2003;10(5):490-495.
4. Atlas SJ, Delitto A. Spinal stenosis: Surgical versus nonsurgical treatment. Clin Orthop Relat Res. 2006;(443):198-207.
5. Axelsson P, Johnsson R, Strömqvist B. Is there increased intervertebral mobility in isthmic adult spondylolisthesis? A matched comparative study using roentgen stereophotogrammetry. Spine. 2000;25(13), 1701-1703.
6. Baker ADL, Sanderson P. Spinal surgery in older people: Indications, techniques and outcomes. Rev Clin Gerontol., 2011;21(4), 277-285.
7. Bashir EF, Ajani O. (2012). Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-146.
8. Belfi LM, Ortiz AO, Katz DS. Computed tomography evaluation of spondylolysis and spondylolisthesis in asymptomatic patients. Spine. 2006;31(24), E907-910.
9. Bendo JA, Ong B. Importance of correlating static and dynamic imaging studies in diagnosing degenerative lumbar spondylolisthesis. Am J Orthop. 2001;30(3):247-250.
10. Benini A, Plotz G. Reduction and stabilization without laminectomy for unstable degenerative spondylolisthesis: a preliminary report. Neurosurgery. 1995;37(4):843-844.
11. Bjarke Christensen F, Stender Hansen E, Laursen M, Thomsen K, Bünger CE. Long-term functional outcome of pedicle screw instrumentation as a support for posterolateral spinal fusion: Randomized clinical study with a 5-year follow-up. Spine. 2002;27(12):1269-1277.
12. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2)133-137.
13. Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis. Instr Course Lect. 1989;38:157-165.
14. Bono CM, Lee CK. The influence of subdiagnosis on radiographic and clinical outcomes after lumbar fusion for degenerative disc disorders: an analysis of the literature from two decades. Spine 2005;30(2):227-234.
15. Brown MD, Wehman KF, Heiner AD. The clinical usefulness of intraoperative spinal stiffness measurements. Spine. 2002;27(9):959-961.
16. Cansever T, Civelek E, Kabatas S, Ylmaz C, Caner H, Altinrs MN. Dysfunctional segmental motion treated with dynamic stabilization in the lumbar spine. World Neurosurg. 2011;75(5-6):743-749.
17. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD. SF-6D values stratified by specific diagnostic indication. Spine. 2012;37(13):E804-E808.
18. Cauchoix J, Benoist M, Chassaing V. Degenerative spondylolisthesis. Clin Orthop Relat Res. 1976 Mar-Apr;(115):122-129.
19. Çavuşoğlu, H., Türkmenoğulu O, Kaya RA, Tuncer C, Çolak I, Şahin Y, Aydin Y. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-108.
20. Crawford CH, Smail J, Carreon LY, Glassman SD. Health-related quality of life after posterolateral lumbar arthrodesis in patients seventy-five years of age and older. Spine. 2011;36(13):1065-1068.
21. D'Andrea G, Ferrante L, Dinia L, Caroli E, Orlando ER. "Supine-prone" dynamic X-ray examination: new method to evaluate low-grade lumbar spondylolisthesis. J Spinal Disord Tech. 2005;18(1):80-83.
22. Dean, CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6), 439-446.
23. DeWald CJ, Vartabedian JE, Rodts MF, Hammerberg KW. Evaluation and management of high-grade spondylolisthesis in adults. Spine. 2005;30(6 Suppl):S49-59.
24. Dimar JR, Djurasovic M, Carreon, LY. Surgical management of degenerative and postsurgical spondylolisthesis. Semin Spine Surg. 2005;17(3):186-194.
25. Dong YL, Jung TG, Lee SH. Single-level instrumented mini-open transforaminal lumbar interbody fusion in elderly patients. J Neurosurg Spine. 2008;9(2):137-144.
26. Dupuis PR, Yong-Hing K, Cassidy JD, Kirkaldy-Willis WH. Radiologic diagnosis of degenerative lumbar spinal instability. Spine. 1985;10(3):262-276.
27. Elhawary Y, Azzazi A. Dynamic stabilization using X-stop vs. trans-pedicular screw fixation in the treatment of lumbar canal stenosis: Comparative study of the clinical outcome. Spine J. 2010;10(9):S130.
28. Epstein NE. Evaluation of varied surgical approaches used in the management of 170 far-lateral lumbar disc herniations: Indications and results. J Neurosurg. 1995;83(4):648-656.
29. Epstein NE. Primary fusion for the management of 'unstable' degenerative spondylolisthesis. Neuro-Orthopedics. 1998;23(1-2):45-52.
30. Epstein NE. Lumbar Laminectomy for the Resection of Synovial Cysts and Coexisting Lumbar Spinal Stenosis or Degenerative Spondylolisthesis: An Outcome Study. Spine.

2004;29(9):1049-1055.
31. Epstein NE. An analysis of noninstrumented posterolateral lumbar fusions performed in predominantly geriatric patients using lamina autograft and beta tricalcium phosphate. Spine J. 2008;8(6):882-887.
32. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech., 2010;23(4):236-241.
33. Ferrari S, Costa F, Fornari M. Conservative treatment with spontaneous stabilization of Grade II isthmic spondylolisthesis L5/S1 in a forty-four-year old woman, with a six-year follow-up: a case report. Eur J Phys Rehabil Med., 2012;48(2):275-281.
34. Fitzgerald JAW, Newman PH. Degenerative spondylolisthesis. J Bone Joint Surg Br. 1976;58(2):184-192.
35. Flynn JC, Hoque MA. Anterior fusion of the lumbar spine. End-result study with long-term follow-up. J Bone Joint Surg Am. 1979;61(8):1143-1150.
36. Fraser J, Gebhard, H., Irie, D., Parikh, K., & Härtl, R. Iso-C/3-dimensional neuronavigation versus conventional fluoroscopy for minimally invasive pedicle screw placement in lumbar fusion. Minim Invasive Neurosurg. 2010;53(4):184-190.
37. Friberg O. Lumbar instability: A dynamic approach by traction-compression radiography. Spine 1987;12(2):119-129.
38. Fujiya M, Saita M, Kaneda K, Abumi K. Clinical study on stability of combined distraction and compression rod instrumentation with posterolateral fusion for unstable degenerative spondylolisthesis. Spine. 1990;15(11):1216-1222.
39. Gaetani P, Aimar E, Panella L, Levi D, Tancioni F, Di Leva A, Rodriguez y Baena R. Functional disability after instrumented stabilization in lumbar degenerative spondylolisthesis: A follow-up study. Funct. Neurol. 2006;21(1):31-37.
40. Gelalis ID, Kang JD. Thoracic and lumbar fusions for degenerative disorders: Rationale for selecting the appropriate fusion techniques. Orthop Clin N Am. 1998;29(4):829-842.
41. Gertzbein SD, Seligman J, Holtby R, Chan KH, Kapasouri A, Tile M, Cruickshank B. Centrode patterns and segmental instability in degenerative disc disease. Spine. 1985;10(3):257-261.
42. Ghiselli G, Wang JC, Hsu WK, Dawson EG. L5-S1 segment survivorship and clinical outcome analysis after L4-L5 isolated fusion. Spine. 2003;28(12):1275-1280.
43. Glassman SD, Carreon LY, Djurasovic M, Dimar JR, Johnson JR, Puno RM, Campbell MJ. Lumbar fusion outcomes stratified by specific diagnostic indication. Spine J. 2009;9(1):13-21.
44. Haberl H, Cripton PA, Orr TE, Beutler T, Frei H, Lanksch WR, Nolte LP. Kinematic response of lumbar functional spinal units to axial torsion with and without superimposed compression and flexion/extension. Eur Spine J. 2004;13(6):560-566.
45. Hahn F, Kissling R, Weishaupt D, Boos N. The extremes of spinal motion: A kinematic study of a contortionist in an open-configuration magnetic resonance scanner: Case report. Spine. 2006;31(16):E565-E567.
46. Hambly MF, Wiltse LL, Raghavan N, Schneiderman G, Koenig C. The transition zone above a lumbosacral fusion. Spine. 1998;23(16):1785-1792.
47. Hanley Jr EN. The indications for lumbar spinal fusion with and without instrumentation. Spine. 1995;20(24 SUPPL.):143S-153S.
48. Hanley Jr EN. Indications for fusion in the lumbar spine. Bull Hosp Jt Dis. 1996;55(3):154-157.
49. Hasegawa K, Kitahara K, Hara T, Takano K, Shimoda H, Homma T. Evaluation of lumbar segmental instability in degenerative diseases by using a new intraoperative measurement system. J Neurosurg Spine. 2008;8(3):255-262.
50. Hasegawa K, Kitahara K, Shimoda H, Hara T. Facet joint opening in lumbar degenerative diseases indicating segmental instability: Clinical article. J Neurosurg Spine. 2010;12(6):687-693.
51. Hasegawa K, Shimoda H, Kitahara K, Sasaki K, Homma T. What are the reliable radiological indicators of lumbar segmental instability? J Bone Joint Surg Br. 2011 May;93(5):650-657.
52. Hashimoto T, Oha F, Shigenobu K, Kanayama M, Harada M, Ohkoshi Y, Yamane S. Mid-term clinical results of Graf stabilization for lumbar degenerative pathologies. a minimum 2-year follow-up. Spine J. 2001;1(4):283-289.
53. Heo DH, Cho YJ, Cho SM, Choi HC, Kang SH. Adjacent segment degeneration after lumbar dynamic stabilization using pedicle screws and a nitinol spring rod system with 2-year minimum follow-up. J Spinal Disord Tech. 2012;25(8): 409-414.
54. Herkowitz HN, Abraham DJ, Albert TJ. Management of degenerative disc disease above an L5-S1 segment requiring arthrodesis. Spine. 199924(12):1268-1270.
55. Hilibrand AS, Rand N. Degenerative lumbar stenosis: diagnosis and management. J Am Acad Orthop Surg. 1999;7(4):239-249.
56. Hirabayashi S, Kumano K, Kuroki T. Cotrel-Dubousset pedicle screw system for various spinal disorders: Merits and problems. Spine. 1991;16(11):1298-1304.
57. Hrabálek L, Wanek T, Adamus M. Treatment of Degenerative Spondylolisthesis of the Lumbosacral Spine by Decompression and Dynamic Transpedicular Stabilisation. Acta Chir Orthop Traumatol Cech. 2011;78(5):431-436.
58. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-175.
59. Huang KY, Lin RM, Lee YL, Li JD. Factors affecting disability and physical function in degenerative lumbar spondylolisthesis of L4-5: evaluation with axially loaded MRI. Eur Spine J. 2009;18(12):1851-1857.
60. Ibrahimi DM, Beaty NB, Crandall KM, Hamilton DK, Sansur CA. A review of lumbar spondylolisthesis. Eur Musculoskel Rev. 2011;6(2):110-113.
61. Ido K, Urushidani H. Radiographic evaluation of posterolateral lumbar fusion for degenerative spondylolisthesis: long-term follow-up of more than 10 years vs. midterm follow-up of 2-5 years. Neurosurg Rev. 2001;24(4):195-199.
62. Ikuta K, Tono O, Oga M. Prevalence and clinical features of intraspinal facet cysts after decompression surgery for lumbar spinal stenosis: Clinical article. J Neurosurg Spine. 2009;10(6):617-622.
63. Ito K. Reviewer's comments concerning "biomechanical evaluation of segmental instability in degenerative lumbar spondylolisthesis" by K. Hasegawa et al. (ESJO-D-08-00441R1). Eur Spine J. 2009;18(4):471-472.
64. Iwamoto J, Takeda T. Effect of surgical treatment on physical activity and bone resorption in patients with neurogenic intermittent claudication. J Orthop Sci. 7(1):84-90.
65. Jayakumar P, Nnadi C, Saifuddin A, Macsweeney E, Casey A. Dynamic degenerative lumbar spondylolisthesis: diagnosis with axial loaded magnetic resonance imaging. Spine. 2006;31(10):E298-301.
66. Jiang SD, Jiang LS, Dai LY. Degenerative cervical spondylolisthesis: a systematic review. Int Orthop. 2011;35(6):869-875.
67. Jinkins JR. Acquired degenerative changes of the intervertebral segments at and supradjacent to the lumbosacral junction: A radioanatomic analysis of the discal and nondiscal structures of the spinal column and perispinal soft tissues. Neuroradiol J. 2002;15(4):359-392.
68. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17(3):327-335.

69. Kamioka Y, Yamamoto H. Lumbar trapezoid plate for lumbar spondylolisthesis. A clinical study on preoperative and postoperative instability. Spine. 1990;15(11):1198-1203.
70. Kanayama M, Hashimoto T, Shigenobu K, Oha F, Ishida T, Yamane S. Intraoperative biomechanical assessment of lumbar spinal instability: Validation of radiographic parameters indicating anterior column support in lumbar spinal fusion. Spine. 2003;28(20):2368-2372.
71. Kaner T, Dalbayrak S, Oktenoglu T, Sasani M, Aydin AL, Ozer AF. Comparison of posterior dynamic and posterior rigid transpedicular stabilization with fusion to treat degenerative spondylolisthesis. Orthopedics. 2010;33(5).
72. Kang BU, Choi WC, Lee SH, Sang HJ, Jong DP, Dae HM, Choi YG. An analysis of general surgery-related complications in a series of 412 minilaparotomic anterior lumbosacral procedures: Clinical article. J Neurosurg Spine. 2009;10(1):60-65.
73. Kauppila LI, Eustace S, Kiel DP, Felson DT, Wright AM. Degenerative displacement of lumbar vertebrae: A 25-year follow-up study in Framingham. Spine. 1998;23(17): 1868-1874.
74. Khan AM, Girardi F. Spinal lumbar synovial cysts. Diagnosis and management challenge. Eur Spine J. 2006;15(8), 1176-1182.
75. Khan AM, Synnot K, Cammisa FP, Girardi FP. Lumbar synovial cysts of the spine: An evaluation of surgical outcome. J Spinal DisordTech. 2005;18(2): 127-131.
76. Kim SY, Maeng DH, Lee SH, Jang JS. Anterior lumbar interbody fusion for lumbosacral junction in steep sacral slope. J Spinal Disord Tech. 2008;21(1), 33-38.
77. Kirkman MA, Sridhar K. Posterior listhesis of a lumbar vertebra in spinal tuberculosis. Eur Spine J. 2011;20(1):1-5.
78. Klopfenstein JD, Kim LJ, Feiz-Erfan I, Dickman CA. Retroperitoneal approach for lumbar interbody fusion with anterolateral instrumentation for treatment of spondylolisthesis and degenerative foraminal stenosis. Surg Neurol. 2006;65(2):111-116.
79. Konno S, Kikuchi S. Prospective study of surgical treatment of degenerative spondylolisthesis: comparison between decompression alone and decompression with graf system stabilization. Spine 2000;25(12):1533-1537.
80. Kristof RA, Aliashkevich AF, Schuster M, Meyer B, Urbach H, Schramm J. Degenerative lumbar spondylolisthesis-induced radicular compression: Nonfusion-related decompression in selected patients without hypermobility on flexion-extension radiographs. J Neurosurg. 2002;97(3 SUPPL.):281-286.
81. Kroppenstedt S, Gulde M, Schönmayr R. Radiological comparison of instrumented posterior lumbar interbody fusion with one or two closed-box plasmapore coated titanium cages: Follow-up study over more than seven years. Spine. 2008;33(19):2083-2088.
82. Kuroki H, Tajima N, &Kubo, S. Clinical results of posterolateral fusion for degenerative lumbar spinal diseases: A follow-up study of more than 10 years. J Orthop Sci. 2003;7(3), 317-324.
83. Lawhorne III TW, Girardi FP, Mina CA, Pappou I, Cammisa Jr FP Treatment of degenerative spondylolisthesis: Potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-822.
84. Lee SE, Park SB, Jahng TA, Chung CK, Kim HJ. Clinical experience of the dynamic stabilization system for the degenerative spine disease. J Kor Neurosurg Soc., 2008;43(5):221-226.
85. Lee SH, Kang BU, Sang HJ, Jong DP, Dae HM, Choi YG, Choi WC. Revision surgery of the lumbar spine: Anterior lumbar interbody fusion followed by percutaneous pedicle screw fixation. J Neurosurg Spine. 2006;5(3):228-233.
86. Lee SH, Lee JH, Hong SW, Chung SE, Yoo SH, Lee HY. Spinopelvic alignment after interspinous soft stabilization with a tension band system in grade 1 degenerative lumbar spondylolisthesis. Spine. 2010;35(15):E691-701.
87. Lee SH, Lee JH, Hong SW, Shim CS, Chung SE, Yoo SH, Lee HY. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7): 563-572.
88. Lee TC. Reduction and stabilization without laminectomy for unstable degenerative spondylolisthesis: a preliminary report. Neurosurgery. 1994;35(6):1072-1076.
89. Leone A, Cianfoni A, Cerase A, Magarelli N, Bonomo L. Lumbar spondylolysis: A review. Skeletal Radiol. 2011;40(6):683-700.
90. Liao JC, Chen WJ, Chen LH, Niu CC. Outcome of the L5-S1 segment after posterior instrumented spinal surgery in degenerative lumbar diseases. Chang Gung Med J. 2009;32(1):81-88.
91. Mahmud T, Basu D, Dyson PH. Crystal arthropathy of the lumbar spine: a series of six cases and a review of the literature. J Bone Joint Surg Br. 2005;87(4), 513-517.
92. Malter AD, McNeney B, Loeser JD, Deyo RA. 5-year reoperation rates after different types of lumbar spine surgery. Spine. 1998;23(7):814-820.
93. Margulies JY, Seimon LP. Clinical efficacy of lumbar and lumbosacral fusion using the Boucher facet screw fixation technique. Bull Hosp Jt Dis. 2000;59(1): 33-39.
94. Mariconda M, Fava R, Gatto A, Longo C, Milano C. Unilateral laminectomy for bilateral decompression of lumbar spinal stenosis: a prospective comparative study with conservatively treated patients. 2002 Feb;15(1):39-46.
95. Markwalder TM. Surgical management of neurogenic claudication in 100 patients with lumbar spinal stenosis due to degenerative spondylolisthesis. Acta Neurochir. 1993;120(3-4):136-142.
96. Martin BI, Mirza SK, Comstock BA, Gray DT, Kreuter W, Deyo RA. Are lumbar spine reoperation rates falling with greater use of fusion surgery and new surgical technology? Spine. 2007;32(19), 2119-2126.
97. Mazzocchio R, Scarfò GB, Cartolari R, Bolognini A, Mariottini A, Muzii VF, Palma L. Abnormalities of the soleus H-reflex in lumbar spondylolisthesis: A possible early sign of bilateral S1 root dysfunction. J Spinal Disord. 13(6), 487-495.
98. McAfee PC, DeVine JG, Chaput CD, Prybis BG, Fedder I L, Cunningham BW, Vigna FE. The indications for interbody fusion cages in the treatment of spondylolisthesis: Analysis of 120 cases. Spine. 2005;30(6 Suppl):S60-S65.
99. McGregor AH, Cattermole HR, Hughes SPF. Global spinal motion in subjects with lumbar spondylolysis and spondylolisthesis: Does the grade or type of slip affect global spinal motion? Spine. 2001;26(3):282-286.
100. Métellus P, Fuentes S, Adetchessi T, Levrier O, Flores-Parra I, Talianu D, Grisoli F. Retrospective study of 77 patients harbouring lumbar synovial cysts: Functional and neurological outcome. Acta Neurochir. 2006;148(1):47-54.
101. Miscusi M, Petrozza V, Polli FM, Forcato S, Rocca CD, Raco A. Symptomatic ganglion cyst of ligamentum flavum as a late complication of lumbar fixation. Neurol Neurochir Pol. 2012;46(1):82-86.
102. Molina M, Wagner P, Campos M Spinal lumbar stenosis. An update. Rev Med Chil. 2011;139(11):1488-1495.
103. Moller J, Wittenberg RH, Nolte LP, Jergas M, Willburger R, Kramer J. Results of lumbosacral distraction spondylodesis for the treatment of spondylolisthesis, failed-back syndrome, and lumbar instability. Eur Spine J. 1992;1(2):117-124.
104. Morishita Y, Ohta H, Naito M, Matsumoto Y, Huang G, Tatsumi M, Kida H. Kinematic evaluation of the adjacent segments after lumbar instrumented surgery: A comparison between rigid fusion and dynamic non-fusion stabilization. Eur Spine J. 2011;20(9):1480-1485.
105. Murat Müslüman A, Cansever T, Yilmaz A, Çavuşoğlu H, Yüce

I, Aydin Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis: Clinical article. J Neurosurg Spine. 2012;16(1):68-76.
106. Nagaosa Y, Kikuchi S, Hasue M, Sato S. Pathoanatomic mechanisms of degenerative spondylolisthesis. A radiographic study. Spine. 1998;23(13):1447-1451.
107. Nakashima H, Sato K, Ando T, Inoh H, Nakamura H. Comparison of the percutaneous screw placement precision of isocentric C-arm 3-dimensional fluoroscopy-navigated pedicle screw implantation and conventional fluoroscopy method with minimally Invasive Surgery. J Spinal Disord Tech. 2009;22(7):468-472.
108. Nathan M, Keller TS. Measurement and analysis of the in vivo posteroanterior impulse response of the human thoracolumbar spine: A feasibility study. JManipulative Physiol Ther. 1994;17(7):431-441.
109. Newman PH. Degenerative spondylolisthesis. Orthop Clin North Am. 1975;6(1):197-198.
110. Nizard RS, Wybier M, Laredo JD. Radiologic assessment of lumbar intervertebral instability and degenerative spondylolisthesis. Radiol Clin North Am. 2001;39(1):55-71.
111. Oh IS, Ha KY. Matrix metalloproteinase-3 on ligamentum flavum in degenerative lumbar spondylolisthesis. Spine. 2009;34(16):E552-557.
112. Ohmori K, Suzuki K, Ishida Y. Translamino-pedicular screw fixation with bone grafting for symptomatic isthmic lumbar spondylolysis. Neurosurgery. 1992;30(3):379-384.
113. Ohtori S, Yamashita M, Inoue G, Yamauchi K, Koshi T, Suzuki M, Takahashi K. Rotational hypermobility of disc wedging using kinematic CT: Preliminary study to investigate the instability of discs in degenerated scoliosis in the lumbar spine. Eur Spine J. 2010;19(6):989-994.
114. Panagiotis ZE, Athanasios K, Panagiotis D, Minos T, Charis M, Elias L.. Functional outcome of surgical treatment for multilevel lumbar spinal stenosis. Acta Orthop. 2006;77(4):670-676.
115. Park H, Zhang HY, Cho BY, Park JY. Change of lumbar motion after multi-level posterior dynamic stabilization with bioflex system: 1 Year follow up. J Korean Neurosurg Soc. 2009;46(4):285-291.
116. Park JH, Hyun SJ, Roh SW, Rhim SC A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis. Acta Neurochir. 154(7), 1205-1212
117. Park Y, Ha JW, Lee YT, Sung NY. The effect of a radiographic solid fusion on clinical outcomes after minimally invasive transforaminal lumbar interbody fusion. Spine J. 2011;11(3):205-212.
118. Piñera AR, Duran C, Lopez B, Saez I, Correia E, Alvarez L. Instrumented lumbar arthrodesis in elderly patients: prospective study using cannulated cemented pedicle screw instrumentation. Eur Spine J. 2011;20 Suppl 3, 408-414.
119. Postacchini F, Cinotti G, Perugia D, Gumina S. The surgical treatment of central lumbar stenosis. Multiple laminotomy compared with total laminectomy. J Bone Joint Surg Br. 1993;75(3):386-392.
120. Raley DA, Mobbs RJ. Retrospective computed tomography scan analysis of percutaneously inserted pedicle screws for posterior transpedicular stabilization of the thoracic and lumbar spine: accuracy and complication rates. Spine. 2012;37(12):1092-1100.
121. Reddy SJ, Al-Holou WN, Leveque JC, La Marca F, Park P. Traumatic lateral spondylolisthesis of the lumbar spine with a unilateral locked facet: description of an unusual injury, probable mechanism, and management. J Neurosurg Spine. 2009;9(6):576-580.
122. Resnick D. Degenerative diseases of the vertebral column. Radiology. 1985;156(1):3-14.
123. Resnick DK, Choudhri TF, Dailey AT, Groff MW, Khoo L, Matz PG, Mummaneni P, Watters WC 3rd, Wang J, Walters BC, Hadley MN; American Association of Neurological Surgeons Congress of Neurological Surgeons. Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 12: pedicle screw fixation as an adjunct to posterolateral fusion for low-back pain. J Neurosurg Spine. 2005;2(6):700-706.
124. Sachs BL, Zindrick MR, Beasley RD. Reflex sympathetic dystrophy after operative procedures on the lumbar spine. J Bone Joint Surg Am. 1993;75(5):721-725.
125. Sandu N, Schaller B, Arasho B, Orabi M. Wallis interspinous implantation to treat degenerative spinal disease: Description of the method and case series. Expert Rev Neurother. 2011;11(6), 799-807. doi: 10.1586/ern.10.187
126. Sapkas GS, Mavrogenis AF, Themistocleous GS, Zachos VC, Kelalis G, Papagelopoulos PJ. Posterior lumbar interbody fusion versus circumferential fusion using the B-Twin expandable spinal system. J Long Term Eff Med Imp. 2007;17(3):217-227.
127. Schiffman M, Brau SA, Henderson R, Gimmestad G. Bilateral implantation of low-profile interbody fusion cages: subsidence, lordosis, and fusion analysis. Spine J. 2003;3(5):377-387.
128. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: restoration of sagittal balance using insert-and-rotate interbody spacers. Spine J. 2005;5(2):170-179.
129. Sienkiewicz PJ, Flatley TJ. Postoperative spondylolisthesis. Clin Orthop Relat Res. 1987 Aug;(220):172-180.
130. Sirvanci M, Ulusoy L, Duran C. Pedicular stress fracture in lumbar spine. Clin Imaging. 2002;26(3):187-193.
131. Soini J, Slatis P, Kannisto M, Sandelin J. External transpedicular fixation test of the lumbar spine correlates with the outcome of subsequent lumbar fusion. Clinical Orthop Relat Res. 1993 Aug;(293):89-96.
132. Song KJ, Lee KB. Spontaneous fusion of L5-S1 isthmic spondylolisthesis. J Back Musculoskel Rehabil. 2007;20(4):177-179.
133. Sonntag VK, Marciano FF. Is fusion indicated for lumbar spinal disorders? Spine. 1995;20(24 Suppl):138S-142S.
134. Takahashi T, Hanakita J, Minami M, Kitahama Y, Kuraishi K, Watanabe M, Uesaka T. Clinical outcomes and adverse events following transforaminal interbody fusion for lumbar degenerative spondylolisthesis in elderly patients. Neurologia Med Chi. 2011;51(12), 829-835.
135. Tarantino U, Fanucci E, Iundusi R, Celi M, Altobelli S, Gasbarra E, Manenti G. Lumbar spine MRI in upright position for diagnosing acute and chronic low back pain: Statistical analysis of morphological changes. JOrthop Traumatol. 2013;14(1):15-22. doi:
136. Taylor JA, Bussières A. Diagnostic imaging for spinal disorders in the elderly: a narrative review. Chiropr Man Therap. 2012 May 24;20:16.
137. Tillich M, Trummer M, Lindbichler F, Flaschka G. Symptomatic intraspinal synovial cysts of the lumbar spine: Correlation of MR and surgical findings. Neuroradiology 2001;43(12):1070-1075.
138. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H. Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: Minimum five-year follow-up. Spine. 2011;36(5):410-415.
139. Tsai KH, Chang GL, Lin HT, Kuo DC, Chang LT, Lin RM. Differences of lumbosacral kinematics between degenerative and induced spondylolisthetic spine. Clin Biomech. 2003;18(6):S10-S16.
140. Tsutsumimoto T, Shimogata M, Yoshimura Y, Misawa H. Union versus nonunion after posterolateral lumbar fusion: a comparison of long-term surgical outcomes in patients with degenera-

tive lumbar spondylolisthesis. Eur Spine J. 2008;17(8):1107-1112.
141. Vaccaro AR, Whang PG, Patel T, Phillips FM, Anderson DG, Albert TJ, Fischgrund JS. The safety and efficacy of OP-1 (rh-BMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-465.
142. Vital JM, Gille O, Pointillart V, Pedram M, Bacon P, Razanabola F, Azzouz S. Course of Modic 1 six months after lumbar posterior osteosynthesis. Spine. 2003;28(7): 715-720.
143. Vitzthum HE, Konig A, Seifert V. Dynamic examination of the lumbar spine by using vertical, open magnetic resonance imaging. Journal Neurosurg. 2000;93(1 Suppl): 58-64.
144. Willems P. Decision making in surgical treatment of chronic low back pain: The performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop Suppl. 2013 Feb;84(349):1-35.
145. Wiltse LL, Guyer RD, Spencer CW, Glenn WV, Porter IS. Alar transverse process impingement of the L5 spinal nerve: The far-out syndrome. Spine. 1984;9(1): 31-41.
146. Zhang HY, Park JY, Cho BY The BioFlex System as a dynamic stabilization device: Does it preserve lumbar motion? J Korean Neurosurg Soc. 2009;46(5):431-436.
147. Zhang ZM, Jin DD, Chen JT. Comparative study of dynamic fixation with rigid fixation in the management of degenerative lumbar spondylosis. Zhonghua Wai Ke Za Zhi. 2008 Mar 1;46(5):346-9.

New Guideline Question:

Is dynamic MRI and/or dynamic CT myelography imaging (including standing imaging, imaging with axial loading) helpful in the diagnostic testing for degenerative lumbar spondylolisthesis?

There is insufficient evidence to make a recommendation for or against the utility of dynamic MRI and dynamic CT myelography in the diagnosis of degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

Huang et al[1] investigated the effect of axial loading on spine and spinal canal morphology in patients with degenerative spondylolisthesis of L4–5 and evaluated the correlation between morphologic changes and disability and physical functioning. A total of 32 consecutive cases with degenerative L4–5 spondylolisthesis, grade 1–2, intermittent claudication and low back pain without sciatica were included in this study. All patients underwent unloaded and axially loaded MRI of the lumbosacral spine in supine position to elucidate the morphological findings and to measure the parameters of MRI, including disc height (DH), sagittal translation (ST), segmental angulation (SA), dural sac cross-sectional area (DCSA) at L4–5, and lumbar lordotic angles (LLA) at L1–5 between the unloaded and axially loaded condition. Each patient's disability was evaluated by the Oswestry Disability Index (ODI) questionnaire and physical functioning (PF) was evaluated by the Physical Function scale. Comparisons and correlations were done to determine which parameters were critical to the patient's disability and PF. The morphologies of the lumbar spine changed after axially loaded MRI. In 6 patients, the authors observed adjacent segment degeneration (4 at L3–L4 and 2 at L5–S1) coexisting with degenerative spondylolisthesis of L4–L5 under axially loaded MRI. The mean values of the SA under preload and postload were 7.14° and 5.90° at L4–L5 (listhetic level), respectively. The mean values of the LLA under preload and postload were 37.03° and 39.28°, respectively. There were significant correlations only between the ODI, PF, and the difference of SA, and between PF and the postloaded LLA. The changes in SA (L4–L5) during axial loading were well correlated to the ODI and PF scores. In addition, the LLA (L1–L5) under axial loading was well correlated to the PF of patients with degenerative L4–L5 spondylolisthesis. The authors conclude that axially loaded MRI is a useful tool for study of the anatomical changes of the spinal canal of the lumbar spine. It can also aid diagnosis of instability, or occult spinal disorders, such as equivocal herniated discs or stenosis, by simulating the upright position under normal gravity. This study provides Level IV prognostic evidence that axially loaded MRI using the Dynawell device demonstrates morphological changes in patients with symptomatic degenerative spondylolisthesis and that segmental angulation at L4-5 was correlated with physical disability (ODI).

In a study by McGregor et al[2], authors conducted a radiographic study to investigate patterns of intervertebral mobility

(using flexion-extension positions in open MRI) in subjects with spondylolisthesis to determine level of spinal instability. Twenty-nine patients, including 15 with a diagnosis of isthmic spondylolisthesis and 14 with a diagnosis of degenerative spondylolisthesis, were enrolled and compared with a preexisting database of 12 patients with no history of back pain (controls). The motion characteristics of these patients in flexed and extended positions were investigated using open MRI. In all of the subjects, the level of resting pain, grade of slip and level of defect were evaluated. No mobility differences of angular or translatory motion were found between the spondylolisthesis (degenerative or isthmic) and asymptomatic controls. In critique of this study, it is unclear how patients were recruited, whether there was consecutive enrollment and a clear subgroup analysis was not included. This study provides Level IV diagnostic evidence that that the presence of degenerative spondylolisthesis does not lead to hypermobility. A spondylolytic defect may not lead to detectable instability or hypermobility in the lumbar spine on dynamic MRI.

Ozawa et al[3] compared the dural sac cross sectional area (DCSA) in patients with degenerative spondylolisthesis and spinal stenosis on axially loaded MR imaging. All patients had neurogenic intermittent claudication and leg pain or numbness with associated neurologic signs and had radiographically confirmed lumbar spinal canal narrowing on cross-sectional imaging. For the comparative analysis in this study, the patients with >3mm spondylolisthesis were assigned to the degenerative spondylolisthesis group, while the other patients were assigned to the spinal stenosis group. A total of 88 patients were included in the study, including 40 with degenerative spondylolisthesis patients. All patients received MR imaging. After conventional MR imaging, axial loading was applied by using an external commercially available nonmagnetic compression device. The DCSA was measured from the L2-3 to L5-S1 on the axial image. The measurement was performed three times and the mean value was calculated and used for analysis in this study. Results indicated that a >15mm^2 change in the DCSA was found in 8 patients (16.7%) in the spinal stenosis group and 25 patients (62.5%) in the degenerative spondylolisthesis group. In the degenerative spondylolisthesis group, patients with a >15mm^2 change had a significantly larger DCSA on conventional MR imaging (58 ± 26mm^2) than those with a <15mm^2 change (41 ± 18mm^2) (p=0.028), while the axial loaded MR imaging showed no significant difference between the patients with a >15 and a <15mm^2 change in the DCSA (p=0.897). The authors conclude that DCSA in patients with degenerative spondylolisthesis is more likely to be decreased by axial loading than in those with spinal stenosis. Axial loaded MRI may be a more useful tool to provide valuable imaging findings for the assessment of spinal canal narrowing in patients with degenerative spondylolisthesis than those with spinal stenosis. In critique, use of a 15mm^2 criterion as significant change in DCSA is not a universally accepted diagnostic standard; therefore, this study has been downgraded from Level II to III. This study provides Level III diagnostic evidence that axially loaded MRI may reveal more severe stenosis in patients with degenerative spondylolisthesis than might be apparent on conventional MRI.

Future Directions for Research

The work group recommends prospective, appropriately powered studies to better assess the utility of dynamic MRI and/or CT myleography in the diagnostic testing for degenerative spondylolisthesis.

References

1. Huang KY, Lin RM, Lee YL, Li JD. Factors affecting disability and physical function in degenerative lumbar spondylolisthesis of L4-5: evaluation with axially loaded MRI. Eur Spine J. 2009;18(12):1851-1857.
2. McGregor AH, Anderton L, Gedroyc WM, Johnson J, Hughes SP. The use of interventional open MRI to assess the kinematics of the lumbar spine in patients with spondylolisthesis. Spine. 2002;27(14):1582-1586.
3. Ozawa H, Kanno H, Koizumi Y, Morozumi N, Aizawa T, Kusakabe T, Itoi E. Dynamic changes in the dural sac cross-sectional area on axial loaded MR imaging: is there a difference between degenerative spondylolisthesis and spinal stenosis? Am J Neuroradiol. 2012;33(6):1191-1197.

Bibliography

1. Alexander E Jr, Kelly DL Jr, Davis CH Jr, McWhorter JM, Brown W. Intact arch spondylolisthesis. A review of 50 cases and description of surgical treatment. J Neurosurg. 1985;63(6):840-844.
2. Barrey C, Jund J, Perrin G, Roussouly P. Spinopelvic alignment of patients with degenerative spondylolisthesis. Neurosurgery. 2007;61(5):981-986.
3. Bendo JA, Ong B. Importance of correlating static and dynamic imaging studies in diagnosing degenerative lumbar spondylolisthesis. Am J Orthop. 2001;30(3), 247-250.
4. Berlemann U, Jeszenszky DJ, Buhler DW, Harms J. Mechanisms of retrolisthesis in the lower lumbar spine. A radiographic study. Acta Orthop Belg. 1999;65(4):472-477.
5. Berlemann U, Jeszenszky DJ, Buhler DW, Harms J. The role of lumbar lordosis, vertebral end-plate inclination, disc height, and facet orientation in degenerative spondylolisthesis. J Spinal Disord. 1999;12(1):68-73.
6. Boden SD Spinescope. Semin Spine Surg. 2012;24(2):133-137.
7. Cansever T, Civelek E, Kabatas S, Yilmaz C, Caner H, Altinors MN. Dysfunctional segmental motion treated with dynamic stabilization in the lumbar spine. World Neurosurg. 2011;75(5-6):743-749.
8. Caterini R, Mancini F, Bisicchia S, Maglione P, Farsetti P. The correlation between exaggerated fluid in lumbar facet joints and degenerative spondylolisthesis: prospective study of 52 patients. J Orthop Traumatol. 2011;12(2):87-91.
9. Chaput C, Padon D, Rush J, Lenehan E, Rahm M. The significance of increased fluid signal on magnetic resonance imaging in lumbar facets in relationship to degenerative spondylolisthesis. Spine 2007;32(17):1883-1887.
10. Cho BY, Murovic JA, Park J. Imaging correlation of the degree of degenerative L4-5 spondylolisthesis with the corresponding amount of facet fluid. J Neurosurg Spine. 2009;11(5):614-9.
11. Gaetani P, Aimar E, Panella L, Levi D, Tancioni F, Di Ieva A, Rodriguez y Baena R. Functional disability after instrumented stabilization in lumbar degenerative spondylolisthesis: a follow-up study. Functional Neurol. 2006;21(1):31-37.
12. Gilbert JW, Wheeler GR, Kreft MP, et al. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-31.

13. Haberl H, Cripton PA, Orr TE, Beutler T, Frei H, Lanksch WR, Nolte LP. Kinematic response of lumbar functional spinal units to axial torsion with and without superimposed compression and flexion/extension. Eur Spine J. 2004;13(6):560-566.
14. Hasegawa K, Kitahara K, Hara T, Takano K, Shimoda H, Homma T. Evaluation of lumbar segmental instability in degenerative diseases by using a new intraoperative measurement system. J Neurosurg Spine. 2008;8(3):255-62.
15. Hayeri MR, Tehranzadeh J. Diagnostic imaging of spinal fusion and complications. App Radiol. 2009;38(7-8):14-28.
16. Heo DH, Cho YJ, Cho SM, Choi HC, KangSH. Adjacent segment degeneration after lumbar dynamic stabilization using pedicle screws and a nitinol spring rod system with 2-year minimum follow-up. J Spinal Disord Tech. 2012;25(8):409-414.
17. Hong SW, Lee HY, Kim KH, Lee SH. Interspinous ligamentoplasty in the treatment of degenerative spondylolisthesis: midterm clinical results. J Neurosurg Spine. 2010;13(1):27-35.
18. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-75.
19. Jagannathan J, Sansur CA, Oskouian RJ, Fu KM, Shaffrey CI. Radiographic restoration of lumbar alignment after transforaminal lumbar interbody fusion. Neurosurgery. 2009;64(5):955-63.
20. Jayakumar P, Nnadi C, Saifuddin A, Macsweeney E, Casey A. Dynamic degenerative lumbar spondylolisthesis: diagnosis with axial loaded magnetic resonance imaging. Spine. 2006;31(10):E298-301.
21. Kalpakcioglu B, Altinbilek T, Senel K. Determination of spondylolisthesis in low back pain by clinical evaluation. J Back Musculoskelet Rehabil. 2009;22(1):27-32
22. Kelleher MO, Timlin M, Persaud O, Rampersaud YR. Success and failure of minimally invasive decompression for focal lumbar spinal stenosis in patients with and without deformity. Spine. 2010;35(19):E981-7.
23. Khan JA, Bajracharya AR. Surgical treatment of isthmic spondylolisthesis with radicular pain in adults. Journal Nepal Med Assoc. 2007;46(168):170-174.
24. Kizilkilic O, Yalcin O, Sen O, Aydin MV, Yildirim T, Hurcan C. The role of standing flexion-extension radiographs for spondylolisthesis following single level disk surgery. Neurol Res. 2007;29(6):540-3.
25. Konno S, Kikuchi S, Tanaka Y, Yamazaki K, Shimada Y, Takei H, et al. A diagnostic support tool for lumbar spinal stenosis: A self-administered, self-reported history questionnaire. BMC Musculoskel Disord. 2007 Oct 30;8:102.
26. Korovessis P, Repantis T, Zacharatos S, Zafiropoulos A. Does Wallis implant reduce adjacent segment degeneration above lumbosacral instrumented fusion?. Eur Spine J. 2009;18(6):830-40.
27. Lakdawala RH, Rahmat R, Tan L, Wong HK. Aortic flap valve presenting as neurogenic claudication: a case report. Spine 2004;29(4):E79-81.
28. Langerak NG, Vaughan CL, Hoffman EB, Figaji AA, Fieggen AG, Peter JC. Incidence of spinal abnormalities in patients with spastic diplegia 17 to 26 years after selective dorsal rhizotomy. Childs Nerv Syst. 2009;25(12):1593-1603.
29. Lattig F, Fekete TF, Grob D, Kleinstuck F S, Jeszenszky D, Mannion AF. Lumbar facet joint effusion in MRI: a sign of instability in degenerative spondylolisthesis? Eur Spine J. 2012;21(2):276-281.
30. Lauryssen C. Appropriate selection of patients with lumbar spinal stenosis for interspinous process decompression with the X STOP device. Neurosurg Foc. 2007;22(1):E5.
31. Lee DY, Lee SH. L2 radicular compression caused by a foraminal extradural gas pseudocyst. J Korean Neurosurg Soc. 2010;47(3):232-4.
32. Manenti G, Liccardo G, Sergiacomi G, Ferrante L, D'Andrea G, Konda D, Masala S. Axial loading MRI of the lumbar spine. In Vivo. 2003;17(5):413-420.
33. McCulloch JA. Microdecompression and uninstrumented single-level fusion for spinal canal stenosis with degenerative spondylolisthesis. Spine. 1998;23(20):2243-2252.
34. Miyazaki M, Morishita Y, Takita C, Yoshiiwa T, Wang JC, Tsumura H. Analysis of the relationship between facet joint angle orientation and lumbar spine canal diameter with respect to the kinematics of the lumbar spinal unit. J Spinal Disord Tech. 2010;23(4):242-248.
35. Moke L, Debeer P, Moens P. Spondylolisthesis in twins: multifactorial etiology: a case report and review of the literature. Spine. 2011;36(11):E741-746.
36. Morishita Y, Ohta H, Naito M, Matsumoto Y, Huang G, Tatsumi M, Kida H. Kinematic evaluation of the adjacent segments after lumbar instrumented surgery: A comparison between rigid fusion and dynamic non-fusion stabilization. Eur Spine J. 2011;20(9):1480-1485.
37. Murtagh RD, Quencer RM, Castellvi AE, Yue JJ. New techniques in lumbar spinal instrumentation: What the radiologist needs to know. Radiology. 2011;260(2):317-330.
38. Naderi S, Manisali M, Acar F, Ozaksoy D, Mertol T, Arda MN. Factors affecting reduction in low-grade lumbosacral spondylolisthesis. J Neurosurg. 2003;99(2 Suppl) :151-156.
39. Niggemann P, Simons P, Kuchta J, Beyer HK, Frey H, Grosskurth D. Spondylolisthesis and posterior instability. Acta Radiol. 2009;50(3):301-305.
40. Ohtori S, Yamashita M, Inoue G, Yamauchi K, Koshi T, Suzuki M, Takahashi K. Rotational hypermobility of disc wedging using kinematic CT: Preliminary study to investigate the instability of discs in degenerated scoliosis in the lumbar spine. Eur Spine J. 2010;19(6): 989-994.
41. Oishi Y, Murase M, Hayashi Y, Ogawa T, Hamawaki J. Smaller facet effusion in association with restabilization at the time of operation in Japanese patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2010;12(1):88-95.
42. Paajanen H, Tertti M. Association of incipient disc degeneration and instability in spondylolisthesis. A magnetic resonance and flexion-extension radiographic study of 20-year-old low back pain patients. Arch Orthop Trauma Surg. 1991;111(1):16-19.
43. Palmer S, Turner R, Palmer R. Bilateral decompression of lumbar spinal stenosis involving a unilateral approach with microscope and tubular retractor system. J Neurosurg. 2002;97(2 Suppl):213-217.
44. Ranjith RK, Mullett JH, Burke TE. Hangman's fracture caused by suspected child abuse. A case report. J Pediatr Orthop B. 2002;11(4):329-332.
45. Resnick DK, Choudhri TF, Dailey AT, Groff MW, Khoo L, Matz PG, Mummaneni P, Watters WC 3rd, Wang J, Walters BC, Hadley MN; American Association of Neurological Surgeons Congress of Neurological Surgeons. (Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 12: pedicle screw fixation as an adjunct to posterolateral fusion for low-back pain. J Neurosurg Spine. 2005;2(6):700-706.
46. Schlenzka D, Remes V, Helenius I, Lamberg T, Tervahartiala P, Yrjonen T, Poussa M. Direct repair for treatment of symptomatic spondylolysis and low-grade isthmic spondylolisthesis in young patients: no benefit in comparison to segmental fusion after a mean follow-up of 14.8 years. Eur Spine J. 2006;15(10):1437-1447.

47. Schlenzka D, Seitsalo S, Poussa M, Osterman K. Operative treatment of symptomatic lumbar spondylolysis and mild isthmic spondylolisthesis in young patients: direct repair of the defect or segmental spinal fusion? Eur Spine J. 1993;2(2):104-112.
48. Schuller S, Charles YP, Steib JP. Sagittal spinopelvic alignment and body mass index in patients with degenerative spondylolisthesis. Eur Spine J. 2011;20(5):713-719.
49. Stone AT, Tribus CB. Acute progression of spondylolysis to isthmic spondylolisthesis in an adult. Spine 2002;27(16), E370-372.
50. Tarantino U, Fanucci E, Iundusi R, et al. Lumbar spine MRI in upright position for diagnosing acute and chronic low back pain: statistical analysis of morphological changes. J Orthop Traumatol. 2013;14(1):15-22.
51. Van den heuvel R, Hertel M, Gallagher J, Naidoo V. A toddler who refused to stand or walk: lumbar spondylodiscitis. BMJ Case Rep. 2012;
52. Vitzthum HE, Konig A, Seifert, V. Dynamic examination of the lumbar spine by using vertical, open magnetic resonance imaging. J Neurosurg. 2000;93(1 Suppl):58-64.
53. Wildermuth S, Zanetti M, Duewell S, Schmid MR, Romanowski B, Benini A, Hodler J. Lumbar spine: quantitative and qualitative assessment of positional (upright flexion and extension) MR imaging and myelography. Radiology. 1998;207(2):391-398.
54. Zhao Y, Wang YP, Qiu GX, Zhao H, Zhang JG, Zhou X. Efficacy of the dynamic interspinous assisted motion system in clinical treatment of degenerative lumbar disease. Chin Med J. 2010;123(21):2974-2977.

B. Outcome Measures for Medical/Interventional and Surgical Treatment

Original Guideline Question:
What are the appropriate outcome measures for the treatment of degenerative lumbar spondylolisthesis?

An updated literature search was not conducted. For more information on appropriate outcome measures for degenerative lumbar spondylolisthesis, the North American Spine Society has a publication entitled *Compendium of Outcome Instruments for Assessment and Research of Spinal Disorders*. To purchase a copy of the Compendium, visit https://webportal.spine.org/Purchase/ProductDetail.aspx?Product_code=68cdd1f4-c4ac-db11-95b2-001143edb1c1.

For additional information about the Compendium, please contact the NASS Research Department at nassresearch@spine.org.

C. Medical and Interventional Treatment

An updated systematic review of the literature yielded no studies to adequately address any of the medical/interventional treatment questions from the original guideline posed below:

- **What is the role of pharmacological treatment in the management of degenerative lumbar spondylolisthesis?**
- **What is the role of physical therapy/exercise in the treatment of degenerative lumbar spondylolisthesis?**
- **What is the role of manipulation in the treatment of degenerative lumbar spondylolisthesis?**
- **What is the role of ancillary treatments such as bracing, traction, electrical stimulation and transcutaneous electrical stimulation (TENS) in the treatment of degenerative lumbar spondylolisthesis?**
- **What is the long-term result (4+ years) of medical/interventional management of degenerative lumbar spondylolisthesis?**

Results from the Spine Patient Outcomes Research Trial (SPORT), a research trial analyzing nonoperative and surgical treatment effects in patients with degenerative spondylolisthesis associated with spinal stenosis, are summarized below. Due to the uncontrolled nonoperative protocol, lack of nonoperative treatment details and high treatment cross-over rate of the SPORT Trial at 4 years, the work group is cautioned to use this trial as support for a recommendation for or against the role or long term efficacy of any specific medical/interventional treatment for the management of degenerative lumbar spondylolisthesis. However, given the paucity of nonoperative treatment evidence from the original and current guideline literature searches, the work group included the summary below as background information.

Weinstein et al[1,2] compared the surgical and nonsurgical outcomes in patients enrolled in either a randomized or observational cohort of the Spine Patient Outcomes Research Trial (SPORT). All patients in the trial had neurogenic claudication or radicular leg pain with associated neurologic signs, spinal stenosis shown on cross-sectional imaging and degenerative spondylolisthesis shown on lateral radiographs obtained with the patient in a standing position. Investigators enrolled 304 patients in the randomized cohort and 303 in the observational cohort. Pre-enrollment nonoperative care was not specified, but included physical therapy (68%), epidural injections (55%), chiropractic care (25%), anti-inflammatory medications (63%) and opioid analgesics (30%). Going forward, the nonoperative protocol was "usual recommended care," which included, at least, active physical therapy, education and counseling with instructions regarding home exercise, and nonsteroidal anti-inflammatory drugs if the patient could tolerate them. In the randomized cohort, 159 patients were assigned to surgery and 145 were assigned to nonsurgical treatment. Of the 145 patients assigned to receive nonoperative care, 54% underwent surgery by 4 years. In the observational cohort, 173 initially chose surgery and 130 initially chose nonsurgical care. Of the 130 patients who initially chose nonoperative treatment, 33% underwent surgery by 4 years. Patients were evaluated over 4 years using the SF-36 for bodily pain and physical function scores and the modified Oswestry Disability Index. Results indicated that patients enrolled in the nonoperative treatment group experienced modest improvement from baseline over a period of four years. In patients with neurogenic claudication, the SF-36 score improved 12.9 points, SF-36 physical function score improved 8.3 points, and the Oswestry Disability Index decreased 7.4 points. Additionally, results from a post hoc analysis of SPORT,3 analyzing whether the duration of symptoms (less than or more than one year) affect outcomes after the treatment of degenerative spondylolisthesis, suggest that symptom duration does not impact nonoperative or surgical treatment success for patients with this disease.

Original Guideline Question:
What is the role of injections for the treatment of degenerative lumbar spondylolisthesis?

There is insufficient evidence to make a recommendation for or against the use of injections for the treatment of degenerative lumbar spondylolisthesis. *New recommendation statement*

Grade of Recommendation: I (Insufficient Evidence)

New study retrieved from the updated literature search:

Klessinger et al[4] conducted a retrospective case-series study of 40 patients to determine if radiofrequency neurotomy is an effective treatment option for patients with low back pain and degenerative spondylolisthesis. An electronic medical record system was used to identify all patients in a single spine center with a positive MRI diagnosis of degenerative spondylolisthesis who had received lumbar radiofrequency neurotomy during a 3-year period. Most of the patients (82.1%) were tested before the neurotomy with controlled medial branch blocks; the other patients only had single medial branch blocks before radiofrequency neurotomy. A radiofrequency neurotomy was only considered after positive testing (at least 80% pain relief). Injections were performed with fluoroscopic visualization using bupivacaine (0.25%). Patients had a mean age of 67.8 years, were mostly women, had Grade 1 or 2 spondylolisthesis according to Meyerding grades, and included in the analysis only if they had at least 3 months treatment follow-up. The authors did not utilize a validated outcome measurement tool to evaluate treatment success. According to their criteria, treatment response was considered positive if at least a 50% reduction in pain was achieved. A pain reduction of at least 50% and satisfying results for the patients in the radiofrequency group for a minimum of 3 months was achieved in 26 patients (65%). Eight of these patients had a minimum of 50% pain relief; 18 had a minimum of 80%. Eleven patients did not respond to radiofrequency neurotomy. In addition, 3 patients with a positive response to radiofrequency neurotomy, but with pain relief lasting only one month, were treated as negative successes. All patients with pain relief of 3 months had continuing pain relief at a mean follow-up of 18.6 months. This study provides level IV therapeutic evidence that degenerative facet joints represent one possible pain generator in patients with degenerative spondylolisthesis. Radiofrequency neurotomy may lead to pain reduction in a subset of patients with degenerative spondylolisthesis who have symptomatic facet joint pain diagnosed by controlled medial branch nerve blocks.

Medical/interventional treatment for degenerative lumbar spondylolisthesis, when the radicular symptoms of stenosis predominate, most logically should be similar to treatment for symptomatic degenerative lumbar spinal stenosis. *Consensus Statement maintained from original guideline*

Work Group Consensus Statement

Treatment recommendations and the supporting evidence are available in the NASS clnical guideline *Diagnosis and Treatment of Degenerative Lumbar Spinal Stenosis* (2011)[5] available on the NASS website at www.spine.org.

Future Directions For Research

The work group identified the following suggestions for future studies which would generate meaningful evidence to assist in further defining the role of medical treatment for degenerative lumbar spondylolisthesis.

Recommendation #1:

Future outcome studies of degenerative lumbar spondylolisthesis should include results specific to each of the medical/interventional treatment methods, presenting results stratified by patient symptomatology (eg, axial back pain only, combination of axial back pain and radiculopathy).

Recommendation #2:

Although the review was devoid of studies examining the benefits of physical therapy with a directional preference (eg, avoiding extension) in patients with degenerative lumbar spondylolisthesis, this appears to be an area of growing interest. Ac-

cordingly, the work group suggests that a randomized controlled study comparing the benefits of physical therapy with directional preference versus non-preferential therapy for the treatment of degenerative lumbar spondylolisthesis would be useful. Ideally the directional preference study would also address inter-rater reliability as there is some evidence in low back pain literature that clinician training in mechanical diagnosis and treatment affects the clinician's ability to identify directional preference and symptomatic patterns within the exam.[6-7]

Recommendation #3:

The work group recommends the undertaking of large multicenter registry database studies with long term follow-up evaluating the outcomes of various medical/interventional treatments for the management of degenerative lumbar spondylolisthesis.

References

1. Radcliff KE, Rihn J, Hilibrand A, Diiorio T, Tosteson T, Lurie JD, Weinstein JN. Does the duration of symptoms in patients with spinal stenosis and degenerative spondylolisthesis affect outcomes?: Analysis of the spine outcomes research trial. Spine. 2011;36(25):2197-2210.
2. Weinstein JN, Lurie JD, Tosteson TD, Hanscom B, Tosteson AN, Blood EA, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007 May 31;356(22):2257-2270.
3. Weinstein JN, Lurie JD, Tosteson TD, Zhao W, Blood EA, Tosteson AN, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-1304.
4. Klessinger S. Radiofrequency neurotomy for treatment of low back pain in patients with minor degenerative spondylolisthesis. Pain Physician. 2012;Jan-Feb;15(1):E71-8.
5. Aina S, May S, Clare H. The centralization phenomenon of spinal symptoms - a systematic review. Man Ther. 2004;9:134-43.
6. Werneke M, Deutscher D, Hart D, et al. McKenzie Lumbar Classification: Inter-rater Agreement by Physical Therapists With Different Levels of Formal McKenzie Postgraduate Training. Spine. February 2014;39(3):E182–E190.

Bibliography from updated literature search

1. Abbott AD, Tyni-Lenne R, Hedlund R. Early rehabilitation targeting cognition, behavior, and motor function after lumbar fusion: a randomized controlled trial. Spine. 2010;35(8):848-857.
2. Adogwa O, Parker SL, Bydon A, Cheng J, McGirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-484.
3. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurg Q. 2009;19(3), 200-206.
4. Baker AD, Sanderson P. Spinal surgery in older people: Indications, techniques and outcomes. Rev Clinical Gerontology, 2011;21(4):277-285.
5. Bashir el F, Ajani O. Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-6.
6. Boden SD. Spinescope. Semin Spine Surg. 2011;23(2), 151-156.
7. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2), 133-137.
8. Burkus JK, Gornet MF, Schuler TC, Kleeman TJ, Zdeblick TA. Six-year outcomes of anterior lumbar interbody arthrodesis with use of interbody fusion cages and recombinant human bone morphogenetic protein-2. J Bone Joint Surg Am. 2009;91(5):1181-1189.
9. Butt MF, Hakeem IH, Halwal MA, Farooq M, Mir MR, Kangu KA. Complication of variable screw placement system (VSP) in instrumented fusion of non-traumatic lumbosacral spinal disorders. JK Pract. 2007;14(2), 84-87.
10. Carragee EJ, Cheng I. Minimum acceptable outcomes after lumbar spinal fusion. Spine J. 2010;10(4): 313-320.
11. Carreon LY, Glassman SD, Howard J. Fusion and nonsurgical treatment for symptomatic lumbar degenerative disease: a systematic review of Oswestry Disability Index and MOS Short Form-36 outcomes (Structured abstract). Spine J. 2008;8(5):747-755.
12. Cavusoglu H, Turkmenoglu O, Kaya RA, Tuncer C, Colak I, Sahin Y, et al. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-108.
13. Chad DA. Lumbar Spinal Stenosis. Neurol Clin. 2007;25(2):407-418.
14. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
15. Clarke JA, van Tulder MW, Blomberg SE, de Vet HC, van der Heijden GJ, Brønfort G, Bouter LM. Traction for low-back pain with or without sciatica Cochrane Database Syst Rev. 2007;8:CD003010.
16. Cloyd JM, Acosta Jr FL, Ames CP. Complications and outcomes of lumbar spine surgery in elderly people: A review of the literature. J Am Geriatr Soc. 2008;56(7):1318-1327.
17. Dai F, Belfer I, Schwartz CE, Banco R, Martha JF, Tighioughart H, Kim DH. Association of catechol-O-methyltransferase genetic variants with outcome in patients undergoing surgical treatment for lumbar degenerative disc disease. Spine J. 2010;10(11):949-957.
18. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-446.
19. Debusscher F, Troussel S. Direct repair of defects in lumbar spondylolysis with a new pedicle screw hook fixation: Clinical, functional and Ct-assessed study. Eur Spine J. 2007;16(10):1650-1658.
20. Delawi D, Dhert WJ, Rillardon L, Gay E, Prestamburgo D, Garcia-Fernandez C, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010 May 20;35(12):1185-1191.
21. Ekman P, Moller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-1186.
22. Eliyas JK, Karahalios D. Surgery for Degenerative Lumbar Spine Disease. Dis Mon. 2011;57(10):592-606.
23. Excoffon SG, Wallace H. Chiropractic and rehabilitative management of a patient with progressive lumbar disk injury, spondylolisthesis, and spondyloptosis. J Manipulative Physiol Ther. 2006;29(1): 66-71.
24. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.
25. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization

system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech. 2010;23(4):236-241.
26. Ferrari S, Costa F, Fornari M. Conservative treatment with spontaneous stabilization of Grade II isthmic spondylolisthesis L5/S1 in a forty-four-year old woman, with a six-year follow-up: a case report. Eur J Phys Rehabil Med. 2012;48(2), 275-281.
27. Fersum KV, Dankaerts W, O'Sullivan PB, Maes J, Skouen JS, Bjordal JM, Kvale A. Integration of subclassification strategies in randomised controlled clinical trials evaluating manual therapy treatment and exercise therapy for non-specific chronic low back pain: a systematic review. Br J Sports Med. 2010 Nov;44(14):1054-1062.
28. Furlan AD, Yazdi F, Tsertsvadze A, Lao L, Sherman K, Ammendolia C, Wang E, Shin BC, Wakayama I, van Tulder MW. Acupuncture for (sub)acute non-specific low-back pain (Protocol). Cochrane Database Syst Rev. 2011;8:CD009265
29. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database System Rev. 2005 Oct 19;(4) CD001352.
30. Gilbert JW, Wheeler GR, Kreft MP, Upadhyay SP, Storey BB, Spitalieri JR, Gibbs RA. Repeat Upright Positional Magnetic Resonance Imaging for Diagnosis of Disorders Underlying Chronic Noncancer Lumbar Pain. J Manipulative Physiol Ther. 2008;31(8):627-631.
31. Graham N, Gross A, Goldsmith CH, Klaber Moffett J, Haines T, Burnie SJ, et al. Mechanical traction for neck pain with or without radiculopathy. Cochrane Database Syst Rev. 2008 Jul 16;(3):CD006408.
32. Grob D. Surgery for degenerative lumbar disease: Transforaminal lumbar interbody fusion. Eur Spine J. 2009;18(12):1991-1992.
33. Gross A, Forget M, St George K, Fraser MM, Graham N, Perry L, et al. Patient education for neck pain. Cochrane Database of Syst Rev. 2012 Mar 14;3:CD005106.
34. Herkowitz HN. Degenerative lumbar spondylolisthesis: A surgeon's perspective of 30 years in practice. Spine J. 2010;10(10):916-917.
35. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Audiosynop Contin Med Educ. 2011;3(3):167-175.
36. Huang TY, Lee KS, Tsai TH, Su YF, Hwang SL. Posterior epidural migration of sequestrated lumbar disc fragments into the bilateral facet joints: Case report. Neurosurgery. 2011;69(5):E1148-E1151.
37. Ibrahimi, DM, Beaty NB, Crandall KM, Hamilton DK, Sansur CA. A review of lumbar spondylolisthesis. Eur Musculoskel Rev. 2011;6(2), 110-113.
38. Peloso P, Gross A, Haines T, Trinh K, Goldsmith CH, Burnie S. Medicinal and injection therapies for mechanical neck disorders. Cochrane Database Syst Rev. 2007 Jul 18;(3):CD000319.
39. Jacobs W, Van der Gaag NA, Tuschel A, de Kleuver M, Peul W, Verbout AJ, et al. Total disc replacement for chronic back pain in the presence of disc degeneration. 2012 Sep 12;9:CD008326.
40. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17(3):327-335.
41. Kanayama M, Hashimoto, T, Shigenobu K, Oha F, Togawa D. Effective prevention of surgical site infection using a Centers for Disease Control and Prevention guideline-based antimicrobial prophylaxis in lumbar spine surgery. J Neurosurg Spine. 2007;6(4):327-329.
42. Kanayama M, Hashimoto T, Shigenobu K, Togawa D, Oha F. A minimum 10-year follow-up of posterior dynamic stabilization using Graf artificial ligament. Spine. 2007;32(18):1992-6.
43. Kay TM, Gross A, Goldsmith CH, Rutherford S, Voth S, Hoving JL, et al. (2012). Exercises for mechanical neck disorders. Cochrane Database Syst Rev. 2012 Aug 15;8:CD004250.
44. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
45. Manchikanti L, Cash KA, McManus CD, Pampati V, Abdi S. Preliminary results of a randomized, equivalence trial of fluoroscopic caudal epidural injections in managing chronic low back pain: Part 4--Spinal stenosis. Pain physician. 2008; 11(6):833-848.
46. Lawhorne TW 3rd, Girardi FP, Mina CA, Pappou I, Cammisa FP Jr. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-822.
47. Lee JW, Myung JS, Park KW, Yeom JS, Kim KJ, Kim HJ, Kang HS. Fluoroscopically guided caudal epidural steroid injection for management of degenerative lumbar spinal stenosis: Short-term and long-term results. Skeletal Radiol. 2010;39(7):691-699.
48. Lee SC, Chen JF, Wu CT, Lee ST In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
49. Leone A, Cianfoni A, Cerase A, Magarelli N, Bonomo L. Lumbar spondylolysis: A review. Skeletal Radiol. 2011;40(6), 683-700.
50. Lindley EM, McCullough MA, Burger EL, Brown CW, Patel VV. Complications of axial lumbar interbody fusion: Clinical article. J Neurosurg Spine. 2011;15(3):273-279.
51. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-215.
52. Manchikanti L, Cash KA, McManus CD, Pampati V, Abdi S. Preliminary results of a randomized, equivalence trial of fluoroscopic caudal epidural injections in managing chronic low back pain: Part 4 - Spinal stenosis. Pain Physician. 2008;11(6):833-848.
53. McAfee PC, Cunningham BW, Tortolani PJ, Fedder IL, Sefter JC, Davis C. 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS J. 2009;3(1):1-11.
54. Mcgregor AH, Probyn K, Cro S, et al. Rehabilitation following surgery for lumbar spinal stenosis. Cochrane Database Syst Rev. 2013;12:CD009644.
55. Mercaitis OP, Dropkin, B. M., Kaufman, E. L., & Carl, A. L. (2009). Epidural granuloma arising from epidural catheter placement. Orthopedics, 32(4), 293.
56. Miyamoto H, Sumi M, Uno K, Tadokoro K, Mizuno K. Clinical outcome of nonoperative treatment for lumbar spinal stenosis, and predictive factors relating to prognosis, in a 5-year minimum follow-up. J Spinal Disord Tech. 2008;21(8):563-8.
57. Molina M, Wagner P, Campos M. Spinal lumbar stenosis. An update. Rev Med Chil. 2011;139(11):1488-1495.
58. Monticone M, Giovanazzi E. Usefulness of a cognitive behavioural and rehabilitative approach to enhance long lasting benefit after lumbar spinal stenosis and degenerative spondylolisthesis surgery. A case report. Eur J Phys Rehabil Med. 2008;44(4):467-471.
59. Musluman AM, Cansever T, Yilmaz A, Cavusoglu H, Yuce I, Aydin Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16(1):68-76.
60. Niemisto L, Kalso E, Malmivaara A, Seitsalo S, Hurri H. Radiofrequency denervation for neck and back pain. A systematic review of randomized trials. Cochrane Database Syst Rev. 2003;(1): CD004058.

61. Ohtori S, Inoue G, Orita S, Yamauchi K, Eguchi Y, Ochiai N, Toyone T Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: Prospective study. Spine. 2012;37(23):E1464-E1468.
62. Palmer S, Davison L. Minimally invasive surgical treatment of lumbar spinal stenosis: Two-year follow-up in 54 patients. Surg Neurol Int. 2012;3(1):41.
63. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine. 2010;35(4):439-46.
64. Parker SL, Adogwa O, Bydon A, Cheng J, McGirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2), 178-184.
65. Pearson A, Blood E, Lurie J, et al. Degenerative spondylolisthesis versus spinal stenosis: does a slip matter? Comparison of baseline characteristics and outcomes (SPORT). Spine. 2010;35(3):298-305.
66. Peloso P1, Gross A, Haines T, Trinh K, Goldsmith CH, Burnie S; Cervical Overview Group. (2007). Medicinal and injection therapies for mechanical neck disorders. Cochrane Database Syst Rev. 2007;(3):CD000319.
67. Rihn JA, Radcliff K, Hilibrand AS, et al. (2012). Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-1946.
68. Tanaka M, Shimizu H, Yato Y, Asazuma T, Nemoto K. Acute pyogenic discitis in a degenerative intervertebral disc in an adult 2010; 3:77-80.
69. Templin CR, Garfin SR. Surgical Management of Scoliosis and/or Spondylolisthesis Associated with Spinal Stenosis. Semin Spine Surg. 2007;19(3):187-199.
70. Terao T, Ishii T, Tani S, Abe T. Combination therapy of radiofrequency lumbar facet joint denervation and epidural spinal cord stimulation for failed back surgery syndrome. Neurol Med Chir. 2011;51(11):805-809.
71. Van oostrom SH, Driessen MT, De vet HC, et al. Workplace interventions for preventing work disability. Cochrane Database Syst Rev. 2009;(2):CD006955.
72. Wang HL1, Lü FZ, Jiang JY, Ma X, Xia XL, Wang LX. Minimally invasive lumbar interbody fusion via MAST Quadrant retractor versus open surgery: A prospective randomized clinical trial. Chin Med J. 2011;124(23):3868-3874.
73. Welch WC, Cheng BC, Awad TE, Davis R, Maxwell JH, Delamarter R, Macenski MM. Clinical outcomes of the Dynesys dynamic neutralization system: 1-year preliminary results. Neurosurg Focus. 2007;22(1):E8.
74. Jacobs W, Van der gaag NA, Tuschel A, et al. Total disc replacement for chronic back pain in the presence of disc degeneration. Cochrane Database Syst Rev. 2012;9:CD008326.
75. Willems P. Decision making in surgical treatment of chronic low back pain: The performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop. 2013;84(349S):1-37.
76. Wu RH, Fraser JF, Hartl R. Minimal access versus open transforaminal lumbar interbody fusion: meta-analysis of fusion rates. Spine. 2010;35(26):2273-2281.
77. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
78. Yao N, Wang W, Liu Y. Percutaneous endoscopic lumbar discectomy and interbody fusion with B-Twin expandable spinal spacer. Arch Orthop Trauma Surg. 2011;131(6):791-6.
79. Yee AJ, Yoo JU, Marsolais EB, et al. Use of a postoperative lumbar corset after lumbar spinal arthrodesis for degenerative conditions of the spine. A prospective randomized trial. J Bone Joint Surg Am. 2008;90(10):2062-8.
80. Yoshimoto, H., Sato, S., Nakagawa, I., Hyakumachi, T., Yanagibashi, Y., Nitta, F., & Masuda, T. Deep vein thrombosis due to migrated graft bone after posterior lumbosacral interbody fusion: Case report. J Neurosurg Spine. 2007;6(1), 47-51.
81. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis. Cochrane Database Syst Rev. 2012;(12).

D. Surgical Treatment

Original Guideline Question:
Does surgical decompression alone improve surgical outcomes in the treatment of degenerative lumbar spondylolisthesis compared to medical/interventional treatment alone?

Direct surgical decompression may be considered for the treatment of patients with symptomatic spinal stenosis associated with low grade degenerative lumbar spondylolisthesis whose symptoms have been recalcitrant to a trial of medical/interventional treatment. *Updated recommendation statement*

Grade of Recommendation: C

Study obtained from updated literature search:
Murat et al[1] conducted a prospective case series of 84 patients with degenerative spondylolisthesis to evaluate the efficacy of bilateral decompression using a unilateral approach. Patients had a mean age of 62 years old, had lower back pain with or without sciatica, neurogenic claudication that had not improved after at least 6 months of conservative treatment and a radiological diagnosis of Grade I degenerative spondylolisthesis and lumbar stenosis. The surgical technique involved the midline approach, with special attention given to maintaining stability of the supraspinous ligaments and spinous processes. Patients were followed for a minimum of 24 months and evaluated via Visual Analog Scale (VAS), Oswestry Disability Index (ODI) and Neurogenic Claudication Outcomes Score (NCOS). Results indicated that neural and dynamic slip percentages did not significantly change after surgery. Spinal canal size increased from 50.6 to 102.8 ($p<0.001$). The ODI decreased significantly in both the early and late follow-up evaluations, and good to excellent results were obtained in 64 cases. The NCOS demonstrated improvement in late follow-up results ($p<0.001$). Among all of the treated spine levels, 4 patients experienced accidental durotomy; however, these durotomies were not associated with noticeable postoperative morbidity. One patient experienced a wound infection requiring antibiotic therapy, and one patient required secondary fusion due to progressively increasing back pain. While this study doesn't directly address the efficacy of medical/interventional treatment alone, it does provide Level IV therapeutic evidence that bilateral decompression via a unilateral approach is a safe and effective treatment option for degenerative spondylolisthesis patients whose symptoms did not improve after at least 6 months of conservative treatment.

Study included in original guideline:
Matsudaira et al[2] conducted a retrospective comparative study of patients with spinal stenosis and grade I degenerative spondylolisthesis. Eighteen patients underwent decompressive laminoplasty without fusion and 16 patients, who served as the control group, were treated conservatively. All patients received a trial of conservative therapy, which included medication and nerve blocks, for at least three months prior to surgery. At a minimum of 2 years follow-up, decompressive laminoplasty patients showed significantly better improvements in Japanese Orthopaedic Association (JOA) scores than the conservative treatment group ($p<0.001$). The L4-5 range of motion showed no change in the conservative treatment group, whereas it showed a significant decrease in the decompressive laminoplasty group (9.1 ± 4.5 to 9.1 ± 4.3 vs. 11.1 ± 3.8 to 9.3 ± 4.0, $p=0.0443$). The L4-5 angle on flexion also showed no change in the conservative treatment group, whereas posterior enlargement tended to decrease in the decompressive laminoplasty group ($p=0.0671$). In critique of this study, the sample size was modest, particularly considering there were only 16 patients in the medical/interventional group. This paper provides Level III therapeutic evidence that decompressive surgery alone in the form of a decompressive laminoplasty results in better outcomes than conservative treatment in patients with spinal stenosis and Grade I degenerative spondylolisthesis.

There is insufficient evidence to make a recommendation for or against the use of indirect surgical decompression for the treatment of patients with symptomatic spinal stenosis associated with low grade degenerative lumbar spondylolisthesis whose symptoms have been recalcitrant to a trial of medical/interventional treatment.
Maintained from original guideline

Grade of Recommendation: I (Insufficient Evidence)

The updated literature search did not retrieve new evidence to support a recommendation for the use of indirect surgical decompression over medical/interventional treatment in patients with spinal stenosis and low grade degenerative lumbar spondylolisthesis. The Anderson study, included in the original guideline, was the only study retrieved that addressed the clinical question and is summarized below.

Study included in original guideline:

Anderson et al[3] performed a subgroup analysis of 75 patients with Grade I degenerative spondylolisthesis who were originally included in the pivotal randomized controlled trial comparing the X-STOP device and medical/interventional treatment for spinal stenosis with neurogenic claudication that was relieved by flexion and sitting. Although examined prospectively, this subgroup was not appropriated to surgical and medical/interventional treatment in a truly randomized fashion. Forty-two patients had the X-STOP device placed, while 33 had medical/interventional treatment that included at least one epidural steroid injection, medications and physical therapy as needed. Only 70 of 75 patients had a minimum of 2-year follow-up. Of patients in the X-STOP group, 63% had significant improvements in the Zurich Claudication Questionnaire (ZCQ) score, while 12% in the medical/interventional group had significant improvements. In critique of this study, although labeled by the authors as a randomized controlled trial, it was not such for patients with degenerative spondylolisthesis. Patient numbers were relatively low. In support of their findings, there was a low attrition rate (7% at 2-year follow-up). Furthermore, the investigators utilized a validated outcome instrument, the ZCQ. This study offers Level III therapeutic evidence that an interspinous distraction device that provides indirect decompression leads to better outcomes in patients with spinal stenosis and Grade I degenerative spondylolisthesis than does medical/interventional treatment. Although use of the interspinous spacers in the setting of listhesis has been associated with high complication rates.[4,5]

Future Directions for Research

Due to the lack of clarity of the ideal candidate for decompression alone, a large scale randomized controlled trial may be logistically and ethically difficult to perform. The work group acknowledges that previously published high profile studies (SPORT trials) demonstrated the intrinsic difficulties in conducting RCTs comparing surgical to medical/interventional treatment in the North American patient population. It is unlikely that higher quality data are achievable for the comparison of surgical and medical/interventional treatment.

A greater number of nonindustry-sponsored, independent, retrospective or prospective studies need to be done to further investigate a potentially effective and minimally invasive means (interspinous spacers) of decompressing the spinal canal in patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis.

In addition, with increased focus on and use of data registries, the work group recommends the undertaking of large multicenter registry database studies with long term follow-up evaluating the outcomes of both surgical and medical/interventional treatment outcomes in the management of degenerative lumbar spondylolisthesis.

References

1. Matsudaira K, Yamazaki T, Seichi A, et al. Spinal stenosis in grade I degenerative lumbar spondylolisthesis: a comparative study of outcomes following laminoplasty and laminectomy with instrumented spinal fusion. J Orthop Sci. 2005;10(3):270-276.
2. Murat MA, Cansever T, Yilmaz A, Çavuşoğlu H, Yüce I, Aydin Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis: Clinical article. J Neurosurg Spine. 2012;16(1):68-76.
3. Anderson PA, Tribus CB, Kitchel SH. Treatment of neurogenic claudication by interspinous decompression: application of the X STOP device in patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2006;4(6):463-471.
4. Kim DH, Shanti N, Tantorski ME, Shaw JD, Li L, Martha JF, Kwon B. (2012). Association between degenerative spondylolisthesis and spinous process fracture after interspinous process spacer surgery. Spine J. 2012;12(6):466-472.
5. Verhoof OJ, Bron JL, Wapstra FH, van Royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-192.

Bibliography from updated literature search

1. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurgery Q. 2009;19(3):200-206.
2. Bashir EF, Ajani O. Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-146.
3. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2):133-137.
4. Çavuşoğlu H, Türkmenoğlu O, Kaya RA, Tuncer C, Çolak I, Şahin Y, Aydin Y. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-108.
5. Chad DA. Lumbar Spinal Stenosis. Neurol Clin. 2007;25(2):407-418.
6. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: A review of the evidence for an American pain society clinical practice guideline. Spine. 2009;34(10):1094-1109.
7. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-446.

8. Delawi D, Dhert WJ, Rillardon L, Gay E, Prestamburgo D, Garcia-Fernandez C, Oner FC. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-1191.
9. Di Silvestre M, Lolli, F, Bakaloudis G, Parisini P. Dynamic stabilization for degenerative lumbar scoliosis in elderly patients. Spine. 2010;35(2):227-234.
10. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-1186.
11. Eliyas JK, Karahalios D. Surgery for Degenerative Lumbar Spine Disease. Dis Mon. 2011;57(10):592-606.
12. Gilbert JW, Wheeler GR, Kreft MP, Upadhyay SP, Storey BB, Spitalieri JR, Gibbs RA. Repeat Upright Positional Magnetic Resonance Imaging for Diagnosis of Disorders Underlying Chronic Noncancer Lumbar Pain. J Manipulative Physiol Ther. 2008;31(8):627-631.
13. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. Spine J. 2008;8(2):380-384.
14. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3): 167-175.
15. Ibrahimi DM, Beaty NB, Crandall KM, Hamilton DK, Sansur CA. A review of lumbar spondylolisthesis. Eur Musculoskel Rev. 2011;6(2):110-113.
16. Ikuta K, Tono O, Oga M. Prevalence and clinical features of intraspinal facet cysts after decompression surgery for lumbar spinal stenosis. J Neurosurg Spine. 2009;10(6):617-22.
17. Jones TR, Rao RD. Adult isthmic spondylolisthesis. J Am Acad Orthop Surg. 2009;17(10):609-617.
18. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
19. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
20. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surgeons. 2008;16(4):208-215.
21. McAfee PC, Cunningham BW, Tortolani PJ, Fedder IL, Sefter JC, Davis C. 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS J. 2009;3(1):1-11.
22. Musluman AM, Cansever T, Yilmaz A, Cavusoglu H, Yuce I, Aydin Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16(1):68-76.
23. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
24. Pao JL, Chen WC, Chen PQ. Clinical outcomes of microendoscopic decompressive laminotomy for degenerative lumbar spinal stenosis. Eur Spine J. 2009;18(5):672-678.
25. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine 2010;35(4):439-446.
26. Pearson A, Blood E, Lurie J, et al. Degenerative spondylolisthesis versus spinal stenosis: Does a slip matter? Comparison of baseline characteristics and outcomes (SPORT). Spine. 2010;35(3):298-305.
27. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-1946.
28. Surace MF, Fagetti A, Fozzato S, Cherubino P. (2012). Lumbar spinal stenosis treatment with aperius perclid interspinous system. Eur Spine J. 2012;21 Suppl 1:S69-S74.
29. Terao T, Ishii T, Tani S, Abe T. Combination therapy of radiofrequency lumbar facet joint denervation and epidural spinal cord stimulation for failed back surgery syndrome. Neurol Med Chir. 2011;51(11):805-809.
30. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-465.
31. Weinstein JN, Lurie JD, Tosteson TD, et al. (2007). Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 356(22), 2257-2270.
32. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-1304.
33. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis. Cochrane Database Syst Rev. 2012;CD010264.

Original Guideline Question:

Does the addition of lumbar fusion, with or without instrumentation, to surgical decompression improve surgical outcomes in the treatment of degenerative lumbar spondylolisthesis compared to treatment by decompression alone?

Surgical decompression with fusion is suggested for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis to improve clinical outcomes compared with decompression alone. *Maintained from original guideline with minor word modifications*

Grade of Recommendation: B

For symptomatic single-level degenerative spondylolisthesis that is low-grade (<20%) and without lateral foraminal stenosis, decompression alone with preservation of midline structures provide equivalent outcomes when compared to surgical decompression with fusion. *New recommendation statement*

Grade of Recommendation: B (Suggested)

Studies obtained from updated literature search:

Aihara et al[1] conducted a prospective, comparative study of 50 consecutive patients to compare decompression with fusion to microendoscopic decompression (MED) for the treatment of degenerative lumbar spondylolisthesis. The first 17 patients underwent decompression with fusion and the next 33 patients underwent MED. In the fusion group, 14 patients had slippage at L4 and 3 patients had slippage at both L3 and L4. In the MED group, 21 patients had slippage at L4, 7 patients had slippage at L3, one patient at L5, and 4 patients at both L3 and L4. Before the operation, plain radiographs of the lumbosacral spine were taken in all patients to measure the intervertebral angle between the adjacent vertebral end-plates at the operative level as seen on the lateral flexion-extension radiographs and to measure the percentage of slipping at the level of the slip. These radiographs were repeated at follow-up, which ranged from 25 to 40 months for both groups. Clinical outcomes were also evaluated using the Japanese Orthopaedic Association Back Pain Evaluation Questionnaire (JOABPEQ), which consists of 5 functional scores selected from the Roland Morris Disability Questionnaire and SF-36. Operation time, blood loss and postoperative hospitalization were significantly less in the MED group (p=0.0000431, p=0.00000859, p-0.00141, respectively). As measured by the JOABPEQ, the degrees of improvement for low-back pain, lumbar function, walking ability, social life function and mental health were greater in patients in the MED group compared to the fusion group; however, the differences were not statistically significant between groups. Degree of improvement in lumbar function was significantly greater in the decompression with fusion group compared to the MED group in regard to the percentage of slipping in neutral position among those with over 20% slipping (p=0.0396). Although not statistically significant, degrees of improvement in low-back pain, walking ability, social life function and mental health were greater in the decompression and fusion group compared to the MED group among those with over 20% slippage. Postoperative complications included one patient with transient foot drop and 2 patients with pseudarthrosis in the decompression and fusion group and 2 patients with transient urinary retention in the MED group. No major internal complications or surgical site infections were observed. This study provides therapeutic Level II evidence that decompression with fusion and MED for the treatment of degenerative lumbar spondylolisthesis result in similar outcomes for lower grade slips. When the slippage exceeds 20%, posterior decompression and fusion with pedicular screws may be the preferred surgical treatment.

In a retrospective comparative study, Kleinstueck et al[2] examined whether the outcomes of surgery for degenerative lumbar spondylolisthesis varied depending on the predominant baseline symptoms and the treatment administered. A total of 213 pa-

tients underwent surgical treatment including 56 with decompression alone and 157 with decompression and fusion. Patients were followed for 12 months and outcomes were evaluated using the multidimensional Core Outcome Measures Index (COMI) questionnaire. At 12 months, there was greater reduction in back pain, leg pain and neurological deficit in the decompression and fusion group compared to the decompression alone group (p=0.04). Using the global outcome measure of either "good" or "poor," 86.2% of patients in the decompression and fusion group had a good outcome compared to 70.4% of patients in the decompression-only group (p=0.01). Multivariable regression analysis suggested that decompression and fusion was a significant predictor for the 12 month COMI and Global outcomes. An odds ratio of 2.6 was calculated favoring decompression and fusion over decompression alone. The level of back pain and leg pain, and the category of the main problem at baseline had no significant influence on outcome. There were no statistically significant differences in complication rates between the groups. In the decompression only group 7 of 56 patients experienced surgical complications, including 2 bleeding in spinal canal, 2 dura lesion, one wound infection, one continuing back pain and one wound dehiscence. In the decompression and fusion group, 14 of 157 experienced complications, including one bleeding in spinal canal, 3 bleeding outside spinal canal, 6 dural tears, 2 wound infections and 2 necrotic wounds. In critique of this study, there was a statistically significant difference in age between the two groups, with an average age of 73 years ± 8 in the decompression alone group and 67.4 years ± 9.4 in the decompression and fusion group (p<0.0001). Although multivariate regression analysis suggested that increased age was not an independent predictor of poor outcome, the favored results in the decompression and fusion group should be interpreted cautiously as the analysis may have not accounted for all variables associated with morbidity in older aged individuals. This study provides Level III therapeutic evidence that instrumented fusion and decompression may provide superior outcomes to decompression alone in patients under 70 years old regardless of baseline symptoms.

Park et al[3] retrospectively compared the outcomes of patients undergoing either decompression alone or decompression with fusion and fixation for the treatment of degenerative spondylolisthesis. A total of 45 patients underwent surgical treatment after being unresponsive to conservative treatment for 3 or more months, including 20 unilateral laminectomy and bilateral decompression (ULBD) patients and 25 decompression and instrumented fusion patients. All patients had stable Grade I, single level degenerative spondylolisthesis with translation < 5mm. Patients were followed for a minimum of 3 years and outcomes were assessed using the numeric rating scale (NRS) for back and leg pain, the Oswestry Disability Index (ODI), the physical component summary (PCS), the mental component summary (MCS), and Short Form 36 (SF-36). Radiological outcomes were analyzed by determining changes in slippage, disc height translation, and angular difference on simple and dynamic x-ray films. Results suggested that there was a statistically significant greater decrease in the mean NRS for back pain in the fusion group (6.6 ± 2.4 to 2.4 ± 1.88) compared to the ULBD group (2.8 ± 3.10 to 1.2 ± 2.20, p=0.0001). However, it is important to note that fusion patients had much higher preoperative and postoperative back pain scores compared to ULBD patients; therefore, the significance of this finding is questionable. There was no significant difference in the mean ODI, SF-36 PCS, SF-36 MCS and NRS of leg pain between the groups. Excellent or good outcomes occurred in 13 ULBD and 14 fusion group patients based on Odom's criteria. In the ULBD group, 3 patients had residual pain and 3 had recurrent pain. The 3 patients with residual pain had nonquantified preoperative foraminal narrowing. Complaints of recurrent pain occurred 1, 1.5 and 2 years after surgery. Those with recurrent pain had unilaterally more collapsed discs on the painful side on preoperative AP radiograph. In comparison, no patients in the fusion group had residual pain and 5 had recurrent pain and intermittent radiculopathy. Radiologically, the ULBD group showed a 2.1 ± 3.10% change in mean slippage, a 0.15 ± 1.58 mm change in mean translation, a 0.91 ± 4.48 degrees change in mean angular difference and a -1.83 ± 1.69 mm change in mean disc height. In the fusion the mean reductions in upper and lower disc heights were 1.38 ± 1.10 mm and 1.19 ± 0.80 mm, respectively. In critique, the sample size of this study was small and the diagnostic methods used for the initial diagnosis of degenerative lumbar spondylolisthesis were vaguely described; however, the group did not feel that these were sufficient reasons to downgrade the study. In conclusion, this study provides Level III therapeutic evidence that in patients with stable degenerative lumbar spondylolisthesis, results of unilateral laminectomy and bilateral decompression may be similar to instrumented fusion for functional outcomes and lower extremity pain scores.

Kim et al[4] compared the cost effectiveness of decompression with and without instrumented fusion in patients undergoing surgical treatment for degenerative spondylolisthesis. The primary study outcome was the incremental cost/utility ratio (ICR) expressed as the differential cost per relative gain in quality-adjusted life-year (QALY). A total of 115 patients underwent surgery, including 57 in the decompression group and 58 in the decompression with fusion group. Patients were included in the study if postoperative data, including SF-6D health utility scores, hospital cost/case rates and revision rates were available for at least one year after surgery. A Markov Cost Model was developed for a 10-year period with a one-year cycle for a hypothetical cohort of 1,000 surgical candidates undergoing decompression only or decompression with fusion. Average costs for these surgeries over a period of 4 years was captured and calculated in the Markov model. The average cost used for the cohort simulation was $18,161 per case for decompression with instrumented fusion and $5,243 per case for decompression alone. All costs were represented in 2010 Canadian dollars. The authors suggest that for a specific subpopulation of degenerative lumbar spondylolisthesis patients (ie, those with leg-dominant pain and stable spondylolisthesis), decompression alone and decompression plus fusion are almost similar in clinical effectiveness with a slight advantage for fusion. However, this small advantage comes at a large cost ($185,878/QALY gained compared with decompression alone) that makes it unfavorable in the context of health-care decision making with limited resources. Due to the limited clinical outcomes provided in the study's results, this study has been included to provide background support only and has been not assigned a level of evidence grade to provide support to the recommendation.

Studies from original guideline:

Bridwell et al[5] described a prospective, comparative study of 44 surgically treated patients with degenerative lumbar spondylolisthesis followed for a minimum of two years. Of the 44 patients, 9 underwent laminectomy alone, 10 had laminectomy and noninstrumented fusion and 24 had laminectomy and instrumented fusion (18 single-level, 6 two-level). Patients were radiographically assessed and a functional assessment was conducted by asking whether they felt their ability to walk distances was worse (-), the same (0) or significantly better (+). Of the 44 patients, 43 were followed for 2 years or more. The authors determined that instrumented fusion had higher fusion rates than noninstrumented fusion (ρ=0.002). The authors further observed greater progression of spondylolisthesis in patients treated with laminectomy alone (44%) and in laminectomy without instrumented fusion (70%) compared to patients who received laminectomy with instrumented fusion (4%,ρ=0.001). A higher proportion of the patients without slippage progression reported that they were helped by the surgery than those whose slippage progressed postoperatively (ρ<0.01). In critique, this was a small study in which selection bias entered into the randomization process, reviewers were not masked to patient treatment and validated outcome measures were not utilized. Because of these weaknesses, this potential Level II study was downgraded to Level III. This study provides Level III therapeutic evidence that instrumented fusion patients had less chance of progressive slippage postoperatively than laminectomy alone or noninstrumented fusions and a higher proportion of patients with stable or unchanged spondylolisthesis reported greater improvement after surgery.

Herkowitz et al[6] conducted a prospective, comparative study of 50 patients with degenerative lumbar spondylolisthesis to determine if concomitant intertransverse process arthrodesis provided better results than decompression alone. Clinical outcomes were assessed using a rudimentary outcome scale (excellent, good, fair, poor) with a mean follow-up of 3 years. Preoperative and postoperative plain radiographs of the lumbosacral spine were also taken. The authors reported that of the 25 patients treated with decompression and fusion, 11 reported excellent results, 13 good, one fair and zero poor. Of the 25 patients treated with decompression alone, 2 reported excellent results, 9 good, 12 fair and 2 poor. Improved results in the patients who had an arthrodesis concomitantly with decompression were significant by the Fisher exact test (ρ=0.0001). The authors concluded that in patients who had a concomitant arthrodesis, the results were significantly better with respect to relief of low back pain and lower limb pain. In critique, this was a small study which did not utilize validated clinical outcome measures or describe baseline characteristics of the groups. Because of these weaknesses, this potential level II study was downgraded to Level III. This study offers Level III therapeutic evidence that decompression with arthrodesis in patients with degenerative lumbar spondylolisthesis provides significantly better relief of low back pain and leg pain than decompression alone.

Mardjetko et al[7] performed a meta-analysis of primarily Level III studies. The objective of the study was to analyze the published data on degenerative spondylolisthesis to evaluate the feasibility of its use as a literature control to compare with the historical cohort pedicle screw study data. The authors conducted a comprehensive literature search to identify studies published in English peer-reviewed journals between 1970 and 1993 addressing degenerative spondylolisthesis with radicular leg pain or neurogenic claudication. Inclusion criteria included a minimum of 4 cases reviewed and reporting of the primary outcome variable of fusion in articles in which this was part of the treatment. Clinical outcome variables of back pain, leg pain, function, neurogenic claudication and global outcome scores were recorded when available. A total of 25 papers representing 889 patients were accepted for inclusion. Twenty-one were retrospective, nonrandomized and uncontrolled. One paper was retrospective and nonrandomized, but compared 2 different treatments. Three prospective, randomized studies were included. The primary outcome variable, fusion, was determined by each author. The most constant clinical outcome variable reported was pain with 16 papers reporting pain only, 6 papers reporting pain and function, and 2 papers reporting patient-determined outcomes. Patient function was reported in 6 papers and referred to the presence or absence of neurogenic claudication. In addition to these clinical outcomes, four papers reported a global evaluation. Two used Kaneda's rating system and two used the Japanese Orthopedic Association (JOA) score. Excellent and good results were reassigned as satisfactory; poor results were classified as unsatisfactory. The authors reported that in the decompression alone category, 11 papers representing 216 patients accepted for inclusion in the decompression category. Sixty-nine percent of patients had a satisfactory outcome. The incidence of worsened postoperative slip was 31% but was not associated with a poorer clinical result in the majority of patients. In the category of decompression with fusion and no instrumentation, 6 papers qualified for inclusion. In one paper, only fusion data were broken out for the diagnosis of degenerative spondylolisthesis and were used just for this outcome variable. Ninety percent of the patients in this category had a satisfactory outcome; 86% achieved solid spinal fusion. With regard to clinical outcome, the difference between patients treated with decompression without fusion (69% satisfactory) and those treated with decompression and fusion without instrumentation (90% satisfactory) was statistically significant ($p< 0.0001$). In the decompression with fusion and pedicle screws category, 5 studies met the inclusion criteria. Fusion status was analyzed in 101 patients. Eighty-five patients were analyzed with respect to clinical outcome. One paper did not separately analyze clinical data, but did so for fusion data; therefore, only fusion data were included. The proportionally weighted fusion rates for this group were 93%. When comparing the fusion without instrumentation group to the fusion with pedicle screw group, there was not a statistically significant increase in fusion rate ($p = 0.08$). Analysis of the clinical outcomes reveals an 86% satisfactory rating for the pedicle screw group. This compares favorably to the 69% satisfactory rate in the decompression without fusion group ($p <0.0001$). In the anterior spinal fusion category, three papers presenting the results for 72 patients who received anterior spinal fusion for the treatment of degenerative spondylolisthesis were included. Pooling the data from these three studies yielded a 94% fusion rate with an 86% rate of patient satisfaction. The authors concluded that the meta-analysis results support the clinical impression that, in the surgical management of degenerative lumbar spondylolisthesis,

spinal fusion significantly improves patient satisfaction. In critique of this study, only 3 Level II studies were reviewed and data was very heterogeneous. This paper offers Level III therapeutic evidence that the addition of fusion with or without instrumentation to decompression improves clinical outcomes.

Martin et al[8] conducted a systematic review designed to identify and analyze comparative studies that examined the surgical management of degenerative lumbar spondylolisthesis, specifically the differences in outcomes between fusion and decompression alone, and between instrumented fusion and noninstrumented fusion. Relevant randomized controlled trials (RCTs) and comparative observational studies were identified in a comprehensive literature search (1966 to June 2005). The inclusion criteria required that a study be an RCT or comparative observational study that investigated the surgical management of degenerative lumbar spondylolisthesis by comparing:

1. fusion to decompression and/or
2. instrumented fusion to noninstrumented fusion.

A minimum one-year follow-up was required. Studies also had to include at least 5 patients per treatment group. A study was excluded if it included patients who had received previous spine surgery or patients with cervical injuries, spinal fractures, tumors or isthmic spondylolisthesis. A study was also excluded if it was not possible to analyze patients with degenerative spondylolisthesis separately from another included patient population or if it was not clearly a comparative study. Data from the included studies were extracted by 2 independent reviewers using a standard data abstraction sheet. The data abstraction sheet identified the following information:

1. patient population's age, sex, symptoms and degree of spondylolisthesis;
2. type of decompression, fusion, instrumentation, bone graft material, and preoperative and postoperative treatment;
3. study design and methodological quality using the Cochrane RCT/CCT/Crossover Studies Checklist, modified by the additional criterion that observational studies state the use of a consecutive series of patients; and
4. study outcomes.

The main abstracted outcomes were clinical outcome, reoperation rate and solid fusion status. An attempt was made to compare patient-centered, validated and disease-specific outcomes, complications and spondylolisthesis progression, but because of heterogeneity in reporting these outcomes in the primary studies, no pooled analysis could be performed on these outcomes. When appropriate, a study's clinical outcome rating scale was altered to match a dichotomous rating scale of "satisfactory" or "unsatisfactory" clinical outcome, and results were entered into Review Manager 4.2 for weighted grouped analyses. The authors reported that 8 studies were included in the fusion versus decompression alone analysis, including two RCTs. Limitations were found in the methodologies of both RCTs and most of the observational studies. Grouped analysis detected a significantly higher probability of achieving a satisfactory clinical outcome with spinal fusion than with decompression alone (relative risk, 1.40; 95% confidence interval, 1.04–1.89; $P < 0.05$). The clinical benefit favoring fusion decreased when analysis was limited to studies where the majority of patients were reported to be experiencing neurologic symptoms such as intermittent claudication and/or leg pain. Six studies were included in the instrumented fusion versus noninstrumented fusion analysis, including three RCTs. The use of adjunctive instrumentation significantly increased the probability of attaining solid fusion (relative risk, 1.37; 95% confidence interval, 1.07–1.75; $P < 0.05$), but no significant improvement in clinical outcome was recorded (relative risk, 1.19; 95% confidence interval, 0.92–1.54). There was a nonsignificant trend towards a lower repeat operation rate in the fusion group compared with both decompression alone and instrumented fusion. The authors concluded there is moderate evidence that fusion may lead to a better clinical outcome compared with decompression alone. Evidence that the use of adjunctive instrumentation leads to improved fusion status and less risk of pseudarthrosis is also moderate. No conclusion could be made about the clinical effectiveness of instrumented fusion versus noninstrumented fusion. In critique of this study, it was a systematic review of studies ranging down to Level III, and is thus classified as a Level III systematic review. Limitations were found in the methodologies of all RCTs, specifically in the pseudorandomization, absence of masking and/or the lack of validated outcome measures to assess clinical outcomes. This paper offers Level III therapeutic evidence that fusion leads to a better clinical outcome compared with decompression alone and the use of adjunctive instrumentation leads to improved fusion status and less risk of pseudarthrosis. Their data does not demonstrate any difference in clinical outcomes between instrumented and noninstrumented fusions.

Matsudaira et al[9] described a retrospective, comparative study of 55 patients with spinal stenosis and Grade I degenerative lumbar spondylolisthesis. Of the 55 patients, 20 underwent laminectomy plus posterolateral fusion and pedicle screw instrumentation (Group 1), 19 underwent laminoplasty alone (Group 2) and 16 refused surgery and received medical/interventional treatment (Group 3). One patient in each surgical group was lost to follow-up. Outcomes were assessed by the Japanese Orthopedic Association (JOA) score, along with radiographic evaluation at minimum 2-year follow-up. The authors reported that alleviation of symptoms was noted in the fusion and laminoplasty groups but not in the medical/interventional treatment group. No statistically significant difference in clinical improvement was noted between the fusion and laminoplasty groups. The percent slip increased significantly in groups 2 and 3, whereas spondylolisthesis was stabilized in Group 1. The authors concluded that decompression with preservation of the posterior elements can be useful in treating patients with symptomatic lumbar spinal stenosis resulting from Grade I degenerative spondylolisthesis. In critique of this study, the numbers were small, patients were not randomized and no clearly defined indications for specific treatment selections were included. This paper offers Level III therapeutic evidence that decompression with posterolateral fusion and instrumentation, as well as laminoplasty alone yield improved outcomes in the treatment of symptomatic lumbar spinal stenosis resulting from Grade I degenerative spondylolisthesis as compared with medical/interventional treatment alone.

Future Directions for Research

Because of the lack of clarity of the ideal candidate for decompression alone, a large scale randomized controlled trial may be logistically and ethically difficult to perform in comparison to decompression and fusion.

The work group recommends the undertaking of large multicenter registry database studies with long term follow-up evaluating the outcomes of various surgical techniques, including decompression with and without fusion, for the surgical treatment of degenerative lumbar spondylolisthesis. It will be important for these databases to be populated with comprehensive demographic and radiographic detail in order to appropriately distinguish various cohorts.

References

1. Aihara T, Toyone T, Aoki Y, et al. Surgical management of degenerative lumbar spondylolisthesis. Journal of Musculoskelet Res. 2012;15(4):1250020.
2. Kleinstueck FS, Fekete TF, Mannion AF, Grob D, Porchet F, Mutter U, Jeszenszky D. To fuse or not to fuse in lumbar degenerative spondylolisthesis: do baseline symptoms help provide the answer? Eur Spine J. 2012;21(2):268-275.
3. Park JH, Hyun SJ, Roh SW, Rhim SC. A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis. Acta Neurochir. 2012;154(7):1205-1212.
4. Kim S, Mortaz Hedjri S, Coyte PC, Rampersaud YR. Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis. Spine J. 2012;12(1):44-54.
5. Bridwell KH, Sedgewick TA, O'Brien MF, Lenke LG, Baldus C. The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. J Spinal Disord. 1993;6(6):461-472.
6. Herkowitz HN, Kurz LT. Degenerative lumbar spondylolisthesis with spinal stenosis. A prospective study comparing decompression with decompression and intertransverse process arthrodesis. J Bone Joint Surg Am. 1991;73(6):802-808.
7. Mardjetko SM, Connolly PJ, Shott S. Degenerative lumbar spondylolisthesis. A meta-analysis of literature 1970-1993. Spine. 1994;19(20 Suppl):2256S-2265S.
8. Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'Neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: A systematic review. Spine. 2007;32(16):1791-1798.
9. Matsudaira K, Yamazaki T, Seichi A, et al. Spinal stenosis in grade I degenerative lumbar spondylolisthesis: A comparative study of outcomes following laminoplasty and laminectomy with instrumented spinal fusion. J Orthop Sci. 2005;10(3):270-276.

Bibliography from updated literature search

1. Abdul Q, Qayum M, Saradhi M, Panigrahi M, Sreedhar V. Clinico-radiological profile of indirect neural decompression using cage or auto graft as interbody construct in posterior lumbar interbody fusion in spondylolisthesis: Which is better. J Craniovertebr Junction Spine 2011;2(1):12-16.
2. Agabegi SS, Majid K, Fischgrund JS, Vaccaro AR, Patel T. Can preoperative radiographic parameters be used to predict fusion in non-instrumented posterolateral fusion for degenerative spondylolisthesis? Spine. 2011;36(26):E1709-1714.
3. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurg Q. 2009;19(3):200-206.
4. Allen RT, Rihn JA, Glassman SD, Currier B, Albert TJ, Phillips FM. An evidence-based approach to spine surgery. Am J Med Qual. 2009;24; 6 Suppl:15S-24S.
5. Aono H, Iwasaki M, Ohwada T, Okuda S, Hosono N, Fuji T, Yoshikawa H. Surgical outcome of drop foot caused by degenerative lumbar diseases. Spine. 2007;32(8):E262-E266.
6. Bashir EF, Ajani O. Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-146.
7. Bederman SS, Coyte PC, Kreder HJ, Mahomed NN, McIsaac WJ, Wright JG. Who's in the driver's seat? The influence of patient and physician enthusiasm on regional variation in degenerative lumbar spinal surgery: a population-based study. Spine. 2011;36(6):481-489.
8. Boden SD. Spinescope. Semin Spine Surg. 2011;23(2):151-156.
9. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2):133-137.
10. Bono CM, Kadaba M, Vaccaro AR. Posterior pedicle fixation-based dynamic stabilization devices for the treatment of degenerative diseases of the lumbar spine. J Spinal Disord Tech. 2009;22(5):376-383.
11. Brower RS, Vickroy NM. A case of psoas ossification from the use of BMP-2 for posterolateral fusion at L4-L5. Spine. 2008;33(18):E653-655.
12. Cansever T, Civelek E, Sencer A, Karasu A, Turantan I. Intermittent priapism in degenerative lumbar spinal stenosis: Case report. Turk Neurosurg. 2007;17(4):260-263.
13. Chad DA. Lumbar Spinal Stenosis. Neurol Clin. 2007;25(2):407-418.
14. Chaudhary KS, Groff MW. Minimally invasive transforaminal lumbar interbody fusion for degenerative spine. Tech Orthop. 2011;26(3):146-155.
15. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: A review of the evidence for an American pain society clinical practice guideline. Spine. 2009;34(10): 1094-1109.
16. Cole CD, McCall TD, Schmidt MH, Dailey AT. Comparison of low back fusion techniques: Transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) approaches. Cur Rev Musculoskelet Med. 2009;2(2):118-126.
17. Dantas FL, Prandini MN, Ferreira MA. Comparison between posterior lumbar fusion with pedicle screws and posterior lumbar interbody fusion with pedicle screws in adult spondylolisthesis. Arq Neuropsiquiatr. 2007;65(3B):764-770.
18. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. (2009). Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-446.
19. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-1191.
20. Desai A, Ball PA, Bekelis K, et al. Surgery for lumbar degenerative spondylolisthesis in Spine Patient Outcomes Research Trial: does incidental durotomy affect outcome? Spine. 2012;37(5):406-413.
21. Di Silvestre M, Lolli F, Bakaloudis G, Parisini P. Dynamic stabilization for degenerative lumbar scoliosis in elderly patients. Spine. 2010;35(2):227-234.
22. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
23. Eliyas JK, Karahalios D. Surgery for Degenerative Lumbar Spine Disease. Dis Mon. 2011;57(10): 592-606.
24. Epstein NE. An analysis of noninstrumented posterolateral

lumbar fusions performed in predominantly geriatric patients using lamina autograft and beta tricalcium phosphate. Spine J. 2008;8(6):882-887.
25. Epstein NE. X-Stop: foot drop. Spine J. 2009;9(5):e6-e9.
26. Eskander MS, Eskander JP, Drew JM, Pelow-Aidlen JL, Eslami MH, Connolly PJ. (2010). A modified technique for dowel fibular strut graft placement and circumferential fusion in the setting of L5-S1 spondylolisthesis and multilevel degenerative disc disease. Neurosurgery. 2010;67(3 Suppl Operative):ons91-95; discussion ons95.
27. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.
28. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech. 2010;23(4):236-241.
29. Fernandez-Fairen M, Sala P, Ramirez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
30. Fransen P. Increasing pedicle screw anchoring in the osteoporotic spine by cement injection through the implant: Technical note and report of three cases. J Neurosurg Spine. 2007;7(3):366-369.
31. Fujimoto K, Yamazaki M, Hayashi K, et al. Posterior decompression with instrumented fusion in a patient with cervical myelopathy thirty years after cadaveric renal transplantation. Chiba Med J. 2011;87(1):11-15.
32. Gavaskar AS, Achimuthu R. Transfacetal fusion for low-grade degenerative spondylolisthesis of the lumbar spine: results of a prospective single center study. J Spinal Disord Tech. 2010;23(3):162-165.
33. Gelalis ID, Arnaoutoglou C, Christoforou G, Lykissas MG, Batsilas I, Xenakis T. Prospective analysis of surgical outcomes in patients undergoing decompressive laminectomy and posterior instrumentation for degenerative lumbar spinal stenosis. Acta Orthop Traumatol Turc. 2010;44(3):235-40.
34. Gilbert JW, Wheeler GR, Kreft MP, et al. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-31.
35. Ha KY, Na KH, Shin JH, Kim KW. Comparison of posterolateral fusion with and without additional posterior lumbar interbody fusion for degenerative lumbar spondylolisthesis. J Spinal Disord Tech. 2008;21(4):229-34.
36. Hara M, Nishimura Y, Takemoto M, Nakamura S, Wakabayashi T. Posterior fixation for lumbar degenerative spondylosis: Mini-open TLIF. Japan J Neurosurg. 2012;21(2):118-127.
37. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. Spine J. 2008;8(2):380-384.
38. Harris EB, Sayadipour A, Massey P, Duplantier NL, Anderson DG. Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis. A J Orthop. 2011;40(12):E257-261.
39. Hart RA, Prendergast MA. Spine surgery for lumbar degenerative disease in elderly and osteoporotic patients. Instr Course Lect. 2007;56:257-272.
40. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. Surgical technique. J Bone Joint Surg Am. 2008;90 Suppl 2 Pt 1:145-52.
41. Herkowitz HN. Degenerative lumbar spondylolisthesis: evolution of surgical management. Spine J. 2009;9(7):605-606.
42. Hong SW, Lee HY, Kim KH, Lee SH. Interspinous ligamentoplasty in the treatment of degenerative spondylolisthesis: midterm clinical results. J Neurosurg Spine. 2010;13(1):27-35.
43. Hrabálek L, Wanek T, Adamus M. Treatment of Degenerative Spondylolisthesis of the Lumbosacral Spine by Decompression and Dynamic Transpedicular Stabilisation. Acta Chir Orthop Traumatol Cech. 2011;78(5):431-436.
44. Hu SS, Tribus CB, Diab M, Ghanayem AJ. Spondylolisthesis and spondylolysis. Instr Course Lect. 2008;57:431-445.
45. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-75.
46. Huang TY, Lee KS, Tsai TH, Su YF, Hwang SL. Posterior epidural migration of sequestrated lumbar disc fragments into the bilateral facet joints: case report. Neurosurgery. 2011;69(5):E1148-51.
47. Hunt T, Shen FH, Shaffrey CI, Arlet V. Contralateral radiculopathy after transforaminal lumbar interbody fusion. Eur Spine J. 2007;16 Suppl 3:311-314.
48. Hussain NS, Hanscom D, Oskouian RJ. Chyloretroperitoneum following anterior spinal surgery. J Neurosurg Spine. 2012;17(5):415-21.
49. Hwang CJ, Vaccaro AR, Hong J, et al. Immunogenicity of osteogenic protein 1: results from a prospective, randomized, controlled, multicenter pivotal study of uninstrumented lumbar posterolateral fusion. J Neurosurg Spine. 2010;13(4):484-93
50. Ikuta K, Tono O, Oga M. Clinical outcome of microendoscopic posterior decompression for spinal stenosis associated with degenerative spondylolisthesis--minimum 2-year outcome of 37 patients. Minim Invasive Neurosurg. 2008;51(5):267-71.
51. Ito Z, Matsuyama Y, Sakai Y, et al. Bone union rate with autologous iliac bone versus local bone graft in posterior lumbar interbody fusion. Spine. 2010;35(21):E1101-5.
52. Jiang SD, Jiang LS, Dai LY. Degenerative cervical spondylolisthesis: a systematic review. Int Orthop. 2011;35(6):869-75.
53. Jones TR, Rao RD. Adult isthmic spondylolisthesis. J Am Acad Orthop Surg. 2009;17(10):609-617.
54. Kaner T, Dalbayrak S, Oktenoglu T, Sasani M, Aydin AL, Ozer AF. Comparison of posterior dynamic and posterior rigid transpedicular stabilization with fusion to treat degenerative spondylolisthesis. Orthopedics. 2010;33(5)
55. Kelleher MO, Timlin M, Persaud O, Rampersaud YR. Success and failure of minimally invasive decompression for focal lumbar spinal stenosis in patients with and without deformity. Spine. 2010;35(19):E981-7.
56. Kirkman MA, Sridhar K. Posterior listhesis of a lumbar vertebra in spinal tuberculosis. Eur Spine J. 2011;20(1):1-5.
57. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
58. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
59. Lattig F, Fekete TF, Grob D, Kleinstück FS, Jeszenszky D, Mannion AF. Lumbar facet joint effusion in MRI: a sign of instability in degenerative spondylolisthesis?. Eur Spine J. 2012;21(2):276-81.
60. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact

of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.
61. Lee DY, Lee SH, Shim CS, Lee HY. Decompression and interspinous dynamic stabilization using the locker for lumbar canal stenosis associated with low-grade degenerative spondylolisthesis. Minim Invasive Neurosurg. 2010;53(3):117-21.
62. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
63. Lee SE, Park SB, Jahng TA, Chung CK, Kim HJ. Clinical experience of the dynamic stabilization system for the degenerative spine disease. J Korean Neurosurg Soc. 2008;43(5):221-6.
64. Lekovic GP, Han PP, Kenny KJ, Dickman CA. Bone dowels in anterior lumbar interbody fusion. J Spinal Disord Tech. 2007;20(5):374-379.
65. Liao JC, Chen WJ, Chen LH, Niu CC. Outcome of the L5-S1 segment after posterior instrumented spinal surgery in degenerative lumbar diseases. Chang Gung Medical J. 2009;32(1):81-88.
66. Liao JC, Chen WJ, Chen LH, Niu CC, Keorochana G. Surgical outcomes of degenerative spondylolisthesis with L5-S1 disc degeneration: comparison between lumbar floating fusion and lumbosacral fusion at a minimum 5-year follow-up. Spine. 2011;36(19):1600-7.
67. Long H, Kazunasa U, Liu S, Akio S, Taito I. Preliminary application of one-level posterior lumbar interbody fusion with prospace and facet fusion using local autograft. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi. 2007;21(11):1155-1159.
68. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: Trends in management. J Am Acad Orthop Surg. 2007;16(4):208-215.
69. Martin BI, Mirza SK, Comstock BA, Gray DT, Kreuter W, Deyo RA. Are lumbar spine reoperation rates falling with greater use of fusion surgery and new surgical technology? Spine. 2007;32(19):2119-2126.
70. Martin BI, Mirza SK, Comstock BA, Gray DT, Kreuter W, Deyo RA. Reoperation rates following lumbar spine surgery and the influence of spinal fusion procedures. Spine. 2007;32(3):382-387.
71. Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'Neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: A systematic review. Spine. 2007;32(16):1791-1798.
72. McAfee P, Khoo LT, Pimenta L, Capuccino A, Sengoz A, Coric D, Anekstein Y. Treatment of lumbar spinal stenosis with a total posterior arthroplasty prosthesis: implant description, surgical technique, and a prospective report on 29 patients. Neurosurg Focus. 2007;22(1).
73. McAfee PC, Cunningham BW, Tortolani PJ, Fedder IL, Sefter JC, Davis C. 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS J. 2009;3(1):1-11.
74. Mehta VA, Mcgirt MJ, Garcés ambrossi GL, et al. Trans-foraminal versus posterior lumbar interbody fusion: comparison of surgical morbidity. Neurol Res. 2011;33(1):38-42.
75. Min JH, Jang JS, Kim SK, Maeng DH, Lee SH. The ligamentotactic effect on a herniated disc at the level adjacent to the anterior lumbar interbody fusion : report of two cases. J Korean Neurosurg Soc. 2009;46(1):65-7.
76. Miscusi M, Petrozza V, Polli FM, Forcato S, Rocca CD, Raco A. Symptomatic ganglion cyst of ligamentum flavum as a late complication of lumbar fixation. Neurol Neurochir Pol. 2012;46(1):82-6.
77. Mokhtar SA, Mccombe PF, Williamson OD, Morgan MK, White GJ, Sears WR. Health-related quality of life: a comparison of outcomes after lumbar fusion for degenerative spondylolisthesis with large joint replacement surgery and population norms. Spine J. 2010;10(4):306-12.
78. Mori E, Okada S, Ueta T, et al. Spinous process-splitting open pedicle screw fusion provides favorable results in patients with low back discomfort and pain compared to conventional open pedicle screw fixation over 1 year after surgery. Eur Spine J. 2012;21(4):745-53.
79. Müslüman AM, Cansever T, Yılmaz A, Çavuşoğlu H, Yüce İ, Aydın Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16(1):68-76.
80. Ohta H, Matsumoto Y, Morishita Y, Sakai T, Huang G, Kida H, Takemitsu Y. Surgical results of dynamic nonfusion stabilization with the Segmental Spinal Correction System for degenerative lumbar spinal diseases with instability: Minimum 2-year follow-up. SAS J. 2011;5(3):69-74.
81. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. Spine. 2012;37(23):E1464-8.
82. Oishi, Y., Murase, M., Hayashi, Y., Ogawa, T., & Hamawaki, J. (2010). Smaller facet effusion in association with restabilization at the time of operation in Japanese patients with lumbar degenerative spondylolisthesis. Journal of Neurosurgery Spine, 12(1), 88-95.
83. Oliveira L, Marchi L, Coutinho E, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. Spine. 2010;35(26 Suppl):S331-7.
84. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. In J Spine Surg. 2012;6(1):157-166.
85. Ozkan N, Sandalcioglu IE, Petr O, et al. Minimally invasive transpedicular dorsal stabilization of the thoracolumbar and lumbar spine using the minimal access non-traumatic insertion system (MANTIS): preliminary clinical results in 52 patients. J Neurol Surg A Cent Eur Neurosurg. 2012;73(6):369-76.
86. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine. 2010;35(4):439-46.
87. Park H, Zhang HY, Cho BY, Park JY. Change of lumbar motion after multi-level posterior dynamic stabilization with bioflex system : 1 year follow up. J Korean Neurosurg Soc. 2009;46(4):285-91.
88. Park JH, Hyun SJ, Roh SW, Rhim SC. A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis. Acta Neurochir (Wien). 2012;154(7):1205-12.
89. Park JY, Chin DK, Cho YE. Accelerated L5-S1 Segment Degeneration after Spinal Fusion on and above L4-5 : Minimum 4-Year Follow-Up Results. J Korean Neurosurg Soc. 2009;45(2):81-4.
90. Park SC, Yoon SH, Hong YP, Kim KJ, Chung SK, Kim HJ. Minimum 2-year follow-up result of degenerative spinal stenosis treated with interspinous u (coflex). J Korean Neurosurg Soc. 2009;46(4):292-9.
91. Park Y, Ha JW, Lee YT, Sung NY. The effect of a radiographic solid fusion on clinical outcomes after minimally invasive transforaminal lumbar interbody fusion. Spine J. 2011;11(3):205-12.
92. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.

93. Pateder DB, Benzel E. Noninstrumented facet fusion in patients undergoing lumbar laminectomy for degenerative spondylolisthesis. J Surg Orthop Adv. 2010;19(3):153-8.
94. Quraishi NA, Lewis SJ, Kelleher MO, Sarjeant R, Rampersaud YR, Fehlings MG. Intraoperative multimodality monitoring in adult spinal deformity: analysis of a prospective series of one hundred two cases with independent evaluation. Spine. 2009;34(14):1504-12.
95. Rampersaud YR, Wai EK, Fisher CG, et al. Postoperative improvement in health-related quality of life: a national comparison of surgical treatment for focal (one- to two-level) lumbar spinal stenosis compared with total joint arthroplasty for osteoarthritis. Spine J. 2011;11(11):1033-41.
96. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-46.
97. Rodgers WB, Lehmen JA, Gerber EJ, Rodgers JA. Grade 2 spondylolisthesis at L4-5 treated by XLIF: safety and midterm results in the "worst case scenario". ScientificWorldJournal. 2012;2012:356712.
98. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96.
99. Sasai K, Umeda M, Maruyama T, Wakabayashi E, Iida H. Microsurgical bilateral decompression via a unilateral approach for lumbar spinal canal stenosis including degenerative spondylolisthesis. J Neurosurg Spine. 2008;9(6):554-9.
100. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
101. Shen NJ, Lin MX, Lin QB, Wang XA, Chen J, Wang GJ. Domestic vertebral internal fixation system for treating lumbar spondylolisthesis in 55 cases. A follow-up study. J Clin Rehabil Tissue Eng Res. 2009;13(9):1793-1796.
102. Skowroński J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. Ortop Traumatol Rehabil. 2007;9(2):149-55.
103. Sugawara A, Isu T, Kim K, Morimoto D, Isobe M, Matsumoto R, Ogasawara K. Surgical results using only posterior decompression for lumbar canal stenosis with lumbar degenerative spondylolisthesis. Japan J Neurosurg. 2012;21(2), 111-117.
104. Tokuhashi Y, Ajiro Y, Umezawa N. Subsidence of metal interbody cage after posterior lumbar interbody fusion with pedicle screw fixation. Orthopedics, 2009;32(4):259.
105. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H. Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: minimum five-year follow-up. Spine. 2011;36(5):410-5.
106. Turunen V, Nyyssönen T, Miettinen H, et al. Lumbar instrumented posterolateral fusion in spondylolisthetic and failed back patients: a long-term follow-up study spanning 11-13 years. Eur Spine J. 2012;21(11):2140-8.
107. Vaccaro AR, Lawrence JP, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis: a long-term (>4 years) pivotal study. Spine. 2008;33(26):2850-62.
108. Vaccaro AR, Stubbs HA, Block JE. Demineralized bone matrix composite grafting for posterolateral spinal fusion. Orthopedics. 2007;30(7):567-70.
109. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-65.
110. Vanek P, Saur K. (2007). Transforaminal lumbar interbody fusion (TLIF) and instruments. Prospective study with the minimum of 20-month follow-up. Cesk Neurol Neurochir. 2007;70(5), 552-557.
111. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.
112. Watters WC, Bono CM, Gilbert TJ, et al. An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2009;9(7):609-14.
113. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
114. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
115. Welch WC, Cheng BC, Awad TE, et al. Clinical outcomes of the Dynesys dynamic neutralization system: 1-year preliminary results. Neurosurg Focus. 2007;22(1):E8.
116. Wong Chung-Ting M, Chan Pak-Ho A, Cheung KK. A Prospective Study on the Outcome of Degenerative Lumbar Spinal Stenosis Treated With Open Laminotomy. J Orthop Trauma Rehabil. 2012;16(2), 62-65.
117. Xu H, Tang H, Li Z. Surgical treatment of adult degenerative spondylolisthesis by instrumented transforaminal lumbar interbody fusion in the Han nationality. J Neurosurg Spine. 2009;10(5):496-9.
118. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
119. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.
120. Zaina F, Tomkins-Lane, C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis. Cochrane Database Syst Rev. 2012;(12):CD010264

New Guideline Question:

Does the addition of lumbar fusion, with or without instrumentation, to surgical decompression improve surgical outcomes in the treatment of degenerative lumbar spondylolisthesis compared to medical/ interventional treatment alone?

Surgical decompression with fusion, with or without instrumentation, is suggested to improve the functional outcomes of single-level degenerative lumbar spondylolisthesis compared to medical/ interventional treatment alone.

Grade of Recommendation: B

There is insufficient evidence to make a recommendation for or against efficacy of surgical decompression with fusion, with or without instrumentation, for treatment of multi-level degenerative lumbar spondylolisthesis compared to medical/interventional treatment alone.

Grade of Recommendation: I (Insufficient Evidence)

In a retrospective comparative study, Matsudaira et al[1] compared the surgical and medical management of Japanese patients undergoing treatment for Grade I lumbar degenerative spondylolisthesis. A total of 53 patients were included in the study, including 19 patients treated with decompression laminectomy with posterolateral fusion and pedicle screw instrumentation, 18 patients treated with decompression alone and 16 control patients treated with conservative therapy after refusing surgical treatment. All patients had undergone a trial of conservative therapy, which included medication and nerve blocks, for at least 3 months before being offered surgery. Clinical outcomes were evaluated according to the Japanese Orthopedic Association Score (JOA). At 2-years follow-up, the JOA score of subjective symptoms showed no significant improvement compared to baseline measurements in the control patients, but significant improvement in symptoms in the surgical groups ($p<0.0001$). The total JOA score did not improve in the control group (17.3 pre vs 17.1 post), but significantly improved in the decompression and fusion group (14.1 pre vs 21.7 post, $p<0.0001$) and the decompression only group (13.4 pre vs 23.4 post, $p<0.0001$). The degree of improvement was significantly greater in the surgical groups compared to the control group ($p<0.001$), but there were no significant differences in scores between the surgical groups. When evaluating radiographic findings, the slippage increased significantly in the decompression only and control groups compared to the decompression and instrumented fusion groups. The difference in percent slip between flexion and extension showed little change in the decompression only and control group, but was almost eliminated in the decompression and instrumented fusion group. In critique, the diagnostic methods used to diagnosis degenerative spondylolisthesis are vaguely described, the medical/interventional treatment was not standardized, and the sample size was small. This study provides level III therapeutic evidence that patients with single level spinal stenosis due to Grade I degenerative spondylolisthesis show significantly greater alleviation of symptoms when treated with decompression and instrumented fusion compared to a control group.

Weinstein et al[2] evaluated the surgical and nonsurgical outcomes in patients enrolled in either a randomized or observational cohort of the Spine Patient Outcomes Research Trial (SPORT). All patients in the trial had neurogenic claudication or radicular leg pain with associated neurologic signs, spinal stenosis shown on cross-sectional imaging, and degenerative spondylolisthesis shown on lateral radiographs obtained with the patient in a standing position. Investigators enrolled 304 patients in the randomized cohort and 303 in the observational cohort. Treatment was standard decompressive laminectomy, with or without fusion, or usual nonsurgical care, which included at least physical therapy, education or counseling on home exercises, and nonsteroidal anti-inflammatory agents, if tolerated. In the randomized cohort, 6% underwent decompression only, 21% underwent fusion without instrumentation and 73% underwent fusion with instrumentation. In the observational

cohort, 5% received decompression only, 21% received fusion without instrumentation, and 74% underwent fusion with instrumentation. In the randomized cohort, 159 patients were assigned to surgery and 145 were assigned to nonsurgical treatment. In the observational cohort, 173 initially chose surgery and 130 initially chose nonsurgical care. The one year cross-over rates were high in the randomized cohort (approximately 40% in each direction), but moderate in the observational cohort (17% to surgery and 3% to non-surgical care). Patients were evaluated over 2years using the SF-36 for bodily pain and physical function scores and the modified Oswestry Disability Index. It is important to note that in the randomized cohort, only 6% received decompression only, 21% received fusion without instrumentation and 73% received fusion with instrumentation. Results suggest that there were no significant differences in treatment effects between the randomized and observational surgical cohorts. For the nonsurgical group, treatment effects at 2 years were 1.5 for SF-36 bodily pain (95% confidence interval [CI], −4.2 to 7.3; P = 0.52), 1.9 for physical function (95% CI, −3.7 to 7.5; P = 0.71), and 2.2 for the Oswestry Disability Index (95% CI, −2.3 to 6.8; P = 0.68). Combined treatment effects for the surgical groups at 2 years were 18.1 for SF-36 bodily pain (95% CI, 14.5 to 21.7), 18.3 for physical function (95% CI, 14.6 to 21.9), and −16.7 for the Oswestry Disability Index (95% CI, −19.5 to −13.9). The authors suggest that patients with degenerative spondylolisthesis and spinal stenosis treated surgically showed substantially greater improvement in pain and function after 2 years compared to nonsurgical patients.

In a follow-up analysis of SPORT, Weinstein et al[3] reported the treatment effects after 4 years. An as-treated analysis combining the randomized and observational cohorts that adjusted for potential confounders demonstrated that the clinically relevant advantages of surgery that had been previously reported through 2 years were maintained at 4 years, with treatment effects of 15.3 (95% confidence interval, 11 to 19.7) for bodily pain, 18.9 (95% confidence interval, 14.8 to 23) for physical function, and -14.3 (95% confidence interval, -17.5 to -11.1) for the Oswestry Disability Index. In critique, conservative treatments were not controlled, there was high-cross over rates in the SPORT Trial, and some groups had less than 80% follow-up at 4 years. These 2 studies provide Level II therapeutic evidence that in patients undergoing treatment for degenerative spondylolisthesis, decompression and fusion provided greater improvement in pain, function and patient satisfaction outcomes compared to medical management after 2- and 4-years follow-up.

Park et al[4] conducted a post hoc retrospective subgroup analysis of SPORT to compare multilevel spinal stenosis outcomes to single level spinal stenosis outcomes, including a subset of patients with spondylolisthesis, against those who did not have surgery ("usual nonoperative care"). Outcomes were measured by Bodily Pain and Physical Function scales of the Medical Outcomes Study 36-item Short-Form General Health Survey (SF-36) and the modified Oswestry Disability Index at 6 weeks, 3 months, 6 months, one year and 2 years. Secondary outcome measures included the stenosis bothersomeness index, leg pain bothersomeness, low back pain bothersomeness and patient satisfaction. In the degenerative spondylolisthesis group, only patients with one level of spondylolisthesis were included and treatment included decompression with or without fusion or standard nonoperative care. A total of 607 degenerative spondylolisthesis patients were enrolled in the study, including 304 into the randomized cohort and 303 in the observational cohort. Of these groups, 328 patients received surgical treatment. The authors do not discuss the specific number of patients enrolled in the nonoperative care group; however, through deduction, one may assume that 279 patients were initially enrolled in this group. Results suggest that the surgical outcomes were significantly better at 2 years in the single-level degenerative spondylolisthesis patients compared to those with multilevel spinal stenosis. Surgical treatment demonstrated significant treatment improvement over nonoperative measures within each subgroup of degenerative spondylolisthesis patients. This study provides Level III therapeutic evidence that patients with concomitant degenerative spondylolisthesis and single-level stenosis have better surgical outcomes than those with additional levels of stenosis. In these patients, decompression and fusion of stenotic levels improves outcomes compared to nonoperative management.

Mardjetko et al[5] performed a meta-analysis of literature from 1970-1993 to evaluate the outcomes of surgical fusion treatment for degenerative spondylolisthesis. The studies included in this analysis were primarily Level III or IV studies. Prior to undertaking the review, the authors identified a null hypothesis that posterior decompression with posterolateral spinal fusion (PLSF) performed with pedicular instrumentation demonstrates equivalent fusion rates and clinical outcomes to alterative techniques of PLSF without instrumentation or controlled instrumentation. In review of the articles, the authors accepted 11 papers for the decompression without fusion category representing 216 patients. Results from these surgical decompression procedures suggested that 69% of patients had a satisfactory outcome. Six papers, representing 74 patients, met inclusion for decompression with fusion without instrumentation. Results suggested that 90% of patients had a satisfactory outcome and 86% achieved a solid spinal fusion. Four papers, representing 138 patients, were included in the decompression with fusion with control device category with 90% of patients achieving a satisfactory outcome. In the decompression with fusion with pedicle screws category, including 5 studies representing 101 patients, 93% of patients had successful fusion rates. The pooling of three studies in the anterior spinal fusion category, representing 72 patients, suggested a 94% fusion rate with an 86% patient satisfaction rate. When comparing the pooled results, the authors found a statistically significant difference in satisfactory clinical outcomes between the decompression without fusion and decompression and fusion without instrumentation (69% vs. 90%, p<0.0001), fusion rates between the fusion/no instrumentation group and fusion with control device group (86% vs. 96%, p=0.009), and satisfactory outcome rates of the decompression without fusion compared to decompression with fusion with pedicle screws groups (69% vs. 86%, p<0.0001). The authors suggest that in patients undergoing the surgical management of degenerative spondylolisthesis, spinal fusion significantly improves patient satisfaction and the adjunctive spinal instrumentation enhances fusion rates. In critique of this study, the groups were very heterogeneous for comparison purposes and the studies included

were primarily retrospective and of lower quality. In addition, this study doesn't evaluate the efficacy of fusion and decompression versus medical/interventional treatment for the management of degenerative lumbar spondylolisthesis. However, it does provide background information on the effectiveness of adding lumbar fusion to decompression procedures. This potential Level III study provides Level IV therapeutic evidence that the addition of fusion to decompression results in satisfactory outcomes and the use of adjunctive spinal instrumentation increases fusion success.

Surgical decompression with fusion, with or without instrumentation, has been shown to improve the functional outcomes of single-level degenerative spondylolisthesis in patients with a BMI > 30 compared to medical/interventional treatment alone with an understanding that the risk of surgical complications increases. Although this clinical question was not developed to address the impact of obesity (BMI > 30) on treatment outcomes, the work group felt it was important to include the findings below from a post hoc analysis of SPORT. As addressing this question was not the primary intent of the work group, the literature search was not designed to address obesity. The summary below is included for information purposes only.

In another post hoc retrospective subgroup analysis of SPORT, Rihn et al[6] evaluated the impact of obesity on the treatment outcomes for lumbar stenosis and degenerative spondylolisthesis patients. In the cohort of degenerative spondylolisthesis patients, there were 376 patients with a BMI of less than 30 (non-obese) and 225 patients with a BMI more than 30 (obese). It is important to note that in addition to obesity, obese patients had a significantly higher incidence of comorbidities, including hypertension, diabetes, and stomach problems ($p<0.001$). A higher proportion of obese patients underwent instrumented fusion and fewer underwent decompression alone compared to nonobese patients. The incidence of intraoperative complications was significantly lower in the obese patient group; however, there was a trend toward increase rate of wound infection in the obese patients compared to nonobese patients (5% vs. 1%, $p=0.051$). At 4-year follow-up, there was a significantly higher rate of reoperation in the obese patient group compared to the nonobese group (20% vs. 11%, $p=0.013$). At four year follow-up in the nonoperative group, obese patients had SF-36 physical function scores that worsened from baseline by a mean of 3.5 compared to a mean improvement of 13.9 points in the non-obese group ($p<0.001$). The treatment effect for the SF-36 Physical Function score was significantly higher for the obese surgical patient group compared to nonoperative obese patient group (25.6 vs. 14, $p=0.004$) suggesting that surgery has a significantly greater benefit over nonsurgical treatment of degenerative spondylolisthesis in obese patients. This study provides Level III therapeutic evidence that decompression and fusion in patients with BMIs greater than 30 with degenerative spondylolisthesis may prove beneficial due to the poor progress they make with nonoperative therapy. However, risk of infection and reoperation after four years is greater compared to nonobese surgical patients.

Future Directions for Research

The work group recommends the undertaking of large prospective studies or multicenter registry database studies with long-term follow-up comparing the outcomes of various surgical techniques, including decompression with fusion (with or without instrumentation) to medical/interventional treatments for the management of single level and multi-level degenerative lumbar spondylolisthesis.

References

1. Mardjetko SM, Connolly PJ, Shott S. (1994). Degenerative lumbar spondylolisthesis: A meta-analysis of literature 1970- 1993. Spine, 19(20 SUPPL.), 2256S-2265S.
2. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
3. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
4. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine. 2010;35(4):439-46.
5. Matsudaira K, Yamazaki T, Seichi A, et al. Spinal stenosis in grade I degenerative lumbar spondylolisthesis: a comparative study of outcomes following laminoplasty and laminectomy with instrumented spinal fusion. J Orthop Sci. 2005;10(3):270-6.
6. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-46.

Bibliography

1. Agabegi SS, Majid K, Fischgrund JS, Vaccaro AR, Patel T. Can preoperative radiographic parameters be used to predict fusion in non-instrumented posterolateral fusion for degenerative spondylolisthesis?. Spine. 2011;36(26):E1709-14.
2. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurg Q. 2009;19(3):200-206.
3. Allen RT, Rihn JA, Glassman SD, Currier B, Albert TJ, Phillips FM. An evidence-based approach to spine surgery. Am J Med Qual. 2009;24(6 Suppl):15S-24S.
4. Anderson PA, Tribus CB, Kitchel SH. Treatment of neurogenic claudication by interspinous decompression: application of the X STOP device in patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2006;4(6):463-71.
5. Aoki Y, Yamagata M, Nakajima F, Ikeda Y, Takahashi K. Posterior migration of fusion cages in degenerative lumbar disease treated with transforaminal lumbar interbody fusion: a report of three patients. Spine. 2009;34(1):E54-8.
6. Atlas SJ, Delitto A. Spinal stenosis: surgical versus nonsurgical treatment. Clin Orthop Relat Res. 2006;443:198-207.
7. Bashir el F, Ajani O. Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-6.
8. Bassewitz H, Herkowitz H. Lumbar stenosis with spondylolisthesis: current concepts of surgical treatment. Clin Orthop Relat Res. 2001;(384):54-60.
9. Bederman SS, Coyte PC, Kreder HJ, Mahomed NN, Mcisaac WJ, Wright JG. Who's in the driver's seat? The influence of patient and physician enthusiasm on regional variation in degenerative lumbar spinal surgery: a population-based study. Spine. 2011;36(6):481-489.
10. Boden SD Spinescope. Semin Spine Surg. 2012;24(2):133-137.
11. Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis. Instr Course Lect. 1989;38:157-165.

12. Bose B. Fracture of S1-2 after L4-S1 decompression and fusion. Case report and review of the literature. J Neurosurg. 2003;99(3 Suppl):310-2.
13. Bridwell KH, Sedgewick TA, O'brien MF, Lenke LG, Baldus C. The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. J Spinal Disord. 1993;6(6):461-72.
14. Brown MD, Lockwood, JM. Degenerative spondylolisthesis. Instr Course Lect. 1983;32:162-169.
15. Brown MD, Wehman KF, Heiner AD. The clinical usefulness of intraoperative spinal stiffness measurements. Spine. 2002;27(9):959-61.
16. Cauchoix J, Benoist M, Chassaing V. Degenerative spondylolisthesis. Clin Orthop Relat Res. 1976;115:122-129.
17. Chad DA. Lumbar Spinal Stenosis. Neurol Clin. 2007;25(2):407-418.
18. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
19. Cloyd JM, Acosta FL, Ames CP. Complications and outcomes of lumbar spine surgery in elderly people: a review of the literature. J Am Geriatr Soc. 2008;56(7):1318-27.
20. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-46.
21. Deinsberger R, Kinn E, Ungersböck K. Microsurgical treatment of juxta facet cysts of the lumbar spine. J Spinal Disord Tech. 2006;19(3):155-60.
22. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-91.
23. Detwiler PW, Porter RW, Han PP, Karahalios DG, Masferrer R, Sonntag VK. Surgical treatment of lumbar spondylolisthesis. Adv Tech Stand Neurosurg. 2000;26:331-346.
24. Di silvestre M, Lolli F, Bakaloudis G, Parisini P. Dynamic stabilization for degenerative lumbar scoliosis in elderly patients. Spine. 2010;35(2):227-34.
25. Dimar JR II, Djurasovic M, Carreon LY. Surgical management of degenerative and postsurgical spondylolisthesis. Semin Spine Surg. 2005;17(3 Spec Iss):186-194.
26. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
27. Eliyas JK, Karahalios D. Surgery for degenerative lumbar spine disease. Dis Mon. 2011;57(10):592-606.
28. Epstein JA, Epstein BS, Lavine LS, Rosenthal AD, Decker RE, Carras R. Obliterative arachnoiditis complicating lumbar spinal stenosis. J Neurosurg. 1978;48(2):252-8.
29. Feffer HL, Wiesel SW, Cuckler JM, Rothman RH. Degenerative spondylolisthesis: To fuse or not to fuse. Spine. 1985;10(3):287-289.
30. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
31. Frazier DD, Lipson SJ, Fossel AH, Katz JN. Associations between spinal deformity and outcomes after decompression for spinal stenosis. Spine. 1997;22(17):2025-9.
32. Gibson JN, Grant IC, Waddell G. The Cochrane review of surgery for lumbar disc prolapse and degenerative lumbar spondylosis. Spine. 1999;24(17):1820-32.
33. Gibson, JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2005;(4):CD001352.
34. Gibson JN, Waddell G, Grant IC. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2000;(2):CD001352.
35. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis: Updated Cochrane review. Spine. 2005;30(20):2312-2320.
36. Gilbert JW, Wheeler GR, Kreft MP, et al. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-31.
37. Grobler LJ, Robertson PA, Novotny JE, Ahern JW. Decompression for degenerative spondylolisthesis and spinal stenosis at L4-5. The effects on facet joint morphology. Spine. 1993;18(11):1475-82. Hanley EN. Decompression and distraction-derotation arthrodesis for degenerative spondylolisthesis. Spine. 1986;11(3):269-76.
38. Hanley EN. The indications for lumbar spinal fusion with and without instrumentation. Spine. 1995;20(24 Suppl):143S-153S.
39. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. Spine J. 2008;8(2):380-4.
40. Herkowitz HN. Spine update degenerative lumbar spondylolisthesis. Spine. 1995;20(9):1084-1090.
41. Herkowitz HN, Kurz LT. (1991). Degenerative lumbar spondylolisthesis with spinal stenosis: A prospective study comparing decompression with decompression and intertransverse process arthrodesis. Journal of Bone and Joint Surgery - Series A, 1991;73(6):802-808.
42. Herron LD, Newman MH. The failure of ethylene oxide gas-sterilized freeze-dried bone graft for thoracic and lumbar spinal fusion. Spine. 1989;14(5):496-500.
43. Hilibrand AS, Rand N. Degenerative lumbar stenosis: diagnosis and management. J Am Acad Orthop Surg. 1999;7(4):239-249.
44. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-75.
45. Indar R, Tsiridis E, Morgan M, Aldham CH, Hussein AA. Intraspinal lumbar synovial cysts: diagnosis and surgical management. Surgeon. 2004;2(3):141-4.
46. Irwin ZN, Hilibrand A, Gustavel M, et al. Variation in surgical decision making for degenerative spinal disorders. Part I: lumbar spine. Spine. 2005;30(19):2208-13.
47. Jackson RK, Boston DA, Edge AJ. Lateral mass fusion. A prospective study of a consecutive series with long-term follow-up. Spine. 1985;10(9):828-32.
48. Jayakumar P, Nnadi C, Saifuddin A, Macsweeney E, Casey A. Dynamic degenerative lumbar spondylolisthesis: diagnosis with axial loaded magnetic resonance imaging. Spine. 2006;31(10):E298-301.
49. Jones TR, Rao RD. Adult isthmic spondylolisthesis. J Am Acad Orthop Surg. 2009;17(10):609-617.
50. Khan AM, Girardi F. Spinal lumbar synovial cysts. Diagnosis and management challenge. Eur Spine J. 2006;15(8):1176-82.
51. Khan AM, Synnot K, Cammisa FP, Girardi FP. Lumbar synovial cysts of the spine: an evaluation of surgical outcome. J Spinal Disord Tech. 2005;18(2):127-31.
52. Kim DH, Albert TJ. Update on use of instrumentation in lumbar spine disorders. Best Pract Res Clin Rheumatol. 2002;16(1):123-40.
53. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.

54. Knaub MA, Won DS, Mcguire R, Herkowitz HN. Lumbar spinal stenosis: indications for arthrodesis and spinal instrumentation. Instr Course Lect. 2005;54:313-9.
55. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
56. Laus M, Tigani D, Alfonso C, Giunti A. Degenerative spondylolisthesis: lumbar stenosis and instability. Chir Organi Mov. 1992;77(1):39-49.
57. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.
58. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
59. 59. Lombardi JS, Wiltse LL, Reynolds J, Widell EH, Spencer C 3rd. Treatment of degenerative spondylolisthesis. Spine. 1985;10(9):821-827.
60. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-15.
61. McAfee PC, Cunningham BW, Tortolani PJ, Fedder IL, Sefter JC, Davis C. 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS J. 2009;3(1):1-11.
62. Mcculloch JA. Microdecompression and uninstrumented single-level fusion for spinal canal stenosis with degenerative spondylolisthesis. Spine. 1998;23(20):2243-52.
63. Molina M, Wagner P, Campos M. Spinal lumbar stenosis. An update. Rev Med Chil. 2011;139(11):1488-1495.
64. Müslüman AM, Cansever T, Yilmaz A, Çavuşoğlu H, Yüce I, Aydin Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis: Clinical article. J Neurosurg Spine. 2012;16(1):68-76.
65. Nasca RJ. Lumbar spinal stenosis: surgical considerations. J South Orthop Assoc. 2002;11(3):127-134.
66. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. Spine. 2012;37(23):E1464-8.
67. Onda A, Otani K, Konno S, Kikuchi S. Mid-term and long-term follow-up data after placement of the Graf stabilization system for lumbar degenerative disorders. J Neurosurg Spine. 2006;5(1):26-32.
68. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
69. Robertson PA, Grobler LJ, Novotny JE, Katz JN. Postoperative spondylolisthesis at L4-5. The role of facet joint morphology. Spine. 1993;18(11):1483-90.
70. Rubery PT. Degenerative spondylolisthesis. Curr Opin Orthop. 2001;12(3) 183-188.
71. Sachs BL, Zindrick MR, Beasley RD. Reflex sympathetic dystrophy after operative procedures on the lumbar spine. J Bone Joint Surg Am. 1993;75(5):721-725.
72. Schnee CL, Freese A, Ansell LV. Outcome analysis for adults with spondylolisthesis treated with posterolateral fusion and transpedicular screw fixation. J Neurosurg. 1997;86(1):56-63.
73. Sengupta DK, Herkowitz HN. Lumbar spinal stenosis. Treatment strategies and indications for surgery. Orthop Clin North Am. 2003;34(2):281-95.
74. Sengupta DK, Herkowitz HN. Degenerative spondylolisthesis: review of current trends and controversies. Spine. 2005;30(6 Suppl):S71-81.
75. Sheehan JM, Shaffrey CI, Jane JA. Degenerative lumbar stenosis: the neurosurgical perspective. Clin Orthop Relat Res. 2001;(384):61-74.
76. Sienkiewicz PJ, Flatley TJ. Postoperative spondylolisthesis. Clin Orthop Relat Res. 1987;(221):172-180.
77. Soren A, Waugh TR. Spondylolisthesis and related disorders. A correlative study of 105 patients. Clin Orthop Relat Res. 1985;(193):171-7.
78. Templin CR, Garfin SR. Surgical Management of Scoliosis and/or Spondylolisthesis Associated with Spinal Stenosis. Semin Spine Surg. 2007;19(3):187-199.
79. Tile M, McNeil SR, Zarins RK, Pennal GF, Garside SH. Spinal stenosis. Results of treatment. Clin Orthop Relat Res. 1976;(115):104-108.
80. Vaccaro AR, Patel T, Fischgrund J, et al. A 2-year follow-up pilot study evaluating the safety and efficacy of op-1 putty (rhbmp-7) as an adjunct to iliac crest autograft in posterolateral lumbar fusions. Eur Spine J. 2005;14(7):623-9.
81. Vaccaro AR, Patel T, Fischgrund J, et al. A 2-year follow-up pilot study evaluating the safety and efficacy of op-1 putty (rhbmp-7) as an adjunct to iliac crest autograft in posterolateral lumbar fusions. Eur Spine J. 2005;14(7):623-9.
82. Vaccaro AR, Patel T, Fischgrund J, et al. A pilot study evaluating the safety and efficacy of OP-1 Putty (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis for degenerative spondylolisthesis. Spine. 2004;29(17):1885-1892.
83. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.
84. Watters WC 3rd. If, when, and how to fuse when treating lumbar degenerative stenosis. Semin Spine Surg. 2011;23(4):218-221.
85. Yong-hing K. Pathophysiology and rationale for treatment in lumbar spondylosis and instability. Chir Organi Mov. 1994;79(1):3-10.
86. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis (Protocol). Cochrane Database Syst Rev. 2012;12:CD010264.
87. Zhao J, Wang X, Hou T, He S. One versus two BAK fusion cages in posterior lumbar interbody fusion to L4-L5 degenerative spondylolisthesis: a randomized, controlled prospective study in 25 patients with minimum two-year follow-up. Spine. 2002;27(24):2753-7.

Original Guideline Question:

Does the addition of instrumentation to decompression and fusion for degenerative lumbar spondylolisthesis improve surgical outcomes compared with decompression and fusion alone?

The addition of instrumentation is suggested to improve fusion rates in patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. *Maintained from original guideline with minor word modifications*

Grade of Recommendation: B

The addition of instrumentation is not suggested to improve clinical outcomes for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis. *Maintained from original guideline with minor word modifications*

Grade of Recommendation: B (Suggested)

The updated literature search did not retrieve any new evidence that would provide additional support in addressing this clinical question; therefore, the work group maintains the above guideline recommendations from the original guideline.

Articles from original guideline:

Bridwell et al[1] described a prospective comparative study of 44 surgically treated patients with degenerative lumbar spondylolisthesis followed for a minimum of 2 years. Of the 44 patients, 9 underwent laminectomy alone, 10 had laminectomy and noninstrumented fusion and 24 had laminectomy and instrumented fusion (18 single-level, 6 two-level). Patients were radiographically assessed and a functional assessment was conducted by asking whether they felt their ability to walk distances was worse (-), the same (0) or significantly better (+). Of the 44 patients, 43 were followed for 2 years or more. The authors reported that instrumented fusion had higher fusion rates than noninstrumented fusion (ρ=0.002) and observed greater progression of spondylolisthesis in patients treated with laminectomy alone and laminectomy without instrumented fusion compared to patients who received laminectomy with instrumented fusion (ρ=0.001). A higher proportion of the patients without slippage progression reported that they were helped by the surgery than those whose slippage progressed postoperatively (ρ<0.01). In critique, this was a small study in which selection bias entered into the randomization process, reviewers were not masked to patient treatment and validated outcome measures were not utilized. Because of these weaknesses, this potential Level II study was downgraded to Level III. This study provides Level III therapeutic evidence that addition of instrumentation to fusion results in higher fusion rates and subjective improvement in walking distance when compared with fusion alone.

Fischgrund et al[2] conducted a randomized comparative study of 76 consecutive patients with symptomatic spinal stenosis associated with degenerative lumbar spondylolisthesis who underwent posterior decompression and posterolateral fusion. Patients were randomized into a transpedicular fixation group or noninstrumented group with a study objective to determine whether instrumentation improves clinical outcomes and fusion rates. Outcomes were assessed at 2-year follow-up using a five-point visual analog scale (VAS) and an operative result rating (excellent, good, fair, poor) based on examiner assessment of pain and functional level. The authors reported that of the 76 patients included in the study, 68 (89%) were available at 2-year follow-up. Clinical outcome with a rating of excellent or good was achieved in 76% of instrumented patients and 85% of noninstrumented patients (ρ=0.45). Successful arthrodesis was achieved in 82% of instrumented versus 45% of noninstrumented patients (ρ=0.0015). The authors found that successful fusion did not correlate with clinical outcome (ρ=0.435). The authors concluded that for single-level degenerative lumbar spondylolisthesis, use of instrumentation may lead to a higher fusion rate, but clinical outcome showed no improvement in low back pain and lower limb pain with their nonvalidated outcome measures. In critique of this study, the follow-up may have been too short

to detect the effects of pseudarthrosis in this nonmasked study. Validated outcome measures were not utilized to assess clinical outcomes. Because of these weaknesses, this potential Level II study was downgraded to Level III. This study offers Level III therapeutic evidence that the addition of instrumentation to posterolateral fusion for the treatment of degenerative lumbar spondylolisthesis increases the likelihood of obtaining a solid arthrodesis, but does not correlate with improved clinical outcomes at 2-year follow-up.

Kimura et al[3] described a retrospective, comparative study of 57 patients with Grade I or II L4-5 degenerative lumbar spondylolisthesis. Group A consisted of 28 patients who underwent decompression and posterolateral fusion without instrumentation. Group B was comprised of 29 patients who had decompression and posterolateral fusion with pedicle screw instrumentation. Following surgery, Group A was immobilized with bed rest and a cast for 4-6 weeks, whereas Group B was mobilized much more quickly. Outcomes were assessed using the Japanese Orthopedic Association (JOA) scores and radiographs with mean follow-up in Group A of 6 years and in Group B of 3 years. The authors indicated that patients in Group A (noninstrumented) reported 72.4% satisfaction rate, with an 82.8% fusion rate. Patients in Group B (instrumented) reported an 82.1% satisfaction rate, with a 92.8% fusion rate. The authors did not find any significant differences in outcomes between the 2 groups, except that Group B (instrumented) had less low back pain. In critique of this study, patients were not randomized and there was varying duration of follow-up between groups. Although there was a trend toward improved satisfaction and fusion rates with instrumentation, with the numbers available no significant difference was detected. This paper offers Level III therapeutic evidence of no significant benefit with the addition of instrumentation for L4-5 degenerative lumbar spondylolisthesis.

Mardjetko et al[4] performed a meta-analysis of primarily Level III studies. The objective of the study was to analyze the published data on degenerative spondylolisthesis to evaluate the feasibility of its use as a literature control to compare with the historical cohort pedicle screw study data. The authors conducted a comprehensive literature search to identify studies published in English peer-reviewed journals between 1970 and 1993 addressing degenerative spondylolisthesis with radicular leg pain or neurogenic claudication. Inclusion criteria included:

1. a minimum of four cases reviewed, and
2. reporting of the primary outcome variable of fusion in articles in which this was part of the treatment.

Clinical outcome variables of back pain, leg pain, function, neurogenic claudication and global outcome scores were recorded when available. A total of 25 papers representing 889 patients were accepted for inclusion. Twenty-one were retrospective, nonrandomized and uncontrolled. One paper was retrospective and nonrandomized, but compared 2 different treatments. Three prospective, randomized studies were included. The primary outcome variable, fusion, was determined by each author. The most constant clinical outcome variable reported was pain with 16 papers reporting pain only, 6 papers reporting pain and function and 2 papers reporting patient-determined outcomes. Patient function was reported in 6 papers and referred to the presence or absence of neurogenic claudication. In addition to these clinical outcomes, 4 papers reported a global evaluation. Two used Kaneda's rating system and two used the Japanese Orthopedic Association (JOA) score. Excellent and good results were reassigned as satisfactory; poor results were classified as unsatisfactory. In the decompression alone category, the authors reported 11 papers representing 216 patients were accepted for inclusion. Sixty-nine percent of patients had a satisfactory outcome. The incidence of worsened postoperative slip was 31%, but was not associated with a poorer clinical result in the majority of patients. In the category of decompression with fusion and no instrumentation, 6 papers qualified for inclusion. In one paper, only fusion data were broken out for the diagnosis of degenerative spondylolisthesis and were used just for this outcome variable. Ninety percent of the patients in this category had a satisfactory outcome; 86% achieved solid spinal fusion. With regard to clinical outcome, the difference between patients treated with decompression without fusion (69% satisfactory) and those treated with decompression and fusion without instrumentation (90% satisfactory) was statistically significant ($P < 0.0001$). In the decompression with fusion and pedicle screws category, 5 studies met the inclusion criteria. Fusion status was analyzed in a total of 101. Eighty-five patients were analyzed with respect to clinical outcome. One paper did not separately analyze clinical data, but did so for fusion data; therefore, only fusion data were included. The proportionally weighted fusion rates for this group were 93%. When comparing the fusion without instrumentation group to the fusion with pedicle screw group, there was not a statistically significant increase in fusion rate ($P = 0.08$). Analysis of the clinical outcomes reveals an 86% satisfactory rating for the pedicle screw group. This compares favorably to the 69% satisfactory rate in the decompression without fusion group ($P <0.0001$). In the anterior spinal fusion category, three papers presenting the results for 72 patients who received anterior spinal fusion for the treatment of degenerative spondylolisthesis were included. Pooling the data from these 3 studies yielded a 94% fusion rate with an 86% rate of patient satisfaction. The authors concluded that the meta-analysis results support that spinal fusion significantly improves patient satisfaction in patients undergoing surgical treatment for degenerative lumbar spondylolisthesis. In critique of this study, only 3 Level II studies were reviewed and data was very heterogeneous. This paper offers Level III therapeutic evidence that addition of instrumentation to fusion does not result in improved clinical outcome or fusion rate.

Martin et al[5] conducted a systematic review designed to identify and analyze comparative studies that examined the surgical management of degenerative lumbar spondylolisthesis, specifically the differences in outcomes between fusion and decompression alone, and between instrumented fusion and noninstrumented fusion. Relevant randomized controlled trials (RCTs) and comparative, observational studies were identified in a comprehensive literature search (1966 to June 2005). The inclusion criteria required that a study be an RCT or comparative observational study that investigated the surgical management of degenerative lumbar spondylolisthesis by comparing:

1. fusion to decompression and/or
2. instrumented fusion to noninstrumented fusion.

A minimum one-year follow-up was required. Studies also

had to include at least 5 patients per treatment group. A study was excluded if it included patients who had received previous spine surgery, or patients with cervical injuries, spinal fractures, tumors or isthmic spondylolisthesis. A study was also excluded if it was not possible to analyze patients with degenerative spondylolisthesis separately from another included patient population, or if it was not clearly a comparative study. Data from the included studies were extracted by two independent reviewers using a standard data abstraction sheet which identified the following information:

1. patient population's age, sex, symptoms and degree of spondylolisthesis;
2. type of decompression, fusion, instrumentation, bone graft material, and preoperative and postoperative treatment;
3. study design and methodological quality using the Cochrane RCT/CCT/Crossover Studies Checklist, modified by the additional criterion that observational studies state the use of a consecutive series of patients; and
4. study outcomes.

Clinical outcome, reoperation rate and solid fusion status were the main outcomes evaluated. An attempt was made to compare patient-centered, validated and disease-specific outcomes, complications and spondylolisthesis progression, but pooled analysis could not be performed due to heterogeneity in how outcomes were reported. When appropriate, a study's clinical outcome rating scale was altered to match a dichotomous rating scale of "satisfactory" or "unsatisfactory," and these results were entered into Review Manager 4.2 for weighted group anlaysis. The authors reported that 8 studies were included in the fusion versus decompression alone analysis, including two RCTs. Limitations were found in the methodologies of both RCTs and most of the observational studies. Grouped analysis detected a significantly higher probability of achieving a satisfactory clinical outcome with spinal fusion than with decompression alone (relative risk, 1.40; 95% confidence interval, 1.04–1.89; $P < 0.05$). The clinical benefit favoring fusion decreased when analysis was limited to studies where the majority of patients were reported to be experiencing neurologic symptoms such as intermittent claudication and/or leg pain. Six studies were included in the instrumented fusion versus noninstrumented fusion analysis, including three RCTs. The use of adjunctive instrumentation significantly increased the probability of attaining solid fusion (relative risk, 1.37; 95% confidence interval, 1.07–1.75; $P < 0.05$), but no significant improvement in clinical outcome was recorded (relative risk, 1.19; 95% confidence interval, 0.92–1.54). There was a non-significant trend towards a lower repeat operation rate in the fusion group compared with both decompression alone and instrumented fusion. The authors concluded there is moderate evidence that fusion may lead to a better clinical outcome compared with decompression alone, and the use of adjunctive instrumentation may lead to improved fusion status and less risk of pseudarthrosis. Conclusions regarding the clinical effectiveness of instrumented versus noninstrumented fusion could not be made. In critique of this study, it was a systematic review of studies ranging down to Level III, and is thus classified as a Level III systematic review. Limitations were found in the methodologies of all RCTs, specifically in the pseudorandomization, absence of masking and/or the lack of validated outcome measures to assess clinical outcomes. This paper offers Level III therapeutic evidence that the use of adjunctive instrumentation leads to improved fusion rates, but failed to show a statistically significant improvement in clinical outcomes.

Future Directions for Research

The work group recommends the undertaking of large prospective studies or multicenter registry database studies with long-term follow-up to compare the postoperative outcomes of decompression and fusion with and without adjunctive use of instrumentation in the management of degenerative lumbar spondylolisthesis.

References

1. Bridwell KH, Sedgewick TA, O'Brien MF, Lenke LG, Baldus C. The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. J Spinal Disord. 1993;6(6):461-472.
2. Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT. 1997 Volvo Award winner in clinical studies. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation. Spine. 1997;22(24):2807-2812.
3. Kimura I, Shingu H, Murata M, Hashiguchi H. Lumbar posterolateral fusion alone or with transpedicular instrumentation in L4--L5 degenerative spondylolisthesis. J Spinal Disord. 2001;14(4):301-310.
4. Mardjetko SM, Connolly PJ, Shott S. Degenerative lumbar spondylolisthesis. A meta-analysis of literature 1970-1993. Spine. 1994;19(20 Suppl):2256S-2265S.
5. Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'Neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: a systematic review. Spine. 2007;32(16):1791-1798.

Bibliography from updated literature search

1. Abdul QR, Qayum MS, Saradhi MV, Panigrahi MK, Sreedhar V. Clinico-radiological profile of indirect neural decompression using cage or auto graft as interbody construct in posterior lumbar interbody fusion in spondylolisthesis: Which is better? J Craniovertebr Junction Spine. 2011;2(1):12-6.
2. Agabegi SS, Majid K, Fischgrund JS, Vaccaro AR, Patel T. Can preoperative radiographic parameters be used to predict fusion in non-instrumented posterolateral fusion for degenerative spondylolisthesis? Spine. 2011;36(26):E1709-14.
3. Aihara T, Toyone T, Aoki Y, et al. (2012). Surgical management of degenerative lumbar spondylolisthesis. J Musculoskel Res. 2012;15(4).
4. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurg Quart. 2009;19(3):200-206.
5. Allen RT, Rihn JA, Glassman SD, Currier B, Albert TJ, Phillips FM. An evidence-based approach to spine surgery. Am J Med Qual. 2009;24(6 Suppl):15S-24S.
6. Aoki Y, Yamagata M, Nakajima F, Ikeda Y, Takahashi K. Posterior migration of fusion cages in degenerative lumbar disease treated with transforaminal lumbar interbody fusion: a report of three patients. Spine. 2009;34(1):E54-8.
7. Baker AD, Sanderson P. Spinal surgery in older people: Indications, techniques and outcomes. Rev Clin Geront. 2011;21(4):277-285.

8. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2):133-137.
9. Bono CM, Kadaba M, Vaccaro AR. Posterior pedicle fixation-based dynamic stabilization devices for the treatment of degenerative diseases of the lumbar spine. J Spinal Disord Tech. 2009;22(5):376-83.
10. Brotis AG, Paterakis KN, Tsiamalou PM, Fountas KN, Hahjigeorgiou GM, Karavelis A. Instrumented posterior lumbar fusion outcomes for lumbar degenerative disorders in a southern European, semirural population. J Spinal Disord Tech. 2010;23(7):444-50.
11. Brower RS, Vickroy NM. A case of psoas ossification from the use of BMP-2 for posterolateral fusion at L4-L5. Spine. 2008;33(18):E653-E655.
12. Chen KX, Yang QY, Liu XC, Li HJ. [Treatment of degenerative lumbar spondylolisthesis through posterolateral fusion and fixation with pedicle screws]. Zhongguo Gu Shang. 2010;23(4):254-6.
13. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
14. Cole CD, Mccall TD, Schmidt MH, Dailey AT. Comparison of low back fusion techniques: transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) approaches. Curr Rev Musculoskelet Med. 2009;2(2):118-26.
15. Dantas FL, Prandini MN, Ferreira MA. Comparison between posterior lumbar fusion with pedicle screws and posterior lumbar interbody fusion with pedicle screws in adult spondylolisthesis. Arq Neuropsiquiatr. 2007;65(3B):764-70
16. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-91.
17. Di Silvestre M, Lolli F, Bakaloudis G, Parisini P. Dynamic stabilization for degenerative lumbar scoliosis in elderly patients. Spine. 2010;35(2):227-234.
18. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
19. Eliyas JK, Karahalios D. Surgery for Degenerative Lumbar Spine Disease. Dis Mon. 2011;57(10):592-606.
20. Epstein NE. X-Stop: foot drop. Spine J. 2009;9(5):e6-9.
21. Eskander MS, Eskander JP, Drew JM, Pelow-aidlen JL, Eslami MH, Connolly PJ. A modified technique for dowel fibular strut graft placement and circumferential fusion in the setting of L5-S1 spondylolisthesis and multilevel degenerative disc disease. Neurosurgery. 2010;67(3 Suppl Operative):ons91-5.
22. Faldini C, Pagkrati S, Acri F, et al. (2007). Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.
23. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech. 2010;23(4):236-41.
24. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
25. Fransen P. Increasing pedicle screw anchoring in the osteoporotic spine by cement injection through the implant. Technical note and report of three cases. J Neurosurg Spine. 2007;7(3):366-9.
26. Fujimoto K, Yamazaki M, Hayashi K, et al. Posterior decompression with instrumented fusion in a patient with cervical myelopathy thirty years after cadaveric renal transplantation. Chiba Med J. 2011;87(1):11-15.
27. Gavaskar AS, Achimuthu R. Transfacetal fusion for low-grade degenerative spondylolisthesis of the lumbar spine: results of a prospective single center study. J Spinal Disord Tech. 2010;23(3):162-5.
28. Gelalis ID, Arnaoutoglou C, Christoforou G, Lykissas MG, Batsilas I, Xenakis T. Prospective analysis of surgical outcomes in patients undergoing decompressive laminectomy and posterior instrumentation for degenerative lumbar spinal stenosis. Acta Orthop Traumatol Turc. 2010;44(3):235-40.
29. Ha KY, Na KH, Shin JH, Kim KW. Comparison of posterolateral fusion with and without additional posterior lumbar interbody fusion for degenerative lumbar spondylolisthesis. J Spinal Disord Tech. 2008;21(4):229-34.
30. Hara M, Nishimura Y, Takemoto M, Nakamura S, Wakabayashi T. Posterior fixation for lumbar degenerative spondylosis: Mini-open TLIF. Neurol Med Chir. 2012;21(2):118-127.
31. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. Spine J. 2008;8(2):380-4.
32. Harris EB, Sayadipour A, Massey P, Duplantier NL, Anderson DG. Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis. Am J Orthop. 2011;40(12):E257-61.
33. Hart RA, Prendergast MA. Spine surgery for lumbar degenerative disease in elderly and osteoporotic patients. Instr Course Lect. 2007;56:257-72.
34. Herkowitz HN. Degenerative lumbar spondylolisthesis: evolution of surgical management. Spine J. 2009;9(7):605-6.
35. Hrabálek L, Wanek T, Adamus M. [Treatment of degenerative spondylolisthesis of the lumbosacral spine by decompression and dynamic transpedicular stabilisation]. Acta Chir Orthop Traumatol Cech. 2011;78(5):431-6.
36. Hwang CJ, Vaccaro AR, Hong J, et al. Immunogenicity of osteogenic protein 1: results from a prospective, randomized, controlled, multicenter pivotal study of uninstrumented lumbar posterolateral fusion. J Neurosurg Spine. 2010;13(4):484-93.
37. Ikuta K, Tono O, Oga M. Clinical outcome of microendoscopic posterior decompression for spinal stenosis associated with degenerative spondylolisthesis--minimum 2-year outcome of 37 patients. Minim Invasive Neurosurg. 2008;51(5):267-71.
38. Ito Z, Matsuyama Y, Sakai Y, et al. Bone union rate with autologous iliac bone versus local bone graft in posterior lumbar interbody fusion. Spine. 2010;35(21):E1101-5.
39. Kaner T, Dalbayrak S, Oktenoglu T, Sasani M, Aydin AL, Ozer AF. Comparison of posterior dynamic and posterior rigid transpedicular stabilization with fusion to treat degenerative spondylolisthesis. Orthopedics. 2010;33(5)
40. Kirkman MA, Sridhar K. Posterior listhesis of a lumbar vertebra in spinal tuberculosis. Eur Spine J. 2011;20(1):1-5.
41. Kleinstueck FS, Fekete TF, Mannion AF, et al. To fuse or not to fuse in lumbar degenerative spondylolisthesis: do baseline symptoms help provide the answer?. Eur Spine J. 2012;21(2):268-75.
42. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
43. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
44. Lattig F, Fekete TF, Grob D, Kleinstück FS, Jeszenszky D, Man-

nion AF. Lumbar facet joint effusion in MRI: a sign of instability in degenerative spondylolisthesis?. Eur Spine J. 2012;21(2):276-81.
45. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.
46. Lee DY, Lee SH, Shim CS, Lee HY. Decompression and interspinous dynamic stabilization using the locker for lumbar canal stenosis associated with low-grade degenerative spondylolisthesis. Minim Invasive Neurosurg. 2010;53(3):117-21.
47. Lee JC, Jang HD, Shin BJ. Learning curve and clinical outcomes of minimally invasive transforaminal lumbar interbody fusion: our experience in 86 consecutive cases. Spine. 2012;37(18):1548-57.
48. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
49. Lekovic GP, Han PP, Kenny KJ, Dickman CA. Bone dowels in anterior lumbar interbody fusion. J Spinal Disord Tech. 2007;20(5):374-9.
50. Liao JC, Chen WJ, Chen LH, Niu CC. Outcome of the L5-S1 segment after posterior instrumented spinal surgery in degenerative lumbar diseases. Chang Gung Med J. 2009;32(1):81-8.
51. Liao JC, Chen WJ, Chen LH, Niu CC, Keorochana G. Surgical outcomes of degenerative spondylolisthesis with L5-S1 disc degeneration: comparison between lumbar floating fusion and lumbosacral fusion at a minimum 5-year follow-up. Spine. 2011;36(19):1600-7.
52. Long H, Kazunasa U, Liu S, Akio S, Taito I. Preliminary application of one-level posterior lumbar interbody fusion with prospace and facet fusion using local autograft. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi. 2007;21(11):1155-9.
53. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-15.
54. Mcafee P, Khoo LT, Pimenta L, et al. Treatment of lumbar spinal stenosis with a total posterior arthroplasty prosthesis: implant description, surgical technique, and a prospective report on 29 patients. Neurosurg Focus. 2007;22(1):E13.
55. McAfee PC, Cunningham BW, Tortolani PJ, Fedder IL, Sefter JC, Davis C. 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS Journal. 2009;3(1):1-11.
56. Min JH, Jang JS, Kim SK, Maeng DH, Lee SH. The ligamentotactic effect on a herniated disc at the level adjacent to the anterior lumbar interbody fusion : report of two cases. J Korean Neurosurg Soc. 2009;46(1):65-7.
57. Mori E, Okada S, Ueta T, et al. Spinous process-splitting open pedicle screw fusion provides favorable results in patients with low back discomfort and pain compared to conventional open pedicle screw fixation over 1 year after surgery. Eur Spine J. 2012;21(4):745-53.
58. Ohta H, Matsumoto Y, Morishita Y, et al. Surgical results of dynamic nonfusion stabilization with the Segmental Spinal Correction System for degenerative lumbar spinal diseases with instability: Minimum 2-year follow-up. SAS J. 2011;5(3):69-74.
59. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. Spine. 2012;37(23):E1464-8.
60. Oliveira L, Marchi L, Coutinho E, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. Spine. 2010;35(26 Suppl):S331-7.
61. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1), 157-166.
62. Ozkan N, Sandalcioglu IE, Petr O, et al. Minimally invasive transpedicular dorsal stabilization of the thoracolumbar and lumbar spine using the minimal access non-traumatic insertion system (MANTIS): preliminary clinical results in 52 patients. J Neurol Surg A Cent Eur Neurosurg. 2012;73(6):369-76.
63. Park H, Zhang HY, Cho BY, Park JY. Change of lumbar motion after multi-level posterior dynamic stabilization with bioflex system : 1 year follow up. J Korean Neurosurg Soc. 2009;46(4):285-91.
64. Park JH, Hyun SJ, Roh SW, Rhim SC. A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis. Acta Neurochir (Wien). 2012;154(7):1205-12.
65. Park JY, Chin DK, Cho YE. Accelerated L5-S1 Segment Degeneration after Spinal Fusion on and above L4-5 : Minimum 4-Year Follow-Up Results. J Korean Neurosurg Soc. 2009;45(2):81-4.
66. Park SC, Yoon SH, Hong YP, Kim KJ, Chung SK, Kim HJ. Minimum 2-year follow-up result of degenerative spinal stenosis treated with interspinous u (coflex). J Korean Neurosurg Soc. 2009;46(4):292-9.
67. Quraishi NA, Lewis SJ, Kelleher MO, Sarjeant R, Rampersaud YR, Fehlings MG. Intraoperative multimodality monitoring in adult spinal deformity: analysis of a prospective series of one hundred two cases with independent evaluation. Spine. 2009;34(14):1504-12.
68. Rampersaud YR, Wai EK, Fisher CG, et al. Postoperative improvement in health-related quality of life: a national comparison of surgical treatment for focal (one- to two-level) lumbar spinal stenosis compared with total joint arthroplasty for osteoarthritis. Spine J. 2011;11(11):1033-41.
69. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
70. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. Neurosurgery. 2007;60(4 SUPPL. 2):203-212.
71. Skowroński J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. Ortop Traumatol Rehabil. 2007;9(2):149-55.
72. Templin CR, Garfin SR. Surgical Management of Scoliosis and/or Spondylolisthesis Associated with Spinal Stenosis. Semin Spine Surg. 2007;19(3):187-199.
73. Tokuhashi Y, Ajiro Y, Umezawa N. Subsidence of metal interbody cage after posterior lumbar interbody fusion with pedicle screw fixation. Orthopedics. 2009;32(4):259.
74. Traynelis VC. Comments. Neurosurgery. 2009;64(5):963-964.
75. Turunen V, Nyyssönen T, Miettinen H, et al. Lumbar instrumented posterolateral fusion in spondylolisthetic and failed back patients: a long-term follow-up study spanning 11-13 years. Eur Spine J. 2012;21(11):2140-8.
76. Vaccaro AR, Lawrence JP, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis: a long-term (>4 years) pivotal study. Spine. 2008;33(26):2850-62.
77. Vaccaro AR, Stubbs HA, Block JE. Demineralized bone matrix composite grafting for posterolateral spinal fusion. Orthopedics. 2007;30(7):567-70.
78. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for

posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-65.
79. Vanek P, Saur K. Transforaminal lumbar interbody fusion (TLIF) and instruments. Prospective study with the minimum of 20-month follow-up. [Czech]. Cesk Neurol Neurochir. 2007;70(5):552-557.
80. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.
81. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
82. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
83. Welch WC, Cheng BC, Awad TE, et al. Clinical outcomes of the Dynesys dynamic neutralization system: 1-year preliminary results. Neurosurg Focus. 2007;22(1):E8.
84. Xu H, Tang H, Li Z. Surgical treatment of adult degenerative spondylolisthesis by instrumented transforaminal lumbar interbody fusion in the Han nationality. J Neurosurg Spine. 2009;10(5):496-9. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
85. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.
86. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis. Cochrane Database Syst Rev. 2012;(12).

Original Guideline Question:

How do outcomes of decompression with posterolateral fusion compare with those for 360° fusion in the treatment of degenerative lumbar spondylolisthesis?

For the purposes of this guideline, the work group defined "360° fusion" as a procedure involving interbody fusion.

There is insufficient evidence to make a recommendation for or against the use of either decompression with posterolateral fusion or 360° fusion in the surgical treatment of patients with degenerative lumbar spondylolisthesis. *Maintained from original guideline*

Grade of Recommendation: I (Insufficient Evidence)

New article from updated literature search:

In a retrospective comparative study, Ha et al[1] evaluated the effects of posterior lumbar interbody fusion (PLIF) after posterolateral fusion (PLF) on patients undergoing surgical treatment for degenerative spondylolisthesis. Forty patients, who underwent single level decompression and posterior instrumentation at L4-5, were followed for at least 2 years. The patients were divided into 4 groups: the stable PLF group (S-PLF, n=13); the stable PLF with additional PLIF group (S-PLIF, n=11); the unstable PLF group (U-PLF, n=8); and the unstable PLF with additional PLIF group (U-PLIF, n=8). Clinical and radiographic comparisons were carried out between the S-PLF and S-PLIF groups and between the U-PLF and U-PLIF groups. The Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) questionnaires were administered preoperatively and at the final follow-up to compare the severity of pain and its effect on the patients' lives. Radiographic assessments, including plain radiography with dynamic flexion and extension standing lateral radiographs, were also taken. In the U-PLF group, the VAS decreased by 2.6%±1.9%, and in the U-PLIF group, the VAS decreased by 5.9%±1.8%; the difference between the groups was statistically significant (p=0.004). Thus, in the unstable group, the U-PLIF group had a significantly greater improvement in the VAS than the U-PLF group. In the U-PLF group, the ODI decreased by 22.0%±16.1%, and in the U-PLIF group, the ODI decreased by 42.3%±17.9%; the difference between the groups was statistically significant (p=0.032). In the unstable group, the U-PLIF group had a significantly higher improvement in the ODI than the U-PLF group. The degree of slip did not change between stable and unstable groups with the addition of PLIF; however, disc height did change significantly in both groups. This study suggests that preoperative segmental instability may be a criterion for determining whether an additional PLIF would be beneficial in the treatment of degenerative spondylolisthesis. In critique of this study, the sample size was small, initial diagnostic methods were vaguely described, and there was limited description of patient

characteristics. Without statistical analysis comparing the differences of patient characteristics between groups, it is difficult to determine the impact of confounding on the outcomes. This potential Level III study provides Level IV therapeutic evidence that the addition of PLIF to unstable segments may improve the surgical outcome for degenerative spondylolisthesis and appears to improve disc height.

Article from original guideline:

Rousseau et al[2] conducted a retrospective comparative study of 24 consecutive patients undergoing decompression and transpedicular fixation to treat symptomatic degenerative lumbar spondylolisthesis. Of the 24 patients, 8 also underwent posterior lumbar interbody fusion (PLIF). Outcomes were assessed using the Beaujon scoring system with a mean follow-up of 2.87 years. The authors reported that the Beaujon score was improved in all 24 patients ($\rho<0.001$) and fusion was successful in all cases. Preoperative leg pain and the addition of PLIF were significantly correlated with greater improvement ($\rho=0.016$ and $\rho=0.003$), respectively. The authors concluded that posterior decompression and fusion is successful in treating degenerative lumbar spondylolisthesis and that the additional circumferential fusion yields significant improvement in functional outcomes. In critique, this study was retrospective with a small sample size of nonrandomized patients. Of the 24 patients included, only 8 underwent PLIF. In addition, of the 24 patients included in the study, only 18 (75%) were available for follow-up beyond 2 years and it is unclear how many of the 8 PLIF patients remained in this subset. Because of these deficiencies, this potential Level III study was downgraded to Level IV. This study provides Level IV therapeutic evidence that posterior decompression and fusion is successful in treating degenerative lumbar spondylolisthesis and that additional circumferential fusion results in slightly better outcomes than posterior decompression and fusion alone.

Future Directions for Research

The work group identified the following suggestions for future studies which would generate meaningful evidence to assist in further evaluating the efficacy of surgical techniques, including posterolateral fusion and 360° fusion, for the treatment of degenerative lumbar spondylolisthesis.

Recommendation 1:

The work group recommends the undertaking of a retrospective analysis comparing instrumented posterolateral fusion to decompression with 360° (circumferential) instrumented fusion in patients with degenerative lumbar spondylolisthesis.

Recommendation 2:

The work group recommends the undertaking of large multicenter registry database studies with long term follow up comparing the outcomes of surgical treatments, including instrumented posterolateral fusion to decompression with 360° (circumferential) instrumented fusion, in patients with degenerative lumbar spondylolisthesis.

References

1. Ha KY, Na KH, Shin JH, Kim KW. Comparison of posterolateral fusion with and without additional posterior lumbar interbody fusion for degenerative lumbar spondylolisthesis. J Spinal Disord Tech. 2008;21(4):229-34.
2. Rousseau MA, Lazennec JY, Bass EC, Saillant G. Predictors of outcomes after posterior decompression and fusion in degenerative spondylolisthesis. Eur Spine J. 2005;14(1):55-60.

Bibliography from updated literature search

1. Abdul QR, Qayum MS, Saradhi MV, Panigrahi MK, Sreedhar V. Clinico-radiological profile of indirect neural decompression using cage or auto graft as interbody construct in posterior lumbar interbody fusion in spondylolisthesis: Which is better?. J Craniovertebr Junction Spine. 2011;2(1):12-6.
2. Agabegi SS, Majid K, Fischgrund JS, Vaccaro AR, Patel T. Can preoperative radiographic parameters be used to predict fusion in non-instrumented posterolateral fusion for degenerative spondylolisthesis?. Spine. 2011;36(26):E1709-14.
3. Aihara T, Toyone T, Aoki Y, et al. Surgical management of degenerative lumbar spondylolisthesis. J Musculoskelet Res. 2012;15(4):1250020.
4. Brower RS, Vickroy NM. A case of psoas ossification from the use of BMP-2 for posterolateral fusion at L4-L5. Spine. 2008;33(18):E653-655.
5. Chen KX, Yang QY, Liu XC, Li HJ. [Treatment of degenerative lumbar spondylolisthesis through posterolateral fusion and fixation with pedicle screws]. Zhongguo Gu Shang. 2010;23(4):254-6.
6. Dantas FL, Prandini MN, Ferreira MA. Comparison between posterior lumbar fusion with pedicle screws and posterior lumbar interbody fusion with pedicle screws in adult spondylolisthesis. Arq Neuropsiquiatr. 2007;65(3B):764-70
7. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-46.
8. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-91.
9. Di silvestre M, Lolli F, Bakaloudis G. Degenerative lumbar scoliosis in elderly patients: dynamic stabilization without fusion versus posterior instrumented fusion. Spine J. 2014;14(1):1-10.
10. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
11. Epstein NE. An analysis of noninstrumented posterolateral lumbar fusions performed in predominantly geriatric patients using lamina autograft and beta tricalcium phosphate. Spine J. 2008;8(6):882-7.
12. Eskander MS, Eskander JP, Drew JM, Pelow-aidlen JL, Eslami MH, Connolly PJ. A modified technique for dowel fibular strut graft placement and circumferential fusion in the setting of L5-S1 spondylolisthesis and multilevel degenerative disc disease. Neurosurgery. 2010;67(3 Suppl Operative):ons91-5.
13. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133
14. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.

15. Gavaskar AS, Achimuthu R. Transfacetal fusion for low-grade degenerative spondylolisthesis of the lumbar spine: results of a prospective single center study. J Spinal Disord Tech. 2010;23(3):162-165
16. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2005;(4):CD001352.
17. Hara M, Nishimura Y, Takemoto M, Nakamura S, Wakabayashi T. Posterior fixation for lumbar degenerative spondylosis: Mini-open TLIF. Japan J Neurosurg. 2012;21(2):118-127.
18. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. Spine J. 2008;8(2):380-384.
19. Harris EB, Sayadipour A, Massey P, Duplantier NL, Anderson DG. Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis. A J Orthop. 2011;40(12):E257-261.
20. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. Surgical technique. J Bone Joint Surg Am. 2008;90 Suppl 2 Pt 1:145-52
21. Huang TY, Lee KS, Tsai TH, Su YF, Hwang SL. Posterior epidural migration of sequestrated lumbar disc fragments into the bilateral facet joints: case report. Neurosurgery. 2011;69(5):E1148-51.
22. Hunt T, Shen FH, Shaffrey CI, Arlet V. Contralateral radiculopathy after transforaminal lumbar interbody fusion. Eur Spine J. 2007;16 Suppl 3:311-314.
23. Hwang CJ, Vaccaro AR, Hong J, et al. Immunogenicity of osteogenic protein 1: results from a prospective, randomized, controlled, multicenter pivotal study of uninstrumented lumbar posterolateral fusion. J Neurosurg Spine. 2010;13(4):484-93.
24. Ito Z, Matsuyama Y, Sakai Y, et al. Bone union rate with autologous iliac bone versus local bone graft in posterior lumbar interbody fusion. Spine. 2010;35(21):E1101-5.
25. Jones TR, Rao RD. Adult isthmic spondylolisthesis. J Am Acad Orthop Surg. 2009;17(10):609-617.
26. Kaner T, Dalbayrak S, Oktenoglu T, Sasani M, Aydin AL, Ozer AF. Comparison of posterior dynamic and posterior rigid transpedicular stabilization with fusion to treat degenerative spondylolisthesis. Orthopedics. 2010;33(5).
27. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
28. Lee JC, Jang HD, Shin BJ. Learning curve and clinical outcomes of minimally invasive transforaminal lumbar interbody fusion: our experience in 86 consecutive cases. Spine. 2012;37(18):1548-57.
29. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
30. Liao JC, Chen WJ, Chen LH, Niu CC. Outcome of the L5-S1 segment after posterior instrumented spinal surgery in degenerative lumbar diseases. Chang Gung Med J. 2009;32(1):81-8.
31. Liao JC, Chen WJ, Chen LH, Niu CC, Keorochana G. Surgical outcomes of degenerative spondylolisthesis with L5-S1 disc degeneration: comparison between lumbar floating fusion and lumbosacral fusion at a minimum 5-year follow-up. Spine. 2011;36(19):1600-7.
32. Mehta VA, Mcgirt MJ, Garcés ambrossi GL, et al. Trans-foraminal versus posterior lumbar interbody fusion: comparison of surgical morbidity. Neurol Res. 2011;33(1):38-42.
33. Mokhtar SA, Mccombe PF, Williamson OD, Morgan MK, White GJ, Sears WR. Health-related quality of life: a comparison of outcomes after lumbar fusion for degenerative spondylolisthesis with large joint replacement surgery and population norms. Spine J. 2010;10(4):306-12.
34. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. Spine. 2012;37(23):E1464-8.
35. Oliveira L, Marchi L, Coutinho E, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. Spine. 2010;35(26 Suppl):S331-7.
36. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.
37. Rampersaud YR, Gray R, Lewis SJ, Massicotte EM, Fehlings MG. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. SAS J. 2011;5(2):29-35.
38. Rodgers WB, Lehmen JA, Gerber EJ, Rodgers JA. Grade 2 spondylolisthesis at L4-5 treated by XLIF: safety and midterm results in the "worst case scenario". ScientificWorldJournal. 2012;2012:356712.
39. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96
40. Shen NJ, Lin MX, Lin QB, Wang XA, Chen J, Wang GJ. Domestic vertebral internal fixation system for treating lumbar spondylolisthesis in 55 cases. A follow-up study. J Clin Rehabil Tissue Eng Res. 2009;13(9):1793-1796.
41. Skowroński J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. Ortop Traumatol Rehabil. 2007;9(2):149-55.
42. Sugawara A, Isu T, Kim K, Morimoto D, Isobe M, Matsumoto R, Ogasawara K. Surgical results using only posterior decompression for lumbar canal stenosis with lumbar degenerative spondylolisthesis. Neurol Med Chir. 2012;21(2), 111-117.
43. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H. Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: minimum five-year follow-up. Spine. 2011;36(5):410-5.
44. Vaccaro AR, Lawrence JP, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis: a long-term (>4 years) pivotal study. Spine. 2008;33(26):2850-62.
44. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-65.
45. Vanek P, Saur K. (2007). Transforaminal lumbar interbody fusion (TLIF) and instruments. Prospective study with the minimum of 20-month follow-up. Cesk Neurol Neurochir. 2007;70(5), 552-557.
46. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.
47. Xu H, Tang H, Li Z. Surgical treatment of adult degenerative spondylolisthesis by instrumented transforaminal lumbar interbody fusion in the Han nationality. J Neurosurg Spine. 2009;10(5):496-9.
48. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.

New Guideline Question:

Does 360° fusion with decompression lead to better outcomes versus 360° fusion without decompression for treatment of degenerative lumbar spondylolisthesis?

No evidence was found to address this question. Due to the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question.

Future Directions For Research

The work group recommends the undertaking of a registry database study that would provide outcomes data comparing 360° fusion with and without decompression in patients undergoing surgical treatment for degenerative lumbar spondylolisthesis.

Bibliography

1. Chaloupka R, Krbec, M, Cienciala J, et al. Two year clinical results of 360 degree fusion of lumbar spondylolisthesis managed by transpedicular fixation and plif or alif technique. Eur Spine J. 2006;15(Suppl 4):S506-s507.
2. Chaudhary KS, Groff MW. Minimally invasive transforaminal lumbar interbody fusion for degenerative spine. Tech Orthop. 2011;26(3):146-155.
3. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
4. Eskander MS, Eskander JP, Drew JM, Pelow-aidlen JL, Eslami MH, Connolly PJ. A modified technique for dowel fibular strut graft placement and circumferential fusion in the setting of L5-S1 spondylolisthesis and multilevel degenerative disc disease. Neurosurgery. 2010;67(3 Suppl Operative):ons91-5.
5. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2005;(4):CD001352.
6. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis: updated Cochrane Review. Spine. 2005;30(20):2312-20.
7. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. Surgical technique. J Bone Joint Surg Am. 2008;90 Suppl 2 Pt 1:145-52.
8. Jones TR, Rao RD. Adult isthmic spondylolisthesis. J Am Acad Orthop Surg. 2009.17(10), 609-617.
9. Kim S, Mortaz hedjri S, Coyte PC, Rampersaud YR. Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis. Spine J. 2012;12(1):44-54.
10. Mcafee PC, Devine JG, Chaput CD, et al. The indications for interbody fusion cages in the treatment of spondylolisthesis: analysis of 120 cases. Spine. 2005;30(6 Suppl):S60-5.
11. Mehta VA, Mcgirt MJ, Garcés ambrossi GL, et al. Trans-foraminal versus posterior lumbar interbody fusion: comparison of surgical morbidity. Neurol Res. 2011;33(1):38-42.
12. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.
13. Rodgers WB, Lehmen JA, Gerber EJ, Rodgers JA. Grade 2 spondylolisthesis at L4-5 treated by XLIF: safety and midterm results in the "worst case scenario". ScientificWorldJournal. 2012;2012:356712.
14. Rosenberg WS, Mummaneni PV. Transforaminal lumbar interbody fusion: technique, complications, and early results. Neurosurgery. 2001;48(3):569-74.
15. Rousseau MA, Lazennec JY, Bass EC, Saillant G. Predictors of outcomes after posterior decompression and fusion in degenerative spondylolisthesis. Eur Spine J. 2005;14(1):55-60.

New Guideline Question:

Do flexible fusions improve outcomes in the treatment of degenerative lumbar spondylolisthesis compared to nonoperative treatment?

For the purposes of this guideline, the work group defined "flexible fusion" as a procedure involving dynamic stabilization without arthrodesis.

No evidence was found to address this question. Due to the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question.

Although no studies were found to directly address this question, the work group included the case-series summaries below as background support to demonstrate the safety and effectiveness of flexible fusions in single-armed studies.

Fayyazi et al[1] conducted a prospective case series study of 6 patients with degenerative spondylolisthesis to evaluate the efficacy of the Dynesys posterior dynamic stabilization system. Patients were followed over 2 years and outcomes were evaluated by VAS, ODI and radiographic measurements. Results suggest that the stabilization system led to significant decreases in VAS and ODI clinical scores after stabilization ($p<0.05$). Over the 24-month follow-up period, mean flexion, extension, left, and right lateral bending of the motion segments were noted to be 1.0°, 2.4°, 0.6° and 0.6° or less, respectively. There were no statistically significant changes in the degree of motion. The authors suggest that the Dynesys dynamic instrumentation system stabilizes degenerative spondylolisthesis and may prevent further progression of listhesis.

In a retrospective case series, Lee et al[2] evaluated the outcomes of 65 patients who underwent surgical treatment with an interspinous soft stabilization (ISS) and tension band system for Grade I degenerative spondylolisthesis. Patients were evaluated via VAS, ODI and radiographic assessment after a mean follow-up of 72.5 months. The patients were divided according to the postsurgical clinical improvements into the optimal ($n = 44$) and suboptimal groups ($n = 21$), and the radiological intergroup differences were analyzed. Multiple linear regression analysis was performed to determine the impact of the radiological factors on the clinical outcomes. Radiologically, total lumbar lordosis (TLL) and segmental lumbar lordosis (SLL) were significantly improved only in the optimal group, resulting in significant intergroup differences in TLL ($p = 0.023$), SLL ($p = 0.001$), and the L1 tilt ($p = 0.002$). All of these measures were closely associated with postoperative segmental lumbar lordosis, which also was the most influential radiological variable for the clinical parameters. The study results suggest that dynamic stabilization outcomes were correlated with radiographic improvement and may be an alternative to fusion surgery for Grade I degenerative spondylolisthesis patients who do not require fixation or reduction.

Onda et al[3] conducted a retrospective case series of 31 patients who underwent decompression and stabilization with a graf stabilization system. Of the 31 patients enrolled, 23 had a diagnosis of degenerative spondylolisthesis. Patients were follow-up over 5 years and outcomes were assessed using Japanese Orthopedic Association (JOA) and ODI outcome measures. Results indicated that there was significantly better clinical improvement from preoperatively to postoperatively in JOA and VAS scores (6.1 preoperatively vs 2.2 postoperatively and 14.8 preoperatively vs 23.3 postoperatively, respectively). In patients with degenerative spondylolisthesis, the Graf System resulted in motion inhibition only in flexion ($p<0.05$). The mobility indicating a difference in the spondylolisthesis between flexion and extension was significantly reduced in relation to the inhibition of that in flexion ($p<0.05$). Study results indicate that Graf stabilization may be associated with satisfactory clinical outcomes in patients undergoing surgery for degenerative spondylolisthesis.

Schaeren et al[4] conducted a prospective case series to evaluate whether posterior dynamic stabilization in situ with Dynesys can maintain enough stability to prevent progression of spondylolisthesis in long-term follow-up. Patients were followed-up at a mean of 52 months using VAS and radiographic measurements. Results indicated that pain on VAS and walking distance significantly improved ($p<0.001$) at 2 years and remained unchanged at 4 years follow-up. Radiographically, spondylolisthesis did not progress and the motion segments remained stable. At 2 year follow-up, anterior and posterior disc height had significantly increased from 2.9 to 3.5mm ($p=0.02$). At 4 years follow-up, anterior and posterior disc height did not show significant alteration ($p=0.02$ and 0.05). At 4 years follow-up, 47% of the patients showed some degeneration at adjacent levels. Overall, patient satisfaction remained high as 95% would undergo the same procedure again. Study results suggest that dynamic stabilization with Dynesys may be associated with satisfactory clinical and radiographic outcomes after 4 years in patients undergoing surgery for degenerative spondylolisthesis.

In a prospective case series of 26 patients, Schanake et al[5] evaluated whether elastic stabilization with the Dynesys system provided enough stability to prevent further progression of spondylolisthesis as well as instability after decompression for spinal stenosis with degenerative spondylolisthesis. Minimum follow-up was 2 years. Results indicated that the mean pain score on VAS decreased significantly from 80 to 23 (range 0–82) ($p < 0.00001$). The mean walking distance improved significantly from 250 m to over 1000 m (range 100 to infinite) ($p < 0.00001$). Radiographically, overall progression of spondylolisthesis at follow-up was 2.1% and was not significant ($p=0.056$). Study results suggest that the use of dynamic stabilization with Dynesys may be associated with satisfactory clinical and radiographic outcomes after 2 years in patients undergoing surgery for degenerative spondylolisthesis.

Future Directions for Research

The work group identified the following suggestions for future studies which would generate meaningful evidence to assist in further evaluating the role of flexible fusions and medical/interventional treatment in the management of degenerative lumbar spondylolisthesis patients.

Recommendation 1:

The work group recommends the undertaking of large multicenter registry database studies with long term follow up comparing the outcomes of surgical treatment, including flexible fusions, to medical/interventional treatment in the management of degenerative lumbar spondylolisthesis patients.

Recommendation 2:

The work group recommends the undertaking of a prospective study comparing long term outcomes of flexible fusions to medical/interventional management in the treatment of degenerative lumbar spondylolisthesis.

References

1. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech. 2010;23(4):236-41.
2. Lee SH, Lee JH, Hong SW, et al. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7):563-72.
3. Onda A, Otani K, Konno S, Kikuchi S. Mid-term and long-term follow-up data after placement of the Graf stabilization system for lumbar degenerative disorders. J Neurosurg Spine. 2006;5(1):26-32.
4. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
5. Schnake KJ, Schaeren S, Jeanneret B. Dynamic stabilization in addition to decompression for lumbar spinal stenosis with degenerative spondylolisthesis. Spine. 2006;31(4):442-449.

Bibliography

1. Di silvestre M, Lolli F, Bakaloudis G. Degenerative lumbar scoliosis in elderly patients: dynamic stabilization without fusion versus posterior instrumented fusion. Spine J. 2014;14(1):1-10.
2. Dimar JR II, Djurasovic M, Carreon LY. Surgical management of degenerative and postsurgical spondylolisthesis. Semin Spine Surg. 2005;17(3):186-194.
3. El Elhawary Y, Azzazi A. Dynamic stabilization using X-stop vs. trans-pedicular screw fixation in the treatment of lumbar canal stenosis: Comparative study of the clinical outcome. Spine J. 2010;10(9)Supplement, S130.
4. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech. 2010;23(4):236-41.
5. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database System Rev. 2005 Oct 19;(4) CD001352.
6. Haberl H, Cripton PA, Orr TE, et al. Kinematic response of lumbar functional spinal units to axial torsion with and without superimposed compression and flexion/extension. Eur Spine J. 2004;13(6):560-6.
7. H Hong SW, Lee HY, Kim KH, Lee SH. Interspinous ligamentoplasty in the treatment of degenerative spondylolisthesis: midterm clinical results. J Neurosurg Spine. 2010;13(1):27-35.
8. Hrabálek L, Wanek T, Adamus M. [Treatment of degenerative spondylolisthesis of the lumbosacral spine by decompression and dynamic transpedicular stabilisation]. Acta Chir Orthop Traumatol Cech. 2011;78(5):431-6.
9. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-75.
10. Kanayama M, Hashimoto T, Shigenobu K, Togawa D, Oha F. A minimum 10-year follow-up of posterior dynamic stabilization using graf artificial ligament. Spine. 2007;32(18):1992-1996.
11. Kaner T, Dalbayrak S, Oktenoglu T, Sasani M, Aydin AL, Ozer AF. Comparison of posterior dynamic and posterior rigid transpedicular stabilization with fusion to treat degenerative spondylolisthesis. Orthopedics. 2010;33(5)
12. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.
13. Lee DY, Lee SH, Shim CS, Lee HY. Decompression and interspinous dynamic stabilization using the locker for lumbar canal stenosis associated with low-grade degenerative spondylolisthesis. Minim Invasive Neurosurg. 2010;53(3):117-21.
14. Lee SH, Lee JH, Hong SW, et al. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7):563-72.
15. Morishita Y, Ohta H, Naito M, et al. Kinematic evaluation of the adjacent segments after lumbar instrumented surgery: a comparison between rigid fusion and dynamic non-fusion stabilization. Eur Spine J. 2011;20(9):1480-5.
16. Müslüman AM, Cansever T, Yılmaz A, Çavuşoğlu H, Yüce İ, Aydın Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16(1):68-76.
17. Onda A, Otani K, Konno S, Kikuchi S. Mid-term and long-term follow-up data after placement of the Graf stabilization system for lumbar degenerative disorders. J Neurosurg Spine. 2006;5(1):26-32.
18. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis

treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
19. Schnake KJ, Schaeren S, Jeanneret B. Dynamic stabilization in addition to decompression for lumbar spinal stenosis with degenerative spondylolisthesis. Spine. 2006;31(4):442-449.
20. Sengupta DK. Point of view: Dynamic stabilization in addition to decompression for lumbar spinal stenosis with degenerative spondylolisthesis. Spine. 2006;31(4):450.
21. Sengupta DK, Herkowitz HN. Degenerative spondylolisthesis: review of current trends and controversies. Spine. 2005;30(6 Suppl):S71-81.
22. Siewe J, Otto C, Knoell P, et al. Comparison of standard fusion with a "topping off" system in lumbar spine surgery: a protocol for a randomized controlled trial. BMC Musculoskelet Disord. 2011;12:239.
23. Stoll TM, Dubois G, Schwarzenbach O. The dynamic neutralization system for the spine: a multi-center study of a novel non-fusion system. Eur Spine J. 2002;11 Suppl 2:S170-8.
24. Welch WC, Cheng BC, Awad TE, et al. Clinical outcomes of the Dynesys dynamic neutralization system: 1-year preliminary results. Neurosurg Focus. 2007;22(1):E8.
25. Willems P. Decision making in surgical treatment of chronic low back pain: the performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop Suppl. 2013;84(349):1-35.

New Guideline Question:

Does the use of interspinous spacers in the treatment of degenerative lumbar spondylolisthesis improve outcomes compared to medical/interventional treatment?

There is insufficient and conflicting evidence to make a recommendation for or against the efficacy of interspinous spacers versus medical/interventional treatment in the management of degenerative lumbar spondylolisthesis patients.

Grade of Recommendation: I (Insufficient Evidence)

Although one study showed clinical benefit of using interspinous spacers over medical/interventional treatments, 2 studies demonstrated that there may be increased risk of spinous process fracture and reoperation with the surgical use of interspinous spacers.

Anderson et al[1] reported subgroup analysis data from a large, randomized controlled trial dealing with spinal stenosis. The subgroup analysis evaluated 75 patients with Grade I degenerative spondylolisthesis and spinal stenosis with neurogenic claudication who were treated with either the X-STOP device or medical/interventional treatment. The medical/interventional group received at least one epidural steroid injection, medications and physical therapy. Outcomes were evaluated by the Zurich Claudication Questionnaire (ZCQ), SF-36 and radiographic assessment. At 2-years follow-up, there were statistically significant improvements in the ZCQ score and patient satisfaction in those treated with X-STOP; however, there were no statistically significant improvements in the medical/interventional group. Overall success occurred in 63.4% of X-STOP device treated patients compared to only 12.9% of medical/interventional patients ($p<0.05$). In critique of this study, the cohort of 75 patients was derived from a larger pool of candidates with spinal stenosis (and not necessarily spondylolisthesis) that were randomized into the X-STOP treatment group and medical/interventional group. Additionally, medical treatments administered to the medical/interventional patients were not controlled. Due to these limitations, this study has been downgraded from Level II to III. This potential Level II study offers Level III therapeutic evidence that interspinous distraction device for indirect decompression may lead to better outcomes at 2 years in patients with spinal stenosis and Grade I degenerative spondylolisthesis compared to nonoperative treatment.

In a prospective case series, Kim et al[2] examined the risk factors associated with early spinous process fracture after interspinous process spacer surgery (IPS). Of the 38 total patients included in the study, 20 patients had degenerative spondylolisthesis, which was observed prior to surgery. Postoperatively, patients underwent repeat CT imaging within 6 months of surgery and serial radiographs at 2 weeks, 6 weeks, 3 months, 6 months and one year. Eleven of 20 patients (55%) with spondylolisthesis experienced a fracture within 6 months of surgery. The 18 patients without spondylolisthesis did not experience a fracture. This difference was strongly significant ($p=0.0001$; OR, 29.00; 95% CI, 4.11–infinity). The authors concluded that degenerative spon-

dylolisthesis appears strongly associated with the occurrence of spinous process fracture after IPS surgery. While the Anderson study discusses the benefits of using IPS, this study suggests that there are risks. In critique, this single-armed study's sample size was small. This study provides Level IV therapeutic evidence that IPS placement increases the risk of spinous process fracture when used in degenerative spondylolisthesis patients.

In a retrospective case series, Verhoof et al[3] examined the effectiveness of the X-STOP interspinous distraction device in the treatment of symptomatic degenerative lumbar spinal stenosis caused by degenerative spondylolisthesis. A cohort of 12 consecutive patients were evaluated over a period of two years. The primary endpoint of this study was secondary surgical intervention of the lumbar spine. Results suggested that reoperation for recurrent symptoms was performed in 7 patients (58%) within 24 months. The authors suggest that the X-STOP interspinous distraction device showed an extremely high failure rate, defined as surgical reintervention, after short-term follow-up in patients with spinal stenosis caused by degenerative spondylolisthesis. X-STOP is not recommended for the treatment of lumbar spinal stenosis with degenerative spondylolisthesis and is considered a contraindication in these patients. This study provides Level IV therapeutic evidence that the use of X-STOP in unstable degenerative spondylolisthesis patients may result in a high rate of short-term reoperations.

Future Directions for Research

The work group identified the following suggestions for future studies which would generate meaningful evidence to assist in further evaluating the role of interspinous spacers and medical/interventional treatment in the management of degenerative lumbar spondylolisthesis patients.

Recommendation 1:

The work group recommends the undertaking of large multicenter registry database studies with long term follow up comparing the outcomes of surgical treatment with interspinous spacers to medical/interventional treatment in the management of degenerative lumbar spondylolisthesis patients.

Recommendation 2:

The work group recommends that the future analysis of interspinous spacers in the treatment of single level degenerative spondylolisthesis should include a group treated with decompression with or without fusion in addition to medical management as patients have benefited from this therapy.

Recommendation 3:

The work group recommends that future analysis of interspinous spacers should include longer term outcome analysis to investigate whether complication rates fall within acceptable limits.

References

1. Anderson PA, Tribus CB, Kitchel SH. Treatment of neurogenic claudication by interspinous decompression: application of the X STOP device in patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2006;4(6):463-71.
2. Kim DH, Shanti N, Tantorski ME, et al. Association between degenerative spondylolisthesis and spinous process fracture after interspinous process spacer surgery. Spine J. 2012;12(6):466-72.
3. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.

Bibliography

1. Austin RC, Branch CL, Alexander JT. Novel bioabsorbable interbody fusion spacer-assisted fusion for correction of spinal deformity. Neurosurg Focus. 2003;14(1):e11
2. Caserta S, La maida GA, Misaggi B, et al. Elastic stabilization alone or combined with rigid fusion in spinal surgery: a biomechanical study and clinical experience based on 82 cases. Eur Spine J. 2002;11 Suppl 2:S192-7.
3. Chaput C, Padon D, Rush J, Lenehan E, Rahm M. The significance of increased fluid signal on magnetic resonance imaging in lumbar facets in relationship to degenerative spondylolisthesis. Spine. 2007;32(17):1883-7.
4. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
5. Cutler AR, Siddiqui S, Mohan AL, Hillard VH, Cerabona F, Das K. Comparison of polyetheretherketone cages with femoral cortical bone allograft as a single-piece interbody spacer in transforaminal lumbar interbody fusion. J Neurosurg Spine. 2006;5(6):534-9.
6. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2005;(4):CD001352.
7. Hatta Y, Shiraishi T, Sakamoto A, et al. Muscle-preserving interlaminar decompression for the lumbar spine: a minimally invasive new procedure for lumbar spinal canal stenosis. Spine. 2009;34(8):E276-80.
8. Hong SW, Lee HY, Kim KH, Lee SH. Interspinous ligamentoplasty in the treatment of degenerative spondylolisthesis: midterm clinical results. J Neurosurg Spine. 2010;13(1):27-35.
9. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-75
10. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.
11. Lee DY, Lee SH, Shim CS, Lee HY. Decompression and interspinous dynamic stabilization using the locker for lumbar canal stenosis associated with low-grade degenerative spondylolisthesis. Minim Invasive Neurosurg. 2010;53(3):117-21.
12. Lee SH, Lee JH, Hong SW, Chung SE, Yoo SH, Lee HY. Spinopelvic alignment after interspinous soft stabilization with a tension band system in grade 1 degenerative lumbar spondylolisthesis. Spine. 2010;35(15):E691-701.
13. Lee SH, Lee JH, Hong SW, et al. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7):563-72.
14. Park SC, Yoon SH, Hong YP, Kim KJ, Chung SK, Kim HJ. Minimum 2-year follow-up result of degenerative spinal stenosis treated with interspinous u (coflex). J Korean Neurosurg Soc. 2009;46(4):292-9.
15. Postacchini F, Cinotti G, Perugia D. Degenerative lumbar spondylolisthesis. II. Surgical treatment. Ital J Orthop Traumatol. 1991;17(4):467-77.
16. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: restoration of sagittal balance using insert-

and-rotate interbody spacers. Spine J. 2005;5(2):170-9.
17. Surace MF, Fagetti A, Fozzato S, Cherubino P. Lumbar spinal stenosis treatment with Aperius perclid interspinous system. Eur Spine J. 2012;21 Suppl 1:S69-74.
18. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis. Cochrane Database Syst Rev. 2012;CD010264.

Original Guideline Question:

What is the role of reduction (deliberate attempt to reduce via surgical technique) with fusion in the treatment of degenerative lumbar spondylolisthesis?

There is insufficient evidence to make a recommendation for or against the use of reduction with fusion in the treatment of degenerative lumbar spondylolisthesis. *Revised wording, but Recommendation Grade maintained*

Grade of Recommendation: I (Insufficient Evidence)

The updated literature search did not retrieve new evidence to support a recommendation for or against the use of reduction with fusion; therefore, the work group maintains the original guideline's "Insufficient Recommendation" grading. Although reduction and fusion can be performed, the evidence reviewed does not substantiate any improvement in clinical outcomes and reduction may increase the risk of neurological complications.

Studies included in original guideline:

Bednar et al[1] described a retrospective consecutive case series of 56 patients with degenerative spondylolisthesis and symptoms of back pain and/or stenosis treated with bilateral foraminotomies, reduction and instrumented fusion. The procedure had a 7% major complication rate. Outcomes measures were the Visual Analog Scale (VAS), Oswestry Disability Index (ODI) and radiographs. Of the 56 patients, 42 were available for follow-up at an average of 33 months (range 14-53 months). Of the 42 patients, 82% experienced relief of leg pain, 75% experienced improvement in low back pain, and 77% experienced significant improvement in their ODI scores (average preoperatively of 56% versus average of 26% postoperatively). Only 38 patients were available for late review of X-ray studies at an average of 33 months. Average preoperative slip was 16%, and of the 38 patients available at late review, 75% had perfect reduction. Of the 38 patients, 16% had minor loss of reduction. Outcome measures (VAS and ODI) were not compared based on the presence or absence of a perfect reduction. In critique, this is a moderately small, retrospective review of a consecutive case series of surgical patients from one surgeon with no comparison group and with less than 80% follow-up. This paper offers Level IV therapeutic evidence that limited bilateral foraminotomies with instrumented reduction and fusion for symptomatic degenerative spondylolisthesis and stenosis is as effective as laminectomy and in situ fusion without as much operative exposure of neural structures.

Lee et al[2] reported on a prospective case series of 52 consecutive patients with objectively defined unstable degenerative spondylolisthesis who underwent reduction and fusion without decompression using the Fixater Interne pedicle fixation device. Forty-seven patients had low back pain, 40 patients had radicular pain and 36 patients had intermittent claudication. Follow-up was at a minimum of 12 months (range 12-16 months). Subjective measurement of success was classified as excellent, good, fair and poor for pain. An excellent or good outcome was considered satisfactory and a fair or poor outcome was considered unsatisfactory. A satisfactory outcome (excellent and good results) occurred in 42 of 47 patients with complaints of back pain, 37 of 40 patients with radicular pain and 31 of 36 patients with claudication. The authors commented that only 2 groups, based on their findings, are not good candidates for this procedure: (1) those with a positive Lasegue's sign and (2) those with borderline instability. In critique of this study, this was a prospective case series, which lacked a comparison group, and validated outcome measures were not used. This paper presents Level IV therapeutic evidence that patients with degenerative spondylolisthesis who do not have borderline instability or a positive Lasegue's sign can undergo reduction, fixation and fusion without decompression.

Sears et al[3] reviewed a prospective case series of 34 patients with degenerative spondylolisthesis who underwent decompression, reduction, internal fixation and fusion. Twenty-five patients had a one-level fusion and 9 patients had a 2-level fusion. Of the 34 patients, 32 had surgery to relieve leg pain. Outcome measures included the VAS, Low Back Pain Outcome Score (LBOS), SF-12 and patient satisfaction questionnaire. Preoperative and postoperative measurement of slip by radiograph were also recorded. Mean preoperative slip was 20% (range was 12% to 33%). Follow-up occurred at a mean of 21.2 months (range 12 to 32 months),

with no dropouts. Significant improvements (p<.001) occurred in mean VAS and LBOS scores. Ninety-one percent of the patients considered their results excellent or good on the subjective satisfaction rating. Radiograph analysis revealed mean slip reduction from 20.2% to 1.7% and focal lordosis (available in only 17 of 34 patients) increased from 13.1 to 16.1 degrees. Both of these findings were clinically significant. Three of the 34 patients had postoperative nerve root irritation, with 2 of these persisting up to the time of final report. There were no procedure-related complications were reported postoperatively, but one patient required adjacent level decompression and fusion 12 months after surgery. In critique, this is a small prospective case series on nonconsecutive patients with degenerative spondylolisthesis with no comparison group. This paper offers Level IV therapeutic evidence that reduction of a degenerative spondylolisthesis with internal fixation and posterior lumbar interbody fusion can provide good deformity correction with few complications and good short-term patient outcomes on validated patient outcome measures.

Future Directions For Research

The work group recommends the undertaking of comparative studies and multicenter registry database studies evaluating reduction spondylolisthesis to fusion in situ.

References

1. Bednar DA. Surgical management of lumbar degenerative spinal stenosis with spondylolisthesis via posterior reduction with minimal laminectomy. J Spinal Disord Tech. 2002;15(2):105-109.
2. Lee TC. Reduction and stabilization without laminectomy for unstable degenerative spondylolisthesis: a preliminary report. Neurosurgery. 1994;35(6):1072-1076.
3. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: restoration of sagittal balance using insert-and-rotate interbody spacers. Spine J. 2005;5(2):170-179.

Bibliography from updated literature search

1. Abdul QR, Qayum MS, Saradhi MV, Panigrahi MK, Sreedhar V. Clinico-radiological profile of indirect neural decompression using cage or auto graft as interbody construct in posterior lumbar interbody fusion in spondylolisthesis: Which is better?. J Craniovertebr Junction Spine. 2011;2(1):12-6.
2. Chad DA. Lumbar Spinal Stenosis. Neurol Clin. 2007;25(2):407-418.
3. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
4. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.
5. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2005;(2):CD001352.
6. Harris EB, Sayadipour A, Massey P, Duplantier NL, Anderson DG. Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis. Am J Orthop. 2011;40(12):E257-61.
7. Hrabálek L, Wanek T, Adamus M. [Treatment of degenerative spondylolisthesis of the lumbosacral spine by decompression and dynamic transpedicular stabilisation]. Acta Chir Orthop Traumatol Cech. 2011;78(5):431-6.
8. Kepler CK, Rihn JA, Radcliff KE, et al. Restoration of lordosis and disk height after single-level transforaminal lumbar interbody fusion. Orthop Surg. 2012;4(1):15-20.
9. Kim SY, Maeng DH, Lee SH, Jang JS. Anterior lumbar interbody fusion for lumbosacral junction in steep sacral slope. J Spinal Disord Tech. 2008;21(1):33-8.
10. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
11. Lattig F, Fekete TF, Grob D, Kleinstück FS, Jeszenszky D, Mannion AF. Lumbar facet joint effusion in MRI: a sign of instability in degenerative spondylolisthesis?. Eur Spine J. 2012;21(2):276-81.
12. Lerner T, Frobin W, Bullmann V, Schulte T, Brinckmann P, Liljenqvist U. Changes in disc height and posteroanterior displacement after fusion in patients with idiopathic scoliosis: a 9-year follow-up study. J Spinal Disord Tech. 2007;20(3):195-202.
13. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
14. Park P, Foley KT. Minimally invasive transforaminal lumbar interbody fusion with reduction of spondylolisthesis: technique and outcomes after a minimum of 2 years' follow-up. Neurosurg Focus. 2008;25(2):E16.
15. Park SC, Yoon SH, Hong YP, Kim KJ, Chung SK, Kim HJ. Minimum 2-year follow-up result of degenerative spinal stenosis treated with interspinous u (coflex). J Korean Neurosurg Soc. 2009;46(4):292-9.
16. Park Y, Ha JW, Lee YT, Sung NY. The effect of a radiographic solid fusion on clinical outcomes after minimally invasive transforaminal lumbar interbody fusion. Spine J. 2011;11(3):205-12.
17. Robertson PA, Plank LD. Prospective cohort analysis of disability reduction with lumbar spinal fusion surgery in community practice. J Spinal Disord Tech. 2008;21(4):235-40.
18. Schizas C, Tzinieris N, Tsiridis E, Kosmopoulos V. Minimally invasive versus open transforaminal lumbar interbody fusion: evaluating initial experience. Int Orthop. 2009;33(6):1683-8.
19. Schulte TL, Leistra F, Bullmann V, et al. Disc height reduction in adjacent segments and clinical outcome 10 years after lumbar 360 degrees fusion. Eur Spine J. 2007;16(12):2152-8.
20. Shen NJ, Lin MX, Lin QB, Wang XA, Chen J, Wang GJ. Domestic vertebral internal fixation system for treating lumbar spondylolisthesis in 55 cases. A follow-up study. J Clin Rehabil Tissue Eng Res. 2009;13(9):1793-1796.
21. St clair S, Tan JS, Lieberman I. Oblique lumbar interbody fixation: a biomechanical study in human spines. J Spinal Disord Tech. 2012;25(4):183-9.
22. Tsutsumimoto T, Shimogata M, Ohta H, Misawa H. Mini-open versus conventional open posterior lumbar interbody fusion for the treatment of lumbar degenerative spondylolisthesis: comparison of paraspinal muscle damage and slip reduction. Spine. 2009;34(18):1923-8.
23. Xu H, Tang H, Li Z. Surgical treatment of adult degenerative spondylolisthesis by instrumented transforaminal lumbar interbody fusion in the Han nationality. J Neurosurg Spine. 2009;10(5):496-9.
24. Yan DL, Pei FX, Li J, Soo CL. Comparative study of PILF and TLIF treatment in adult degenerative spondylolisthesis. Eur Spine J. 2008;17(10):1311-6.
25. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.

New Guideline Question:

For patients undergoing posterolateral fusion, does the use of autogenous bone graft improve surgical outcomes compared to those fused with bone graft substitutes?

Due to the paucity of literature addressing this question, the work group was unable to generate a recommendation to answer this question.

There is insufficient evidence to make a recommendation for or against the use of autogenous bone graft or bone graft substitutes in patients undergoing posterolateral fusion for the surgical treatment of degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

Vaccaro et al[1] conducted a randomized controlled trial comparing OP-1 (rhBMP-7) with iliac crest autograft in patients with symptomatic degenerative spondylolisthesis and spinal stenosis treated with decompression and uninstrumented posterolateral arthrodesis. All patients had failed at least 6 months of nonoperative treatment, including physical therapy, lumbar epidural injections, anti-inflammatory medications, and activity modifications for their spinal symptoms. A total of 335 patients were randomized in 2:1 fashion to receive either OP-1 Putty or autograft in the setting of an uninstrumented posterolateral arthrodesis. Out of the 335 patients, 295 patients were actually treated. A total of 208 patients received OP-1 Putty and 87 received autograft. The OP-1 putty consisted of 3.5 mg of rhOP-1 formulated with bovine-derived collagen and carboxymethylcellulose to create a powdered mixture and was reconstituted at the time of surgery with the addition of saline. Patients in the autograft group received corticocancellous bone harvested from the posterior iliac crest. After surgery, patients were evaluated clinically and radiographically at 6 weeks, and at 3, 6, 9, 12, 24, and at a minimum of 36 months. Clinical assessments consisted of an evaluation of subjective pain and function using the Oswestry Low Back Pain Disability (ODI) questionnaire, the Visual Analog Scale (VAS), neurologic evaluation, and functional outcome assessment via completion of the Short-Form 36 (SF-36) outcomes survey. Imaging consisted of anteroposterior (AP), lateral, and flexion-extension radiographs. Regarding imaging findings, there were no statistical differences between the study groups in terms of angular or translational motion at either 24 or 36 months follow-up. One hundred seven of 143 (74.8%) of the OP-1 Putty patients and 41 of 53 (77.4%) of the autograft patients had presence of new bone on CT scan. Bridging bone was detected in 56% of patients in the OP-1 Putty group and 83% (p=0.001) of patients in the autograft group. At 24 months, 74.5% of OP-1 subjects and 75.7% of autograft subjects had a >20% improvement from baseline in ODI. At 36+ months, 68.6% of OP-1 subjects and 77.3% of autograft subjects had a >20% improvement from baseline in ODI. There were no statistical differences between the groups at either time point (p=0.839 at 24 months, p=0.201 at 36+ months). Mean operative time for the OP-1 Putty group was significantly shorter than the autograft group (144 minutes for the OP-1 Putty group vs 164 minutes for the autograft group, p<0.006). Mean operative blood loss was also significantly lower for the OP-1 Putty group than the autograft group (309 cc vs. 471 cc, p< 0.00004). There were no differences in the mean length of stay after surgery (p=0.529). This study provides level I therapeutic evidence that OP-1 putty is a safe and effective alternative to autograft in the setting of uninstrumented posterolateral spinal arthrodesis.

The studies below were retrieved in the literature search, but did not meet the guideline's inclusion criteria as they are either mixed diagnosis or do not include sub-group analysis of degenerative lumbar spondylolisthesis patient outcomes. However, as this is an area of interest to many, the work group included the studies below as background information.

In a randomized controlled trial, Alexander et al[2] compared the efficacy of calcium sulfate pellets plus bone obtained from decompression with fresh autologous iliac crest bone in posterolateral lumbar and lumbosacral spinal fusion with decompression. Patients acted as their own controls with one side acting as the intervention side (decompression bone plus an equal volume of calcium sulfate pellets) and the other side as the control side (autologous posterior iliac crest bone of equal volume to test material). Thirty-two patients suffering from either degenerative disc disease or spondylolisthesis completed a one-year follow-up. Outcome assessment was conducted via blinded radiographic evaluation at 6 and 12 months after surgery. The radiologist utilized 2 methods for reviewing the radiographs. Method A involved viewing the posteroanterior radiograph with the lateral

radiograph as the reference for the presence of new bone mass. If new bone was apparent, the mass on that side was compared with the mass on the other side. The side with the larger mass was noted and the side with the smaller mass was graded as a percentage of the larger side as follows: 0 to 24%, 25 to 49%, 50 to 74%, 75 to 100% or equal. Method B also involved comparing the sides for new bone mass. If new bone mass was apparent, the outline of this mass on either side was obtained and these outlines provided area measurements, which were quantified by placing outlines over graph paper and totaling the 1mm^2 areas within the outlines, allowing comparison between the lines. The authors considered the bone mass formation at the site of test material placement to be "equivalent" to the bone mass at the control site if the test material bone mass was in the category of 75% to 100% of, equal to, or better than the control side. Results from Method A suggested that 88% of patients at 12 months produced bone formation at the test site graded as equivalent to the control site. Method B indicated that the bone mass formation was equal for both graft sites. The test material increased bone formation an average of 9.18 cm^2 and the control material increased bone formation an average of 6.44cm^2 from 6-12 months after fusion surgery. The authors suggest that the use of calcium sulfate pellets plus decompression bone provides equivalent bone formation to the use of autologous iliac crest bone.

Delawi et al[3] conducted a multicenter prospective randomized controlled trial to evaluate the safety and feasibility of osteogenic protein (OP-1) compared to iliac crest autograft in patients undergoing decompression and one level lumbar spine instrumented posterolateral fusions for either degenerative or isthmic spondylolisthesis. The OP-1 material consisted of 3.5 mg lyophilized rhOP-1 in 1 g of collagen type I combined with locally obtained bone during laminectomy. Thirty-four patients were included in this study and completed follow-up, including 21 patients with a diagnosis of degenerative spondylolisthesis (10 OP-1 Group; 11 Autograft Group) and 13 with a diagnosis of isthmic spondylolisthesis (8 OP-1 Group; 5 Autograft Group). The primary outcome measure was fusion rate one year after surgery based on blinded computed tomography assessment by a spinal surgeon and radiologist resident. Clinical assessments were conducted preoperatively and at 6 weeks and 3, 6 and 12 months postoperatively using the Visual Analog Scale (VAS) and Oswestry Disability Index (ODI). In addition, adverse events, including any untoward medical occurrence in a patient, were documented. Results indicated that fusion rates were not statistically significantly different between the treatment groups. Fusion rates of 63% were found in the OP-1 Group and 67% in the control/Autograft Group (p=0.95). ODI scores improved significantly in both groups compared to preoperative assessment (p<0.001); however, there were no significant differences in mean ODI scores between the groups at any study point (p=0.52). VAS scores at the donor site were only measured in the autograft group and therefore are unavailable for comparison. In addition, adverse events were experienced by 17 (50%) of patients; however, there were no statistically significant differences in adverse event rates between the treatment groups (p=0.48). The authors suggest that OP-1 is a safe and effective alternative for iliac crest autograft in instrumented single-level posterolateral fusions of the lumbar spine.

Korvessis et al[4] conducted a randomized clinical trial and radiological study to compare the surgical outcomes of instrumented posterolateral lumbar and lumbosacral fusion using either coralline hydroxyapatite (CH), Group A; or iliac bone graft (IBG), Group B; or both, Group C. A total of 57 patients who suffered from symptomatic degenerative lumbar spinal stenosis, including 19 in Group A, 18 in Group B and 20 in Group C, participated in the study and underwent decompression and fusion with bone graft, bone graft substitute or both. According to the documented technique, autologous IBG was applied bilaterally in Group A; in Group B, IBG was applied on the left side and hydroxyapatite mixed with local bone and bone marrow was applied on the right side; and in Group C, hydroxyapatite mixed with local bone and bone marrow was applied bilaterally. Patients were followed up to 4 years postoperatively, with a minimal observation of 3 years, and outcomes were evaluated with the SF-36, Oswestry Disability Index (ODI), Roland-Morris (R-M) survey, Visual Analogue Scale (VAS) for pain severity, and plain roentgenograms and CT scan evaluated the evolution of the fusion. Preoperative ODI scores improved postoperatively in all groups up to the 2-year follow-up with Group A improving 41±27%, Group B improving 47±39% and Group C improving 43±28%; however, there were no significant changes measured after 2 years. R-M scores were also improved up to the 2-year follow-up with Group A improving 47±43%, Group B improving 60±46%, and Group C improving 55±28%. Thereafter, there were no significant changes in any group. VAS scores were significantly improved in all groups with a peak at 2 years postoperatively. VAS scores improved from 8.1±1.2 to 4.7±3.6 in Group A; 8±1.7 to 3.5±3.1 in Group B, and 7±2 to 3.7±2.7 in Group C. The authors suggest that the use of autologous IBG results in superior fusion results when compared to fusion using CH.

McGuire et al[5] conducted a systematic literature review of articles published through January 2011, including the Alexander[2] and Korvessis[4] studies, to compare the fusion rate, functional outcomes, and safety of local bone graft plus bone extender compared with iliac crest bone graft in posterolateral spinal fusion procedures. After review of 20 potential citations, the authors identified 3 articles meeting inclusion criteria, including 2 studies discussed above and provided as support in addressing this clinical question. All 3 randomized controlled trials included patients with a diagnosis of degenerative disc disease, spondylolisthesis, spinal stenosis or deformity. Fusion rates were high across studies and there were no significant differences between treatment groups in fusion rates, functional outcomes, or quality of life. This systematic review suggests that local bone graft plus bone extender and iliac crest bone graft used in posterolateral spinal fusion procedures have similar fusion rates, functional outcomes, and quality of life scores.

FDA Indications and Warnings

For informational purposes only, the work group has provided the following links to the FDA website to inform readers of the indications and warnings that may be associated with the use of autograft and bone graft substitutes.

Autogenous Bone Graft
http://www.fda.gov/downloads/AdvisoryCommittees/CommitteesMeetingMaterials/MedicalDevices/MedicalDevicesAdvisoryCommittee/OrthopaedicandRehabilitationDevicesPanel/UCM254662.pdf

Recombinant Human Bone Morphogenetic Protein
http://www.fda.gov/MedicalDevices/safety/alertsandnotices/publichealthnotifications/ucm062000.htm

Infuse Bone Graft
http://www.accessdata.fda.gov/cdrh_docs/pdf/P000054c.pdf

Future Directions for Research

The work group identified the following suggestions for future studies, which would generate meaningful evidence to assist in further defining the role autogenous bone graft and bone graft substitutes in the surgical treatment of patients with degenerative lumbar spondylolisthesis:

Recommendation #1:

A multicenter registry database study evaluating the morbidity of bone graft (and type of bone graft) versus autograft in patients undergoing surgical treatment for degenerative lumbar spondylolisthesis.

Recommendation #2:

A comparative cost-analysis study to evaluate the cost-effectiveness of bone graft (and type of bone graft) versus autograft in patients undergoing surgical treatment for degenerative lumbar spondylolisthesis.

References

1. Vaccaro AR, Lawrence JP, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis: a long-term (>4 years) pivotal study. Spine. 2008;33(26):2850-62.
2. Alexander DI, Manson NA, Mitchell MJ. Efficacy of calcium sulfate plus decompression bone in lumbar and lumbosacral spinal fusion: preliminary results in 40 patients. Can J Surg. 2001;44(4):262-6.
3. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-91.
4. Korovessis P, Koureas G, Zacharatos S, Papazisis Z, Lambiris E. Correlative radiological, self-assessment and clinical analysis of evolution in instrumented dorsal and lateral fusion for degenerative lumbar spine disease. Autograft versus coralline hydroxyapatite. Eur Spine J. 2005;14(7):630-8.
5. Mcguire RA, Pilcher LE, Dettori JR. Lumbar posterolateral fusion with local bone graft plus bone extender compared with iliac crest bone graft: a systematic review. Evid Based Spine Care J. 2011;2(2):35-40.

Bibliography

1. Abbott AD, Tyni-lenné R, Hedlund R. Early rehabilitation targeting cognition, behavior, and motor function after lumbar fusion: a randomized controlled trial. Spine. 2010;35(8):848-57.
2. Abdul QR, Qayum MS, Saradhi MV, Panigrahi MK, Sreedhar V. Clinico-radiological profile of indirect neural decompression using cage or auto graft as interbody construct in posterior lumbar interbody fusion in spondylolisthesis: Which is better?. J Craniovertebr Junction Spine. 2011;2(1):12-6.
3. Adogwa O, Parker SL, Bydon A, Cheng J, Mcgirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-84.
4. Adogwa O, Parker SL, Davis BJ, et al. Cost-effectiveness of transforaminal lumbar interbody fusion for Grade I degenerative spondylolisthesis. J Neurosurg Spine. 2011;15(2):138-43.
5. Agabegi SS, Majid K, Fischgrund JS, Vaccaro AR, Patel T. Can preoperative radiographic parameters be used to predict fusion in non-instrumented posterolateral fusion for degenerative spondylolisthesis?. Spine. 2011;36(26):E1709-14.
6. Albert TJ, Desai D, Mcintosh T, Lamb D, Balderston RA. Early versus late replacement of autotransfused blood in elective spinal surgery. A prospective randomized study. Spine. 1993;18(8):1071-8.
7. Alfieri, A., Gazzeri, R., Prell, J., Scheller, C., Rachinger, J., Strauss, C., & Schwarz, A. (2012). Role of lumbar interspinous distraction on the neural elements. Neurosurgical review, 35(4), 477-484. doi: 10.1007/s10143-012-0394-1
8. Alfieri A, Gazzeri R, Prell J, et al. Role of lumbar interspinous distraction on the neural elements. Neurosurg Rev. 2012;35(4):477-84.
9. Alt V, Chhabra A, Franke J, Cuche M, Schnettler R, Le huec JC. An economic analysis of using rhBMP-2 for lumbar fusion in Germany, France and UK from a societal perspective. Eur Spine J. 2009;18(6):800-6.
10. Andersen T, Christensen FB, Høy KW, et al. The predictive value of pain drawings in lumbar spinal fusion surgery. Spine J. 2010;10(5):372-9.
11. Aono H, Iwasaki M, Ohwada T, et al. Surgical outcome of drop foot caused by degenerative lumbar diseases. Spine. 2007;32(8):E262-6.
12. Aryan HE, Newman CB, Gold JJ, Acosta FL, Coover C, Ames CP. Percutaneous axial lumbar interbody fusion (AxiaLIF) of the L5-S1 segment: initial clinical and radiographic experience. Minim Invasive Neurosurg. 2008;51(4):225-30.
13. Asazuma T, Masuoka K, Motosuneya T, Tsuji T, Yasuoka H, Fujikawa K. Posterior lumbar interbody fusion using dense hydroxyapatite blocks and autogenous iliac bone: clinical and radiographic examinations. J Spinal Disord Tech. 2005;18 Suppl:S41-7.
14. Asghar FA, Hilibrand AS. The impact of the Spine Patient Outcomes Research Trial (SPORT) results on orthopaedic practice. J Am Acad Orthop Surg. 2012;20(3):160-6.
15. Bagaria V. Re: Vaccaro AR, Patel T, Fischgrund J, et al. A pilot study evaluating safety and efficacy of OP-1 putty (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis for degenerative spondylolisthesis. Spine 2004;29:1885-92. Spine. 2006;31(7):851.
16. Barbagallo GM, Olindo G, Corbino L, Albanese V. Analysis of complications in patients treated with the X-Stop Interspinous Process Decompression System: proposal for a novel anatomic scoring system for patient selection and review of the literature. Neurosurgery. 2009;65(1):111-19.
17. Bederman SS, Coyte PC, Kreder HJ, Mahomed NN, Mcisaac WJ, Wright JG. Who's in the driver's seat? The influence of patient and physician enthusiasm on regional variation in degenerative lumbar spinal surgery: a population-based study. Spine. 2011;36(6):481-489.
18. Blumenthal C, Curran J, Benzel EC, et al. Radiographic predictors of delayed instability following decompression without

fusion for degenerative grade I lumbar spondylolisthesis. J Neurosurg Spine. 2013;18(4):340-6.
19. Blumenthal SL, Ohnmeiss DD. Intervertebral cages for degenerative spinal diseases. Spine J. 2003;3(4):301-9.
20. Boden SD. Spinescope. Semin Spine Surg. 2011;23(2):151-156.
21. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2):133-137.
22. Booth KC, Bridwell KH, Eisenberg BA, Baldus CR, Lenke LG. Minimum 5-year results of degenerative spondylolisthesis treated with decompression and instrumented posterior fusion. Spine. 1999;24(16):1721-7.
23. Brantigan JW, Neidre A. Achievement of normal sagittal plane alignment using a wedged carbon fiber reinforced polymer fusion cage in treatment of spondylolisthesis. Spine J. 2003;3(3):186-96.
24. Bridwell KH, Sedgewick TA, O'brien MF, Lenke LG, Baldus C. The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. J Spinal Disord. 1993;6(6):461-72.
25. Brislin B, Vaccaro AR. Advances in posterior lumbar interbody fusion. Orthop Clin North Am. 2002;33(2):367-74.
26. Burkus JK, Dryer RF, Peloza JH. Retrograde ejaculation following single-level anterior lumbar surgery with or without recombinant human bone morphogenetic protein-2 in 5 randomized controlled trials: clinical article. J Neurosurg Spine. 2013;18(2):112-21.
27. Burkus JK, Gornet MF, Schuler TC, Kleeman TJ, Zdeblick TA. Six-year outcomes of anterior lumbar interbody arthrodesis with use of interbody fusion cages and recombinant human bone morphogenetic protein-2. J Bone Joint Surg Am. 2009;91(5):1181-9.
28. Burkus JK, Sandhu HS, Gornet MF. Influence of rhBMP-2 on the healing patterns associated with allograft interbody constructs in comparison with autograft. Spine. 2006;31(7):775-81.
29. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD. SF-6D values stratified by specific diagnostic indication. Spine. 2012;37(13):E804-8.
30. Carreon LY, Puno RM, Dimar JR, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. J Bone Joint Surg Am. 2003;85-A(11):2089-92.
31. Cavagna R, Daculsi G, Bouler JM. Macroporous calcium phosphate ceramic: a prospective study of 106 cases in lumbar spinal fusion. J Long Term Eff Med Implants. 1999;9(4):403-12.
32. Cavuşoğlu H, Türkmenoğlu O, Kaya RA, et al. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-8.
33. Chad, D. A. (2007). Lumbar Spinal Stenosis. Neurologic clinics, 25(2), 407-418. doi: 10.1016/j.ncl.2007.01.003
34. Chaloupka R, Krbec M, Cienciala J, et al. Two year clinical results of 360 degree fusion of lumbar spondylolisthesis managed by transpedicular fixation and PLIF or ALIF technique. Eur Spine J. 2006;15(Suppl 4):S506-s507.
35. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
36. Chu G, Aikenmu K, He ZS. Unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis: A randomized controlled trial. J Clin Rehabil Tissue Eng Res. 2011;15(35):6540-6545.
37. Cloyd JM, Acosta FL, Ames CP. Complications and outcomes of lumbar spine surgery in elderly people: a review of the literature. J Am Geriatr Soc. 2008;56(7):1318-27.
38. Coe JD, Kitchel SH, Meisel HJ, Wingo CH, Lee SE, Jahng TA. NFlex Dynamic Stabilization System : Two-Year Clinical Outcomes of Multi-Center Study. J Korean Neurosurg Soc. 2012;51(6):343-9.
39. Cole CD, Mccall TD, Schmidt MH, Dailey AT. Comparison of low back fusion techniques: transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) approaches. Curr Rev Musculoskelet Med. 2009;2(2):118-26.
40. Crawford CH, Smail J, Carreon LY, Glassman SD. Health-related quality of life after posterolateral lumbar arthrodesis in patients seventy-five years of age and older. Spine. 2011;36(13):1065-8.
41. Csécsei G, Klekner A, Sikula J. Posterior lumbar interbody fusion (PLIF) using the bony elements of the dorsal spinal segment. Acta Chir Hung. 1997;36(1-4):54-6.
42. Cutler AR, Siddiqui S, Mohan AL, Hillard VH, Cerabona F, Das K. Comparison of polyetheretherketone cages with femoral cortical bone allograft as a single-piece interbody spacer in transforaminal lumbar interbody fusion. J Neurosurg Spine. 2006;5(6):534-9.
43. Dai, F., Belfer, I., Schwartz, C. E., Banco, R., Martha, J. F., Tighioughart, H., Kim, D. H. (2010). Association of catechol-O-methyltransferase genetic variants with outcome in patients undergoing surgical treatment for lumbar degenerative disc disease. Spine Journal, 10(11), 949-957. doi: 10.1016/j.spinee.2010.07.387
44. Dai F, Belfer I, Schwartz CE, et al. Association of catechol-O-methyltransferase genetic variants with outcome in patients undergoing surgical treatment for lumbar degenerative disc disease. Spine J. 2010;10(11):949-57.
45. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-46.
46. Desai A, Ball PA, Bekelis K, et al. Surgery for lumbar degenerative spondylolisthesis in Spine Patient Outcomes Research Trial: does incidental durotomy affect outcome?. Spine. 2012;37(5):406-13.
47. Dimar JR II, Djurasovic M, Carreon LY. Surgical management of degenerative and postsurgical spondylolisthesis. Semin Spine Surg. 2005;17(3 SPEC. ISS.):186-194.
48. Dimar JR, Glassman SD, Burkus JK, Pryor PW, Hardacker JW, Carreon LY. Clinical and radiographic analysis of an optimized rhBMP-2 formulation as an autograft replacement in posterolateral lumbar spine arthrodesis. J Bone Joint Surg Am. 2009;91(6):1377-86.
49. Djurasovic M, Glassman SD, Dimar JR, Crawford CH, Bratcher KR, Carreon LY. Changes in the Oswestry Disability Index that predict improvement after lumbar fusion. J Neurosurg Spine. 2012;17(5):486-90.
50. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
51. Eliyas JK, Karahalios D. Surgery for degenerative lumbar spine disease. Dis Mon. 2011;57(10):592-606.
52. Epstein NE. An analysis of noninstrumented posterolateral lumbar fusions performed in predominantly geriatric patients using lamina autograft and beta tricalcium phosphate. Spine J. 2008;8(6):882-7.
53. Escobar E, Transfeldt E, Garvey T, Ogilvie J, Graber J, Schultz L. Video-assisted versus open anterior lumbar spine fusion surgery: a comparison of four techniques and complications in 135 patients. Spine. 2003;28(7):729-32.
54. Etame AB, Wang AC, Than KD, Park P. Clinical and radiographic outcomes after minimally invasive transforaminal lumbar interbody fusion. SAS J. 2010;4(2):47-53.
55. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative

lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.
56. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
57. Fischgrund JS. The argument for instrumented decompressive posterolateral fusion for patients with degenerative spondylolisthesis and spinal stenosis. Spine. 2004;29(2):173-4.
58. Flynn JC, Hoque MA. Anterior fusion of the lumbar spine. End-result study with long-term follow-up. J Bone Joint Surg Am. 1979;61(8):1143-50.
59. Fu KM, Rhagavan P, Shaffrey CI, Chernavvsky DR, Smith JS. Prevalence, severity, and impact of foraminal and canal stenosis among adults with degenerative scoliosis. Neurosurgery. 2011;69(6):1181-7.
60. Fujimoto K, Yamazaki M, Hayashi K, et al. Posterior decompression with instrumented fusion in a patient with cervical myelopathy thirty years after cadaveric renal transplantation. Chiba Med J. 2011;87(1):11-15.
61. Gavaskar AS, Achimuthu R. Transfacetal fusion for low-grade degenerative spondylolisthesis of the lumbar spine: results of a prospective single center study. J Spinal Disord Tech. 2010;23(3):162-5.
62. Gelalis ID, Arnaoutoglou C, Christoforou G, Lykissas MG, Batsilas I, Xenakis T. Prospective analysis of surgical outcomes in patients undergoing decompressive laminectomy and posterior instrumentation for degenerative lumbar spinal stenosis. Acta Orthop Traumatol Turc. 2010;44(3):235-40.
63. Gilbert JW, Wheeler GR, Kreft MP, et al. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-31.
64. Gillet P, Petit M. Direct repair of spondylolysis without spondylolisthesis, using a rod-screw construct and bone grafting of the pars defect. Spine. 1999;24(12):1252-6.
65. Glaser JA, Bernhardt M, Found EM, McDowell GS, Wetzel FT. Lumbar arthrodesis for degenerative conditions. Instr Course Lect. 2004;53:325-340.
66. Glassman SD, Carreon LY, Dimar JR, Campbell MJ, Puno RM, Johnson JR. Clinical outcomes in older patients after posterolateral lumbar fusion. Spine J. 2007;7(5):547-51.
67. Grob D. Surgery for degenerative lumbar disease: transforaminal lumbar interbody fusion. Eur Spine J. 2009;18(12):1991-2.
68. Hasegawa K, Shimoda H, Kitahara K, Sasaki K, Homma T. What are the reliable radiological indicators of lumbar segmental instability?. J Bone Joint Surg Br. 2011;93(5):650-7.
69. Hashimoto T, Shigenobu K, Kanayama M, et al. Clinical results of single-level posterior lumbar interbody fusion using the Brantigan I/F carbon cage filled with a mixture of local morselized bone and bioactive ceramic granules. Spine. 2002;27(3):258-62.
70. Herron LD, Newman MH. The failure of ethylene oxide gas-sterilized freeze-dried bone graft for thoracic and lumbar spinal fusion. Spine. 1989;14(5):496-500.
71. Hilibrand AS, Rand N. Degenerative lumbar stenosis: diagnosis and management. J Am Acad Orthop Surg. 1999;7(4):239-49.
72. Hitchon PW, Taggard DA. Lumbar spine fusion enhanced by pedicle screw fixation. Tech Neurosurg. 1998;4(3):211-215.
73. Houten JK, Post NH, Dryer JW, Errico TJ. Clinical and radiographically/neuroimaging documented outcome in transforaminal lumbar interbody fusion. Neurosurg Focus. 2006;20(3):E8.
74. Hunt T, Shen FH, Shaffrey CI, Arlet V. Contralateral radiculopathy after transforaminal lumbar interbody fusion. Eur Spine J. 2007;16 Suppl 3:311-4.
75. Hwang CJ, Vaccaro AR, Hong J, et al. Immunogenicity of osteogenic protein 1: results from a prospective, randomized, controlled, multicenter pivotal study of uninstrumented lumbar posterolateral fusion. J Neurosurg Spine. 2010;13(4):484-93.
76. Ibrahimi DM, Beaty NB, Crandall KM, Hamilton DK, Sansur CA. A review of lumbar spondylolisthesis. Eur Musculoskel Rev. 2011;6(2):110-113.
77. Ito Z, Matsuyama Y, Sakai Y, et al. Bone union rate with autologous iliac bone versus local bone graft in posterior lumbar interbody fusion. Spine. 2010;35(21):E1101-5.
78. Jenis LG, Banco RJ, Kwon B. A prospective study of Autologous Growth Factors (AGF) in lumbar interbody fusion. Spine J. 2006;6(1):14-20.
79. Jo DJ, Jun JK, Kim KT, Kim SM. Lumbar Interbody Fusion Outcomes in Degenerative Lumbar Disease : Comparison of Results between Patients Over and Under 65 Years of Age. J Korean Neurosurg Soc. 2010;48(5):412-8.
80. Kai Y, Oyama M, Morooka M. Posterior lumbar interbody fusion using local facet joint autograft and pedicle screw fixation. Spine. 2004;29(1):41-6.
81. Kakiuchi M, Ono K. Defatted, gas-sterilised cortical bone allograft for posterior lumbar interbody vertebral fusion. Int Orthop. 1998;22(2):69-76.
82. Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. Spine. 2009;34(18):1963-9.
83. Kalichman L, Hunter DJ. Degenerative lumbar spondylolisthesis: Anatomy, biomechanics and risk factors. J Back Musculoskel Rehabil. 2008;21(1):1-12.
84. Kanayama M, Hashimoto T, Shigenobu K, Yamane S, Bauer TW, Togawa D. A prospective randomized study of posterolateral lumbar fusion using osteogenic protein-1 (OP-1) versus local autograft with ceramic bone substitute: emphasis of surgical exploration and histologic assessment. Spine. 2006;31(10):1067-74.
85. Kasliwal MK, Deutsch H. Clinical and radiographic outcomes using local bone shavings as autograft in minimally invasive transforaminal lumbar interbody fusion. World Neurosurg. 2012;78(1-2):185-90.
86. Katonis P, Christoforakis J, Kontakis G, et al. Complications and problems related to pedicle screw fixation of the spine. Clin Orthop Relat Res. 2003;(411):86-94.
87. Kelleher MO, Timlin M, Persaud O, Rampersaud YR. Success and failure of minimally invasive decompression for focal lumbar spinal stenosis in patients with and without deformity. Spine. 2010;35(19):E981-7.
88. Kim DH, Jeong ST, Lee SS. Posterior lumbar interbody fusion using a unilateral single cage and a local morselized bone graft in the degenerative lumbar spine. Clin Orthop Surg. 2009;1(4):214-21.
89. Kim KW, Ha KY, Moon MS, Kim YS, Kwon SY, Woo YK. Volumetric change of the graft bone after intertransverse fusion. Spine. 1999;24(5):428-33.
90. Kim MK, Lee SH, Kim ES, Eoh W, Chung SS, Lee CS. The impact of sagittal balance on clinical results after posterior interbody fusion for patients with degenerative spondylolisthesis: a pilot study. BMC Musculoskelet Disord. 2011;12:69.
91. Kim S, Mortaz hedjri S, Coyte PC, Rampersaud YR. Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis. Spine J. 2012;12(1):44-54.
92. Kleinstueck FS, Fekete TF, Mannion AF, et al. To fuse or not to fuse in lumbar degenerative spondylolisthesis: do baseline symptoms help provide the answer?. Eur Spine J. 2012;21(2):268-75.
93. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Compari-

son of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
94. Kornblum MB, Fischgrund JS, Herkowitz HN, Abraham DA, Berkower DL, Ditkoff JS. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. Spine. 2004;29(7):726-33.
95. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
96. Krishna M, Pollock RD, Bhatia C. Incidence, etiology, classification, and management of neuralgia after posterior lumbar interbody fusion surgery in 226 patients. Spine J. 2008;8(2):374-9.
97. Lee JW, Myung JS, Park KW, et al. Fluoroscopically guided caudal epidural steroid injection for management of degenerative lumbar spinal stenosis: short-term and long-term results. Skeletal Radiol. 2010;39(7):691-9.
98. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
99. Lee SH, Lee JH, Hong SW, Chung SE, Yoo SH, Lee HY. Spinopelvic alignment after interspinous soft stabilization with a tension band system in grade 1 degenerative lumbar spondylolisthesis. Spine. 2010;35(15):E691-701.
100. Lee SH, Lee JH, Hong SW, et al. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7):563-72.
101. Lekovic GP, Han PP, Kenny KJ, Dickman CA. Bone dowels in anterior lumbar interbody fusion. J Spinal Disord Tech. 2007;20(5):374-9.
102. Lewandrowski KU, Nanson C, Calderon R. Vertebral osteolysis after posterior interbody lumbar fusion with recombinant human bone morphogenetic protein 2: a report of five cases. Spine J. 2007;7(5):609-14.
103. Lindley EM, Mccullough MA, Burger EL, Brown CW, Patel VV. Complications of axial lumbar interbody fusion. J Neurosurg Spine. 2011;15(3):273-9.
104. Long H, Kazunasa U, Liu S, Akio S, Taito I. Preliminary application of one-level posterior lumbar interbody fusion with prospace and facet fusion using local autograft. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi. 2007;21(11):1155-9.
105. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-15.
106. Marchesi DG, Thalgott JS, Aebi M. Application and results of the AO internal fixation system in nontraumatic indications. Spine. 1991;16(3 Suppl):S162-9.
107. Markwalder TM, Reulen HJ. Translaminar screw fixation in lumbar spine pathology. Technical note. Acta Neurochir (Wien). 1989;99(1-2):58-60.
108. Matgé G, Leclercq TA. Rationale for interbody fusion with threaded titanium cages at cervical and lumbar levels. Results on 357 cases. Acta Neurochir (Wien). 2000;142(4):425-33.
109. Maus T. Imaging the back pain patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-66.
110. Mayer HM, Wiechert K. Microsurgical anterior approaches to the lumbar spine for interbody fusion and total disc replacement. Neurosurgery. 2002;51(5 Suppl):S159-65.
111. Mcafee PC, Devine JG, Chaput CD, et al. The indications for interbody fusion cages in the treatment of spondylolisthesis: analysis of 120 cases. Spine. 2005;30(6 Suppl):S60-5.
112. Mehta, V. A., Amin, A., Omeis, I., Gokaslan, Z. L., & Gottfried, O. N. (2012). Implications of spinopelvic alignment for the spine surgeon. Neurosurgery, 70(3), 707-721.
113. Mirovsky Y, Halperin N, Anekstein Y, Neuwirth MG. Good results of circumferential spine fusion in smokers, using autograft and allograft. Cell Tissue Bank. 2002;3(3):169-73.
114. Miyamoto H, Sumi M, Uno K, Tadokoro K, Mizuno K. Clinical outcome of nonoperative treatment for lumbar spinal stenosis, and predictive factors relating to prognosis, in a 5-year minimum follow-up. J Spinal Disord Tech. 2008;21(8):563-8.
115. Mochida J, Suzuki K, Chiba M. How to stabilize a single level lesion of degenerative lumbar spondylolisthesis. Clin Orthop Relat Res. 1999;(368):126-34.
116. Mokhtar SA, Mccombe PF, Williamson OD, Morgan MK, White GJ, Sears WR. Health-related quality of life: a comparison of outcomes after lumbar fusion for degenerative spondylolisthesis with large joint replacement surgery and population norms. Spine J. 2010;10(4):306-12.
117. Molina M, Wagner P, Campos M. [Spinal lumbar stenosis: an update]. Rev Med Chil. 2011;139(11):1488-95.
118. Molinari RW, Bridwell KH, Klepps SJ, Baldus C. Minimum 5-year follow-up of anterior column structural allografts in the thoracic and lumbar spine. Spine. 1999;24(10):967-72.
119. Molinari RW, Hunter JG, Mcassey RW. In-hospital postoperative radiographs for instrumented single-level degenerative spinal fusions: utility after intraoperative fluoroscopy. Spine J. 2012;12(7):559-67.
120. Möller J, Wittenberg RH, Nolte LP, Jergas M, Willburger R, Krämer J. Results of lumbosacral distraction spondylodesis for the treatment of spondylolisthesis, failed-back syndrome, and lumbar instability. Eur Spine J. 1992;1(2):117-24
121. Monticone M, Giovanazzi E. Usefulness of a cognitive behavioural and rehabilitative approach to enhance long lasting benefit after lumbar spinal stenosis and degenerative spondylolisthesis surgery. A case report. Eur J Phys Rehabil Med. 2008;44(4):467-71.
122. Moon MS, Kim SS, Sun DH, Moon YW. Anterior spondylodesis for spondylolisthesis: isthmic and degenerative types. Eur Spine J. 1994;3(3):172-6.
123. Mummaneni PV, Pan J, Haid RW, Rodts GE. Contribution of recombinant human bone morphogenetic protein-2 to the rapid creation of interbody fusion when used in transforaminal lumbar interbody fusion: a preliminary report. Invited submission from the Joint Section Meeting on Disorders of the Spine and Peripheral Nerves, March 2004. J Neurosurg Spine. 2004;1(1):19-23.
124. Nasca RJ. Lumbar spinal stenosis: surgical considerations. J South Orthop Assoc. 2002;11(3):127-34.
125. Nelson LD, Montgomery SP, Dameron TB, Nelson RB. Deep vein thrombosis in lumbar spinal fusion: a prospective study of antiembolic and pneumatic compression stockings. J South Orthop Assoc. 1996;5(3):181-4.
126. Ohmori K, Suzuki K, Ishida Y. Translamino-pedicular screw fixation with bone grafting for symptomatic isthmic lumbar spondylolysis. Neurosurgery. 1992;30(3):379-84.
127. Okuyama K, Kido T, Unoki E, Chiba M. PLIF with a titanium cage and excised facet joint bone for degenerative spondylolisthesis--in augmentation with a pedicle screw. J Spinal Disord Tech. 2007;20(1):53-9.
128. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
129. Ozgur BM, Agarwal V, Nail E, Pimenta L. Two-year clinical and radiographic success of minimally invasive lateral transpsoas approach for the treatment of degenerative lumbar conditions.

SAS J. 2010;4(2):41-46.
130. Panagiotis ZE, Athanasios K, Panagiotis D, Minos T, Charis M, Elias L. Functional outcome of surgical treatment for multilevel lumbar spinal stenosis. Acta Orthop. 2006;77(4):670-676.
131. Pao JL, Chen WC, Chen PQ. Clinical outcomes of microendoscopic decompressive laminotomy for degenerative lumbar spinal stenosis. Eur Spine J. 2009;18(5):672-8.
132. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine. 2010;35(4):439-46.
133. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.
134. Parker SL, Mcgirt MJ. Determination of the minimum improvement in pain, disability, and health state associated with cost-effectiveness: introduction of the concept of minimum cost-effective difference. Neurosurgery. 2012;71(6):1149-55.
135. Pelton MA, Phillips FM, Singh K. A comparison of perioperative costs and outcomes in patients with and without workers' compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion. Spine. 2012;37(22):1914-9.
136. Radcliff K, Hwang R, Hilibrand A, et al. The effect of iliac crest autograft on the outcome of fusion in the setting of degenerative spondylolisthesis: a subgroup analysis of the Spine Patient Outcomes Research Trial (SPORT). J Bone Joint Surg Am. 2012;94(18):1685-92.
137. Radcliff KE, Rihn J, Hilibrand A, et al. Does the duration of symptoms in patients with spinal stenosis and degenerative spondylolisthesis affect outcomes?: analysis of the Spine Outcomes Research Trial. Spine. 2011;36(25):2197-210.
138. Rampersaud R, Macwan K, Mahomed NN. Spinal Care in a Single-Payer System: The Canadian Example. Semin Spine Surg. 2012;24(2):117-122.
139. Rampersaud YR, Gray R, Lewis SJ, Massicotte EM, Fehlings MG. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. SAS J. 2011;5(2):29-35.
140. Rechtine GR, Sutterlin CE, Wood GW, Boyd RJ, Mansfield FL. The efficacy of pedicle screw/plate fixation on lumbar/lumbosacral autogenous bone graft fusion in adult patients with degenerative spondylolisthesis. J Spinal Disord. 1996;9(5):382-91.
141. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-46.
142. Robertson PA, Plank LD. Prospective cohort analysis of disability reduction with lumbar spinal fusion surgery in community practice. J Spinal Disord Tech. 2008;21(4):235-40.
143. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96.
144. Rousseau MA, Lazennec JY, Bass EC, Saillant G. Predictors of outcomes after posterior decompression and fusion in degenerative spondylolisthesis. Eur Spine J. 2005;14(1):55-60.
145. Savvidou C, Chatziioannou SN, Pilichou A, Pneumaticos SG. Efficacy and cost-effectiveness of cell saving blood autotransfusion in adult lumbar fusion. Transfus Med. 2009;19(4):202-6.
146. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
147. Schiffman M, Brau SA, Henderson R, Gimmestad G. Bilateral implantation of low-profile interbody fusion cages: subsidence, lordosis, and fusion analysis. Spine J. 2003;3(5):377-87.
148. Schnake KJ, Schaeren S, Jeanneret B. Dynamic stabilization in addition to decompression for lumbar spinal stenosis with degenerative spondylolisthesis. Spine. 2006;31(4):442-449.
149. Schnee CL, Freese A, Ansell LV. Outcome analysis for adults with spondylolisthesis treated with posterolateral fusion and transpedicular screw fixation. J Neurosurg. 1997;86(1):56-63.
150. Schulte TL, Leistra F, Bullmann V, et al. Disc height reduction in adjacent segments and clinical outcome 10 years after lumbar 360 degrees fusion. Eur Spine J. 2007;16(12):2152-8.
151. Schwender JD, Holly LT, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. J Spinal Disord Tech. 2005;18 Suppl:S1-6.
152. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: restoration of sagittal balance using insert-and-rotate interbody spacers. Spine J. 2005;5(2):170-9.
153. Shen M, Razi A, Lurie JD, Hanscom B, Weinstein J. Retrolisthesis and lumbar disc herniation: a preoperative assessment of patient function. Spine J. 2007;7(4):406-13.
154. Siewe J, Otto C, Knoell P, et al. Comparison of standard fusion with a "topping off" system in lumbar spine surgery: a protocol for a randomized controlled trial. BMC Musculoskelet Disord. 2011;12:239.
155. Singh K, Smucker JD, Gill S, Boden SD. Use of recombinant human bone morphogenetic protein-2 as an adjunct in posterolateral lumbar spine fusion: a prospective CT-scan analysis at one and two years. J Spinal Disord Tech. 2006;19(6):416-23.
156. Snider RK, Krumwiede NK, Snider LJ, Jurist JM, Lew RA, Katz JN. Factors affecting lumbar spinal fusion. J Spinal Disord. 1999;12(2):107-14.
157. Soegaard R, Bünger CE, Christiansen T, Høy K, Eiskjaer SP, Christensen FB. Circumferential fusion is dominant over posterolateral fusion in a long-term perspective: cost-utility evaluation of a randomized controlled trial in severe, chronic low back pain. Spine. 2007;32(22):2405-14.
158. Stovall R, Halliday A. Degenerative lumbar spondylolisthesis: Treatment strategies. Seminars in Neurosurgery. 2000;11(2):193-205.
159. Tajima N, Chosa E, Watanabe S. Posterolateral lumbar fusion. J Orthop Sci. 2004;9(3):327-333.
160. Taylor JA, Bussières A. Diagnostic imaging for spinal disorders in the elderly: a narrative review. Chiropr Man Therap. 2012;20(1):16.
161. Templin CR, Garfin SR. Surgical Management of Scoliosis and/or Spondylolisthesis Associated with Spinal Stenosis. Semin Spine Surg. 2007;19(3):187-199.
162. Tokuhashi Y, Ajiro Y, Umezawa N. Follow-up of patients with delayed union after posterior fusion with pedicle screw fixation. Spine. 2008;33(7):786-91.
163. Truumees E. The Role of Fusion in Degenerative Lumbar Disease. Semin Spine Surg. 2004;15(4):430-459.
164. Vaccaro A. Unilateral approach for microsurgical decompression. J Neurosurg Spine. 2008;9(6):552-3.
165. Vaccaro AR, Anderson DG, Patel T, et al. Comparison of OP-1 Putty (rhBMP-7) to iliac crest autograft for posterolateral lumbar arthrodesis: a minimum 2-year follow-up pilot study. Spine. 2005;30(24):2709-16.
166. Vaccaro AR, Garfin SR. Internal fixation (pedicle screw fixation) for fusions of the lumbar spine. Spine. 1995;20(24 Suppl):157S-165S.
167. Vaccaro AR, Patel T, Fischgrund J, et al. A pilot safety and

efficacy study of OP-1 putty (rhBMP-7) as an adjunct to iliac crest autograft in posterolateral lumbar fusions. Eur Spine J. 2003;12(5):495-500.

168. Vaccaro AR, Patel T, Fischgrund J, et al. A pilot safety and efficacy study of OP-1 putty (rhBMP-7) as an adjunct to iliac crest autograft in posterolateral lumbar fusions. Eur Spine J. 2003;12(5):495-500.
169. Vaccaro AR, Patel T, Fischgrund J, et al. A pilot study evaluating the safety and efficacy of OP-1 Putty (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis for degenerative spondylolisthesis. Spine (Phila Pa 1976). 2004;29(17):1885-1892.
170. Vaccaro AR, Stubbs HA, Block JE. Demineralized bone matrix composite grafting for posterolateral spinal fusion. Orthopedics. 2007;30(7):567-70.
171. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-65.
172. Virk S, Sandhu HS, Khan SN. Cost effectiveness analysis of graft options in spinal fusion surgery using a Markov model. J Spinal Disord Tech. 2012;25(7):E204-10.
173. Watters WC III. If, when, and how to fuse when treating lumbar degenerative stenosis. Semin Spine Surg. 2011;23(4):218-221.
174. Weiner BK, Walker M. Efficacy of autologous growth factors in lumbar intertransverse fusions. Spine (Phila Pa 1976). 2003;28(17):1968-1970; discussion 1971.
175. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
176. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
177. Whitecloud TS, Castro FP, Brinker MR, Hartzog CW, Ricciardi JE, Hill C. Degenerative conditions of the lumbar spine treated with intervertebral titanium cages and posterior instrumentation for circumferential fusion. J Spinal Disord. 1998;11(6):479-86.
178. Willems P. Decision making in surgical treatment of chronic low back pain: the performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop Suppl. 2013;84(349):1-35.
179. Wood GW, Boyd RJ, Carothers TA, et al. The effect of pedicle screw/plate fixation on lumbar/lumbosacral autogenous bone graft fusions in patients with degenerative disc disease. Spine. 1995;20(7):819-30.
180. Xiao YX, Chen QX, Li FC. Unilateral transforaminal lumbar interbody fusion: a review of the technique, indications and graft materials. J Int Med Res. 2009;37(3):908-17.
181. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
182. Yan DL, Pei FX, Li J, Soo CL. Comparative study of PILF and TLIF treatment in adult degenerative spondylolisthesis. Eur Spine J. 2008;17(10):1311-6.
183. Yao N, Wang W, Liu Y. Percutaneous endoscopic lumbar discectomy and interbody fusion with B-Twin expandable spinal spacer. Arch Orthop Trauma Surg. 2011;131(6):791-6.
184. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.
185. Zdeblick TA. A prospective, randomized study of lumbar fusion. Preliminary results. Spine. 1993;18(8):983-991.
186. Zhang YF, Yang HL, Tang TS, Shi Y. Mobilization range of the vertebral bodies after treatment of lumbar instability with titanium-coated fusion cage. Chin J Clin Rehabil. 2005;9(10):204-205.
187. Zhao Y, Wang YP, Qiu GX, Zhao H, Zhang JG, Zhou X. Efficacy of the Dynamic Interspinous Assisted Motion system in clinical treatment of degenerative lumbar disease. Chin Med J. 2010;123(21):2974-7.
188. Zhou J, Wang B, Dong J, et al. Instrumented transforaminal lumbar interbody fusion with single cage for the treatment of degenerative lumbar disease. Arch Orthop Trauma Surg. 2011;131(9):1239-45.

New Guideline Question:

Do minimally invasive surgical treatments improve outcomes in the treatment of degenerative lumbar spondylolisthesis compared to:

a. conventional open decompression (laminectomy)?

b. conventional (open) lumbar decompression and fusion, with or without instrumentation?

No evidence was found to assess the efficacy of minimally invasive surgical techniques versus open decompression alone in the surgical treatment of degenerative lumbar spondylolisthesis.

While both minimally invasive techniques and open decompression and fusion, with or without instrumentation, demonstrate significantly improved clinical outcomes for the surgical treatment of degenerative lumbar spondylolisthesis, there is conflicting evidence which technique leads to better outcomes.

Grade of Recommendation: I (Insufficient/Conflicting Evidence)

Harris et al[1] conducted a retrospective comparative study of 51 total patients undergoing 2 types of fusion surgeries with bilateral decompression for the treatment of degenerative spondylolisthesis with spinal stenosis. Patients underwent either fusion using a standard, midline open technique (open group, n=21) or fusion using a mini-open technique, with a small, central incision for the decompression and bilateral paramedian incisions for the posterolateral fusion and placement of cannulated pedicle screws (mini-open group, n=30). All patients in this retrospective review had documented preoperative and postoperative Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores. Postoperative anteroposterior (AP) fluoroscopic images and lateral radiographs were also taken at 12 month after surgery. The mean preoperative VAS score was 7.58 in the open group and 7.78 in the mini-open group (P = .74). By 3-month follow-up, mean VAS score had improved to 2.68 in the open group and 2.89 in the mini-open group. By one-year follow-up, this score had improved to 2.38 in the open group and 2.32 in the mini-open group. The improvement at 3 months and one year after surgery was statistically significant ($p<0.05$); however, there were no statistically significant differences in improvement between the groups at either follow-up periods (p =0.95). Both group's mean preoperative ODI score was 45.7 (consistent with severe disability). By 3-month follow-up, mean ODI score had improved to 27.2 (moderate disability) in the mini-open group and 19.0 (minimal disability) in the open group. By one-year follow-up, mean ODI score had improved further, to 6.4 (minimal disability) in the open group and 13.9 (minimal disability) in the mini-open group. Similar to pain scores, the improvement in disability at 3 months and one year after surgery was statistically significant ($p<0.05$); however, there were no statistically significant differences in improvement between the groups at either follow-up periods (p=0.19). Radiological review found only 2 fusion failures. In the open group, one patient showed isolated radiolucency around one of the L4 pedicle screws, as well as lack of bridging posterolateral bone graft on the AP radiograph. In the mini-open group, one patient showed radiolucency around one of the L5 screws, as well as lack of bridging bone between the L4 and L5 transverse processes. The authors conclude that the standard open fusion and decompression and less invasive fusion techniques are equally effective in providing statistically significant improvement in leg pain (VAS scores) and function (ODI scores) at 3-month and one-year follow-ups. This study provides Level III therapeutic evidence that open exposure decompression and fusion (traditional midline incision) and minimally invasive mini-open exposure (3 small incisions) are effective surgical treatment options with equivalent short-term and medium-term outcomes for patients with degenerative lumbar spondylolisthesis.

In a prospective comparative study, Kotani et al[2] compared the clinical outcomes of degenerative spondylolisthesis with spinal stenosis patients undergoing MIS posterolateral fusion (PLF), n=43, to patients undergoing conventional PLF, n=37. There were no statistically significant differences in gender, age, vertebral level and degree of spondylolisthesis between the groups. Patients were evaluated over a period of at least 2

years using the Japanese Orthopaedic Association (JOA) score, Oswestry-Disability Index (ODI), Roland-Morris Questionnaire (RMQ), the visual analogue scale of low back pain (LBP VAS), and the surgical complication rate. Fusion status was evaluated by radiograph studies and CT scans at the final follow-up visit. Results indicated that the average operation time was statistically equivalent between the 2 groups. Intraoperative blood loss was significantly less ($p<0.01$) in the MIS-PLF group (181 ml) when compared to the open-PLF group (453 ml). The postoperative bleeding on day one was also significantly less ($p<0.01$) in the MIS-PLF group (210 ml) when compared to the open-PLF group (406 ml). There were no statistically significant differences between the average preoperative and follow-up JOA scores in the MIS-PLF Group, 11.1 and 23.5 vs Open-PLF Group, 12.6 and 22.8. The recovery rates of the JOA score were 63.1 and 59.9% in each group, respectively. The average preoperative ODI values were statistically equivalent, 52.0 and 48.9 for each group, respectively. Two weeks after surgery, the MIS-PLF group's ODI value reduced significantly. There was a statistically significant difference in ODI values between the 2 groups at 2 weeks postoperatively ($p<0.01$). At 3 months, the MIS-PLF group demonstrated a further decrease to an average of 13.2; however, the average score for the open-PLF group remained 32.1. This difference was statistically significant ($p<0.001$) and was maintained at 6, 12 and 24 months postoperatively ($p<0.01$). There was a statistical difference of RMQ value at 2 weeks between the 2 groups, 12.2 in the MIS-PLF group and 13.7 in the Open-PLF group ($p<0.01$). At 3 months, MIS-PLF group showed a further decrease to 5.1; however, the Open-PLF group remained at 10.9 ($p<0.01$). This difference was maintained until 6, 12 and 24 months postoperatively ($p<0.01$). The LBP VAS on day 3 in the MIS-PLF group was statistically lower than that in the open-PLF group ($p<0.02$). Radiological evaluation via x-ray films and CT scans demonstrated that solid fusion was achieved in 42 out of 43 cases (98%) in the MIS-PLF group and in all 37 cases (100%) in the open-PLF group. Statistically, there was no difference in fusion success between the groups. The authors suggest that the MIS-PLF utilizing percutaneous pedicle screw fixation serves as an alternative technique to the conventional open approach. In critique, the number of patients who completed follow-up was not addressed and patients had the option to choose their treatment; thus, adding potential bias to the study. Due to these reasons, this potential Level II study has been downgraded to a Level III. This study provides Level III therapeutic evidence that the MIS-PLF procedure is demonstrated to have better short-term and medium-term clinical outcomes when compared to conventional open-PLF in patients undergoing surgical treatment for degenerative spondylolisthesis with spinal stenosis.

In a retrospective comparative study, Mori et al[3] evaluated 53 patients with degenerative lumbar spondylolisthesis who underwent either spinous process-splitting (SPS) open pedicle screw fusion (PSF) (n=27) or conventional open PSF (n=26) for a single-level instrumented posterior lumbar decompression and fusion. Radiographic and clinical outcomes were assessed using MRI, the Japanese Orthopedic Association (JOA) score, the Roland-Morris disability questionnaire (RDQ), and the visual analog scale (VAS) for low back pain and low back discomfort at one to 3 years after surgery. Results indicated that there were no statistically significant differences between the groups for JOA, RDQ, or VAS scores for low back pain and low back discomfort at follow-up. However, one year after the surgery, the average VAS score for low back pain in the SPS open PSF group was significantly lower than that in the conventional open PSF group (1.5 ± 1.6 and 2.8 ± 2.3, respectively, $p<0.05$). The average multifidus atrophy ratios at the fusion level in the SPS open PSF group were significantly greater than those in the conventional open PSF group at one and 3 years after surgery (0.98 ± 0.08 vs 0.87 ± 0.07 and 0.96 ± 0.11 vs 0.84 ± 0.07, respectively, $p<0.01$). At the one-year postoperative follow-up, the multifidus atrophy ratio significantly correlated with the VAS score for discomfort in the low back ($p<0.05$). The authors suggest that SPS open PSF was less damaging to the paraspinal muscle than the conventional open PSF and resulted in improved clinical outcomes and less low back discomfort at one year after the surgery. This study provides Level III therapeutic evidence that the minimally invasive SPS and PSF surgical technique may result in better surgical outcomes when compared to the conventional open PSF technique.

Adogwa et al[4] conducted a retrospective study to compare surgical and functional outcomes of patients undergoing either minimally invasive (MIS) or open transforaminal lumbar interbody fusion (TLIF) for Grade I degenerative spondylolisthesis. Patients were excluded if they were above 70 years of age. Thirty patients were included in the analysis, including 15 in the MIS-TLIF and 15 in the open TLIF. Outcomes were assessed at 2 years via visual analog scale (VAS), low-back disability (ODI), EuroQol-5D, occupational disability, and narcotic use. No patients within the analysis were excluded or lost to follow-up. Overall, the mean age was 50±9.6 years and included 18 women and 12 men. Interbody fusion was performed at L4 to L5 in 19 (63%) patients and L5 to S1 in 11 (37%) patients. All cases were single-level fusions. Results indicated that the median interquartile range (IQR) length of surgery was shorter for open-TLIF cases versus MIS-TLIF procedures, 210 versus 300 minutes ($p=0.008$). The median (IQR) estimated blood loss during surgery was greater for open-TLIF versus MIS-TLIF procedures, 295 versus 200 mL ($p=0.09$). Median (IQR) length of hospitalization after surgery was significantly less for MIS-TLIF versus open-TLIF, 3.0 versus 5.0 days ($p=0.001$). For all patients, the median IQR of the duration of postoperative narcotic use was 3 (1.4 to 4.6) weeks and median (IQR) time to return to work was 13.9 (2.2 to 25.5) weeks. MIS-TLIF patients used narcotics for about 2 weeks compared to 4 weeks for patients in the open-TLIF group ($p=0.008$). Return to work time was also shorter for MIS-TLIF versus open-TLIF, 8.5 weeks versus 17.1 weeks ($p=0.02$). MIS-TLIF versus open TLIF patients showed similar 2-year improvement in VAS for back pain, VAS for leg pain, Oswestry disability index, and EuroQol-5D scores. The authors suggest that MIS-TLIF may allow for shorter hospital stays, reduced postoperative narcotic use, and accelerated return to work resulting in less direct medical costs and indirect costs of lost work productivity associated with TLIF procedures. This study provides Level III therapeutic evidence that both minimally invasive and open TLIF provide long-term improvement in pain and disability and the minimally invasive technique may allow for an accelerated recovery and return to work time.

Future Directions For Research

The work group recommends the undertaking of randomized controlled trials or prospective studies comparing the efficacy and durability of minimally invasive (MIS) to open techniques. It is important to note that MIS recommendations are complicated by the lack of a consistent definition of what constitutes MIS; therefore, the work group recommends that MIS is clearly and consistently defined in any future studies evaluating the efficacy of MIS surgical techniques.

References

1. Harris EB, Sayadipour A, Massey P, Duplantier NL, Anderson DG. Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis. Am J Orthop. 2011;40(12):E257-61.
2. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
3. Mori E, Okada S, Ueta T, et al. Spinous process-splitting open pedicle screw fusion provides favorable results in patients with low back discomfort and pain compared to conventional open pedicle screw fixation over 1 year after surgery. Eur Spine J. 2012;21(4):745-53.
4. Adogwa O, Parker SL, Bydon A, Cheng J, Mcgirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-84.

Bibliography

1. Hatta Y, Shiraishi T, Sakamoto A, et al. Muscle-preserving interlaminar decompression for the lumbar spine: a minimally invasive new procedure for lumbar spinal canal stenosis. Spine. 2009;34(8):E276-80.
2. Ikuta K, Tono O, Oga M. Clinical outcome of microendoscopic posterior decompression for spinal stenosis associated with degenerative spondylolisthesis--minimum 2-year outcome of 37 patients. Minim Invasive Neurosurg. 2008;51(5):267-71.
3. Ikuta K, Tono O, Oga M. Prevalence and clinical features of intraspinal facet cysts after decompression surgery for lumbar spinal stenosis. J Neurosurg Spine. 2009;10(6):617-22.
4. Kantelhardt SR, Török E, Gempt J, et al. Safety and efficacy of a new percutaneously implantable interspinous process device. Acta Neurochir (Wien). 2010;152(11):1961-7.
5. Kelleher MO, Timlin M, Persaud O, Rampersaud YR. Success and failure of minimally invasive decompression for focal lumbar spinal stenosis in patients with and without deformity. Spine. 2010;35(19):E981-7.
6. Kinoshita T, Ohki I, Roth KR, Amano K, Moriya H. Results of degenerative spondylolisthesis treated with posterior decompression alone via a new surgical approach. J Neurosurg. 2001;95(1 Suppl):11-6.
7. Lee HY, Ahn Y, Kim DY, Shin SW, Lee SH. Percutaneous ventral decompression for L4-L5 degenerative spondylolisthesis in medically compromised elderly patients: technical case report. Neurosurgery. 2004;55(2):435.
8. Lin SM, Tseng SH, Yang JC, Tu CC. Chimney sublaminar decompression for degenerative lumbar spinal stenosis. J Neurosurg Spine. 2006;4(5):359-64.
9. Markwalder TM. Surgical management of neurogenic claudication in 100 patients with lumbar spinal stenosis due to degenerative spondylolisthesis. Acta Neurochir (Wien). 1993;120(3-4):136-42.
10. Mcculloch JA. Microdecompression and uninstrumented single-level fusion for spinal canal stenosis with degenerative spondylolisthesis. Spine. 1998;23(20):2243-52.
11. Müslüman AM, Cansever T, Yılmaz A, Çavuşoğlu H, Yüce İ, Aydın Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16(1):68-76.
12. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
13. Palmer S, Turner R, Palmer R. Bilateral decompression of lumbar spinal stenosis involving a unilateral approach with microscope and tubular retractor system. J Neurosurg. 2002;97(2 Suppl):213-7. .
14. Pao JL, Chen WC, Chen PQ. Clinical outcomes of microendoscopic decompressive laminotomy for degenerative lumbar spinal stenosis. Eur Spine J. 2009;18(5):672-8.
15. Podichetty VK, Spears J, Isaacs RE, Booher J, Biscup RS. Complications associated with minimally invasive decompression for lumbar spinal stenosis. J Spinal Disord Tech. 2006;19(3):161-6.
16. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96.
17. Sasai K, Umeda M, Maruyama T, Wakabayashi E, Iida H. Microsurgical bilateral decompression via a unilateral approach for lumbar spinal canal stenosis including degenerative spondylolisthesis. J Neurosurg Spine. 2008;9(6):554-9.
18. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. Neurosurgery. 2007;60(4 SUPPL. 2):203- 212.
19. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H. Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: minimum five-year follow-up. Spine. 2011;36(5):410-5.
20. Vaccaro A. Unilateral approach for microsurgical decompression. J Neurosurg Spine. 2008;9(6):552-3.
21. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.

Original Guideline Question:
What is the long-term result (4 or more years) of surgical management of degenerative lumbar spondylolisthesis?

Decompression and fusion may be considered as a means to provide satisfactory long-term results for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis.
Maintained from original guideline with minor word modifications

Grade of Recommendation: C

Studies obtained from updated literature search:
Schaeren et al[1] conducted a prospective case-series of 26 consecutive patients with symptomatic spinal stenosis and degenerative spondylolisthesis to evaluate whether posterior dynamic stabilization in situ with the Dynesys System can maintain enough stability to prevent progression of spondylolisthesis. Patients were followed-up at a mean of 52 months using VAS and radiographic measurements. At 2 and 4 years follow-up, pain according to VAS assessment and walking distance significantly improved ($p<0.001$). Plain and functional radiographs showed that spondylolisthesis did not progress and the motion segments remained stable. At 2 year follow-up, anterior and posterior disc height had significantly increased from 2.9 to 3.5mm ($p=0.02$). At 4 years follow-up, anterior and posterior disc height did not show significant alteration ($p=0.02$ and 0.05). Some degeneration at adjacent levels was seen in 47% of patients at 4 years follow-up. Patient satisfaction was high and 95% responded that they would undergo the same procedure again. This study provides level IV therapeutic evidence that dynamic stabilization with Dynesys may be associated with satisfactory clinical and radiographic outcomes after 4 years in patients undergoing surgery for degenerative spondylolisthesis.

In a retrospective case-series study, Toyoda et al[2] evaluated clinical and radiologic outcomes in patients who underwent microsurgical bilateral decompression using a unilateral approach. A total of 57 patients were included in the analysis, including 27 with lumbar spinal stenosis, 20 with degenerative spondylolisthesis, and 10 with degenerative lumbar scoliosis. Patients were followed for a minimum of 5 years and the mean follow-up time was 6 years. Clinical outcomes were evaluated by the Japanese Orthopedic Association (JOA) score. Complications, rate of reoperation, and radiographic changes after surgery on plain radiograph were also evaluated. The mean blood loss per level was 113.4±74.8 mL, and the mean operative time per level was 134.2±28.7 minutes. The mean JOA score was 13.8±3.6 points before surgery, but improved to 24.9±3.1 points at 3 months, 25.6±2.5 points at 1 year, and 22.6±4.7 points at latest follow-up. The mean rate of improvement was 71.5% at 3 months, 73.5% at one year, and 57.9% at latest follow-up. Four patients required reoperation due to complications including 2 degenerative spondylolisthesis and 2 degenerative lumbar scoliosis patients. For patients with degenerative spondylolisthesis, the mean rate of improvement at 3 months was 72.3% and 64.1% at the last follow-up. The preoperative percentages of slippage in patients degenerative spondylolisthesis was 13.2% ± 5.9%, whereas the degrees of progression of slippage at latest follow-up was 2.4% ± 4.7%. This study provides Level IV therapeutic evidence that MIS decompression yields satisfactory outcomes at 5 years.

In a retrospective case-series study, Tsutsuminmoto et al[3] evaluated the long-term surgical outcomes of patients with lumbar canal stenosis and Grade I degenerative spondylolisthesis undergoing uninstrumented posterolateral lumbar fusion (PLF) to determine whether the fusion status influences the long-term operative results of PLF. Nine patients were lost to follow-up; therefore, the final analysis included 42 patients. Fusion status was assessed via plain radiographs and clinical outcomes were evaluated using Japanese Orthopaedic Association (JOA) scores. The average preoperative JOA score was 13.2 (range 3-20 points) and 23.5 (range 11-29 points) at the final follow-up. At the final follow-up, the percent recovery was greater than 3 in 69.0% (29/42) of the patients. Nonunion developed in 26.2% (11/42) of the patients. At one and 3-year follow-up, there was no statistically significant difference in the overall percent recovery between the union and nonunion groups (3.5 ± 0.8 vs 3.4 ± 0.7, $p = 0.515$, and 3.4 ± 0.8 vs 3.1 ± 1.2, $P = 0.508$, respectively). However, the union group's percent recovery was significantly better at 5-year and final follow up compared to that of the nonunion group (3.5 ± 0.7 vs 2.5 ± 1.0, $p = 0.006$ and 3.3 ± 0.9 vs 2.2 ± 1.2, $P = 0.008$, respectively). The overall fusion rate achieved by PLF was 74%. Regression analysis revealed that fusion status and the presence of comorbidity were significant risk factors for percent recovery at follow-up. This study provides Level IV therapeutic evidence that fusion status following PLF influences the long-term but not short-term operative results and that improved clinical outcomes are sustained long term in the treatment of patients with lumbar canal stenosis with degenerative spondylolisthesis.

In a retrospective review, Turunen et al[4] assessed the long-term clinical outcome (at least 10 years), late complications, reoperations and postoperative patient satisfaction in patients with different indications for posterolateral fusion. A total of 106 patients were included in the study, including 31 with degenerative spondylolisthesis (Group 1), 33 with isthmic spondylolisthesis (Group 2), 22 with postdiscectomy syndrome (Group 3), and 20 with postlaminectomy syndrome (Group 4). Clinical outcomes were evaluated by an independent orthopedic surgeon, the Oswestry Disability Index (ODI) and the Visual Analog Scale (VAS) questionnaires. The degenerative spondylolisthesis patients (Group 1) showed the greatest improvements in ODI and VAS values compared to the other groups (47.0 vs. 26.4, $p<0.001$ and 6.3 vs. 4.1, $p<0.001$, respectively). In addition, 28 of 31 patients reported experiencing either excellent or good long term results. This study provides Level IV therapeutic evidence that posterolateral fusion provides satisfactory long term outcomes in patients suffering from degenerative lumbar spondylolisthesis.

Studies included in original guideline:

Booth et al[5] described a presumably retrospective study of 41 patients with neurogenic claudication from spinal stenosis and spondylolisthesis who were followed for a minimum of 5 years after a laminectomy and instrumented fusion. At final follow-up, there were no new neurological deficits, no recurrent stenosis at the level of surgery and no symptomatic pseudarthroses. Three patients underwent surgery for adjacent level stenosis, which took place 4 to 12 years after the index procedure. Clinical outcomes were available in 36 patients: 83% reported high satisfaction, 86% reported reduced back and leg pain, and 46% had increased function at follow-up that ranged from 5 to 10.7 years. In critique of this study, it had small patient numbers and there was a considerable amount of attrition (less than 80% follow-up). Of 49 consecutive patients operated during the study interval, 41 were available for follow-up (8 patients died) and only 36 had clinical outcomes measured. Attrition from death, however, is expected in the affected population. This retrospective case series provides Level IV therapeutic evidence that laminectomy and instrumented fusion for stenosis from degenerative spondylolisthesis provides a high rate of satisfaction and pain relief and moderately increased function at long-term follow-up.

Kornblum et al[6] conducted a follow-up study on 47 of 58 patients who had originally been part of a randomized controlled trial comparing instrumented versus noninstrumented fusion for spinal stenosis and degenerative spondylolisthesis. This study's cohort consisted only of the noninstrumented cases, which were followed for a minimum of 5 years. Clinical outcomes were analyzed based on the presence of solid fusion (22 patients) or a pseudarthrosis (25 patients). A statistically greater percentage of patients had good or excellent results in patients with solid fusion (86%) versus pseudarthrosis (56%). Importantly, 5 of the pseudarthrosis patients and 2 of the fusion patients had undergone a second procedure. In critique of this study, the authors used a less frequently implemented outcomes instrument, the Swiss Spinal Stenosis (SSS) Questionnaire, making it difficult to compare directly to other studies in which the ODI or ZCQ were used. Despite these minor limitations, as a prospective case series, the data offer Level IV therapeutic (>80% follow-up) evidence that laminectomy and attempted fusion results in longstanding symptom improvement for spinal stenosis from degenerative spondylolisthesis. Furthermore, this study suggests that those patients who achieved solid fusion have statistically better long-term outcomes than those with pseudarthroses for noninstrumented fusions.

Future Directions for Research

The work group identified the following suggestions for future studies, which would generate meaningful evidence to assist in further defining the role of surgical treatment for degenerative lumbar spondylolisthesis:

Recommendation #1:

Future long-term studies of the effects of surgical interventions for patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis should include a comparison group undergoing best current medical management techniques, when ethically feasible. Continued follow-up of patients already enrolled in ongoing prospective comparative studies will yield higher quality data regarding the relative efficacy of surgery compared to medical/interventional treatments.

Recommendation #2:

Future long-term outcome studies, such as multicenter registry database studies, are necessary to compare different surgical techniques for the treatment of patients with symptomatic spinal stenosis and degenerative lumbar spondylolisthesis.

References

1. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
2. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H. Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: minimum five-year follow-up. Spine. 2011;36(5):410-5.
3. Tsutsumimoto T, Shimogata M, Yoshimura Y, Misawa H. Union versus nonunion after posterolateral lumbar fusion: a comparison of long-term surgical outcomes in patients with degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17(8):1107-12.
4. Turunen V, Nyyssönen T, Miettinen H, et al. Lumbar instrumented posterolateral fusion in spondylolisthetic and failed back patients: a long-term follow-up study spanning 11-13 years. Eur Spine J. 2012;21(11):2140-8.
5. Booth KC, Bridwell KH, Eisenberg BA, Baldus CR, Lenke LG. Minimum 5-year results of degenerative spondylolisthesis treated with decompression and instrumented posterior fusion. Spine. 1999;24(16):1721-7.
6. Kornblum MB, Fischgrund JS, Herkowitz HN, Abraham DA, Berkower DL, Ditkoff JS. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. Spine. 2004;29(7):726-33.

Bibliography from updated literature search

1. Acosta FL Jr, Christensen FB, Coe JD, et al. Early Clinical & Radiographic Results of NFix II Posterior Dynamic Stabilization System. SAS J. 2008;2(2):69-75.
2. Adogwa O, Parker SL, Bydon A, Cheng J, Mcgirt MJ. Comparative effectiveness of minimally invasive versus open transfo-

raminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-84.
3. Azzazi A, Elhawary Y. Dynamic stabilization using X-stop versus transpedicular screw fixation in the treatment of lumbar canal stenosis: comparative study of the clinical outcome. Neurosurg Quart. 2010;20(3):165-169.
4. Bae JS, Lee SH, Kim JS, Jung B, Choi G. Adjacent segment degeneration after lumbar interbody fusion with percutaneous pedicle screw fixation for adult low-grade isthmic spondylolisthesis: minimum 3 years of follow-up. Neurosurgery. 2010;67(6):1600-7.
5. Bashir el F, Ajani O. Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-6.
6. Blondel B, Adetchessi T, Pech-gourg G, Métellus P, Dufour H, Fuentes S. Minimally invasive transforaminal lumbar interbody fusion through a unilateral approach and percutaneous osteosynthesis. Orthop Traumatol Surg Res. 2011;97(6):595-601.
7. Cansever T, Civelek E, Kabatas S, Yılmaz C, Caner H, Altinörs MN. Dysfunctional segmental motion treated with dynamic stabilization in the lumbar spine. World Neurosurg. 2011;75(5-6):743-9.
8. Cavuşoğlu H, Türkmenoğlu O, Kaya RA, et al. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-8.
9. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
10. De iure F, Bosco G, Cappuccio M, Paderni S, Amendola L. Posterior lumbar fusion by peek rods in degenerative spine: preliminary report on 30 cases. Eur Spine J. 2012;21 Suppl 1:S50-4.
11. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-46.
12. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-91.
13. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. J Neurosurg Spine. 2008;9(6):560-5.
14. Disch AC, Schmoelz W, Matziolis G, Schneider SV, Knop C, Putzier M. Higher risk of adjacent segment degeneration after floating fusions: long-term outcome after low lumbar spine fusions. J Spinal Disord Tech. 2008;21(2):79-85.
15. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
16. Elhawary Y, Azzazi A. Dynamic stabilization using X-stop vs. trans-pedicular screw fixation in the treatment of lumbar canal stenosis: Comparative study of the clinical outcome. Spine J. 2010;10(9)Supplement, S130.
17. Etame AB, Wang AC, Than KD, Park P. Clinical and radiographic outcomes after minimally invasive transforaminal lumbar interbody fusion. SAS J. 2010;4(2):47-53.
18. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
19. Hayashi T, Arizono T, Fujimoto T, et al. Degenerative change in the adjacent segments to the fusion site after posterolateral lumbar fusion with pedicle screw instrumentation--a minimum 4-year follow-up. Fukuoka Igaku Zasshi. 2008;99(5):107-13.
20. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. Surgical technique. J Bone Joint Surg Am. 2008;90 Suppl 2 Pt 1:145-52.
21. Hsieh PC, Koski TR, O'shaughnessy BA, et al. Anterior lumbar interbody fusion in comparison with transforaminal lumbar interbody fusion: implications for the restoration of foraminal height, local disc angle, lumbar lordosis, and sagittal balance. J Neurosurg Spine. 2007;7(4):379-86.
22. Ikuta K, Tono O, Oga M. Clinical outcome of microendoscopic posterior decompression for spinal stenosis associated with degenerative spondylolisthesis--minimum 2-year outcome of 37 patients. Minim Invasive Neurosurg. 2008;51(5):267-71.
23. Ito Z, Matsuyama Y, Sakai Y, et al. Bone union rate with autologous iliac bone versus local bone graft in posterior lumbar interbody fusion. Spine. 2010;35(21):E1101-5.
24. Jagannathan J, Sansur CA, Oskouian RJ, Fu KM, Shaffrey CI. Radiographic restoration of lumbar alignment after transforaminal lumbar interbody fusion. Neurosurgery. 2009;64(5):955-63.
25. Jiya TU, Smit T, Van royen BJ, Mullender M. Posterior lumbar interbody fusion using non resorbable poly-ether-ether-ketone versus resorbable poly-L-lactide-co-D,L-lactide fusion devices. Clinical outcome at a minimum of 2-year follow-up. Eur Spine J. 2011;20(4):618-22.
26. Kantelhardt SR, Török E, Gempt J, et al. Safety and efficacy of a new percutaneously implantable interspinous process device. Acta Neurochir (Wien). 2010;152(11):1961-7.
27. Kroppenstedt S, Gulde M, Schönmayr R. Radiological comparison of instrumented posterior lumbar interbody fusion with one or two closed-box plasmapore coated titanium cages: follow-up study over more than seven years. Spine. 2008;33(19):2083-8.
28. Lamberg T, Remes V, Helenius I, Schlenzka D, Seitsalo S, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: Long-term outcome. J Bone Joint Surg Am. 2007;89(3):512-518.
29. Lee DY, Lee SH, Shim CS, Lee HY. Decompression and interspinous dynamic stabilization using the locker for lumbar canal stenosis associated with low-grade degenerative spondylolisthesis. Minim Invasive Neurosurg. 2010;53(3):117-21.
30. Lindley EM, Mccullough MA, Burger EL, Brown CW, Patel VV. Complications of axial lumbar interbody fusion. J Neurosurg Spine. 2011;15(3):273-9.
31. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-15.
32. McAfee, P. C., Cunningham, B. W., Tortolani, P. J., Fedder, I. L., Sefter, J. C., & Davis, C. (2009). 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS Journal, 3(1), 1-11.
33. Ozgur BM, Agarwal V, Nail E, Pimenta L. Two-year clinical and radiographic success of minimally invasive lateral transpsoas approach for the treatment of degenerative lumbar conditions. SAS J. 2010;4(2):41-46.
34. Park SC, Yoon SH, Hong YP, Kim KJ, Chung SK, Kim HJ. Minimum 2-year follow-up result of degenerative spinal stenosis treated with interspinous u (coflex). J Korean Neurosurg Soc. 2009;46(4):292-9.
35. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.

36. Radcliff K, Hwang R, Hilibrand A, et al. The effect of iliac crest autograft on the outcome of fusion in the setting of degenerative spondylolisthesis: a subgroup analysis of the Spine Patient Outcomes Research Trial (SPORT). J Bone Joint Surg Am. 2012;94(18):1685-92.
37. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96.
38. Sapkas GS, Mavrogenis AF, Themistocleous GS, Zachos VC, Kelalis G, Papagelopoulos PJ. Posterior lumbar interbody fusion versus circumferential fusion using the B-Twin expandable spinal system. J Long Term Eff Med Implants. 2007;17(3):217-27.
39. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. Neurosurgery. 2007;60(4 Suppl 2):203-212.
40. Schulte TL, Leistra F, Bullmann V, et al. Disc height reduction in adjacent segments and clinical outcome 10 years after lumbar 360 degrees fusion. Eur Spine J. 2007;16(12):2152-8.
41. Schulte TL, Leistra F, Bullmann V, et al. Disc height reduction in adjacent segments and clinical outcome 10 years after lumbar 360 degrees fusion. Eur Spine J. 2007;16(12):2152-8.
42. Sharma AK, Kepler CK, Girardi FP, Cammisa FP, Huang RC, Sama AA. Lateral lumbar interbody fusion: clinical and radiographic outcomes at 1 year: a preliminary report. J Spinal Disord Tech. 2011;24(4):242-50.
43. Skowroński J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. Ortop Traumatol Rehabil. 2007;9(2):149-55.
44. Soegaard R, Bünger CE, Christiansen T, Høy K, Eiskjaer SP, Christensen FB. Circumferential fusion is dominant over posterolateral fusion in a long-term perspective: cost-utility evaluation of a randomized controlled trial in severe, chronic low back pain. Spine. 2007;32(22):2405-14.
45. Tokuhashi Y, Ajiro Y, Umezawa N. Follow-up of patients with delayed union after posterior fusion with pedicle screw fixation. Spine. 2008;33(7):786-91.
46. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-65.
47. Wang HL, Lü FZ, Jiang JY, Ma X, Xia XL, Wang LX. Minimally invasive lumbar interbody fusion via MAST Quadrant retractor versus open surgery: a prospective randomized clinical trial. Chin Med J. 2011;124(23):3868-74.
48. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
49. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
50. Welch WC, Cheng BC, Awad TE, et al. Clinical outcomes of the Dynesys dynamic neutralization system: 1-year preliminary results. Neurosurg Focus. 2007;22(1):E8.
51. Willems P. Decision making in surgical treatment of chronic low back pain: the performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop Suppl. 2013;84(349):1-35. Xu H, Tang H, Li Z. Surgical treatment of adult degenerative spondylolisthesis by instrumented transforaminal lumbar interbody fusion in the Han nationality. J Neurosurg Spine. 2009;10(5):496-9. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.
52. Zhao Y, Wang YP, Qiu GX, Zhao H, Zhang JG, Zhou X. Efficacy of the Dynamic Interspinous Assisted Motion system in clinical treatment of degenerative lumbar disease. Chin Med J. 2010;123(21):2974-7.

New Guideline Question:

Which patient-specific characteristics influence outcomes (and prognosis) in the treatment (surgical or any) of degenerative lumbar spondylolisthesis?

There is insufficient evidence to make a recommendation for or against the influence of a nonorganic pain drawing on the outcomes/prognosis of treatments for patients with degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

Andersen et al[1] investigated whether pain drawings predicted outcome in patients undergoing lumbar spinal fusion. The study also assessed the differences between spondylolisthesis patients and patients with degenerative disease as well as between patients with or without radicular pain. Patients over the age of 60 were excluded to make the patient population more comparable to other studies. One hundred thirty-five patients, including 28 spondylolisthesis patients, undergoing lumbar spinal fusion were followed for at least one year and evaluated using the Dallas Pain Questionnaire (DPQ), Low Back Pain Rating Scale (LBPRS) pain index and patient satisfaction. Pain drawings were composed by outling each patient's front, back and area under feet. Patients were asked to indicate where their pain was occurring on the drawing. Six different symbols denoting different levels of pain were used for the following: dull/aching, burning, numbness, pins and needles, stabbing/cutting and muscular cramps. Based on visual results, pain drawings were classified as organic or nonorganic. Pain drawings were correlated to outcomes to determine their predictive value. Results indicated that 90 pain drawings were deemed organic (67%) and 45 were deemed nonorganic pain drawings (33%). In the sub-set of spondylolisthesis patients, patients with an organic pain drawing had a greater improvement in all outcome scores, including DPQ daily activity, work/leisure, anxiety/depression, social interest and LBPRS, compared with those with a nonorganic pain drawing; however, this difference was not observed to the same extent in patients operated for degenerative disease. Nonorganic pain drawings were associated with poorer outcomes in patients with low back pain and radicular symptoms, however, not in patients without radicular symptoms. This study provides Level IV prognostic evidence that spondylolisthesis patients with an organic pain drawing had a greater improvement in outcome scores compared with those with a nonorganic pain drawing.

There is insufficient evidence to make a recommendation regarding the influence of age and three or more comorbidities on the outcomes of patients undergoing treatment for degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

Kalanthi et al[2] conducted a retrospective study of degenerative spondylolisthesis patients undergoing posterior lumbar fusion to determine rates of in-patient complications and complex disposition for and evalaute the association of demographic variables. The Nationwide Inpatient Sample (NIS) administrative data was used to retrieve data from 66,601 patients with diagnostic and procedure codes specifying posterior lumbar fusion for acquired spondylolisthesis. Variables assessed included age, sex, race, number of comorbidities, hospital size and time period of procedure. Multivariate analysis revealed an association between age and complex disposition. The reference group was defined as the age Group 45 to 64 years. The likelihood of complex disposition was significantly higher for patients in the age Group 65 to 84 (OR: 5.8, $p<0.0001$), but less likely in younger groups. Patients with 3 or more comorbidities were twice as likely to have complex disposition, regardless of age, when compared with those with no comorbidities ($p<0.0001$). This study provides Level II prognostic evidence that increasing age and the presence of three or more comorbidities may increase the risk of a postoperative complex disposition in patients with degenerative spondylolisthesis.

There is insufficient evidence to make a recommendation regarding the influence of symptom duration on the treatment outcomes of patients with degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

Radcliff et al[3] retrospectively reviewed data from the Spine Outcomes Research Trial (SPORT) study to determine whether the duration of symptoms affects outcomes after the treatment of spinal stenosis (SS) or degenerative spondylolisthesis (DS). The SPORT study compared the surgical and nonsurgical outcomes in patients enrolled in either a randomized or observational cohort. All patients in the trial had neurogenic claudication or radicular leg pain with associated neurologic signs, spinal stenosis shown on cross-sectional imaging, and degenerative spondylolisthesis shown on lateral radiographs obtained with the patient in a standing position. Treatment was standard decompressive laminectomy, with or without fusion, or usual nonsurgical care, which included at least physical therapy, education or counseling on home exercises, and nonsteroidal anti-inflammatory agents, if tolerated. Investigators enrolled 304 patients in the randomized cohort and 303 in the observational cohort. In the randomized cohort, 159 patients were assigned to surgery and 145 were assigned to nonsurgical treatment. Of the 145 patients assigned to receive nonoperative care, 54% underwent surgery by 4 years. In the observational cohort, 173 initially chose surgery and 130 initially chose nonsurgical care. Of the 130 patients who initially chose nonoperative treatment, 33% underwent surgery by four years. Patients were evaluated over 4 years using the SF-36 for bodily pain and physical function scores and the modified Oswestry Disability Index. An as-treated analysis comparison was made between patients with SS with 12 or fewer months' (n = 405) and those with more than 12 months' (n = 227) duration of symptoms. A comparison was also made between patients with DS with 12 or fewer months' (n = 397) and those with more than 12 months' (n = 204) duration of symptoms. Primary and secondary outcomes were measured at baseline and at regular follow-up time intervals up to 4 years. The difference in improvement among patients whose surgical or nonsurgical treatment began less than or greater than 12 months after the onset of symptoms was measured. In addition, the difference in improvement with surgical versus nonsurgical treatment (treatment effect) was determined at each follow-up period for each group. Results indicated that the primary and secondary outcome measures within the DS group did not differ according to symptom duration and suggests that there was no difference in the treatment outcome of patients with degenerative spondylolisthesis according to symptom duration. This study provides Level II prognostic evidence that suggests that symptom duration does not impact nonoperative or surgical treatment success for patients with degenerative lumbar spondylolisthesis.

There is insufficient evidence to make a recommendation regarding the influence of obesity (BMI >30) and its impact on treatment outcomes in patients with degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

In another post hoc retrospective subgroup analysis of SPORT, Rihn et al[4] evaluated the impact of obesity on the treatment outcomes for lumbar stenosis and degenerative spondylolisthesis patients. In the cohort of degenerative spondylolisthesis patients, there were 376 patients with a BMI of less than 30 (non-obese) and 225 patients with a BMI more than 30 (obese). It is important to note that in addition to obesity, obese patients had a significantly higher incidence of comorbidities, including hypertension, diabetes and stomach problems ($p<0.001$). A higher proportion of obese patients underwent instrumented fusion and less underwent decompression alone compared to non-obese patients. The incidence of intraoperative complications was significantly lower in the obese patient group; however, there was a trend toward increase rate of wound infection in the obese patients compared to nonobese patients (5% vs. 1%, $p=0.051$). At 4 year follow-up, there was a significantly higher rate of reoperation in the obese patient group compared to the nonobese group (20% vs. 11%, $p=0.013$). At 4 year follow-up in the nonoperative group, obese patients had SF-36 physical function scores that worsened from baseline by a mean of 3.5 compared to a mean improvement of 13.9 points in the nonobese group ($p<0.001$). The treatment effect for the SF-36 Physical Function score was significantly higher for the obese surgical patient group compared to nonoperative obese patient group (25.6 vs. 14, $p=0.004$) suggesting that surgery has a significantly greater benefit over nonsurgical treatment of degenerative spondylolisthesis in obese patients. This study provides Level II prognostic evidence the risk of infection and reoperation 4 years after surgical treatment is greater in obese patients compared to nonobese surgical patients.

Future Directions for Research

The work group recommends the undertaking of population-based observational studies, such as a multicenter registry data studies, to examine the clinical characteristics associated with poor medical/interventional or surgical treatment in patients with degenerative lumbar spondylolisthesis.

References

1. Andersen T, Christensen FB, Høy KW, et al. The predictive value of pain drawings in lumbar spinal fusion surgery. Spine J. 2010;10(5):372-9.
2. Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. Spine. 2009;34(18):1963-9.
3. Radcliff KE, Rihn J, Hilibrand A, et al. Does the duration of symptoms in patients with spinal stenosis and degenerative spondylolisthesis affect outcomes?: analysis of the Spine Outcomes Research Trial. Spine. 2011;36(25):2197-210.

4. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-46.

Bibliography

1. Alexander DI, Manson NA, Mitchell MJ. Efficacy of calcium sulfate plus decompression bone in lumbar and lumbosacral spinal fusion: preliminary results in 40 patients. Can J Surg. 2001;44(4):262-6.
2. Aono H, Iwasaki M, Ohwada T, et al. Surgical outcome of drop foot caused by degenerative lumbar diseases. Spine. 2007;32(8):E262-6.
3. Barbagallo GM, Olindo G, Corbino L, Albanese V. Analysis of complications in patients treated with the X-Stop Interspinous Process Decompression System: proposal for a novel anatomic scoring system for patient selection and review of the literature. Neurosurgery. 2009;65(1):111-19.
4. Benoist M. The natural history of lumbar degenerative spinal stenosis. Joint Bone Spine. 2002;69(5):450-7.
5. Blumenthal C, Curran J, Benzel EC, et al. Radiographic predictors of delayed instability following decompression without fusion for degenerative grade I lumbar spondylolisthesis. J Neurosurg Spine. 2013;18(4):340-6.
6. Bono CM, Lee CK. The influence of subdiagnosis on radiographic and clinical outcomes after lumbar fusion for degenerative disc disorders: an analysis of the literature from two decades. Spine. 2005;30(2):227-34.
7. Coe JD, Kitchel SH, Meisel HJ, Wingo CH, Lee SE, Jahng TA. NFlex Dynamic Stabilization System : Two-Year Clinical Outcomes of Multi-Center Study. J Korean Neurosurg Soc. 2012;51(6):343-9.
8. Crawford CH, Smail J, Carreon LY, Glassman SD. Health-related quality of life after posterolateral lumbar arthrodesis in patients seventy-five years of age and older. Spine. 2011;36(13):1065-8.
9. Dai F, Belfer I, Schwartz CE, et al. Association of catechol-O-methyltransferase genetic variants with outcome in patients undergoing surgical treatment for lumbar degenerative disc disease. Spine J. 2010;10(11):949-57.
10. Desai A, Ball PA, Bekelis K, et al. Surgery for lumbar degenerative spondylolisthesis in Spine Patient Outcomes Research Trial: does incidental durotomy affect outcome?. Spine. 2012;37(5):406-13.
11. Djurasovic M, Glassman SD, Dimar JR, Crawford CH, Bratcher KR, Carreon LY. Changes in the Oswestry Disability Index that predict improvement after lumbar fusion. J Neurosurg Spine. 2012;17(5):486-90.
12. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
13. Etame AB, Wang AC, Than KD, Park P. Clinical and radiographic outcomes after minimally invasive transforaminal lumbar interbody fusion. SAS J. 2010;4(2):47-53.
14. Fu KM, Rhagavan P, Shaffrey CI, Chernavvsky DR, Smith JS. Prevalence, severity, and impact of foraminal and canal stenosis among adults with degenerative scoliosis. Neurosurgery. 2011;69(6):1181-7.
15. Gehrchen PM, Dahl B, Katonis P, Blyme P, Tøndevold E, Kiaer T. No difference in clinical outcome after posterolateral lumbar fusion between patients with isthmic spondylolisthesis and those with degenerative disc disease using pedicle screw instrumentation: a comparative study of 112 patients with 4 years of follow-up. Eur Spine J. 2002;11(5):423-7.
16. Glassman SD, Carreon LY, Dimar JR, Campbell MJ, Puno RM, Johnson JR. Clinical outcomes in older patients after posterolateral lumbar fusion. Spine J. 2007;7(5):547-51.
17. Hasegawa K, Shimoda H, Kitahara K, Sasaki K, Homma T. What are the reliable radiological indicators of lumbar segmental instability?. J Bone Joint Surg Br. 2011;93(5):650-7.
18. Hee HT, Wong HK. The long-term results of surgical treatment for spinal stenosis in the elderly. Singapore Med J. 2003;44(4):175-80.
19. Jo DJ, Jun JK, Kim KT, Kim SM. Lumbar Interbody Fusion Outcomes in Degenerative Lumbar Disease: Comparison of Results between Patients Over and Under 65 Years of Age. J Korean Neurosurg Soc. 2010;48(5):412-8.
20. Kalichman L, Hunter DJ. Degenerative lumbar spondylolisthesis: Anatomy, biomechanics and risk factors. J Back Musculoskel Rehabil. 2008;21(1):1-12.
21. Kawakami M, Tamaki T, Ando M, Yamada H, Hashizume H, Yoshida M. Lumbar sagittal balance influences the clinical outcome after decompression and posterolateral spinal fusion for degenerative lumbar spondylolisthesis. Spine. 2002;27(1):59-64.
22. Kelleher MO, Timlin M, Persaud O, Rampersaud YR. Success and failure of minimally invasive decompression for focal lumbar spinal stenosis in patients with and without deformity. Spine. 2010;35(19):E981-7.
23. Kim DH, Albert TJ. Update on use of instrumentation in lumbar spine disorders. Best Pract Res Clin Rheumatol. 2002;16(1):123-40.
24. Kim MK, Lee SH, Kim ES, Eoh W, Chung SS, Lee CS. The impact of sagittal balance on clinical results after posterior interbody fusion for patients with degenerative spondylolisthesis: a pilot study. BMC Musculoskelet Disord. 2011;12:69.
25. Kleinstueck FS, Fekete TF, Mannion AF, et al. To fuse or not to fuse in lumbar degenerative spondylolisthesis: do baseline symptoms help provide the answer?. Eur Spine J. 2012;21(2):268-75.
26. Lee JW, Myung JS, Park KW, et al. Fluoroscopically guided caudal epidural steroid injection for management of degenerative lumbar spinal stenosis: short-term and long-term results. Skeletal Radiol. 2010;39(7):691-9.
27. Lee SH, Lee JH, Hong SW, Chung SE, Yoo SH, Lee HY. Spinopelvic alignment after interspinous soft stabilization with a tension band system in grade 1 degenerative lumbar spondylolisthesis. Spine. 2010;35(15):E691-701.
28. Lee SH, Lee JH, Hong SW, et al. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7):563-72.
29. Lindley EM, Mccullough MA, Burger EL, Brown CW, Patel VV. Complications of axial lumbar interbody fusion. J Neurosurg Spine. 2011;15(3):273-9.
30. Maus T. Imaging the back pain patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-66.
31. Mehta VA, Amin A, Omeis I, Gokaslan ZL, Gottfried ON. Implications of spinopelvic alignment for the spine surgeon. Neurosurgery. 2012;70(3):707-21.
32. Miyamoto H, Sumi M, Uno K, Tadokoro K, Mizuno K. Clinical outcome of nonoperative treatment for lumbar spinal stenosis, and predictive factors relating to prognosis, in a 5-year minimum follow-up. J Spinal Disord Tech. 2008;21(8):563-8.
33. Mokhtar SA, Mccombe PF, Williamson OD, Morgan MK, White GJ, Sears WR. Health-related quality of life: a comparison of outcomes after lumbar fusion for degenerative spondylolisthesis with large joint replacement surgery and population norms. Spine J. 2010;10(4):306-12.
34. Molina M, Wagner P, Campos M. [Spinal lumbar stenosis: an update]. Rev Med Chil. 2011;139(11):1488-95.
35. Ozgur BM, Agarwal V, Nai, E, & Pimenta L. Two-year clinical

and radiographic success of minimally invasive lateral transpsoas approach for the treatment of degenerative lumbar conditions. SAS J. 2010;4(2):41-46.
36. Pao JL, Chen WC, Chen PQ. Clinical outcomes of microendoscopic decompressive laminotomy for degenerative lumbar spinal stenosis. Eur Spine J. 2009;18(5):672-8.
37. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine. 2010;35(4):439-46.
38. Rampersaud YR, Gray R, Lewis SJ, Massicotte EM, Fehlings MG. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. SAS J. 2011;5(2):29-35.
39. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96.
40. Rousseau MA, Lazennec JY, Bass EC, Saillant G. Predictors of outcomes after posterior decompression and fusion in degenerative spondylolisthesis. Eur Spine J. 2005;14(1):55-60.
41. Schnee CL, Freese A, Ansell LV. Outcome analysis for adults with spondylolisthesis treated with posterolateral fusion and transpedicular screw fixation. J Neurosurg. 1997;86(1):56-63.
42. Schulte TL, Leistra F, Bullmann V, et al. Disc height reduction in adjacent segments and clinical outcome 10 years after lumbar 360 degrees fusion. Eur Spine J. 2007;16(12):2152-8.
43. Shen M, Razi A, Lurie JD, Hanscom B, Weinstein J. Retrolisthesis and lumbar disc herniation: a preoperative assessment of patient function. Spine J. 2007;7(4):406-13.
44. Vaccaro A. Unilateral approach for microsurgical decompression. J Neurosurg Spine. 2008;9(6):552-553.
45. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
46. Willems P. Decision making in surgical treatment of chronic low back pain: the performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop Suppl. 2013;84(349):1-35.
47. Yan DL, Pei FX, Li J, Soo CL. Comparative study of PILF and TLIF treatment in adult degenerative spondylolisthesis. Eur Spine J. 2008;17(10):1311-6.
48. Zhao Y, Wang YP, Qiu GX, Zhao H, Zhang JG, Zhou X. Efficacy of the Dynamic Interspinous Assisted Motion system in clinical treatment of degenerative lumbar disease. Chin Med J. 2010;123(21):2974-7.

New Guideline Question:

What is the effect of postsurgical rehabilitation including exercise, spinal mobilization/ manipulation or psychosocial interventions on outcomes in the management of degenerative lumbar spondylolisthesis (compared to patients who do not undergo postsurgical rehabilitation)?

There was no evidence found to address this question. Due to the paucity of evidence, a recommendation cannot be made regarding the effect of postsurgical rehabilitation the outcomes of patients undergoing surgical treatment for degenerative lumbar spondylolisthesis.

Future Directions For Research

The work group recommends the undertaking of observational studies to evaluate the effect of various postsurgical rehabilitation strategies on patients with degenerative lumbar spondylolisthesis.

Bibliography

1. Abbott AD, Tyni-lenné R, Hedlund R. Early rehabilitation targeting cognition, behavior, and motor function after lumbar fusion: a randomized controlled trial. Spine. 2010;35(8):848-57.
2. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurg Quart. 2009;19(3):200-206.
3. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2):133-137.
4. Cavuşoğlu H, Türkmenoğlu O, Kaya RA, et al. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-8.
5. Chad DA. Lumbar spinal stenosis. Neurol Clin. 2007;25(2):407-18.
6. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
7. Cloyd JM, Acosta FL, Ames CP. Complications and outcomes of lumbar spine surgery in elderly people: a review of the literature. J Am Geriatr Soc. 2008;56(7):1318-27.
8. Dai F, Belfer I, Schwartz CE, et al. Association of catechol-O-methyltransferase genetic variants with outcome in patients undergoing surgical treatment for lumbar degenerative disc disease. Spine J. 2010;10(11):949-57.
9. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
10. Eliyas JK, Karahalios D. Surgery for degenerative lumbar spine disease. Dis Mon. 2011;57(10):592-606.
11. Faldini C, Pagkrati S, Acri F, Miscione MT, Francesconi D, Giannini S. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.
12. Gilbert JW, Wheeler GR, Kreft MP, et al. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-31.
13. Grob D. Surgery for degenerative lumbar disease: transforaminal lumbar interbody fusion. Eur Spine J. 2009;18(12):1991-2.
14. Ibrahimi DM, Beaty NB, Crandall KM, Hamilton DK, Sansur C. A. A review of lumbar spondylolisthesis. Eur Musculoskel Rev. 2011;6(2):110-113.
15. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
16. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-15.
17. Monticone M, Giovanazzi E. Usefulness of a cognitive behavioural and rehabilitative approach to enhance long lasting benefit after lumbar spinal stenosis and degenerative spondylolisthesis surgery. A case report. Eur J Phys Rehabil Med. 2008;44(4):467-71.
18. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-46.
19. Templin CR, Garfin SR. (2007). Surgical Management of Scoliosis and/or Spondylolisthesis Associated with Spinal Stenosis. Seminars in Spine Surgery, 19(3), 187-199.
20. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
21. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
22. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.

E. Value of Spine Care

New Guideline Question:

What is the cost-effectiveness of the surgical treatment of degenerative lumbar spondylolisthesis compared to medical/interventional treatment (consider with and without fusion separately)?

There was no evidence found to address this question. Due to the paucity of evidence, a recommendation cannot be made regarding the cost-effectiveness of surgical treatment compared to medical/interventional treatment for the management of patients with degenerative lumbar spondylolisthesis.

Future Directions For Research

The work group recommends the undertaking of cost-analysis studies evaluating the long term cost-effectiveness of surgical treatments versus medical/interventional treatment in patients undergoing treatment for degenerative lumbar spondylolisthesis.

Bibliography

1. Adogwa O, Parker SL, Bydon A, Cheng J, Mcgirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-84.
2. Adogwa O, Parker SL, Davis BJ, et al. Cost-effectiveness of transforaminal lumbar interbody fusion for Grade I degenerative spondylolisthesis. J Neurosurg Spine. 2011;15(2):138-43.
3. Alfieri A, Gazzeri R, Prell J, et al. Role of lumbar interspinous distraction on the neural elements. Neurosurg Rev. 2012;35(4):477-84.
4. Alt V, Chhabra A, Franke J, Cuche M, Schnettler R, Le huec JC. An economic analysis of using rhBMP-2 for lumbar fusion in Germany, France and UK from a societal perspective. Eur Spine J. 2009;18(6):800-6.
5. Asghar FA, Hilibrand AS. The impact of the Spine Patient Outcomes Research Trial (SPORT) results on orthopaedic practice. J Am Acad Orthop Surg. 2012;20(3):160-6.
6. Bederman SS, Coyte PC, Kreder HJ, Mahomed NN, Mcisaac WJ, Wright JG. Who's in the driver's seat? The influence of patient and physician enthusiasm on regional variation in degenerative lumbar spinal surgery: a population-based study. Spine. 2011;36(6):481-489.
7. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD. SF-6D values stratified by specific diagnostic indication. Spine. 2012;37(13):E804-8.
8. Chu G, Aikenmu K, He ZS. Unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis: A randomized controlled trial. J Clin Rehabil Tissue Eng Res. 2011;15(35):6540-6545.
9. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
10. Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. Spine. 2009;34(18):1963-9.
11. Katz JN, Lipson SJ, Lew RA, et al. Lumbar laminectomy alone or with instrumented or noninstrumented arthrodesis in degenerative lumbar spinal stenosis. Patient selection, costs, and surgical outcomes. Spine (Phila Pa 1976). 1997;22(10):1123-1131.
12. Kim S, Mortaz hedjri S, Coyte PC, Rampersaud YR. Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis. Spine J. 2012;12(1):44-54.
13. Kuntz KM, Snider RK, Weinstein JN, Pope MH, Katz JN. Cost-effectiveness of fusion with and without instrumentation for patients with degenerative spondylolisthesis and spinal stenosis. Spine. 2000;25(9):1132-9.
14. Maus T. Imaging the back pain patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-66.
15. Molinari RW, Hunter JG, Mcassey RW. In-hospital postoperative radiographs for instrumented single-level degenerative spinal fusions: utility after intraoperative fluoroscopy. Spine J. 2012;12(7):559-67.
16. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
17. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.
18. Parker SL, Mcgirt MJ. Determination of the minimum improvement in pain, disability, and health state associated with cost-effectiveness: introduction of the concept of minimum cost-effective difference. Neurosurgery. 2012;71(6):1149-55.

19. Pelton MA, Phillips FM, Singh K. A comparison of perioperative costs and outcomes in patients with and without workers' compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion. Spine. 2012;37(22):1914-1919.
20. Rampersaud R, Macwan K, Mahomed NN. Spinal Care in a Single-Payer System: The Canadian Example. Semin Spine Surg. 2012;24(2):117-122.
21. Rampersaud YR, Gray R, Lewis SJ, Massicotte EM, Fehlings MG. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. SAS J. 2011;5(2):29-35.
22. Robertson PA, Plank LD. Prospective cohort analysis of disability reduction with lumbar spinal fusion surgery in community practice. J Spinal Disord Tech. 2008;21(4):235-40.
23. Savvidou C, Chatziioannou SN, Pilichou A, Pneumaticos SG. Efficacy and cost-effectiveness of cell saving blood autotransfusion in adult lumbar fusion. Transfus Med. 2009;19(4):202-6.
24. Siewe J, Otto C, Knoell P, et al. Comparison of standard fusion with a "topping off" system in lumbar spine surgery: a protocol for a randomized controlled trial. BMC Musculoskelet Disord. 2011;12:239.
25. Soegaard R, Bünger CE, Christiansen T, Høy K, Eiskjaer SP, Christensen FB. Circumferential fusion is dominant over posterolateral fusion in a long-term perspective: cost-utility evaluation of a randomized controlled trial in severe, chronic low back pain. Spine. 2007;32(22):2405-14.
26. Soegaard R, Christensen FB. Health economic evaluation in lumbar spinal fusion: a systematic literature review anno 2005. Eur Spine J. 2006;15(8):1165-1173.
27. Taylor JA, Bussières A. Diagnostic imaging for spinal disorders in the elderly: a narrative review. Chiropr Man Therap. 2012;20(1):16.
28. Virk S, Sandhu HS, Khan SN. Cost effectiveness analysis of graft options in spinal fusion surgery using a Markov model. J Spinal Disord Tech. 2012;25(7):E204-10.
29. Watters WC. If, when, and how to fuse when treating lumbar degenerative stenosis. Semin Spine Surg. 2011;23(4):218-221.
30. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
31. Zhou J, Wang B, Dong J, et al. Instrumented transforaminal lumbar interbody fusion with single cage for the treatment of degenerative lumbar disease. Arch Orthop Trauma Surg. 2011;131(9):1239-45.

New Guideline Question:

What is the cost-effectiveness of minimal access-based surgical treatments of degenerative lumbar spondylolisthesis compared to traditional open surgical treatments?

There is insufficient evidence to make a recommendation for or against the cost-effectiveness of minimal access-based surgical treatments compared to traditional open surgical treatments for degenerative lumbar spondylolisthesis.

Grade of Recommendation: I (Insufficient Evidence)

In a retrospective cost-effectiveness comparative study of patients undergoing surgical treatment for Grade 1 degenerative spondylolisthesis, Parker et al[1] assessed the cost and cost utility of minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) vs open-TLIF. Fifteen patients received surgical treatment with MIS-TLIF and 15 other patients underwent open-TLIF. Independent investigators not involved in the patients' care conducted phone interviews to assess preoperative and 2-year postoperative pain, disability and quality of life. At 2 years postsurgery, information on duration of narcotic use and time to return to work was collected via phone interview as part of a standard of care protocol. Patient-assessed questionnaires included Visual Analog Scale (VAS) for low back pain and leg pain, the Oswestry Disability Index (ODI), and EuroQuol-5D (EQ-5D). QALY was used to measure the treatment effectiveness and the incremental cost-effectiveness ratio (ICER) was calculated by the difference in the mean total costs between cohorts, divided by the difference in mean QALYs. The analysis indicated that the MIS-TLIF versus the open-TLIF cohorts were similar at baseline. Mean preoperative health state values significantly improved for both the MIS-TLIF and open-TLIF cohorts by two years after surgery. The total mean QALYs gained for MIS-TLIF patients was 0.50 (95% CI, 0.37-0.63) and 0.41 (95% CI, 0.14-0.68) for open-TLIF patients. The total two year mean costs were $35,996 for the MIS-TLIF treated patients and $44,727 for the open-TLIF treated patients (p=0.18). Treatment groups were similar in use of oral steroids (33% MIS vs. 20% open, p=0.68) but differed significantly in the mean duration of narcotics (MIS: 2.6 weeks vs. open: 6.5 weeks, p=0.008). MIS-TLIF patients had accelerated return to work times versus open-TLIF patients (8.3 vs.16.3 weeks, p=0.02). During the 2-year study period, indirect costs accounted for a substantial proportion of total costs in both

groups (32.8% of cost for MIS-TLIF patients and 41.2% of costs for open-TLIF patients). When all costs were considered, MIS-TLIF versus open-TLIF was associated with a nonsignificant trend of mean 2-year cost savings of $8,731 per patient while providing similar QALYs gained (ICER). Two-year cost and utility gained were similar for both techniques. The authors suggest that MIS-TLIF is a cost reducing surgical treatment for patients with Grade I degenerative lumbar spondylolisthesis. In critique, this study may have been too small to show a difference. In addition, open surgery can be done with posterolateral fusion only with similar results to TLIF, but for reduced cost, whereas MIS is more dependent on TLIF to accomplish goals of decompression and fusion. This study provides Level III economic and decision analysis evidence that there is no statistical difference in the cost of MIS-TLIF compared to open-TLIF.

In a follow-up analysis using the same 30 patients as above, Parker et al[2] evaluated 100 patients undergoing TLIF for degenerative lumbar spondylolisthesis were evaluated. Fifty patients underwent MIS-TLIF and the other 50 patients underwent open-TLIF. Preoperative, 3-month and 2-year postoperative pain, disability and quality of life were assessed via phone interview by an independent investigator not involved in care. Patient-assessed questionnaires included Visual Analog Scale (VAS) for low back pain and leg pain, Oswestry Disability Index (ODI), Short-Form (SF)-12 health survey with mental (MCS) and physical (PCS) component scores, Zung depression index and EuroQol-5D (EQ-5D). Cost-effectiveness metrics evaluated included QALY, direct hospital costs, two year resource use and direct costs, indirect costs and incremental cost-effectiveness ratio (ICER). Length of hospitalization and time to return to work were less for MIS-TLIF versus open TLIF (p=0.006 and p=0.03, respectively). MIS-TLIF versus open TLIF demonstrated similar improvement in patient-reported outcomes assessed. MIS-TLIF was associated with a reduced total 2-year cost versus open-TLIF, $38,563 versus $47,858 (p=0.03). MIS vs open TLIF was associated with a reduction in mean hospital cost of $1758, indirect cost of $8474, and total 2-year societal cost of $9295 (p=0.03) but similar 2-year direct health care cost and quality-adjusted life years gained. In critique, open surgery can be done with posterolateral fusion only with similar results to TLIF, but for reduced cost, whereas MIS is more dependent on TLIF to accomplish goals of decompression and fusion. This choice of comparison could affect final analysis. This study provides Level III economic and decision analysis evidence that MIS-TLIF versus open-TLIF was associated with reduced costs over 2 years while providing equivalent improvement in clinical outcomes.

Kim et al[3] conducted a comparative cost-effectiveness study to determine the relative cost-utility of decompression with and without concomitant instrumented fusion for patients with degenerative lumbar spondylolisthesis. All consecutive patients (n=150) with a primary diagnosis of degenerative lumbar spondylolisthesis were assessed. The primary outcome was the incremental cost/utility ratio (ICUR) expressed as the differential cost per relative gain in quality-adjusted life-year (QALY). A Markov model with 10-year follow-up was also developed to compare costs and outcomes of the two operative strategies. The cost-utility of decompression with fusion and decompression alone at 10 years post-intervention was $3,281/QALY and $1,040/QALY, respectively. Compared with decompression alone, decompression plus instrumented fusion was associated with an improvement in quality of life at value of $185,878 per QALY. Because this study does not directly answer this comparative question, the work group did not assign it a level of evidence. However, it does provide background information on the cost of open surgical techniques and has been included for educational reference. The authors suggest that for a specific subpopulation of degenerative lumbar spondylolisthesis patients, decompression alone and decompression and fusion are almost similar in clinical effectiveness with a slight advantage for fusion.

Future Directions for Research

The work group recommends the undertaking of cost-analysis studies evaluating the long term cost-effectiveness of minimally invasive surgeries vs conventional surgery in patients with degenerative lumbar spondylolisthesis. It is important to note that MIS recommendations are complicated by the lack of a consistent definition of what constitutes MIS; therefore, the work group recommends that MIS is clearly and consistently defined in any future studies evaluating the role and cost-effectiveness of MIS surgical techniques.

References

1. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.
2. Parker SL, Mendenhall SK, Shau DN, et al. Minimally Invasive Versus Open Transforaminal Lumbar Interbody Fusion for Degenerative Spondylolisthesis: Comparative Effectiveness and Cost-Utility Analysis. World Neurosurg. 2014;82(1-2):230-238.
3. Kim S, Mortaz hedjri S, Coyte PC, Rampersaud YR. Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis. Spine J. 2012;12(1):44-54.

Bibliography

1. Adogwa O, Parker SL, Bydon A, Cheng J, Mcgirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-84.
2. Adogwa O, Parker SL, Davis BJ, et al. Cost-effectiveness of transforaminal lumbar interbody fusion for Grade I degenerative spondylolisthesis. J Neurosurg Spine. 2011;15(2):138-43.
3. Alfieri A, Gazzeri R, Prell J, et al. Role of lumbar interspinous distraction on the neural elements. Neurosurg Rev. 2012;35(4):477-84.
4. Alt V, Chhabra A, Franke J, Cuche M, Schnettler R, Le huec JC. An economic analysis of using rhBMP-2 for lumbar fusion in Germany, France and UK from a societal perspective. Eur Spine J. 2009;18(6):800-6.
5. Asghar FA, Hilibrand AS. The impact of the Spine Patient Outcomes Research Trial (SPORT) results on orthopaedic practice. J Am Acad Orthop Surg. 2012;20(3):160-6
6. Bederman SS, Coyte PC, Kreder HJ, Mahomed NN, Mcisaac WJ, Wright JG. Who's in the driver's seat? The influence of patient and physician enthusiasm on regional variation in degenerative lumbar spinal surgery: a population-based study. Spine. 2011;36(6):481-489.

7. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD. SF-6D values stratified by specific diagnostic indication. Spine. 2012;37(13):E804-8.
8. Chu G, Aikenmu K, He ZS. Unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis: A randomized controlled trial. J Clin Rehabil Tissue Eng Res. 2011;15(35):6540-6545.
9. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
10. Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. Spine. 2009;34(18):1963-9
11. Kuntz KM, Snider RK, Weinstein JN, Pope MH, Katz JN. Cost-effectiveness of fusion with and without instrumentation for patients with degenerative spondylolisthesis and spinal stenosis. Spine. 2000;25(9):1132-9.
12. Maus T. Imaging the Back Pain Patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-766.
13. Molinari RW, Hunter JG, Mcassey RW. In-hospital postoperative radiographs for instrumented single-level degenerative spinal fusions: utility after intraoperative fluoroscopy. Spine J. 2012;12(7):559-67.
14. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
15. Parker SL, Mcgirt MJ. Determination of the minimum improvement in pain, disability, and health state associated with cost-effectiveness: introduction of the concept of minimum cost-effective difference. Neurosurgery. 2012;71(6):1149-55.
16. Pelton MA, Phillips FM, Singh K. A comparison of perioperative costs and outcomes in patients with and without workers' compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion. Spine. 2012;37(22):1914-1919.
17. Rampersaud R, Macwan K, Mahomed NN. Spinal Care in a Single-Payer System: The Canadian Example. Semin Spine Surg. 2012;24(2):117-122.
18. Rampersaud YR, Gray R, Lewis SJ, Massicotte EM, Fehlings MG. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. SAS J. 2011;5(2):29-35.
19. Robertson PA, Plank LD. Prospective cohort analysis of disability reduction with lumbar spinal fusion surgery in community practice. J Spinal Disord Tech. 2008;21(4):235-40.
20. Savvidou C, Chatziioannou SN, Pilichou A, Pneumaticos SG. Efficacy and cost-effectiveness of cell saving blood autotransfusion in adult lumbar fusion. Transfus Med. 2009;19(4):202-6.
21. Siewe J, Otto C, Knoell P, et al. Comparison of standard fusion with a "topping off" system in lumbar spine surgery: a protocol for a randomized controlled trial. BMC Musculoskelet Disord. 2011;12:239.
22. Soegaard R, Bünger CE, Christiansen T, Høy K, Eiskjaer SP, Christensen FB. Circumferential fusion is dominant over posterolateral fusion in a long-term perspective: cost-utility evaluation of a randomized controlled trial in severe, chronic low back pain. Spine. 2007;32(22):2405-14.
23. Soegaard R, Christensen FB. Health economic evaluation in lumbar spinal fusion: A systematic literature review anno 2005. Eur Spine J. 2006;15(8):1165-1173.
24. Taylor JA, Bussières A. Diagnostic imaging for spinal disorders in the elderly: a narrative review. Chiropr Man Therap. 2012;20(1):16.
25. Virk S, Sandhu HS, Khan SN. Cost effectiveness analysis of graft options in spinal fusion surgery using a Markov model. J Spinal Disord Tech. 2012;25(7):E204-10.
26. Watters WC. If, when, and how to fuse when treating lumbar degenerative stenosis. Semin Spine Surg. 2011;23(4):218-221.
27. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
28. Zhou J, Wang B, Dong J, et al. Instrumented transforaminal lumbar interbody fusion with single cage for the treatment of degenerative lumbar disease. Arch Orthop Trauma Surg. 2011;131(9):1239-45.

VI. Appendices

A. Acronyms

CI	confidence interval
COS	clinical outcome score
CT	computed tomography
DCSA	dural sac cross sectional area
DH	disc height
EBM	evidence-based medicine
EMG	electromyelography
ESI	epidural steroid injection
GROC	Global Rating of Change
JOA	Japanese Orthopaedic Association
LLA	lumbar lordotic angles
LR	likelihood ratio
MED	Microendoscopic decompression
MR	magnetic resonance
MRI	magnetic resonance imaging
NASS	North American Spine Society
NCOS	Neurogenic Claudication Outcome Score
NSAIDs	nonsteroidal anti-inflammatory drugs
ODI	Oswestry Disability Index
PDS	pain and disability score
PLIF	Posterior lumbar interbody fusion
PLF	Posterolateral fusion
PPV	positive predictive value
QALY	quality adjusted life years
QST	quantitative sensory testing
RDQ	Roland-Morris Disability Questionairre
RCT	randomized controlled trial
SR	sagittal rotation
ST	sagittal translation
SLFE	standing lateral flexion-extension radiograph
SLR	straight leg raise
SEP	somatosensory evoked potentials
SNRB	selective nerve root block
TENS	transcutaneous electrical nerve stimulation
VAS	visual analog scale

B. Levels of Evidence for Primary Research Question[1]

Types of Studies				
	Therapeutic Studies – Investigating the results of treatment	Prognostic Studies – Investigating the effect of a patient characteristic on the outcome of disease	Diagnostic Studies – Investigating a diagnostic test	Economic and Decision Analyses – Developing an economic or decision model
Level I	• High quality randomized trial with statistically significant difference or no statistically significant difference but narrow confidence intervals • Systematic review[2] of Level I RCTs (and study results were homogenous[3])	• High quality prospective study[4] (all patients were enrolled at the same point in their disease with ≥ 80% follow-up of enrolled patients) • Systematic review2 of Level I studies	• Testing of previously developed diagnostic criteria on consecutive patients (with universally applied reference "gold" standard) • Systematic review[2] of Level I studies	• Sensible costs and alternatives; values obtained from many studies; with multiway sensitivity analyses • Systematic review[2] of Level I studies
Level II	• Lesser quality RCT (eg, < 80% follow-up, no blinding, or improper randomization) • Prospective[4] comparative study[5] • Systematic review[2] of Level II studies or Level 1 studies with inconsistent results	• Retrospective[6] study • Untreated controls from an RCT • Lesser quality prospective study (eg, patients enrolled at different points in their disease or <80% follow-up) • Systematic review[2] of Level II studies	• Development of diagnostic criteria on consecutive patients (with universally applied reference "gold" standard) • Systematic review[2] of Level II studies	• Sensible costs and alternatives; values obtained from limited studies; with multiway sensitivity analyses • Systematic review[2] of Level II studies
Level III	• Case control study[7] • Retrospective[6] comparative study[5] • Systematic review[2] of Level III studies	Case control study[7]	• Study of non-consecutive patients; without consistently applied reference "gold" standard • Systematic review[2] of Level III studies	• Analyses based on limited alternatives and costs; and poor estimates • Systematic review[2] of Level III studies
Level IV	Case series[8]	Case series	• Case-control study • Poor reference standard	Analyses with no sensitivity analyses
Level V	Expert Opinion	Expert Opinion	Expert Opinion	Expert Opinion

1. A complete assessment of quality of individual studies requires critical appraisal of all aspects of the study design.
2. A combination of results from two or more prior studies.
3. Studies provided consistent results.
4. Study was started before the first patient enrolled.
5. Patients treated one way (eg, cemented hip arthroplasty) compared with a group of patients treated in another way (eg, uncemented hip arthroplasty) at the same institution.
6. The study was started after the first patient enrolled.
7. Patients identified for the study based on their outcome, called "cases" (eg, failed total arthroplasty) are compared to those who did not have outcome, called "controls" (eg, successful total hip arthroplasty).
8. Patients treated one way with no comparison group of patients treated in another way.

C. Grades of Recommendations for Summaries or Reviews of Studies

A: Good evidence (Level I Studies with consistent finding) for or against recommending intervention.

B: Fair evidence (Level II or III Studies with consistent findings) for or against recommending intervention.

C: Poor quality evidence (Level IV or V Studies) for or against recommending intervention.

I: Insufficient or conflicting evidence not allowing a recommendation for or against intervention.

D. Linking Levels of Evidence to Grades of Recommendation

Grade of Recommendation	Standard Language	Levels of Evidence	
A	Recommended	Two or more consistent Level I studies	
B	Suggested	One Level I study with additional supporting Level II or III studies	Two or more consistent Level II or III studies
C	May be considered; is an option	One Level I, II or III study with supporting Level IV studies	Two or more consistent Level IV studies
I (Insufficient or Conflicting Evidence)	Insufficient evidence to make recommendation for or against	A single Level I, II, III or IV study without other supporting evidence	More than one study with inconsistent findings*
*Note that in the presence of multiple consistent studies, and a single outlying, inconsistent study, the Grade of Recommendation will be based on the level of consistent studies.			

E. Protocol for NASS Literature Searches

One of the most crucial elements of evidence analysis to support development of recommendations for appropriate clinical care or use of new technologies is the comprehensive literature search. Thorough assessment of the literature is the basis for the review of existing evidence, which will be instrumental to these activities. It is important that all searches conducted at NASS employ a solid search strategy, regardless of the source of the request. To this end, this protocol has been developed and NASS-wide implementation is recommended.

NASS research staff will work with the requesting parties and the NASS-contracted medical librarian to run a comprehensive search employing at a minimum the following search techniques:

1. A comprehensive search of the evidence will be conducted using the following clearly defined search parameters (as determined by the content experts). The following parameters are to be provided to research staff to facilitate this search.

- Time frames for search
- Foreign and/or English language
- Order of results (chronological, by journal, etc.)
- Key search terms and connectors, with or without MeSH terms to be employed
- Age range
- Answers to the following questions:
  - o Should duplicates be eliminated between searches?
  - o Should searches be separated by term or as one large package?
  - o Should human studies, animal studies or cadaver studies be included?

This search will encompass, at minimum, a search of Medline/PubMed, EMBASE, and Cochrane Library. Additional databases may be searched depending upon the topic.

2. Search results with abstracts will be compiled by the medical librarian in Endnote software. The medical librarian typically responds to requests and completes the searches within two to five business days. Results will be forwarded to the research staff, who will share it with the appropriate NASS staff member or requesting party(ies). (Research staff has access to EndNote software and will maintain a database of search results for future use/documentation.)

3. NASS staff shares the search results with an appropriate content expert (NASS Committee member or other) to assess relevance of articles and identify appropriate articles to review.

4. NASS research staff will work with LoansomeDoc library to obtain requested full-text articles for review.

5. NASS members reviewing full-text articles should also review the references at the end of each article to identify additional articles which should be reviewed, but may have been missed in the search.

Following this protocol will help ensure that NASS recommendations are (1) based on a thorough review of relevant literature; (2) are truly based on a uniform, comprehensive search strategy; and (3) represent the current best research evidence available. Research staff will maintain a search history in EndNote for future use or reference.

VII. Bibliography
(All citations from 2008 and 2013 literature searches)

1. Abbott AD, Tyni-lenné R, Hedlund R. Early rehabilitation targeting cognition, behavior, and motor function after lumbar fusion: a randomized controlled trial. Spine. 2010;35(8):848-57.
2. Abdul QR, Qayum MS, Saradhi MV, Panigrahi MK, Sreedhar V. Clinico-radiological profile of indirect neural decompression using cage or auto graft as interbody construct in posterior lumbar interbody fusion in spondylolisthesis: Which is better?. J Craniovertebr Junction Spine. 2011;2(1):12-6.
3. Acosta FL Jr, Christensen FB, Coe JD, et al. Early Clinical & Radiographic Results of NFix II Posterior Dynamic Stabilization System. SAS J. 2008;2(2):69-75.
4. Acosta FL, Thompson TL, Campbell S, Weinstein PR, Ames CP. Use of intraoperative isocentric C-arm 3D fluoroscopy for sextant percutaneous pedicle screw placement: case report and review of the literature. Spine J. 2005;5(3):339-43.
5. Adachi K, Futami T, Ebihara A, et al. Spinal canal enlargement procedure by restorative laminoplasty for the treatment of lumbar canal stenosis. Spine J. 2003;3(6):471-8.
6. Adogwa O, Parker SL, Bydon A, Cheng J, McGirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24(8):479-484.
7. Adogwa O, Parker SL, Davis BJ, et al. Cost-effectiveness of transforaminal lumbar interbody fusion for Grade I degenerative spondylolisthesis. J Neurosurg Spine. 2011;15(2):138-43.
8. Agabegi SS, Majid K, Fischgrund JS, Vaccaro AR, Patel T. Can preoperative radiographic parameters be used to predict fusion in non-instrumented posterolateral fusion for degenerative spondylolisthesis?. Spine. 2011;36(26):E1709-14.
9. Aihara T, Toyone T, Aoki Y, et al. Surgical management of degenerative lumbar spondylolisthesis. J Musculoskel Res. 2012;15(4).
10. Aiki H, Ohwada O, Kobayashi H, et al. Adjacent segment stenosis after lumbar fusion requiring second operation. J Orthop Sci. 2005;10(5):490-5.
11. Albert TJ, Desai D, Mcintosh T, Lamb D, Balderston RA. Early versus late replacement of autotransfused blood in elective spinal surgery. A prospective randomized study. Spine. 1993;18(8):1071-8.
12. Alexander DI, Manson NA, Mitchell MJ. Efficacy of calcium sulfate plus decompression bone in lumbar and lumbosacral spinal fusion: preliminary results in 40 patients. Can J Surg. 2001;44(4):262-6.
13. Alexander E, Kelly DL, Davis CH, Mcwhorter JM, Brown W. Intact arch spondylolisthesis. A review of 50 cases and description of surgical treatment. J Neurosurg. 1985;63(6):840-4.
14. Alfieri A, Gazzeri R, Prell J, et al. Role of lumbar interspinous distraction on the neural elements. Neurosurg Rev. 2012;35(4):477-84.
15. Aliabadi H, Isaacs R. Lumbar spinal stenosis: A brief review. Neurosurg Quart. 2009;19(3):200-206.
16. Allen RT, Rihn JA, Glassman SD, Currier B, Albert TJ, Phillips FM. An evidence-based approach to spine surgery. Am J Med Qual. 2009;24(6 Suppl):15S-24S.
17. Alt V, Chhabra A, Franke J, Cuche M, Schnettler R, Le huec JC. An economic analysis of using rhBMP-2 for lumbar fusion in Germany, France and UK from a societal perspective. Eur Spine J. 2009;18(6):800-6.
18. Andersen T, Christensen FB, Høy KW, et al. The predictive value of pain drawings in lumbar spinal fusion surgery. Spine J. 2010;10(5):372-9.
19. Anderson PA, Tribus CB, Kitchel SH. Treatment of neurogenic claudication by interspinous decompression: application of the X STOP device in patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2006;4(6):463-71.
20. Aoki Y, Yamagata M, Nakajima F, Ikeda Y, Takahashi K. Posterior migration of fusion cages in degenerative lumbar disease treated with transforaminal lumbar interbody fusion: a report of three patients. Spine. 2009;34(1):E54-8.
21. Aono H, Iwasaki M, Ohwada T, et al. Surgical outcome of drop foot caused by degenerative lumbar diseases. Spine. 2007;32(8):E262-6.
22. Apel DM, Lorenz MA, Zindrick MR. Symptomatic spondylolisthesis in adults: four decades later. Spine. 1989;14(3):345-8.
23. Aryan HE, Newman CB, Gold JJ, Acosta FL, Coover C, Ames CP. Percutaneous axial lumbar interbody fusion (AxiaLIF) of the L5-S1 segment: initial clinical and radiographic experience. Minim Invasive Neurosurg. 2008;51(4):225-30.
24. Asazuma T, Masuoka K, Motosuneya T, Tsuji T, Yasuoka H, Fujikawa K. Posterior lumbar interbody fusion using dense hydroxyapatite blocks and autogenous iliac bone: clinical and radiographic examinations. J Spinal Disord Tech. 2005;18 Suppl:S41-7.
25. Asghar FA, Hilibrand AS. The impact of the Spine Patient Outcomes Research Trial (SPORT) results on orthopaedic practice. J Am Acad Orthop Surg. 2012;20(3):160-6.
26. Atlas SJ, Delitto A. Spinal stenosis: surgical versus nonsurgical treatment. Clin Orthop Relat Res. 2006;443:198-207.
27. Austin RC, Branch CL, Alexander JT. Novel bioabsorbable interbody fusion spacer-assisted fusion for correction of spinal deformity. Neurosurg Focus. 2003;14(1):e11.
28. Axelsson P, Johnsson R, Strömqvist B. Is there increased intervertebral mobility in isthmic adult spondylolisthesis? A matched comparative study using roentgen stereophotogrammetry. Spine. 2000;25(13):1701-3.
29. Azzazi A, Elhawary Y. Dynamic stabilization using X-stop versus transpedicular screw fixation in the treatment of lumbar canal stenosis: comparative study of the clinical outcome. Neurosurg Quart., 2010;20(3):165-169.
30. Bae JS, Lee SH, Kim JS, Jung B, Choi G. Adjacent segment degeneration after lumbar interbody fusion with percutaneous pedicle screw fixation for adult low-grade isthmic spondylolisthesis: minimum 3 years of follow-up. Neurosurgery. 2010;67(6):1600-7.
31. Bagaria V. Re: Vaccaro AR, Patel T, Fischgrund J, et al. A pilot study evaluating safety and efficacy of OP-1 putty (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis for degenerative spondylolisthesis. Spine 2004;29:1885-92. Spine. 2006;31(7):851.
32. Bagheri MH, Hosseini MM, Foroughi AA. Pseudolisthesis secondary to small L5. Eur J Radiol. 2011;80(3):802-4.
33. Baker AD, Sanderson P. Spinal surgery in older people: Indications, techniques and outcomes. Rev Clin Geront. 2011;21(4):277-285.
34. Barbagallo GM, Olindo G, Corbino L, Albanese V. Analysis of complications in patients treated with the X-Stop Interspinous Process Decompression System: proposal for a novel anatomic

scoring system for patient selection and review of the literature. Neurosurgery. 2009;65(1):111-19.
35. Barrey C, Jund J, Perrin G, Roussouly P. Spinopelvic alignment of patients with degenerative spondylolisthesis. Neurosurgery. 2007;61(5):981-6.
36. Bartynski WS, Petropoulou KA. The MR imaging features and clinical correlates in low back pain-related syndromes. Magn Reson Imaging Clin N Am. 2007;15(2):137-54, v.
37. Bashir el F, Ajani O. Management of lumbar spine juxtafacet cysts. World Neurosurg. 2012;77(1):141-6.
38. Bassewitz H, Herkowitz H. Lumbar stenosis with spondylolisthesis: current concepts of surgical treatment. Clin Orthop Relat Res. 2001;(384):54-60.
39. Bederman SS, Coyte PC, Kreder HJ, Mahomed NN, Mcisaac WJ, Wright JG. Who's in the driver's seat? The influence of patient and physician enthusiasm on regional variation in degenerative lumbar spinal surgery: a population-based study. Spine. 2011;36(6):481-489.
40. Bednar DA. Surgical management of lumbar degenerative spinal stenosis with spondylolisthesis via posterior reduction with minimal laminectomy. J Spinal Disord Tech. 2002;15(2):105-9.
41. Been E, Li L, Hunter DJ, Kalichman L. Geometry of the vertebral bodies and the intervertebral discs in lumbar segments adjacent to spondylolysis and spondylolisthesis: pilot study. Eur Spine J. 2011;20(7):1159-65.
42. Belfi LM, Ortiz AO, Katz DS. Computed tomography evaluation of spondylolysis and spondylolisthesis in asymptomatic patients. Spine. 2006;31(24):E907-10.
43. Bendo JA, Ong B. Importance of correlating static and dynamic imaging studies in diagnosing degenerative lumbar spondylolisthesis. Am J Orthop. 2001;30(3):247-50.
44. Ben-galim P, Reitman CA. The distended facet sign: an indicator of position-dependent spinal stenosis and degenerative spondylolisthesis. Spine J. 2007;7(2):245-8.
45. Benini A, Plötz G. Reduction and stabilization without laminectomy for unstable degenerative spondylolisthesis: a preliminary report. Neurosurgery. 1995;37(4):843-4.
46. Benoist M. The natural history of lumbar degenerative spinal stenosis. Joint Bone Spine. 2002;69(5):450-7.
47. Berlemann U, Jeszenszky DJ, Bühler DW, Harms J. Facet joint remodeling in degenerative spondylolisthesis: an investigation of joint orientation and tropism. Eur Spine J. 1998;7(5):376-80.
48. Berlemann U, Jeszenszky DJ, Bühler DW, Harms J. Mechanisms of retrolisthesis in the lower lumbar spine. A radiographic study. Acta Orthop Belg. 1999;65(4):472-7.
49. Berlemann U, Jeszenszky DJ, Bühler DW, Harms J. The role of lumbar lordosis, vertebral end-plate inclination, disc height, and facet orientation in degenerative spondylolisthesis. J Spinal Disord. 1999;12(1):68-73.
50. Berven S, Tay BB, Colman W, Hu SS. The lumbar zygapophyseal (facet) joints: a role in the pathogenesis of spinal pain syndromes and degenerative spondylolisthesis. Semin Neurol. 2002;22(2):187-96.
51. Beutler WJ, Fredrickson BE, Murtland A, Sweeney CA, Grant WD, Baker D. The natural history of spondylolysis and spondylolisthesis: 45-year follow-up evaluation. Spine. 2003;28(10):1027-35.
52. Bjarke christensen F, Stender hansen E, Laursen M, Thomsen K, Bünger CE. Long-term functional outcome of pedicle screw instrumentation as a support for posterolateral spinal fusion: randomized clinical study with a 5-year follow-up. Spine. 2002;27(12):1269-77.
53. Blondel B, Adetchessi T, Pech-gourg G, Métellus P, Dufour H, Fuentes S. Minimally invasive transforaminal lumbar interbody fusion through a unilateral approach and percutaneous osteosynthesis. Orthop Traumatol Surg Res. 2011;97(6):595-601.
54. Blumenthal C, Curran J, Benzel EC, et al. Radiographic predictors of delayed instability following decompression without fusion for degenerative grade I lumbar spondylolisthesis. J Neurosurg Spine. 2013;18(4):340-6.
55. Blumenthal SL, Ohnmeiss DD. Intervertebral cages for degenerative spinal diseases. Spine J. 2003;3(4):301-9.
56. Boden SD. Spinescope. Semin Spine Surg. 2011;23(2):151-156.
57. Boden SD. Spinescope. Semin Spine Surg. 2012;24(2):133-137.
58. Boden SD, Riew KD, Yamaguchi K, Branch TP, Schellinger D, Wiesel SW. Orientation of the lumbar facet joints: association with degenerative disc disease. J Bone Joint Surg Am. 1996;78(3):403-11.
59. Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis. Instruct Course Lect. 1989;38:157-165.
60. Bolesta MJ, Winslow L, Gill K. A comparison of film and computer workstation measurements of degenerative spondylolisthesis: intraobserver and interobserver reliability. Spine. 2010;35(13):1300-3.
61. Bono CM, Kadaba M, Vaccaro AR. Posterior pedicle fixation-based dynamic stabilization devices for the treatment of degenerative diseases of the lumbar spine. J Spinal Disord Tech. 2009;22(5):376-83.
62. Bono CM, Lee CK. The influence of subdiagnosis on radiographic and clinical outcomes after lumbar fusion for degenerative disc disorders: an analysis of the literature from two decades. Spine. 2005;30(2):227-34.
63. Booth KC, Bridwell KH, Eisenberg BA, Baldus CR, Lenke LG. Minimum 5-year results of degenerative spondylolisthesis treated with decompression and instrumented posterior fusion. Spine. 1999;24(16):1721-7.
64. Bose B. Fracture of S1-2 after L4-S1 decompression and fusion. Case report and review of the literature. J Neurosurg. 2003;99(3 Suppl):310-2.
65. Bourassa-moreau E, Mac-thiong JM, Labelle H. Redefining the technique for the radiologic measurement of slip in spondylolisthesis. Spine. 2010;35(14):1401-5.
66. Brantigan JW, Neidre A. Achievement of normal sagittal plane alignment using a wedged carbon fiber reinforced polymer fusion cage in treatment of spondylolisthesis. Spine J. 2003;3(3):186-96.
67. Bridwell KH, Sedgewick TA, O'brien MF, Lenke LG, Baldus C. The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. J Spinal Disord. 1993;6(6):461-72.
68. Brislin B, Vaccaro AR. Advances in posterior lumbar interbody fusion. Orthop Clin North Am. 2002;33(2):367-74.
69. Brotis AG, Paterakis KN, Tsiamalou PM, Fountas KN, Hahjigeorgiou GM, Karavelis A. Instrumented posterior lumbar fusion outcomes for lumbar degenerative disorders in a southern European, semirural population. J Spinal Disord Tech. 2010;23(7):444-50.
70. Brower RS, Vickroy NM. A case of psoas ossification from the use of BMP-2 for posterolateral fusion at L4-L5. Spine. 2008;33(18):E653-5.
71. Brown, MD, Lockwood, JM. Degenerative spondylolisthesis. Instruct Course Lect. 1983;32:162-169.
72. Brown MD, Wehman KF, Heiner AD. The clinical usefulness of intraoperative spinal stiffness measurements. Spine. 2002;27(9):959-61.
73. Burkus JK, Dryer RF, Peloza JH. Retrograde ejaculation following single-level anterior lumbar surgery with or without recombinant human bone morphogenetic protein-2 in 5 randomized controlled trials: clinical article. J Neurosurg Spine. 2013;18(2):112-21.

74. Burkus JK, Gornet MF, Schuler TC, Kleeman TJ, Zdeblick TA. Six-year outcomes of anterior lumbar interbody arthrodesis with use of interbody fusion cages and recombinant human bone morphogenetic protein-2. J Bone Joint Surg Am. 2009;91(5):1181-9.
75. Burkus JK, Sandhu HS, Gornet MF. Influence of rhBMP-2 on the healing patterns associated with allograft interbody constructs in comparison with autograft. Spine. 2006;31:775-81.
76. Buttermann GR, Garvey TA, Hunt AF, et al. Lumbar fusion results related to diagnosis. Spine. 1998;23(1):116-27.
77. Cansever T, Civelek E, Kabatas S, Yılmaz C, Caner H, Altinörs MN. Dysfunctional segmental motion treated with dynamic stabilization in the lumbar spine. World Neurosurg. 2011;75(5-6):743-9.
78. Cansever T, Civelek E, Sencer A, Karasu A, Turantan I. Intermittent priapism in degenerative lumbar spinal stenosis: case report. Turk Neurosurg. 2007;17(4):260-3.
79. Carreon LY, Djurasovic M, Canan CE, Burke LO, Glassman SD. SF-6D values stratified by specific diagnostic indication. Spine. 2012;37(13):E804-8.
80. Carreon LY, Glassman SD, Howard J. Fusion and nonsurgical treatment for symptomatic lumbar degenerative disease: a systematic review of Oswestry Disability Index and MOS Short Form-36 outcomes. Spine J. 2008;8(5):747-55.
81. Carreon LY, Puno RM, Dimar JR, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. J Bone Joint Surg Am. 2003;85-A(11):2089-92.
82. Carrino JA, Lurie JD, Tosteson AN, et al. Lumbar spine: reliability of MR imaging findings. Radiology. 2009;250(1):161-70.
83. Caserta S, La maida GA, Misaggi B, et al. Elastic stabilization alone or combined with rigid fusion in spinal surgery: a biomechanical study and clinical experience based on 82 cases. Eur Spine J. 2002;11 Suppl 2:S192-7.
84. Caterini R, Mancini F, Bisicchia S, Maglione P, Farsetti P. The correlation between exaggerated fluid in lumbar facet joints and degenerative spondylolisthesis: prospective study of 52 patients. J Orthop Traumatol. 2011;12(2):87-91.
85. Cauchoix J, Benoist M, Chassaing V. Degenerative spondylolisthesis. Clin Orthop Relat Res. 1976;115:122-129.
86. Cavagna R, Daculsi G, Bouler JM. Macroporous calcium phosphate ceramic: a prospective study of 106 cases in lumbar spinal fusion. J Long Term Eff Med Implants. 1999;9(4):403-12.
87. Cavuşoğlu H, Türkmenoğlu O, Kaya RA, et al. Efficacy of unilateral laminectomy for bilateral decompression in lumbar spinal stenosis. Turk Neurosurg. 2007;17(2):100-8.
88. Chad DA. Lumbar spinal stenosis. Neurol Clin. 2007;25(2):407-18.
89. Chaloupka R, Krbec M, Cienciala J, et al. TWO YEAR CLINICAL RESULTS OF 360 DEGREE FUSION OF LUMBAR SPONDYLOLISTHESIS MANAGED BY TRANSPEDICULAR FIXATION AND PLIF OR ALIF TECHNIQUE. Eur Spine J. 2006;15(Suppl 4):S506-s507.
90. Chang P, Seow KH, Tan SK. Comparison of the results of spinal fusion for spondylolisthesis in patients who are instrumented with patients who are not. Singapore Med J. 1993;34(6):511-4.
91. Chaput C, Padon D, Rush J, Lenehan E, Rahm M. The significance of increased fluid signal on magnetic resonance imaging in lumbar facets in relationship to degenerative spondylolisthesis. Spine. 2007;32(17):1883-7.
92. Chaudhary KS, Groff MW. Minimally invasive transforaminal lumbar interbody fusion for degenerative spine. Tech Orthop. 2011;26(3):146-155.
93. Chen IR, Wei TS. Disc height and lumbar index as independent predictors of degenerative spondylolisthesis in middle-aged women with low back pain. Spine. 2009;34(13):1402-9.
94. Chen KX, Yang QY, Liu XC, Li HJ. [Treatment of degenerative lumbar spondylolisthesis through posterolateral fusion and fixation with pedicle screws]. Zhongguo Gu Shang. 2010;23(4):254-6. http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/900/CN-00766900/frame.html
95. Cho BY, Murovic JA, Park J. Imaging correlation of the degree of degenerative L4-5 spondylolisthesis with the corresponding amount of facet fluid. J Neurosurg Spine. 2009;11(5):614-9.
96. Chou R, Baisden J, Carragee EJ, Resnick DK, Shaffer WO, Loeser JD. Surgery for low back pain: a review of the evidence for an American Pain Society Clinical Practice Guideline. Spine. 2009;34(10):1094-109.
97. Chu G, Aikenmu K, He ZS. Unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis: A randomized controlled trial. J Clin Rehabil Tissue Eng Res. 2011;15(35):6540-6545.
98. Chung-Ting MW, Pak-Ho, AC, Cheung KK. A Prospective Study on the Outcome of Degenerative Lumbar Spinal Stenosis Treated With Open Laminotomy. J Orthop Trauma Rehabil. 2012;16(2):62-65.
99. Cinotti G, Postacchini F, Fassari F, Urso S. Predisposing factors in degenerative spondylolisthesis. A radiographic and CT study. Int Orthop. 1997;21(5):337-42.
100. Clarke JA, Van tulder MW, Blomberg SE, et al. Traction for low-back pain with or without sciatica. Cochrane Database Syst Rev. 2007;(2):CD003010.
101. Cloyd JM, Acosta FL, Ames CP. Complications and outcomes of lumbar spine surgery in elderly people: a review of the literature. J Am Geriatr Soc. 2008;56(7):1318-27.
102. Coe JD, Kitchel SH, Meisel HJ, Wingo CH, Lee SE, Jahng TA. NFlex Dynamic Stabilization System : Two-Year Clinical Outcomes of Multi-Center Study. J Korean Neurosurg Soc. 2012;51(6):343-9.
103. Cole CD, Mccall TD, Schmidt MH, Dailey AT. Comparison of low back fusion techniques: transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) approaches. Curr Rev Musculoskelet Med. 2009;2(2):118-26.
104. Crawford CH, Smail J, Carreon LY, Glassman SD. Health-related quality of life after posterolateral lumbar arthrodesis in patients seventy-five years of age and older. Spine. 2011;36(13):1065-8.
105. Crawford NR, Cagli S, Sonntag VK, Dickman CA. Biomechanics of grade I degenerative lumbar spondylolisthesis. Part 1: in vitro model. J Neurosurg. 2001;94(1 Suppl):45-50.
106. Csécsei G, Klekner A, Sikula J. Posterior lumbar interbody fusion (PLIF) using the bony elements of the dorsal spinal segment. Acta Chir Hung. 1997;36(1-4):54-6.
107. Cummins J, Lurie JD, Tosteson TD, et al. Descriptive epidemiology and prior healthcare utilization of patients in the Spine Patient Outcomes Research Trial's (SPORT) three observational cohorts: disc herniation, spinal stenosis, and degenerative spondylolisthesis. Spine. 2006;31(7):806-14.
108. Cutler AR, Siddiqui S, Mohan AL, Hillard VH, Cerabona F, Das K. Comparison of polyetheretherketone cages with femoral cortical bone allograft as a single-piece interbody spacer in transforaminal lumbar interbody fusion. J Neurosurg Spine. 2006;5(6):534-9.
109. Dai F, Belfer I, Schwartz CE, et al. Association of catechol-O-methyltransferase genetic variants with outcome in patients undergoing surgical treatment for lumbar degenerative disc disease. Spine J. 2010;10(11):949-57.
110. Dai LY. Orientation and tropism of lumbar facet joints in degenerative spondylolisthesis. Int Orthop. 2001;25(1):40-2.
111. Dai LY, Jia LS, Yuan W, Ni B, Zhu HB. Direct repair of defect in lumbar spondylolysis and mild isthmic spondylolisthesis by

bone grafting, with or without facet joint fusion. Eur Spine J. 2001;10(1):78-83.
112. Dai LY, Jiang LS. Single-level instrumented posterolateral fusion of lumbar spine with beta-tricalcium phosphate versus autograft: a prospective, randomized study with 3-year follow-up. Spine. 2008;33(12):1299-304.
113. Dall BE, Rowe DE. Degenerative spondylolisthesis. Its surgical management. Spine. 1985;10(7):668-672.
114. D'andrea G, Ferrante L, Dinia L, Caroli E, Orlando ER. "Supine-prone" dynamic X-ray examination: new method to evaluate low-grade lumbar spondylolisthesis. J Spinal Disord Tech. 2005;18(1):80-3.
115. Dantas FL, Prandini MN, Ferreira MA. Comparison between posterior lumbar fusion with pedicle screws and posterior lumbar interbody fusion with pedicle screws in adult spondylolisthesis. Arq Neuropsiquiatr. 2007;65(3B):764-70.
116. De iure F, Bosco G, Cappuccio M, Paderni S, Amendola L. Posterior lumbar fusion by peek rods in degenerative spine: preliminary report on 30 cases. Eur Spine J. 2012;21 Suppl 1:S50-4.
117. Dean CL, Gabriel JP, Cassinelli EH, Bolesta MJ, Bohlman HH. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-46.
118. Debusscher F, Troussel S. Direct repair of defects in lumbar spondylolysis with a new pedicle screw hook fixation: clinical, functional and Ct-assessed study. Eur Spine J. 2007;16(10):1650-8.
119. Deinsberger R, Kinn E, Ungersböck K. Microsurgical treatment of juxta facet cysts of the lumbar spine. J Spinal Disord Tech. 2006;19(3):155-60.
120. Delawi D, Dhert WJ, Rillardon L, et al. A prospective, randomized, controlled, multicenter study of osteogenic protein-1 in instrumented posterolateral fusions: report on safety and feasibility. Spine. 2010;35(12):1185-91.
121. Desai A, Ball PA, Bekelis K, et al. Surgery for lumbar degenerative spondylolisthesis in Spine Patient Outcomes Research Trial: does incidental durotomy affect outcome?. Spine. 2012;37(5):406-13.
122. Detwiler PW, Porter RW, Han PP, et al. Surgical treatment of lumbar spondylolisthesis. Adv Tech Stand Neurosurg. 2000;26:331-346.
123. Dewald CJ, Vartabedian JE, Rodts MF, Hammerberg KW. Evaluation and management of high-grade spondylolisthesis in adults. Spine. 2005;30(6 Suppl):S49-59.
124. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. J Neurosurg Spine. 2008;9(6):560-5.
125. Di silvestre M, Lolli F, Bakaloudis G. Degenerative lumbar scoliosis in elderly patients: dynamic stabilization without fusion versus posterior instrumented fusion. Spine J. 2014;14(1):1-10.
126. Dimar JR II, Djurasovic M, Carreon LY. Surgical management of degenerative and postsurgical spondylolisthesis. Semin Spine Surg. 2005;17(3 SPEC. ISS.):186-194.
127. Dimar JR, Glassman SD, Burkus JK, Pryor PW, Hardacker JW, Carreon LY. Clinical and radiographic analysis of an optimized rhBMP-2 formulation as an autograft replacement in posterolateral lumbar spine arthrodesis. J Bone Joint Surg Am. 2009;91(6):1377-86.
128. Disch AC, Schmoelz W, Matziolis G, Schneider SV, Knop C, Putzier M. Higher risk of adjacent segment degeneration after floating fusions: long-term outcome after low lumbar spine fusions. J Spinal Disord Tech. 2008;21(2):79-85.
129. Djurasovic M, Glassman SD, Dimar JR, Crawford CH, Bratcher KR, Carreon LY. Changes in the Oswestry Disability Index that predict improvement after lumbar fusion. J Neurosurg Spine. 2012;17(5):486-90.
130. Don AS, Robertson PA. Facet joint orientation in spondylolysis and isthmic spondylolisthesis. J Spinal Disord Tech. 2008;21(2):112-5.
131. Dupuis PR, Yong-hing K, Cassidy JD, Kirkaldy-willis WH. Radiologic diagnosis of degenerative lumbar spinal instability. Spine. 1985;10(3):262-76.
132. Ekman P, Möller H, Shalabi A, Yu YX, Hedlund R. A prospective randomised study on the long-term effect of lumbar fusion on adjacent disc degeneration. Eur Spine J. 2009;18(8):1175-86.
133. Elhawary Y, Azzazi A. Dynamic stabilization using X-stop vs. trans-pedicular screw fixation in the treatment of lumbar canal stenosis: Comparative study of the clinical outcome. Spine J. 2010; 10(9 suppl. 1):S130.
134. Eliyas JK, Karahalios D. Surgery for Degenerative Lumbar Spine Disease. Dis Mon. 2011;57(10):592-606.
135. Elster AD, Jensen KM. Computed tomography of spondylolisthesis: patterns of associated pathology. J Comput Assist Tomogr. 1985;9(5):867-74.
136. Epstein JA, Epstein BS, Lavine LS, Carras R, Rosenthal AD. Degenerative lumbar spondylolisthesis with an intact neural arch (pseudospondylolisthesis). J Neurosurg. 1976;44(2):139-47.
137. Epstein JA, Epstein BS, Lavine LS, Rosenthal AD, Decker RE, Carras R. Obliterative arachnoiditis complicating lumbar spinal stenosis. J Neurosurg. 1978;48(2):252-8.
138. Epstein NE. Evaluation of varied surgical approaches used in the management of 170 far-lateral lumbar disc herniations: indications and results. J Neurosurg. 1995;83(4):648-56.
139. Epstein NE. Primary fusion for the management of 'unstable' degenerative spondylolisthesis. Neuro Orthop. 1998;23(1-2):45-52.
140. Epstein NE. Lumbar laminectomy for the resection of synovial cysts and coexisting lumbar spinal stenosis or degenerative spondylolisthesis: an outcome study. Spine. 2004;29(9):1049-55.
141. Epstein NE. An analysis of noninstrumented posterolateral lumbar fusions performed in predominantly geriatric patients using lamina autograft and beta tricalcium phosphate. Spine J. 2008;8(6):882-7.
142. Epstein NE. X-Stop: foot drop. Spine J. 2009;9(5):e6-9.
143. Epstein NE, Epstein JA, Carras R, Lavine LS. Degenerative spondylolisthesis with an intact neural arch: a review of 60 cases with an analysis of clinical findings and the development of surgical management. Neurosurgery. 1983;13(5):555-61.
144. Escobar E, Transfeldt E, Garvey T, Ogilvie J, Graber J, Schultz L. Video-assisted versus open anterior lumbar spine fusion surgery: a comparison of four techniques and complications in 135 patients. Spine. 2003;28(7):729-32.
145. Eskander MS, Eskander JP, Drew JM, Pelow-aidlen JL, Eslami MH, Connolly PJ. A modified technique for dowel fibular strut graft placement and circumferential fusion in the setting of L5-S1 spondylolisthesis and multilevel degenerative disc disease. Neurosurgery. 2010;67(3 Suppl Operative):ons91-5.
146. Etame AB, Wang AC, Than KD, Park P. Clinical and radiographic outcomes after minimally invasive transforaminal lumbar interbody fusion. SAS J. 2010;4(2):47-53.
147. Excoffon SG, Wallace H. Chiropractic and rehabilitative management of a patient with progressive lumbar disk injury, spondylolisthesis, and spondyloptosis. J Manipulative Physiol Ther. 2006;29(1):66-71.
148. Faldini C, Pagkrati S, Acri F, et al. Surgical treatment of symptomatic degenerative lumbar spondylolisthesis by decompression and instrumented fusion. J Orthop Traumatol. 2007;8(3):128-133.

149. Fayyazi AH, Ordway NR, Park SA, Fredrickson BE, Yonemura K, Yuan HA. Radiostereometric analysis of postoperative motion after application of dynesys dynamic posterior stabilization system for treatment of degenerative spondylolisthesis. J Spinal Disord Tech. 2010;23(4):236-41.
150. Feffer HL, Wiesel SW, Cuckler JM, Rothman RH. Degenerative spondylolisthesis: To fuse or not to fuse. Spine. 1985;10(3):287-289.
151. Fernández-fairen M, Sala P, Ramírez H, Gil J. A prospective randomized study of unilateral versus bilateral instrumented posterolateral lumbar fusion in degenerative spondylolisthesis. Spine. 2007;32(4):395-401.
152. Ferrari S, Costa F, Fornari M. Conservative treatment with spontaneous stabilization of Grade II isthmic spondylolisthesis L5/S1 in a forty-four-year old woman, with a six-year follow-up: a case report. Eur J Phys Rehabil Med. 2012;48(2):275-81.
153. Ferreiro perez A, Garcia isidro M, Ayerbe E, Castedo J, Jinkins JR. Evaluation of intervertebral disc herniation and hypermobile intersegmental instability in symptomatic adult patients undergoing recumbent and upright MRI of the cervical or lumbosacral spines. Eur J Radiol. 2007;62(3):444-8.
154. Fersum KV, Dankaerts W, O'sullivan PB, et al. Integration of subclassification strategies in randomised controlled clinical trials evaluating manual therapy treatment and exercise therapy for non-specific chronic low back pain: a systematic review. Br J Sports Med. 2010;44(14):1054-62.
155. Fischgrund JS. The argument for instrumented decompressive posterolateral fusion for patients with degenerative spondylolisthesis and spinal stenosis. Spine. 2004;29(2):173-4.
156. Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT. 1997 Volvo Award winner in clinical studies. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation. Spine. 1997;22(24):2807-12.
157. Fitzgerald JA., Newman PH. Degenerative spondylolisthesis. J Bone Joint Surg Br. 1976;58(2):184-192.
158. Flynn JC, Hoque MA. Anterior fusion of the lumbar spine. End-result study with long-term follow-up. J Bone Joint Surg Am. 1979;61(8):1143-50.
159. France JC, Yaszemski MJ, Lauerman WC, et al. A randomized prospective study of posterolateral lumbar fusion. Outcomes with and without pedicle screw instrumentation. Spine. 1999;24(6):553-60.
160. Fransen P. Increasing pedicle screw anchoring in the osteoporotic spine by cement injection through the implant. Technical note and report of three cases. J Neurosurg Spine. 2007;7(3):366-9.
161. Fraser J, Gebhard H, Irie D, Parikh K, Härtl R. Iso-C/3-dimensional neuronavigation versus conventional fluoroscopy for minimally invasive pedicle screw placement in lumbar fusion. Minim Invasive Neurosurg. 2010;53(4):184-90.
162. Frazier DD, Lipson SJ, Fossel AH, Katz JN. Associations between spinal deformity and outcomes after decompression for spinal stenosis. Spine. 1997;22(17):2025-9.
163. Friberg O. Lumbar instability: a dynamic approach by traction-compression radiography. Spine. 1987;12(2):119-29.
164. Frymoyer JW, Selby DK. Segmental instability. Rationale for treatment. Spine. 1985;10(3):280-6.
165. Fu KM, Rhagavan P, Shaffrey CI, Chernavvsky DR, Smith JS. Prevalence, severity, and impact of foraminal and canal stenosis among adults with degenerative scoliosis. Neurosurgery. 2011;69(6):1181-7.
166. Fujimoto K, Yamazaki M, Hayashi K, et al. Posterior decompression with instrumented fusion in a patient with cervical myelopathy thirty years after cadaveric renal transplantation. Chiba Med J. 2011;87(1):11-15.
167. Fujiya M, Saita M, Kaneda K, Abumi K. Clinical study on stability of combined distraction and compression rod instrumentation with posterolateral fusion for unstable degenerative spondylolisthesis. Spine. 1990;15(11):1216-22.
168. Furlan AF, Yazdi F, Tsertsvadze A, et al. Acupuncture for (sub) acute non-specific low-back pain. Cochrane Database Syst Rev. 2011;(8):CD009265.
169. Gaetani P, Aimar E, Panella L, et al. Functional disability after instrumented stabilization in lumbar degenerative spondylolisthesis: a follow-up study. Funct Neurol. 2006;21(1):31-7.
170. Gavaskar AS, Achimuthu R. Transfacetal fusion for low-grade degenerative spondylolisthesis of the lumbar spine: results of a prospective single center study. J Spinal Disord Tech. 2010;23(3):162-5.
171. Gehrchen PM, Dahl B, Katonis P, Blyme P, Tøndevold E, Kiaer T. No difference in clinical outcome after posterolateral lumbar fusion between patients with isthmic spondylolisthesis and those with degenerative disc disease using pedicle screw instrumentation: a comparative study of 112 patients with 4 years of follow-up. Eur Spine J. 2002;11(5):423-7.
172. Gelalis ID, Arnaoutoglou C, Christoforou G, Lykissas MG, Batsilas I, Xenakis T. Prospective analysis of surgical outcomes in patients undergoing decompressive laminectomy and posterior instrumentation for degenerative lumbar spinal stenosis. Acta Orthop Traumatol Turc. 2010;44(3):235-40.
173. Gelalis ID, Kang JD. Thoracic and lumbar fusions for degenerative disorders: rationale for selecting the appropriate fusion techniques. Orthop Clin North Am. 1998;29(4):829-42.
174. Gertzbein SD, Seligman J, Holtby R, et al. Centrode patterns and segmental instability in degenerative disc disease. Spine. 1985;10(3):257-61.
175. Ghiselli G, Wang JC, Hsu WK, Dawson EG. L5-S1 segment survivorship and clinical outcome analysis after L4-L5 isolated fusion. Spine. 2003;28(12):1275-80.
176. Ghogawala Z, Benzel EC, Amin-Hanjani S, et al. Prospective outcomes evaluation after decompression with or without instrumented fusion for lumbar stenosis and degenerative Grade I spondylolisthesis. J Neurosurg Spine. 2004;1(3):267-272.
177. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2005;(4):CD001352.
178. Gibson JN, Grant IC, Waddell G. The Cochrane review of surgery for lumbar disc prolapse and degenerative lumbar spondylosis. Spine. 1999;24(17):1820-32.
179. Gibson JN, Waddell G, Grant IC. Surgery for degenerative lumbar spondylosis. Cochrane Database Syst Rev. 2000;(2):CD001352.
180. Gibson JN, Waddell G. Surgery for degenerative lumbar spondylosis: updated Cochrane Review. Spine. 2005;30(20):2312-20.
181. Gilbert JW, Wheeler GR, Kreft MP, et al. Repeat upright positional magnetic resonance imaging for diagnosis of disorders underlying chronic noncancer lumbar pain. J Manipulative Physiol Ther. 2008;31(8):627-31.
182. Gillet P, Petit M. Direct repair of spondylolysis without spondylolisthesis, using a rod-screw construct and bone grafting of the pars defect. Spine. 1999;24(12):1252-6.
183. Glaser JA, Bernhardt M, Found EM, McDowell GS, Wetzel FT. Lumbar arthrodesis for degenerative conditions. Instruct Course Lect. 2004;53:325-340.
184. Glassman SD, Carreon LY, Dimar JR, Campbell MJ, Puno RM, Johnson JR. Clinical outcomes in older patients after posterolateral lumbar fusion. Spine J. 2007;7(5):547-51.
185. Glassman SD, Carreon LY, Djurasovic M, et al. Lumbar fusion outcomes stratified by specific diagnostic indication. Spine J.

2009;9(1):13-21.
186. Graham N, Gross A, Goldsmith CH, et al. Mechanical traction for neck pain with or without radiculopathy. Cochrane Database Syst Rev. 2008;(3):CD006408.
187. Grob D. Surgery for degenerative lumbar disease: Transforaminal lumbar interbody fusion. Eur Spine J. 2009;18(12):1991-1992.
188. Grob D, Humke T, Dvorak J. Direct pediculo-body fixation in cases of spondylolisthesis with advanced intervertebral disc degeneration. Eur Spine J. 1996;5(4):281-5.
189. Grobler LJ, Robertson PA, Novotny JE, Ahern JW. Decompression for degenerative spondylolisthesis and spinal stenosis at L4-5. The effects on facet joint morphology. Spine. 1993;18(11):1475-82.
190. Grobler LJ, Robertson PA, Novotny JE, Pope MH. Etiology of spondylolisthesis. Assessment of the role played by lumbar facet joint morphology. Spine. 1993;18(1):80-91.
191. Gross A, Forget M, St George K, et al. Patient education for neck pain. Cochrane Database Syst Rev. 2012;3:CD005106.
192. Ha KY, Na KH, Shin JH, Kim KW. Comparison of posterolateral fusion with and without additional posterior lumbar interbody fusion for degenerative lumbar spondylolisthesis. J Spinal Disord Tech. 2008;21(4):229-34.
193. Haberl H, Cripton PA, Orr TE, et al. Kinematic response of lumbar functional spinal units to axial torsion with and without superimposed compression and flexion/extension. Eur Spine J. 2004;13(6):560-6.
194. Hackenberg L, Halm H, Bullmann V, Vieth V, Schneider M, Liljenqvist U. Transforaminal lumbar interbody fusion: a safe technique with satisfactory three to five year results. Eur Spine J. 2005;14(6):551-8.
195. Hahn F, Kissling R, Weishaupt D, Boos N. The extremes of spinal motion: a kinematic study of a contortionist in an open-configuration magnetic resonance scanner: case report. Spine. 2006;31(16):E565-7.
196. Hambly MF, Wiltse LL, Raghavan N, Schneiderman G, Koenig C. The transition zone above a lumbosacral fusion. Spine. 1998;23(16):1785-92.
197. Hammouri QM, Haims AH, Simpson AK, Alqaqa A, Grauer JN. The utility of dynamic flexion-extension radiographs in the initial evaluation of the degenerative lumbar spine. Spine. 2007;32(21):2361-4.
198. Hanley EN. Decompression and distraction-derotation arthrodesis for degenerative spondylolisthesis. Spine. 1986;11(3):269-76.
199. Hanley EN. The indications for lumbar spinal fusion with and without instrumentation. Spine. 1995;20(24 Suppl):143S-153S.
200. Hanley EN. Indications for fusion in the lumbar spine. Bull Hosp Jt Dis. 1996;55(3):154-157.
201. Hansraj KK, O'leary PF, Cammisa FP, et al. Decompression, fusion, and instrumentation surgery for complex lumbar spinal stenosis. Clin Orthop Relat Res. 2001;(384):18-25.
202. Hara M, Nishimura Y, Takemoto M, Nakamura S, Wakabayashi T. Posterior fixation for lumbar degenerative spondylosis: Mini-open TLIF. Neurol Med Chir (Tokyo). 2012;21(2):118-127.
203. Haro H, Maekawa S, Hamada Y. Prospective analysis of clinical evaluation and self-assessment by patients after decompression surgery for degenerative lumbar canal stenosis. Spine J. 2008;8(2):380-4.
204. Harris EB, Sayadipour A, Massey P, Duplantier NL, Anderson DG. Mini-open versus open decompression and fusion for lumbar degenerative spondylolisthesis with stenosis. Am J Orthop. 2011;40(12):E257-61.
205. Hart RA, Prendergast MA. Spine surgery for lumbar degenerative disease in elderly and osteoporotic patients. Instr Course Lect. 2007;56:257-72.
206. Hasegawa K, Kitahara K, Hara T, Takano K, Shimoda H, Homma T. Evaluation of lumbar segmental instability in degenerative diseases by using a new intraoperative measurement system. J Neurosurg Spine. 2008;8(3):255-62.
207. Hasegawa K, Kitahara K, Shimoda H, Hara T. Facet joint opening in lumbar degenerative diseases indicating segmental instability. J Neurosurg Spine. 2010;12(6):687-93.
208. Hasegawa K, Shimoda H, Kitahara K, Sasaki K, Homma T. What are the reliable radiological indicators of lumbar segmental instability?. J Bone Joint Surg Br. 2011;93(5):650-7.
209. Hashimoto T, Oha F, Shigenobu K, et al. Mid-term clinical results of Graf stabilization for lumbar degenerative pathologies. a minimum 2-year follow-up. Spine J. 2001;1(4):283-9.
210. Hashimoto T, Shigenobu K, Kanayama M, et al. Clinical results of single-level posterior lumbar interbody fusion using the Brantigan I/F carbon cage filled with a mixture of local morselized bone and bioactive ceramic granules. Spine. 2002;27(3):258-62.
211. Hatta Y, Shiraishi T, Sakamoto A, et al. Muscle-preserving interlaminar decompression for the lumbar spine: a minimally invasive new procedure for lumbar spinal canal stenosis. Spine. 2009;34(8):E276-80.
212. Hayashi T, Arizono T, Fujimoto T, et al. Degenerative change in the adjacent segments to the fusion site after posterolateral lumbar fusion with pedicle screw instrumentation--a minimum 4-year follow-up. Fukuoka Igaku Zasshi. 2008;99(5):107-13.
213. Hayeri MR, Tehranzadeh J. Diagnostic imaging of spinal fusion and complications. Appl Radiol. 2009;38(7-8):14-28.
214. Hee HT, Wong HK. The long-term results of surgical treatment for spinal stenosis in the elderly. Singapore Med J. 2003;44(4):175-80.
215. Helenius I, Remes V, Poussa M. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. Surgical technique. J Bone Joint Surg Am. 2008;90 Suppl 2 Pt 1:145-52.
216. Heo DH, Cho YJ, Cho SM, Choi HC, Kang SH. Adjacent segment degeneration after lumbar dynamic stabilization using pedicle screws and a nitinol spring rod system with 2-year minimum follow-up. J Spinal Disord Tech. 2012;25(8):409-14.
217. Herkowitz HN. Spine update degenerative lumbar spondylolisthesis. Spine. 1995;20(9):1084-1090.
218. Herkowitz HN. Degenerative lumbar spondylolisthesis: evolution of surgical management. Spine J. 2009;9(7):605-6.
219. Herkowitz HN. Degenerative lumbar spondylolisthesis: a surgeon's perspective of 30 years in practice. Spine J. 2010;10(10):916-7.
220. Herkowitz HN, Abraham DJ, Albert TJ. Management of degenerative disc disease above an L5-S1 segment requiring arthrodesis. Spine. 1999;24(12):1268-70.
221. Herkowitz HN, Kurz LT. Degenerative lumbar spondylolisthesis with spinal stenosis: A prospective study comparing decompression with decompression and intertransverse process arthrodesis. J Bone Jt Surg Am. 1991;73(6):802-808.
222. Herno A, Partanen K, Talaslahti T, et al. Long-term clinical and magnetic resonance imaging follow-up assessment of patients with lumbar spinal stenosis after laminectomy. Spine. 1999;24(15):1533-7.
223. Herron LD, Newman MH. The failure of ethylene oxide gas-sterilized freeze-dried bone graft for thoracic and lumbar spinal fusion. Spine. 1989;14(5):496-500.
224. Herron LD, Trippi AC. L4-5 degenerative spondylolisthesis. The results of treatment by decompressive laminectomy without fusion. Spine. 1989;14(5):534-8.
225. Hilibrand AS, Rand N. Degenerative lumbar stenosis: diagnosis and management. J Am Acad Orthop Surg. 1999;7(4):239-49.
226. Hirabayashi S, Kumano K, Kuroki T. Cotrel-Dubousset pedicle

screw system for various spinal disorders. Merits and problems. Spine. 1991;16(11):1298-304.
227. Hitchon PW, Taggard DA. Lumbar spine fusion enhanced by pedicle screw fixation. Tech Neurosurg. 1998;4(3):211-215.
228. Hong SW, Lee HY, Kim KH, Lee SH. Interspinous ligamentoplasty in the treatment of degenerative spondylolisthesis: midterm clinical results. J Neurosurg Spine. 2010;13(1):27-35.
229. Houten JK, Post NH, Dryer JW, Errico TJ. Clinical and radiographically/neuroimaging documented outcome in transforaminal lumbar interbody fusion. Neurosurg Focus. 2006;20(3):E8.
230. Hrabálek L, Wanek T, Adamus M. [Treatment of degenerative spondylolisthesis of the lumbosacral spine by decompression and dynamic transpedicular stabilisation]. Acta Chir Orthop Traumatol Cech. 2011;78(5):431-6.
231. Hsieh PC, Koski TR, O'shaughnessy BA, et al. Anterior lumbar interbody fusion in comparison with transforaminal lumbar interbody fusion: implications for the restoration of foraminal height, local disc angle, lumbar lordosis, and sagittal balance. J Neurosurg Spine. 2007;7(4):379-86.
232. Hu SS, Tribus CB, Diab M, Ghanayem AJ. Spondylolisthesis and spondylolysis. Instr Course Lect. 2008;57:431-445.
233. Hu Y, Gu YJ, Xu RM, Zhou LJ, Ma WH. Short-term clinical observation of the Dynesys neutralization system for the treatment of degenerative disease of the lumbar vertebrae. Orthop Surg. 2011;3(3):167-75.
234. Huang KF, Chen TY. Clinical results of a single central interbody fusion cage and transpedicle screws fixation for recurrent herniated lumbar disc and low-grade spondylolisthesis. Chang Gung Med J. 2003;26(3):170-7.
235. Huang KY, Lin RM, Lee YL, Li JD. Factors affecting disability and physical function in degenerative lumbar spondylolisthesis of L4-5: evaluation with axially loaded MRI. Eur Spine J. 2009;18(12):1851-7.
236. Huang TY, Lee KS, Tsai TH, Su YF, Hwang SL. Posterior epidural migration of sequestrated lumbar disc fragments into the bilateral facet joints: case report. Neurosurgery. 2011;69(5):E1148-51.
237. Hunt T, Shen FH, Shaffrey CI, Arlet V. Contralateral radiculopathy after transforaminal lumbar interbody fusion. Eur Spine J. 2007;16 Suppl 3:311-314.
238. Hussain NS, Hanscom D, Oskouian RJ. Chyloretroperitoneum following anterior spinal surgery. J Neurosurg Spine. 2012;17(5):415-21.
239. Hwang CJ, Vaccaro AR, Hong J, et al. Immunogenicity of osteogenic protein 1: results from a prospective, randomized, controlled, multicenter pivotal study of uninstrumented lumbar posterolateral fusion. J Neurosurg Spine. 2010;13(4):484-93.
240. Ibrahimi DM, Beaty NB, Crandall KM, Hamilton DK, Sansur CA. A review of lumbar spondylolisthesis. Eur Musculoskel Rev. 2011;6(2):110-113.
241. Ido K, Urushidani H. Radiographic evaluation of posterolateral lumbar fusion for degenerative spondylolisthesis: long-term follow-up of more than 10 years vs. midterm follow-up of 2-5 years. Neurosurg Rev. 2001;24(4):195-9.
242. Ikuta K, Tono O, Oga M. Clinical outcome of microendoscopic posterior decompression for spinal stenosis associated with degenerative spondylolisthesis--minimum 2-year outcome of 37 patients. Minim Invasive Neurosurg. 2008;51(5):267-71.
243. Ikuta K, Tono O, Oga M. Prevalence and clinical features of intraspinal facet cysts after decompression surgery for lumbar spinal stenosis. J Neurosurg Spine. 2009;10(6):617-22.
244. Indar R, Tsiridis E, Morgan M, Aldham CH, Hussein AA. Intraspinal lumbar synovial cysts: diagnosis and surgical management. Surgeon. 2004;2(3):141-4.
245. Inoue S, Watanabe T, Goto S, Takahashi K, Takata K, Sho E. Degenerative spondylolisthesis. Pathophysiology and results of anterior interbody fusion. Clin Orthop Relat Res. 1988;227:90-8.
246. Irwin ZN, Hilibrand A, Gustavel M, et al. Variation in surgical decision making for degenerative spinal disorders. Part I: lumbar spine. Spine. 2005;30(19):2208-13.
247. Ito K. Reviewer's comments concerning "Biomechanical evaluation of segmental instability in degenerative lumbar spondylolisthesis" by K. Hasegawa et al. (ESJO-D-08-00441R1). Eur Spine J. 2009;18(4):471-2.
248. Ito S, Yamada Y, Tuboi S, Yamada Y, Muro T. Specific pattern of ruptured annulus fibrosus in lumbar degenerative spondylolisthesis. Neuroradiology. 1990;32(6):460-3.
249. Ito Y, Oda H, Taguchi T, Inoue H, Kawai S. Results of surgical treatment for lumbar canal stenosis due to degenerative spondylolisthesis: enlargement of the lumbar spinal canal. J Orthop Sci. 2003;8(5):648-56.
250. Ito Z, Matsuyama Y, Sakai Y, et al. Bone union rate with autologous iliac bone versus local bone graft in posterior lumbar interbody fusion. Spine. 2010;35(21):E1101-5.
251. Iwamoto J, Takeda T. Effect of surgical treatment on physical activity and bone resorption in patients with neurogenic intermittent claudication. J Orthop Sci. 2002;7(1):84-90.
252. Peloso P, Gross A, Haines T, et al. Medicinal and injection therapies for mechanical neck disorders. Cochrane Database Syst Rev. 2007;(3):CD000319.
253. Jackson A, Isherwood I. Does degenerative disease of the lumbar spine cause arachnoiditis? A magnetic resonance study and review of the literature. Br J Radiol. 1994;67(801):840-7.
254. Jackson RK, Boston DA, Edge AJ. Lateral mass fusion. A prospective study of a consecutive series with long-term follow-up. Spine. 1985;10(9):828-32.
255. Jacobs W, Van der gaag NA, Tuschel A, et al. Total disc replacement for chronic back pain in the presence of disc degeneration. Cochrane Database Syst Rev. 2012;9:CD008326.
256. Jacobsen S, Sonne-holm S, Rovsing H, Monrad H, Gebuhr P. Degenerative lumbar spondylolisthesis: an epidemiological perspective: the Copenhagen Osteoarthritis Study. Spine. 2007;32(1):120-5.
257. Jagannathan J, Sansur CA, Oskouian RJ, Fu KM, Shaffrey CI. Radiographic restoration of lumbar alignment after transforaminal lumbar interbody fusion. Neurosurgery. 2009;64(5):955-63.
258. Jaovisidha S, Techatipakorn S, Apiyasawat P, Laohacharoensombat W, Poramathikul M, Siriwongpairat P. Degenerative disk disease at lumbosacral junction: plain film findings and related MRI abnormalities. J Med Assoc Thai. 2000;83(8):865-71.
259. Jayakumar P, Nnadi C, Saifuddin A, Macsweeney E, Casey A. Dynamic degenerative lumbar spondylolisthesis: diagnosis with axial loaded magnetic resonance imaging. Spine. 2006;31(10):E298-301..
260. Jenis LG, Banco RJ, Kwon B. A prospective study of Autologous Growth Factors (AGF) in lumbar interbody fusion. Spine J. 2006;6(1):14-20.
261. Jiang SD, Jiang LS, Dai LY. Degenerative cervical spondylolisthesis: a systematic review. Int Orthop. 2011;35(6):869-75.
262. Jin J, Jianxiong S, Guixing Q, Hong Z, Xisheng W, Yipeng W. Surgical treatment of spondylolisthesis with SOCON instrumentation. Chin Med Sci J. 2000;15(2):111-4.
263. Jinkins JR. Acquired degenerative changes of the intervertebral segments at and supradjacent to the lumbosacral junction: A radioanatomic analysis of the discal and nondiscal structures of the spinal column and perispinal soft tissues. Neuroradiol J. 2002;15(4):359-392.
264. Jiya TU, Smit T, Van royen BJ, Mullender M. Posterior lumbar interbody fusion using non resorbable poly-ether-ether-ketone versus resorbable poly-L-lactide-co-D,L-lactide fusion devices.

Clinical outcome at a minimum of 2-year follow-up. Eur Spine J. 2011;20(4):618-22.
265. Jo DJ, Jun JK, Kim KT, Kim SM. Lumbar Interbody Fusion Outcomes in Degenerative Lumbar Disease : Comparison of Results between Patients Over and Under 65 Years of Age. J Korean Neurosurg Soc. 2010;48(5):412-8.
266. Johnson JR, Kirwan EO. The long-term results of fusion in situ for severe spondylolisthesis. J Bone Joint Surg Br. 1983;65(1):43-6.
267. Johnsson KE, Willner S, Johnsson K. Postoperative instability after decompression for lumbar spinal stenosis. Spine. 1986;11(2):107-110.
268. Jones TR, Rao RD. Adult isthmic spondylolisthesis. J Am Acad Orthop Surg. 2009;17(10):609-617.
269. Kai Y, Oyama M, Morooka M. Posterior lumbar interbody fusion using local facet joint autograft and pedicle screw fixation. Spine. 2004;29(1):41-6.
270. Kakiuchi M, Ono K. Defatted, gas-sterilised cortical bone allograft for posterior lumbar interbody vertebral fusion. Int Orthop. 1998;22(2):69-76.
271. Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. Spine. 2009;34(18):1963-9.
272. Kalichman L, Hunter DJ. Degenerative lumbar spondylolisthesis: Anatomy, biomechanics and risk factors. J Back Musculoskel Rehabil. 2008;21(1):1-12.
273. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17(3):327-35.
274. Kalpakcioglu B, Altinbilek T, Senel K. Determination of spondylolisthesis in low back pain by clinical evaluation. J Back Musculoskelet Rehabil. 2009;22(1):27-32.
275. Kamioka Y, Yamamoto H. Lumbar trapezoid plate for lumbar spondylolisthesis. A clinical study on preoperative and postoperative instability. Spine. 1990;15(11):1198-203.
276. Kanayama M, Hashimoto T, Shigenobu K, et al. Adjacent-segment morbidity after Graf ligamentoplasty compared with posterolateral lumbar fusion. J Neurosurg. 2001;95(1 Suppl):5-10.
277. Kanayama M, Hashimoto T, Shigenobu K, Oha F, Ishida T, Yamane S. Intraoperative biomechanical assessment of lumbar spinal instability: validation of radiographic parameters indicating anterior column support in lumbar spinal fusion. Spine. 2003;28(20):2368-72.
278. Kanayama M, Hashimoto T, Shigenobu K, Togawa D, Oha F. A minimum 10-year follow-up of posterior dynamic stabilization using Graf artificial ligament. Spine. 2007;32(18):1992-6.
279. Kanayama M, Hashimoto T, Shigenobu K, Yamane S, Bauer TW, Togawa D. A prospective randomized study of posterolateral lumbar fusion using osteogenic protein-1 (OP-1) versus local autograft with ceramic bone substitute: emphasis of surgical exploration and histologic assessment. Spine. 2006;31(10):1067-74.
280. Kaner T, Dalbayrak S, Oktenoglu T, Sasani M, Aydin AL, Ozer AF. Comparison of posterior dynamic and posterior rigid transpedicular stabilization with fusion to treat degenerative spondylolisthesis. Orthopedics. 2010;33(5)
281. Kang BU, Choi WC, Lee SH, et al. An analysis of general surgery-related complications in a series of 412 minilaparotomic anterior lumbosacral procedures. J Neurosurg Spine. 2009;10(1):60-5.
282. Kang, C. H., Shin, M. J., Kim, S. M., Lee, S. H., & Lee, C. S. (2007). MRI of paraspinal muscles in lumbar degenerative kyphosis patients and control patients with chronic low back pain. Clinical radiology, 62(5), 479-486. doi: 10.1016/j.crad.2006.12.002
283. Kantelhardt SR, Török E, Gempt J, et al. Safety and efficacy of a new percutaneously implantable interspinous process device. Acta Neurochir (Wien). 2010;152(11):1961-7.
284. Karabekir HS, Atar EK, Yaycioglu S, Yildizhan A. Comparison of unilateral posterior lumbar interbody fusion and bilateral posterior interbody fusion with simple discectomy at degenerative disc herniations. Neurosciences (Riyadh). 2008;13(3):248-52.
285. Kasliwal MK, Deutsch H. Clinical and radiographic outcomes using local bone shavings as autograft in minimally invasive transforaminal lumbar interbody fusion. World Neurosurg. 2012;78(1-2):185-90.
286. Katonis P, Christoforakis J, Kontakis G, et al. Complications and problems related to pedicle screw fixation of the spine. Clin Orthop Relat Res. 2003;(411):86-94.
287. Katz JN, Lipson SJ, Lew RA, et al. Lumbar laminectomy alone or with instrumented or noninstrumented arthrodesis in degenerative lumbar spinal stenosis. Patient selection, costs, and surgical outcomes. Spine. 1997;22(10):1123-1131.
288. Kauppila LI, Eustace S, Kiel DP, Felson DT, Wright AM. Degenerative displacement of lumbar vertebrae. A 25-year follow-up study in Framingham. Spine. 1998;23(17):1868-73.
289. Kawakami M, Tamaki T, Ando M, Yamada H, Hashizume H, Yoshida M. Lumbar sagittal balance influences the clinical outcome after decompression and posterolateral spinal fusion for degenerative lumbar spondylolisthesis. Spine. 2002;27(1):59-64.
290. Kay TM, Gross A, Goldsmith CH, et al. Exercises for mechanical neck disorders. Cochrane Database Syst Rev. 2012;8:CD004250.
291. Kelleher MO, Timlin M, Persaud O, Rampersaud YR. Success and failure of minimally invasive decompression for focal lumbar spinal stenosis in patients with and without deformity. Spine. 2010;35(19):E981-7.
292. Kepler CK, Rihn JA, Radcliff KE, et al. Restoration of lordosis and disk height after single-level transforaminal lumbar interbody fusion. Orthop Surg. 2012;4(1):15-20.
293. Khan AM, Girardi F. Spinal lumbar synovial cysts. Diagnosis and management challenge. Eur Spine J. 2006;15(8):1176-82.
294. Khan AM, Synnot K, Cammisa FP, Girardi FP. Lumbar synovial cysts of the spine: an evaluation of surgical outcome. J Spinal Disord Tech. 2005;18(2):127-31.
295. Khan JA, Bajracharya AR. Surgical treatment of isthmic spondylolisthesis with radicular pain in adults. JNMA J Nepal Med Assoc. 2007;46(168):170-4.
296. Kim DH, Albert TJ. Update on use of instrumentation in lumbar spine disorders. Best Pract Res Clin Rheumatol. 2002;16(1):123-40.
297. Kim DH, Jeong ST, Lee SS. Posterior lumbar interbody fusion using a unilateral single cage and a local morselized bone graft in the degenerative lumbar spine. Clin Orthop Surg. 2009;1(4):214-21.
298. Kim DH, Shanti N, Tantorski ME, et al. Association between degenerative spondylolisthesis and spinous process fracture after interspinous process spacer surgery. Spine J. 2012;12(6):466-72.
299. Kim KS, Chin DK, Park JY. Herniated nucleus pulposus in isthmic spondylolisthesis: higher incidence of foraminal and extraforaminal types. Acta Neurochir (Wien). 2009;151(11):1445-50.
300. Kim KW, Ha KY, Moon MS, Kim YS, Kwon SY, Woo YK. Volumetric change of the graft bone after intertransverse fusion. Spine. 1999;24(5):428-33.
301. Kim MK, Lee SH, Kim ES, Eoh W, Chung SS, Lee CS. The impact of sagittal balance on clinical results after posterior interbody fusion for patients with degenerative spondylolisthesis: a pilot study. BMC Musculoskelet Disord. 2011;12:69.
302. Kim NH, Lee JW. The relationship between isthmic and degenerative spondylolisthesis and the configuration of the lamina

and facet joints. Eur Spine J. 1995;4(3):139-44.
303. Kim S, Mortaz Hedjri S, Coyte PC, Rampersaud YR. Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis. Spine J. 2012;12(1):44-54.
304. Kim SY, Maeng DH, Lee SH, Jang JS. Anterior lumbar interbody fusion for lumbosacral junction in steep sacral slope. J Spinal Disord Tech. 2008;21(1):33-8.
305. Kimura I, Shingu H, Murata M, Hashiguchi H. Lumbar posterolateral fusion alone or with transpedicular instrumentation in L4--L5 degenerative spondylolisthesis. J Spinal Disord. 2001;14(4):301-310.
306. Kinoshita T, Ohki I, Roth KR, Amano K, Moriya H. Results of degenerative spondylolisthesis treated with posterior decompression alone via a new surgical approach. J Neurosurg. 2001;95(1 Suppl):11-6.
307. Kirkaldy-willis WH, Wedge JH, Yong-hing K, Reilly J. Pathology and pathogenesis of lumbar spondylosis and stenosis. Spine. 1978;3(4):319-28.
308. Kirkman MA, Sridhar K. Posterior listhesis of a lumbar vertebra in spinal tuberculosis. Eur Spine J. 2011;20(1):1-5.
309. Kizilkilic O, Yalcin O, Sen O, Aydin MV, Yildirim T, Hurcan C. The role of standing flexion-extension radiographs for spondylolisthesis following single level disk surgery. Neurol Res. 2007;29(6):540-3.
310. Kleeman TJ, Hiscoe AC, Berg EE. Patient outcomes after minimally destabilizing lumbar stenosis decompression: the "Port-Hole" technique. Spine. 2000;25(7):865-70.
311. Kleinstueck FS, Fekete TF, Mannion AF, et al. To fuse or not to fuse in lumbar degenerative spondylolisthesis: do baseline symptoms help provide the answer?. Eur Spine J. 2012;21(2):268-75.
312. Klopfenstein JD, Kim LJ, Feiz-erfan I, Dickman CA. Retroperitoneal approach for lumbar interbody fusion with anterolateral instrumentation for treatment of spondylolisthesis and degenerative foraminal stenosis. Surg Neurol. 2006;65(2):111-6.
313. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T. Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg. 2009;129(1):1-5.
314. Knaub MA, Won DS, Mcguire R, Herkowitz HN. Lumbar spinal stenosis: indications for arthrodesis and spinal instrumentation. Instr Course Lect. 2005;54:313-9.
315. Knox BD, Harvell JC, Nelson PB, Hanley EN. Decompression and luque rectangle fusion for degenerative spondylolisthesis. J Spinal Disord. 1989;2(4):223-8.
316. Knuttson F. The instability associated with disc degeneration in the lumbar spine. Acta Radiol. 1944;25:593-609.
317. Konno S, Kikuchi S. Prospective study of surgical treatment of degenerative spondylolisthesis: comparison between decompression alone and decompression with graf system stabilization. Spine. 2000;25(12):1533-7.
318. Konno S, Kikuchi S, Tanaka Y, et al. A diagnostic support tool for lumbar spinal stenosis: a self-administered, self-reported history questionnaire. BMC Musculoskelet Disord. 2007;8:102.
319. Kornblum MB, Fischgrund JS, Herkowitz HN, Abraham DA, Berkower DL, Ditkoff JS. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective long-term study comparing fusion and pseudarthrosis. Spine. 2004;29(7):726-33.
320. Korovessis P, Koureas G, Zacharatos S, Papazisis Z, Lambiris E. Correlative radiological, self-assessment and clinical analysis of evolution in instrumented dorsal and lateral fusion for degenerative lumbar spine disease. Autograft versus coralline hydroxyapatite. Eur Spine J. 2005;14(7):630-8.
321. Korovessis P, Repantis T, Zacharatos S, Zafiropoulos A. Does Wallis implant reduce adjacent segment degeneration above lumbosacral instrumented fusion?. Eur Spine J. 2009;18(6):830-40.
322. Kotani Y, Abumi K, Ito M, Sudo H, Abe Y, Minami A. Mid-term clinical results of minimally invasive decompression and posterolateral fusion with percutaneous pedicle screws versus conventional approach for degenerative spondylolisthesis with spinal stenosis. Eur Spine J. 2012;21(6):1171-7.
323. Krishna M, Pollock RD, Bhatia C. Incidence, etiology, classification, and management of neuralgia after posterior lumbar interbody fusion surgery in 226 patients. Spine J. 2008;8(2):374-9.
324. Kristof RA, Aliashkevich AF, Schuster M, Meyer B, Urbach H, Schramm J. Degenerative lumbar spondylolisthesis-induced radicular compression: nonfusion-related decompression in selected patients without hypermobility on flexion-extension radiographs. J Neurosurg. 2002;97(3 Suppl):281-6.
325. Kroppenstedt S, Gulde M, Schönmayr R. Radiological comparison of instrumented posterior lumbar interbody fusion with one or two closed-box plasmapore coated titanium cages: follow-up study over more than seven years. Spine. 2008;33(19):2083-8.
326. Kuntz KM, Snider RK, Weinstein JN, Pope MH, Katz JN. Cost-effectiveness of fusion with and without instrumentation for patients with degenerative spondylolisthesis and spinal stenosis. Spine. 2000;25(9):1132-9.
327. Kuroki H, Tajima N, Kubo S. Clinical results of posterolateral fusion for degenerative lumbar spinal diseases: a follow-up study of more than 10 years. J Orthop Sci. 2002;7(3):317-24.
328. Kurz LT, Garfin SR, Unger AS, Thorne RP, Rothman RH. Intraspinal synovial cyst causing sciatica. J Bone Joint Surg Am. 1985;67(6):865-71.
329. Kwon BK, Albert TJ. Adult low-grade acquired spondylolytic spondylolisthesis: evaluation and management. Spine. 2005;30(6 Suppl):S35-41.
330. Lakdawala RH, Rahmat R, Tan L, Wong HK. Aortic flap valve presenting as neurogenic claudication: a case report. Spine. 2004;29(4):E79-81.
331. Lamberg T, Remes V, Helenius I, et al. Uninstrumented in situ fusion for high-grade childhood and adolescent isthmic spondylolisthesis: long-term outcome. J Bone Jt Surg Am. 2007;89(3):512-518.
332. Langerak NG, Vaughan CL, Hoffman EB, Figaji AA, Fieggen AG, Peter JC. Incidence of spinal abnormalities in patients with spastic diplegia 17 to 26 years after selective dorsal rhizotomy. Childs Nerv Syst. 2009;25(12):1593-1603.
333. Lattig F, Fekete TF, Grob D, Kleinstück FS, Jeszenszky D, Mannion AF. Lumbar facet joint effusion in MRI: a sign of instability in degenerative spondylolisthesis?. Eur Spine J. 2012;21(2):276-81.
334. Lauber S, Schulte TL, Liljenqvist U, Halm H, Hackenberg L. Clinical and radiologic 2-4-year results of transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. Spine. 2006;31(15):1693-8.
335. Lauryssen C. Appropriate selection of patients with lumbar spinal stenosis for interspinous process decompression with the X STOP device. Neurosurg Focus. 2007;22(1):E5.
336. Laus M, Tigani D, Alfonso C, Giunti A. Degenerative spondylolisthesis: lumbar stenosis and instability. Chir Organi Mov. 1992;77(1):39-49.
337. Laus M, Tigani D, Pignatti G, et al. Posterolateral spinal fusion: a study of 123 cases with a long-term follow-up. Chir Organi Mov. 1994;79(1):69-79.
338. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.

339. Lawhorne TW, Girardi FP, Mina CA, Pappou I, Cammisa FP. Treatment of degenerative spondylolisthesis: potential impact of dynamic stabilization based on imaging analysis. Eur Spine J. 2009;18(6):815-22.
340. Lee DY, Jung TG, Lee SH. Single-level instrumented mini-open transforaminal lumbar interbody fusion in elderly patients. J Neurosurg Spine. 2008;9(2):137-44.
341. Lee DY, Lee SH. L2 radicular compression caused by a foraminal extradural gas pseudocyst. J Korean Neurosurg Soc. 2010;47(3):232-4.
342. Lee DY, Lee SH, Shim CS, Lee HY. Decompression and interspinous dynamic stabilization using the locker for lumbar canal stenosis associated with low-grade degenerative spondylolisthesis. Minim Invasive Neurosurg. 2010;53(3):117-21.
343. Lee HY, Ahn Y, Kim DY, Shin SW, Lee SH. Percutaneous ventral decompression for L4-L5 degenerative spondylolisthesis in medically compromised elderly patients: technical case report. Neurosurgery. 2004;55(2):435.
344. Lee JC, Jang HD, Shin BJ. Learning curve and clinical outcomes of minimally invasive transforaminal lumbar interbody fusion: our experience in 86 consecutive cases. Spine. 2012;37(18):1548-57.
345. Lee JW, Myung JS, Park KW, et al. Fluoroscopically guided caudal epidural steroid injection for management of degenerative lumbar spinal stenosis: short-term and long-term results. Skeletal Radiol. 2010;39(7):691-9.
346. Lee JY, Hohl JB, Fedorka CJ, et al. Surgeons agree to disagree on surgical options for degenerative conditions of the cervical and lumbar spine. Spine. 2011;36(3):E203-12.
347. Lee SC, Chen JF, Wu CT, Lee ST. In situ local autograft for instrumented lower lumbar or lumbosacral posterolateral fusion. J Clin Neurosci. 2009;16(1):37-43.
348. Lee SE, Park SB, Jahng TA, Chung CK, Kim HJ. Clinical experience of the dynamic stabilization system for the degenerative spine disease. J Korean Neurosurg Soc. 2008;43(5):221-6.
349. Lee SH, Kang BU, Jeon SH, et al. Revision surgery of the lumbar spine: anterior lumbar interbody fusion followed by percutaneous pedicle screw fixation. J Neurosurg Spine. 2006;5(3):228-33.
350. Lee SH, Lee JH, Hong SW, Chung SE, Yoo SH, Lee HY. Spinopelvic alignment after interspinous soft stabilization with a tension band system in grade 1 degenerative lumbar spondylolisthesis. Spine. 2010;35(15):E691-701.
351. Lee SH, Lee JH, Hong SW, et al. Factors affecting clinical outcomes in treating patients with grade 1 degenerative spondylolisthesis using interspinous soft stabilization with a tension band system: a minimum 5-year follow-up. Spine. 2012;37(7):563-72.
352. Lee TC. Reduction and stabilization without laminectomy for unstable degenerative spondylolisthesis: a preliminary report. Neurosurgery. 1994;35(6):1072-1076.
353. Lefkowitz DM, Quencer RM. Vacuum facet phenomenon: a computed tomographic sign of degenerative spondylolisthesis. Radiology. 1982;144(3):562.
354. Lekovic GP, Han PP, Kenny KJ, Dickman CA. Bone dowels in anterior lumbar interbody fusion. J Spinal Disord Tech. 2007;20(5):374-9.
355. Leone A, Cianfoni A, Cerase A, Magarelli N, Bonomo L. Lumbar spondylolysis: a review. Skeletal Radiol. 2011;40(6):683-700.
356. Lerner T, Frobin W, Bullmann V, Schulte T, Brinckmann P, Liljenqvist U. Changes in disc height and posteroanterior displacement after fusion in patients with idiopathic scoliosis: a 9-year follow-up study. J Spinal Disord Tech. 2007;20(3):195-202.
357. Lewandrowski KU, Nanson C, Calderon R. Vertebral osteolysis after posterior interbody lumbar fusion with recombinant human bone morphogenetic protein 2: a report of five cases. Spine J. 2007;7(5):609-14.
358. Liao JC, Chen WJ, Chen LH, Niu CC. Outcome of the L5-S1 segment after posterior instrumented spinal surgery in degenerative lumbar diseases. Chang Gung Med J. 2009;32(1):81-8.
359. Liao JC, Chen WJ, Chen LH, Niu CC, Keorochana G. Surgical outcomes of degenerative spondylolisthesis with L5-S1 disc degeneration: comparison between lumbar floating fusion and lumbosacral fusion at a minimum 5-year follow-up. Spine. 2011;36(19):1600-7.
360. Lin SM, Tseng SH, Yang JC, Tu CC. Chimney sublaminar decompression for degenerative lumbar spinal stenosis. J Neurosurg Spine. 2006;4(5):359-64.
361. Lindley EM, McCullough MA, Burger EL, Brown CW, Patel VV. Complications of axial lumbar interbody fusion. J Neurosurg Spine. 2011;15(3):273-9.
362. Lindley EM, Sherman B, Ohnmeiss D, et al. The positive predictive value of provocative discography in artificial disc replacement. Spine J. 2010;10:(9 Suppl. 1):68S-69S.
363. Lombardi JS, Wiltse LL, Reynolds J, Widell EH, Spencer C 3rd. Treatment of degenerative spondylolisthesis. Spine. 1985;10(9):821-827.
364. Long H, Kazunasa U, Liu S, Akio S, Taito I. Preliminary application of one-level posterior lumbar interbody fusion with prospace and facet fusion using local autograft. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi. 2007;21(11):1155-9.
365. Lorenz R. Lumbar spondylolisthesis. Clinical syndrome and operative experience with Cloward's technique. Acta Neurochir (Wien). 1982;60(3-4):223-44.
366. Lowe RW, Hayes TD, Kaye J, Bagg RJ, Luekens CA. Standing roentgenograms in spondylolisthesis. Clin Orthop Relat Res. 1976;(117):80-4.
367. Ly JQ. Systematic approach to interpretation of the lumbar spine MR imaging examination. Magn Reson Imaging Clin N Am. 2007;15(2):155-66, v.
368. Maheshwaran S, Davies AM, Evans N, Broadley P, Cassar-pullicino VN. Sciatica in degenerative spondylolisthesis of the lumbar spine. Ann Rheum Dis. 1995;54(7):539-43.
369. Mahmud T, Basu D, Dyson PH. Crystal arthropathy of the lumbar spine: a series of six cases and a review of the literature. J Bone Joint Surg Br. 2005;87(4):513-7.
370. Majid K, Fischgrund JS. Degenerative lumbar spondylolisthesis: trends in management. J Am Acad Orthop Surg. 2008;16(4):208-15.
371. Malter AD, Mcneney B, Loeser JD, Deyo RA. 5-year reoperation rates after different types of lumbar spine surgery. Spine. 1998;23(7):814-20.
372. Manchikanti L, Cash KA, Mcmanus CD, Pampati V, Abdi S. Preliminary results of a randomized, equivalence trial of fluoroscopic caudal epidural injections in managing chronic low back pain: Part 4--Spinal stenosis. Pain Physician. 2008;11(6):833-48.
373. Manenti G, Liccardo G, Sergiacomi G, et al. Axial loading MRI of the lumbar spine. In Vivo. 2003;17(5):413-20.
374. Marchesi DG, Thalgott JS, Aebi M. Application and results of the AO internal fixation system in nontraumatic indications. Spine. 1991;16(3 Suppl):S162-9.
375. Mardjetko SM, Connolly PJ, Shott S. Degenerative lumbar spondylolisthesis: A meta-analysis of literature 1970- 1993. Spine. 1994;19(20 Suppl.):2256S-2265S.
376. Margulies JY, Seimon LP. Clinical efficacy of lumbar and lumbosacral fusion using the Boucher facet screw fixation technique. Bull Hosp Jt Dis. 2000;59(1):33-9.
377. Mariconda M, Fava R, Gatto A, Longo C, Milano C. Unilateral laminectomy for bilateral decompression of lumbar spinal stenosis: a prospective comparative study with conservatively treated patients. J Spinal Disord Tech. 2002;15(1):39-46.

378. Mariconda M, Galasso O, Imbimbo L, Lotti G, Milano C. Relationship between alterations of the lumbar spine, visualized with magnetic resonance imaging, and occupational variables. Eur Spine J. 2007;16(2):255-66.
379. Markwalder TM. Surgical management of neurogenic claudication in 100 patients with lumbar spinal stenosis due to degenerative spondylolisthesis. Acta Neurochir (Wien). 1993;120(3-4):136-42.
380. Markwalder TM, Reulen HJ. Translaminar screw fixation in lumbar spine pathology. Technical note. Acta Neurochir (Wien). 1989;99(1-2):58-60.
381. Martin BI, Mirza SK, Comstock BA, Gray DT, Kreuter W, Deyo RA. Are lumbar spine reoperation rates falling with greater use of fusion surgery and new surgical technology?. Spine. 2007;32(19):2119-26.
382. Martin BI, Mirza SK, Comstock BA, Gray DT, Kreuter W, Deyo RA. Reoperation rates following lumbar spine surgery and the influence of spinal fusion procedures. Spine. 2007;32(3):382-7.
383. Martin BI, Mirza SK, Franklin GM, Lurie JD, Mackenzie TA, Deyo RA. Hospital and surgeon variation in complications and repeat surgery following incident lumbar fusion for common degenerative diagnoses. Health Serv Res. 2013;48(1):1-25.
384. Martin CR, Gruszczynski AT, Braunsfurth HA, Fallatah SM, O'neil J, Wai EK. The surgical management of degenerative lumbar spondylolisthesis: a systematic review. Spine. 2007;32(16):1791-8.
385. Matgé G, Leclercq TA. Rationale for interbody fusion with threaded titanium cages at cervical and lumbar levels. Results on 357 cases. Acta Neurochir (Wien). 2000;142(4):425-33.
386. Matsudaira K, Yamazaki T, Seichi A, et al. Spinal stenosis in grade I degenerative lumbar spondylolisthesis: a comparative study of outcomes following laminoplasty and laminectomy with instrumented spinal fusion. J Orthop Sci. 2005;10(3):270-6.
387. Matsunaga S, Ijiri K, Hayashi K. Nonsurgically managed patients with degenerative spondylolisthesis: a 10- to 18-year follow-up study. J Neurosurg. 2000;93(2 Suppl):194-8.
388. Matsunaga S, Sakou T, Morizono Y, Masuda A, Demirtas AM. Natural history of degenerative spondylolisthesis. Pathogenesis and natural course of the slippage. Spine. 1990;15(11):1204-10.
389. Maus T. Imaging the back pain patient. Phys Med Rehabil Clin N Am. 2010;21(4):725-66.
390. Mayer HM, Wiechert K. Microsurgical anterior approaches to the lumbar spine for interbody fusion and total disc replacement. Neurosurgery. 2002;51(5 Suppl):S159-65.
391. Mazzocchio R, Scarfò GB, Cartolari R, et al. Abnormalities of the soleus H-reflex in lumbar spondylolisthesis: a possible early sign of bilateral S1 root dysfunction. J Spinal Disord. 2000;13(6):487-95.
392. McAfee P, Khoo LT, Pimenta L, et al. Treatment of lumbar spinal stenosis with a total posterior arthroplasty prosthesis: implant description, surgical technique, and a prospective report on 29 patients. Neurosurg Focus. 2007;22(1):E13.
393. McAfee PC, Cunningham BW, Tortolani PJ, Fedder IL, Sefter JC, Davis C. 100 Consecutive Cases of Degenerative Lumbar Conditions Using a Non-Threaded Locking Screw System With a 90-Degree Locking Cap. SAS J. 2009;3(1):1-11.
394. Mcafee PC, Devine JG, Chaput CD, et al. The indications for interbody fusion cages in the treatment of spondylolisthesis: analysis of 120 cases. Spine. 2005;30(6 Suppl):S60-5.
395. McAfee PC, Ullrich CG, Yuan HA, Sherry RG, Lockwood RC. Computed tomography in degenerative spinal stenosis. Clin Orthop Relat Res. 1981;(161):221-34.
396. McCulloch JA. Microdecompression and uninstrumented single-level fusion for spinal canal stenosis with degenerative spondylolisthesis. Spine. 1998;23(20):2243-52.
397. McGregor AH, Probyn K, Cro S, et al. Rehabilitation following surgery for lumbar spinal stenosis. Cochrane Database Syst Rev. 2013 Dec 9;12:CD009644.
398. McGregor AH, Anderton L, Gedroyc WM, Johnson J, Hughes SP. The use of interventional open MRI to assess the kinematics of the lumbar spine in patients with spondylolisthesis. Spine. 2002;27(14):1582-6.
399. Mcgregor AH, Cattermole HR, Hughes SP. Global spinal motion in subjects with lumbar spondylolysis and spondylolisthesis: does the grade or type of slip affect global spinal motion?. Spine. 2001;26(3):282-6.
400. Mcguire RA, Pilcher LE, Dettori JR. Lumbar posterolateral fusion with local bone graft plus bone extender compared with iliac crest bone graft: a systematic review. Evid Based Spine Care J. 2011;2(2):35-40.
401. Mehta VA, Amin A, Omeis I, Gokaslan ZL, Gottfried ON. Implications of spinopelvic alignment for the spine surgeon. Neurosurgery. 2012;70(3):707-21.
402. Mehta VA, Mcgirt MJ, Garcés ambrossi GL, et al. Trans-foraminal versus posterior lumbar interbody fusion: comparison of surgical morbidity. Neurol Res. 2011;33(1):38-42.
403. Mercaitis OP, Dropkin BM, Kaufman EL, Carl AL. Epidural granuloma arising from epidural catheter placement. Orthopedics. 2009;32(4)
404. Métellus P, Fuentes S, Adetchessi T, et al. Retrospective study of 77 patients harbouring lumbar synovial cysts: functional and neurological outcome. Acta Neurochir (Wien). 2006;148(1):47-54.
405. Min JH, Jang JS, Kim SK, Maeng DH, Lee SH. The ligamentotactic effect on a herniated disc at the level adjacent to the anterior lumbar interbody fusion : report of two cases. J Korean Neurosurg Soc. 2009;46(1):65-7.
406. Mirovsky Y, Halperin N, Anekstein Y, Neuwirth MG. Good results of circumferential spine fusion in smokers, using autograft and allograft. Cell Tissue Bank. 2002;3(3):169-73.
407. Miscusi M, Petrozza V, Polli FM, Forcato S, Rocca CD, Raco A. Symptomatic ganglion cyst of ligamentum flavum as a late complication of lumbar fixation. Neurol Neurochir Pol. 2012;46(1):82-6.
408. Miyamoto H, Sumi M, Uno K, Tadokoro K, Mizuno K. Clinical outcome of nonoperative treatment for lumbar spinal stenosis, and predictive factors relating to prognosis, in a 5-year minimum follow-up. J Spinal Disord Tech. 2008;21(8):563-8.
409. Miyazaki M, Morishita Y, Takita C, Yoshiiwa T, Wang JC, Tsumura H. Analysis of the relationship between facet joint angle orientation and lumbar spine canal diameter with respect to the kinematics of the lumbar spinal unit. J Spinal Disord Tech. 2010;23(4):242-8.
410. Mochida J, Suzuki K, Chiba M. How to stabilize a single level lesion of degenerative lumbar spondylolisthesis. Clin Orthop Relat Res. 1999;(368):126-34.
411. Moke L, Debeer P, Moens P. Spondylolisthesis in twins: multifactorial etiology: a case report and review of the literature. Spine. 2011;36(11):E741-6.
412. Mokhtar SA, Mccombe PF, Williamson OD, Morgan MK, White GJ, Sears WR. Health-related quality of life: a comparison of outcomes after lumbar fusion for degenerative spondylolisthesis with large joint replacement surgery and population norms. Spine J. 2010;10(4):306-12.
413. Molina M, Wagner P, Campos M. [Spinal lumbar stenosis: an update]. Rev Med Chil. 2011;139(11):1488-95.
414. Molinari RW, Bridwell KH, Klepps SJ, Baldus C. Minimum 5-year follow-up of anterior column structural allografts in the thoracic and lumbar spine. Spine. 1999;24(10):967-72.
415. Molinari RW, Hunter JG, Mcassey RW. In-hospital postopera-

tive radiographs for instrumented single-level degenerative spinal fusions: utility after intraoperative fluoroscopy. Spine J. 2012;12(7):559-67.
416. Möller J, Wittenberg RH, Nolte LP, Jergas M, Willburger R, Krämer J. Results of lumbosacral distraction spondylodesis for the treatment of spondylolisthesis, failed-back syndrome, and lumbar instability. Eur Spine J. 1992;1(2):117-24.
417. Monticone M, Giovanazzi E. Usefulness of a cognitive behavioural and rehabilitative approach to enhance long lasting benefit after lumbar spinal stenosis and degenerative spondylolisthesis surgery. A case report. Eur J Phys Rehabil Med. 2008;44(4):467-71.
418. Moon MS, Kim SS, Sun DH, Moon YW. Anterior spondylodesis for spondylolisthesis: isthmic and degenerative types. Eur Spine J. 1994;3(3):172-6.
419. Mori E, Okada S, Ueta T, et al. Spinous process-splitting open pedicle screw fusion provides favorable results in patients with low back discomfort and pain compared to conventional open pedicle screw fixation over 1 year after surgery. Eur Spine J. 2012;21(4):745-53.
420. Morishita Y, Ohta H, Naito M, et al. Kinematic evaluation of the adjacent segments after lumbar instrumented surgery: a comparison between rigid fusion and dynamic non-fusion stabilization. Eur Spine J. 2011;20(9):1480-5.
421. Mummaneni PV, Pan J, Haid RW, Rodts GE. Contribution of recombinant human bone morphogenetic protein-2 to the rapid creation of interbody fusion when used in transforaminal lumbar interbody fusion: a preliminary report. Invited submission from the Joint Section Meeting on Disorders of the Spine and Peripheral Nerves, March 2004. J Neurosurg Spine. 2004;1(1):19-23.
422. Murtagh RD, Quencer RM, Castellvi AE, Yue JJ. New techniques in lumbar spinal instrumentation: what the radiologist needs to know. Radiology. 2011;260(2):317-30.
423. Müslüman AM, Cansever T, Yılmaz A, Çavuşoğlu H, Yüce İ, Aydın Y. Midterm outcome after a microsurgical unilateral approach for bilateral decompression of lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2012;16(1):68-76.
424. Naderi S, Manisali M, Acar F, Ozaksoy D, Mertol T, Arda MN. Factors affecting reduction in low-grade lumbosacral spondylolisthesis. J Neurosurg. 2003;99(2 Suppl):151-6.
425. Nagaosa Y, Kikuchi S, Hasue M, Sato S. Pathoanatomic mechanisms of degenerative spondylolisthesis. A radiographic study. Spine. 1998;23(13):1447-51.
426. Nakashima H, Sato K, Ando T, Inoh H, Nakamura H. Comparison of the percutaneous screw placement precision of isocentric C-arm 3-dimensional fluoroscopy-navigated pedicle screw implantation and conventional fluoroscopy method with minimally invasive surgery. J Spinal Disord Tech. 2009;22(7):468-72.
427. Nasca RJ. Rationale for spinal fusion in lumbar spinal stenosis. Spine. 1989;14(4):451-454.
428. Nasca RJ. Lumbar spinal stenosis: surgical considerations. J South Orthop Assoc. 2002;11(3):127-34.
429. Nathan M, Keller TS. Measurement and analysis of the in vivo posteroanterior impulse response of the human thoracolumbar spine: a feasibility study. J Manipulative Physiol Ther. 1994;17(7):431-41..
430. Nelson LD, Montgomery SP, Dameron TB, Nelson RB. Deep vein thrombosis in lumbar spinal fusion: a prospective study of antiembolic and pneumatic compression stockings. J South Orthop Assoc. 1996;5(3):181-4.
431. Newman PH. Degenerative spondylolisthesis. Orthop Clin N Am. 1975;6(1):197-198.
432. Niemisto L, Kalso E, Malmivaara A, Seitsalo S, Hurri H. Radiofrequency denervation for neck and back pain Cochrane Database Syst Rev. 2003;(1):CD004058.
433. Niggemann P, Simons P, Kuchta J, Beyer HK, Frey H, Grosskurth D. Spondylolisthesis and posterior instability. Acta Radiol. 2009;50(3):301-5.
434. Nizard RS, Wybier M, Laredo JD. Radiologic assessment of lumbar intervertebral instability and degenerative spondylolisthesis. Radiol Clin North Am. 2001;39(1):55-71, v-vi.
435. Nojiri K, Matsumoto M, Chiba K, Toyama Y, Momoshima S. Comparative assessment of pedicle morphology of the lumbar spine in various degenerative diseases. Surg Radiol Anat. 2005;27(4):317-21.
436. Oh IS, Ha KY. Matrix metalloproteinase-3 on ligamentum flavum in degenerative lumbar spondylolisthesis. Spine. 2009;34(16):E552-7.
437. Ohmori K, Suzuki K, Ishida Y. Translamino-pedicular screw fixation with bone grafting for symptomatic isthmic lumbar spondylolysis. Neurosurgery. 1992;30(3):379-84.
438. Ohta H, Matsumoto Y, Morishita Y, et al. Surgical results of dynamic nonfusion stabilization with the Segmental Spinal Correction System for degenerative lumbar spinal diseases with instability: Minimum 2-year follow-up. SAS J. 2011;5(3):69-74.
439. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. Spine. 2012;37(23):E1464-8.
440. Ohtori S, Yamashita M, Inoue G, et al. Rotational hypermobility of disc wedging using kinematic CT: preliminary study to investigate the instability of discs in degenerated scoliosis in the lumbar spine. Eur Spine J. 2010;19(6):989-94.
441. Oishi Y, Murase M, Hayashi Y, Ogawa T, Hamawaki J. Smaller facet effusion in association with restabilization at the time of operation in Japanese patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2010;12(1):88-95.
442. Okawa A, Shinomiya K, Komori H, Muneta T, Arai Y, Nakai O. Dynamic motion study of the whole lumbar spine by videofluoroscopy. Spine. 1998;23(16):1743-9.
443. Okuda S, Oda T, Miyauchi A, Haku T, Yamamoto T, Iwasaki M. Surgical outcomes of posterior lumbar interbody fusion in elderly patients. Surgical technique. J Bone Joint Surg Am. 2007;89 Suppl 2 Pt.2:310-20.
444. Okuda T, Baba I, Fujimoto Y, et al. The pathology of ligamentum flavum in degenerative lumbar disease. Spine. 2004;29(15):1689-97.
445. Okuyama K, Kido T, Unoki E, Chiba M. PLIF with a titanium cage and excised facet joint bone for degenerative spondylolisthesis--in augmentation with a pedicle screw. J Spinal Disord Tech. 2007;20(1):53-9.
446. Oliveira L, Marchi L, Coutinho E, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. Spine. 2010;35(26 Suppl):S331-7.
447. Onda A, Otani K, Konno S, Kikuchi S. Mid-term and long-term follow-up data after placement of the Graf stabilization system for lumbar degenerative disorders. J Neurosurg Spine. 2006;5(1):26-32.
448. Osman SG. Endoscopic transforaminal decompression, interbody fusion, and percutaneous pedicle screw implantation of the lumbar spine: A case series report. Int J Spine Surg. 2012;6(1):157-166.
449. Ozawa H, Kanno H, Koizumi Y, et al. Dynamic changes in the dural sac cross-sectional area on axial loaded MR imaging: is there a difference between degenerative spondylolisthesis and spinal stenosis?. AJNR Am J Neuroradiol. 2012;33(6):1191-7.
450. Ozgur BM, Agarwal V, Nail E, Pimenta L. Two-year clinical and radiographic success of minimally invasive lateral transpsoas approach for the treatment of degenerative lumbar conditions.

SAS J. 2010;4(2):41-46.
451. Ozkan N, Sandalcioglu IE, Petr O, et al. Minimally invasive transpedicular dorsal stabilization of the thoracolumbar and lumbar spine using the minimal access non-traumatic insertion system (MANTIS): preliminary clinical results in 52 patients. J Neurol Surg A Cent Eur Neurosurg. 2012;73(6):369-76.
452. Paajanen H, Tertti M. Association of incipient disc degeneration and instability in spondylolisthesis. A magnetic resonance and flexion-extension radiographic study of 20-year-old low back pain patients. Arch Orthop Trauma Surg. 1991;111(1):16-9.
453. Palmer S, Turner R, Palmer R. Bilateral decompression of lumbar spinal stenosis involving a unilateral approach with microscope and tubular retractor system. J Neurosurg. 2002;97(2 Suppl):213-7.
454. Pao JL, Chen WC, Chen PQ. Clinical outcomes of microendoscopic decompressive laminotomy for degenerative lumbar spinal stenosis. Eur Spine J. 2009;18(5):672-8.
455. Park DK, An HS, Lurie JD, et al. Does multilevel lumbar stenosis lead to poorer outcomes?: a subanalysis of the Spine Patient Outcomes Research Trial (SPORT) lumbar stenosis study. Spine. 2010;35(4):439-46.
456. Park H, Zhang HY, Cho BY, Park JY. Change of lumbar motion after multi-level posterior dynamic stabilization with bioflex system : 1 year follow up. J Korean Neurosurg Soc. 2009;46(4):285-91.
457. Park JH, Hyun SJ, Roh SW, Rhim SC. A comparison of unilateral laminectomy with bilateral decompression and fusion surgery in the treatment of grade I lumbar degenerative spondylolisthesis. Acta Neurochir (Wien). 2012;154(7):1205-12.
458. Park JY, Chin DK, Cho YE. Accelerated L5-S1 Segment Degeneration after Spinal Fusion on and above L4-5 : Minimum 4-Year Follow-Up Results. J Korean Neurosurg Soc. 2009;45(2):81-4.
459. Park P, Foley KT. Minimally invasive transforaminal lumbar interbody fusion with reduction of spondylolisthesis: technique and outcomes after a minimum of 2 years' follow-up. Neurosurg Focus. 2008;25(2):E16.
460. Park SC, Yoon SH, Hong YP, Kim KJ, Chung SK, Kim HJ. Minimum 2-year follow-up result of degenerative spinal stenosis treated with interspinous u (coflex). J Korean Neurosurg Soc. 2009;46(4):292-9.
461. Park Y, Ha JW, Lee YT, Sung NY. The effect of a radiographic solid fusion on clinical outcomes after minimally invasive transforaminal lumbar interbody fusion. Spine J. 2011;11(3):205-12.
462. Park YK, Chung HS. Instrumented facet fusion for the degenerative lumbar disorders. Acta Neurochir (Wien). 1999;141(9):915-20.
463. Parker SL, Adogwa O, Bydon A, Cheng J, Mcgirt MJ. Cost-effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis associated low-back and leg pain over two years. World Neurosurg. 2012;78(1-2):178-84.
464. Parker SL, Mcgirt MJ. Determination of the minimum improvement in pain, disability, and health state associated with cost-effectiveness: introduction of the concept of minimum cost-effective difference. Neurosurgery. 2012;71(6):1149-55.
465. Parker SL, Mendenhall SK, Shau DN, et al. Minimally Invasive versus Open Transforaminal Lumbar Interbody Fusion for Degenerative Spondylolisthesis: Comparative Effectiveness and Cost-Utility Analysis. World Neurosurg. 2014;82(1-2):230-238.
466. Pateder DB, Benzel E. Noninstrumented facet fusion in patients undergoing lumbar laminectomy for degenerative spondylolisthesis. J Surg Orthop Adv. 2010;19(3):153-8.
467. Pearson A, Blood E, Lurie J, et al. Degenerative spondylolisthesis versus spinal stenosis: does a slip matter? Comparison of baseline characteristics and outcomes (SPORT). Spine. 2010;35(3):298-305.
468. Peloso P, Gross A, Haines T, et al. Medicinal and injection therapies for mechanical neck disorders. Cochrane Database Syst Rev. 2007;(3):CD000319.
469. Pelton MA, Phillips FM, Singh K. A comparison of perioperative costs and outcomes in patients with and without workers' compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion. Spine. 2012;37(22):1914-9.
470. Penning L, Blickman JR. Instability in lumbar spondylolisthesis: a radiologic study of several concepts. AJR Am J Roentgenol. 1980;134(2):293-301.
471. Piñera AR, Duran C, Lopez B, Saez I, Correia E, Alvarez L. Instrumented lumbar arthrodesis in elderly patients: prospective study using cannulated cemented pedicle screw instrumentation. Eur Spine J. 2011;20 Suppl 3:408-14.
472. Plötz GM, Benini A. Surgical treatment of degenerative spondylolisthesis in the lumbar spine: no reposition without prior decompression. Acta Neurochir (Wien). 1995;137(3-4):188-91.
473. Ploumis A, Transfeldt EE, Gilbert TJ, Mehbod AA, Dykes DC, Perra JE. Degenerative lumbar scoliosis: radiographic correlation of lateral rotatory olisthesis with neural canal dimensions. Spine. 2006;31(20):2353-8.
474. Podichetty VK, Spears J, Isaacs RE, Booher J, Biscup RS. Complications associated with minimally invasive decompression for lumbar spinal stenosis. J Spinal Disord Tech. 2006;19(3):161-6.
475. Posner I, White AA, Edwards WT, Hayes WC. A biomechanical analysis of the clinical stability of the lumbar and lumbosacral spine. Spine. 1982;7(4):374-89.
476. Postacchini F, Cinotti G. Bone regrowth after surgical decompression for lumbar spinal stenosis. J Bone Joint Surg Br. 1992;74(6):862-9.
477. Postacchini F, Cinotti G, Perugia D. Degenerative lumbar spondylolisthesis. II. Surgical treatment. Ital J Orthop Traumatol. 1991;17(4):467-77.
478. Postacchini F, Cinotti G, Perugia D, Gumina S. The surgical treatment of central lumbar stenosis. Multiple laminotomy compared with total laminectomy. J Bone Joint Surg Br. 1993;75(3):386-92.
479. Postacchini F, Perugia D. Degenerative lumbar spondylolisthesis. Part I: Etiology, pathogenesis, pathomorphology, and clinical features. Ital J Orthop Traumatol. 1991;17(2):165-73.
480. Potter BK, Freedman BA, Verwiebe EG, Hall JM, Polly DW, Kuklo TR. Transforaminal lumbar interbody fusion: clinical and radiographic results and complications in 100 consecutive patients. J Spinal Disord Tech. 2005;18(4):337-46.
481. Pratt RK, Fairbank JC, Virr A. The reliability of the Shuttle Walking Test, the Swiss Spinal Stenosis Questionnaire, the Oxford Spinal Stenosis Score, and the Oswestry Disability Index in the assessment of patients with lumbar spinal stenosis. Spine. 2002;27(1):84-91.
482. Prolo DJ, Oklund SA, Butcher M. Toward uniformity in evaluating results of lumbar spine operations. A paradigm applied to posterior lumbar interbody fusions. Spine. 1986;11(6):601-6.
483. Quraishi NA, Lewis SJ, Kelleher MO, Sarjeant R, Rampersaud YR, Fehlings MG. Intraoperative multimodality monitoring in adult spinal deformity: analysis of a prospective series of one hundred two cases with independent evaluation. Spine. 2009;34(14):1504-12.
484. Radcliff K, Hwang R, Hilibrand A, et al. The effect of iliac crest autograft on the outcome of fusion in the setting of degenerative spondylolisthesis: a subgroup analysis of the Spine Patient Outcomes Research Trial (SPORT). J Bone Joint Surg Am. 2012;94(18):1685-92.

485. Radcliff KE, Rihn J, Hilibrand A, et al. Does the duration of symptoms in patients with spinal stenosis and degenerative spondylolisthesis affect outcomes?: analysis of the Spine Outcomes Research Trial. Spine. 2011;36(25):2197-210.
486. Radu AS, Menkès CJ. Update on lumbar spinal stenosis. Retrospective study of 62 patients and review of the literature. Rev Rhum Engl Ed. 1998;65(5):337-45.
487. Raley DA, Mobbs RJ. Retrospective computed tomography scan analysis of percutaneously inserted pedicle screws for posterior transpedicular stabilization of the thoracic and lumbar spine: accuracy and complication rates. Spine. 2012;37(12):1092-100.
488. Rampersaud R, Macwan K, Mahomed NN. Spinal Care in a Single-Payer System: The Canadian Example. Semin Spine Surg. 2012;24(2):117-122.
489. Rampersaud YR, Gray R, Lewis SJ, Massicotte EM, Fehlings MG. Cost-utility analysis of posterior minimally invasive fusion compared with conventional open fusion for lumbar spondylolisthesis. SAS J. 2011;5(2):29-35.
490. Rampersaud YR, Wai EK, Fisher CG, et al. Postoperative improvement in health-related quality of life: a national comparison of surgical treatment for focal (one- to two-level) lumbar spinal stenosis compared with total joint arthroplasty for osteoarthritis. Spine J. 2011;11(11):1033-41.
491. Ranjith RK, Mullett JH, Burke TE. Hangman's fracture caused by suspected child abuse. A case report. J Pediatr Orthop B. 2002;11(4):329-32.
492. Rechtine GR, Sutterlin CE, Wood GW, Boyd RJ, Mansfield FL. The efficacy of pedicle screw/plate fixation on lumbar/lumbosacral autogenous bone graft fusion in adult patients with degenerative spondylolisthesis. J Spinal Disord. 1996;9(5):382-91.
493. Reddy SJ, Al-holou WN, Leveque JC, La marca F, Park P. Traumatic lateral spondylolisthesis of the lumbar spine with a unilateral locked facet: description of an unusual injury, probable mechanism, and management. J Neurosurg Spine. 2008;9(6):576-80.
494. Remes V, Lamberg T, Tervahartiala P, et al. Long-term outcome after posterolateral, anterior, and circumferential fusion for high-grade isthmic spondylolisthesis in children and adolescents: magnetic resonance imaging findings after average of 17-year follow-up. Spine. 2006;31(21):2491-9.
495. Resnick D. Degenerative diseases of the vertebral column. Radiology. 1985;156(1):3-14.
496. Resnick DK, Choudhri TF, Dailey AT, et al. Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 12: pedicle screw fixation as an adjunct to posterolateral fusion for low-back pain. J Neurosurg Spine. 2005;2(6):700-6.
497. Rihn JA, Radcliff K, Hilibrand AS, et al. Does obesity affect outcomes of treatment for lumbar stenosis and degenerative spondylolisthesis? Analysis of the Spine Patient Outcomes Research Trial (SPORT). Spine. 2012;37(23):1933-46.
498. Robertson PA, Grobler LJ, Novotny JE, Katz JN. Postoperative spondylolisthesis at L4-5. The role of facet joint morphology. Spine. 1993;18(11):1483-90.
499. Robertson PA, Plank LD. Prospective cohort analysis of disability reduction with lumbar spinal fusion surgery in community practice. J Spinal Disord Tech. 2008;21(4):235-40.
500. Rodgers WB, Lehmen JA, Gerber EJ, Rodgers JA. Grade 2 spondylolisthesis at L4-5 treated by XLIF: safety and midterm results in the "worst case scenario". ScientificWorldJournal. 2012;2012:356712.
501. Rosenberg NJ. Degenerative spondylolisthesis. Predisposing factors. J Bone Joint Surg Am. 1975;57(4):467-474.
502. Rosenberg NJ. Degenerative spondylolisthesis: surgical treatment. Clin Orthop Relat Res. 1976;(117):112-120.
503. Rosenberg WS, Mummaneni PV. Transforaminal lumbar interbody fusion: technique, complications, and early results. Neurosurgery. 2001;48(3):569-74.
504. Rothman SL, Glenn WV, Kerber CW. Multiplanar CT in the evaluation of degenerative spondylolisthesis. A review of 150 cases. Comput Radiol. 1985;9(4):223-32.
505. Rouben D, Casnellie M, Ferguson M. Long-term durability of minimal invasive posterior transforaminal lumbar interbody fusion: a clinical and radiographic follow-up. J Spinal Disord Tech. 2011;24(5):288-96.
506. Rousseau MA, Lazennec JY, Bass EC, Saillant G. Predictors of outcomes after posterior decompression and fusion in degenerative spondylolisthesis. Eur Spine J. 2005;14(1):55-60.
507. Roy C. Does the diagnosis of spondylolisthesis matter? Pain Physician. 2012;15(2).
508. Rubery PT. Degenerative spondylolisthesis. Current Opin Orthop. 2001;12(3):183-188.
509. Sachs BL, Zindrick MR, Beasley RD. Reflex sympathetic dystrophy after operative procedures on the lumbar spine. J Bone Joint Surg Am. 1993;75(5):721-725.
510. Sanderson PL, Wood PL. Surgery for lumbar spinal stenosis in old people. J Bone Joint Surg Br. 1993;75(3):393-7.
511. Sandu N, Schaller B, Arasho B, Orabi M. Wallis interspinous implantation to treat degenerative spinal disease: description of the method and case series. Expert Rev Neurother. 2011;11(6):799-807.
512. Sapkas GS, Mavrogenis AF, Themistocleous GS, Zachos VC, Kelalis G, Papagelopoulos PJ. Posterior lumbar interbody fusion versus circumferential fusion using the B-Twin expandable spinal system. J Long Term Eff Med Implants. 2007;17(3):217-27.
513. Sasai K, Umeda M, Maruyama T, Wakabayashi E, Iida H. Microsurgical bilateral decompression via a unilateral approach for lumbar spinal canal stenosis including degenerative spondylolisthesis. J Neurosurg Spine. 2008;9(6):554-9.
514. Sato K, Kikuchi S. Clinical analysis of two-level compression of the cauda equina and the nerve roots in lumbar spinal canal stenosis. Spine. 1997;22(16):1898-903.
515. Sato K, Wakamatsu E, Yoshizumi A, Watanabe N, Irei O. The configuration of the laminas and facet joints in degenerative spondylolisthesis. A clinicoradiologic study. Spine. 1989;14(11):1265-71.
516. Satomi K, Hirabayashi K, Toyama Y, Fujimura Y. A clinical study of degenerative spondylolisthesis. Radiographic analysis and choice of treatment. Spine. 1992;17(11):1329-36.
517. Savvidou C, Chatziioannou SN, Pilichou A, Pneumaticos SG. Efficacy and cost-effectiveness of cell saving blood autotransfusion in adult lumbar fusion. Transfus Med. 2009;19(4):202-6.
518. Schaeren S, Broger I, Jeanneret B. Minimum four-year follow-up of spinal stenosis with degenerative spondylolisthesis treated with decompression and dynamic stabilization. Spine. 2008;33(18):E636-42.
519. Scheufler KM, Dohmen H, Vougioukas VI. Percutaneous transforaminal lumbar interbody fusion for the treatment of degenerative lumbar instability. Neurosurgery. 2007;60(4 Suppl. 2):203- 212.
520. Schiffman M, Brau SA, Henderson R, Gimmestad G. Bilateral implantation of low-profile interbody fusion cages: subsidence, lordosis, and fusion analysis. Spine J. 2003;3(5):377-87.
521. Schizas C, Tzinieris N, Tsiridis E, Kosmopoulos V. Minimally invasive versus open transforaminal lumbar interbody fusion: evaluating initial experience. Int Orthop. 2009;33(6):1683-8.
522. Schlenzka D, Remes V, Helenius I, et al. Direct repair for treatment of symptomatic spondylolysis and low-grade isthmic spondylolisthesis in young patients: no benefit in comparison to segmental fusion after a mean follow-up of 14.8 years. Eur Spine

J. 2006;15(10):1437-47.
523. Schlenzka D, Seitsalo S, Poussa M, Osterman K. Operative treatment of symptomatic lumbar spondylolysis and mild isthmic spondylolisthesis in young patients: direct repair of the defect or segmental spinal fusion? Eur Spine J. 1993;2(2):104-112.
524. Schnake KJ, Schaeren S, Jeanneret B. Dynamic stabilization in addition to decompression for lumbar spinal stenosis with degenerative spondylolisthesis. Spine. 2006;31(4):442-449.
525. Schnee CL, Freese A, Ansell LV. Outcome analysis for adults with spondylolisthesis treated with posterolateral fusion and transpedicular screw fixation. J Neurosurg. 1997;86(1):56-63.
526. Schuller S, Charles YP, Steib JP. Sagittal spinopelvic alignment and body mass index in patients with degenerative spondylolisthesis. Eur Spine J. 2011;20(5):713-9.
527. Schulte TL, Leistra F, Bullmann V, et al. Disc height reduction in adjacent segments and clinical outcome 10 years after lumbar 360 degrees fusion. Eur Spine J. 2007;16(12):2152-8.
528. Schulte TL, Schubert T, Winter C, et al. Step activity monitoring in lumbar stenosis patients undergoing decompressive surgery. Eur Spine J. 2010;19(11):1855-64.
529. Schwender JD, Holly LT, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. J Spinal Disord Tech. 2005;18 Suppl:S1-6.
530. Sears W. Posterior lumbar interbody fusion for degenerative spondylolisthesis: restoration of sagittal balance using insert-and-rotate interbody spacers. Spine J. 2005;5(2):170-9.
531. Sengupta DK. Point of view: Dynamic stabilization in addition to decompression for lumbar spinal stenosis with degenerative spondylolisthesis. Spine. 2006;31(4):450.
532. Sengupta DK, Herkowitz HN. Lumbar spinal stenosis. Treatment strategies and indications for surgery. Orthop Clin North Am. 2003;34(2):281-95.
533. Sengupta DK, Herkowitz HN. Degenerative spondylolisthesis: review of current trends and controversies. Spine. 2005;30(6 Suppl):S71-81.
534. Sharma AK, Kepler CK, Girardi FP, Cammisa FP, Huang RC, Sama AA. Lateral lumbar interbody fusion: clinical and radiographic outcomes at 1 year: a preliminary report. J Spinal Disord Tech. 2011;24(4):242-50.
535. Sheehan JM, Shaffrey CI, Jane JA. Degenerative lumbar stenosis: the neurosurgical perspective. Clin Orthop Relat Res. 2001;(384):61-74.
536. Shen M, Razi A, Lurie JD, Hanscom B, Weinstein J. Retrolisthesis and lumbar disc herniation: a preoperative assessment of patient function. Spine J. 2007;7(4):406-13.
537. Shen NJ, Lin MX, Lin QB, Wang XA, Chen J, Wang GJ. Domestic vertebral internal fixation system for treating lumbar spondylolisthesis in 55 cases. A follow-up study. J Clin Rehabil Tissue Eng Res. 2009;13(9):1793-1796.
538. Sienkiewicz PJ, Flatley TJ. Postoperative spondylolisthesis. Clin Orthop Relat Res. 1987;(221):172-180.
539. Siewe J, Otto C, Knoell P, et al. Comparison of standard fusion with a "topping off" system in lumbar spine surgery: a protocol for a randomized controlled trial. BMC Musculoskelet Disord. 2011;12:239.
540. Silvers HR, Lewis PJ, Asch HL. Decompressive lumbar laminectomy for spinal stenosis. J Neurosurg. 1993;78(5):695-701.
541. Sinaki M, Lutness MP, Ilstrup DM, Chu CP, Gramse RR. Lumbar spondylolisthesis: retrospective comparison and three-year follow-up of two conservative treatment programs. Arch Phys Med Rehabil. 1989;70(8):594-8.
542. Singh K, Smucker JD, Gill S, Boden SD. Use of recombinant human bone morphogenetic protein-2 as an adjunct in posterolateral lumbar spine fusion: a prospective CT-scan analysis at one and two years. J Spinal Disord Tech. 2006;19(6):416-23.
543. Sirvanci M, Ulusoy L, Duran C. Pedicular stress fracture in lumbar spine. Clin Imaging. 2002;26(3):187-93.
544. Skowroński J, Wojnar J, Bielecki M. Interbody fusion and transpedicular fixation in the treatment of spondylolisthesis. Ortop Traumatol Rehabil. 2007;9(2):149-55.
545. Snider RK, Krumwiede NK, Snider LJ, Jurist JM, Lew RA, Katz JN. Factors affecting lumbar spinal fusion. J Spinal Disord. 1999;12(2):107-14.
546. Soegaard R, Bünger CE, Christiansen T, Høy K, Eiskjaer SP, Christensen FB. Circumferential fusion is dominant over posterolateral fusion in a long-term perspective: cost-utility evaluation of a randomized controlled trial in severe, chronic low back pain. Spine. 2007;32(22):2405-14.
547. Soegaard R, Christensen FB. Health economic evaluation in lumbar spinal fusion: A systematic literature review anno 2005. Eur Spine J. 2006;15(8):1165-1173.
548. Soini J, Slätis P, Kannisto M, Sandelin J. External transpedicular fixation test of the lumbar spine correlates with the outcome of subsequent lumbar fusion. Clin Orthop Relat Res. 1993;(293):89-96.
549. Song KJ, Lee KB. Spontaneous fusion of L5-S1 isthmic spondylolisthesis. J Back Musculoskel Rehabil. 2007;20(4):177-179.
550. Sonntag VK, Marciano FF. Is fusion indicated for lumbar spinal disorders?. Spine. 1995;20(24 Suppl):138S-142S.
551. Soren A, Waugh TR. Spondylolisthesis and related disorders. A correlative study of 105 patients. Clin Orthop Relat Res. 1985;(193):171-7.
552. St Clair S, Tan JS, Lieberman I. Oblique lumbar interbody fixation: a biomechanical study in human spines. J Spinal Disord Tech. 2012;25(4):183-9. Stoll, T. M., Dubois, G., & Schwarzenbach, O. (2002). The dynamic neutralization system for the spine: a multi-center study of a novel non-fusion system. European Spine Journal, 11 Suppl 2, S170-178.
553. Stone AT, Tribus CB. Acute progression of spondylolysis to isthmic spondylolisthesis in an adult. Spine. 2002;27(16):E370-2.
554. Stovall R, Halliday A. Degenerative lumbar spondylolisthesis: Treatment strategies. Semin Neurosurg. 2000;11(2):193-205.
555. Stucki G, Daltroy L, Liang MH, Lipson SJ, Fossel AH, Katz JN. Measurement properties of a self-administered outcome measure in lumbar spinal stenosis. Spine. 1996;21(7):796-803.
556. Sugawara A, Isu T, Kim K, et al. (2012). Surgical results using only posterior decompression for lumbar canal stenosis with lumbar degenerative spondylolisthesis. Japanese J Neurosurg. 2012;21(2) 111-117.
557. Surace MF, Fagetti A, Fozzato S, Cherubino P. Lumbar spinal stenosis treatment with Aperius perclid interspinous system. Eur Spine J. 2012;21 Suppl 1:S69-74.
558. Tajima N, Chosa E, Watanabe S. Posterolateral lumbar fusion. J Orthop Sci. 2004;9(3):327-333.
559. Takahashi K, Kitahara H, Yamagata M, et al. Long-term results of anterior interbody fusion for treatment of degenerative spondylolisthesis. Spine. 1990;15(11):1211-1215.
560. Takahashi T, Hanakita J, Minami M, et al. Clinical outcomes and adverse events following transforaminal interbody fusion for lumbar degenerative spondylolisthesis in elderly patients. Neurol Med Chir (Tokyo). 2011;51(12):829-35.
561. Takayanagi K, Takahashi K, Yamagata M, Moriya H, Kitahara H, Tamaki T. Using cineradiography for continuous dynamic-motion analysis of the lumbar spine. Spine. 2001;26(17):1858-65.
562. Tanaka M, Shimizu H, Yato Y, Asazuma T, Nemoto K. Acute pyogenic discitis in a degenerative intervertebral disc in an adult. Int Med Case Rep J. 2010;3:77-80.
563. Tarantino U, Fanucci E, Iundusi R, et al. Lumbar spine MRI in upright position for diagnosing acute and chronic low back

pain: statistical analysis of morphological changes. J Orthop Traumatol. 2013;14(1):15-22.
564. Taylor JA, Bussières A. Diagnostic imaging for spinal disorders in the elderly: a narrative review. Chiropr Man Therap. 2012;20(1):16.
565. Templin CR, Garfin SR. Surgical Management of Scoliosis and/or Spondylolisthesis Associated with Spinal Stenosis. Sem Spine Surg. 2007;19(3):187-199.
566. Teplick JG, Laffey PA, Berman A, Haskin ME. Diagnosis and evaluation of spondylolisthesis and/or spondylolysis on axial CT. AJNR Am J Neuroradiol. 1986;7(3):479-491.
567. Terao T, Ishii T, Tani S, Abe T. Combination therapy of radiofrequency lumbar facet joint denervation and epidural spinal cord stimulation for failed back surgery syndrome. Neurol Med Chir (Tokyo). 2011;51(11):805-9.
568. Tile M, McNeil SR, Zarins RK, Pennal GF, Garside SH. Spinal stenosis. Results of treatment. Clin Orthop Relat Res. 1976;115:104-108.
569. Tillich M, Trummer M, Lindbichler F, Flaschka G. Symptomatic intraspinal synovial cysts of the lumbar spine: correlation of MR and surgical findings. Neuroradiology. 2001;43(12):1070-5.
570. Tokuhashi Y, Ajiro Y, Umezawa N. Follow-up of patients with delayed union after posterior fusion with pedicle screw fixation. Spine. 2008;33(7):786-91.
571. Tokuhashi Y, Ajiro Y, Umezawa N. Subsidence of metal interbody cage after posterior lumbar interbody fusion with pedicle screw fixation. Orthopedics. 2009;32(4):259.
572. Tokuhashi Y, Matsuzaki H, Sano S. Evaluation of clinical lumbar instability using the treadmill. Spine. 1993;18(15):2321-4.
573. Toyoda H, Nakamura H, Konishi S, Dohzono S, Kato M, Matsuda H. Clinical outcome of microsurgical bilateral decompression via unilateral approach for lumbar canal stenosis: minimum five-year follow-up. Spine. 2011;36(5):410-5.
574. Trayneli, VC. Comments. Neurosurgery. 2009;64(5):963-964.
575. Truumees E. The Role of Fusion in Degenerative Lumbar Disease. Semin Spine Surg. 2003;15(4):430-459.
576. Tsai KH, Chang GL, Lin HT, Kuo DC, Chang LT, Lin RM. Differences of lumbosacral kinematics between degenerative and induced spondylolisthetic spine. Clin Biomech (Bristol, Avon). 2003;18(6):S10-6.
577. Tsutsumimoto T, Shimogata M, Ohta H, Misawa H. Mini-open versus conventional open posterior lumbar interbody fusion for the treatment of lumbar degenerative spondylolisthesis: comparison of paraspinal muscle damage and slip reduction. Spine. 2009;34(18):1923-8.
578. Tsutsumimoto T, Shimogata M, Yoshimura Y, Misawa H. Union versus nonunion after posterolateral lumbar fusion: a comparison of long-term surgical outcomes in patients with degenerative lumbar spondylolisthesis. Eur Spine J. 2008;17(8):1107-12.
579. Turunen V, Nyyssönen T, Miettinen H, et al. Lumbar instrumented posterolateral fusion in spondylolisthetic and failed back patients: a long-term follow-up study spanning 11-13 years. Eur Spine J. 2012;21(11):2140-8.
580. Unnanantana A. Posterolateral lumbar fusion for degenerative spondylolisthesis: experiences of a modified technique without instrumentation. J Med Assoc Thai. 1997;80(9):570-4.
581. Vaccaro A. Unilateral approach for microsurgical decompression. J Neurosurg Spine. 2008;9(6):552-3.
582. Vaccaro AR, Anderson DG, Patel T, et al. Comparison of OP-1 Putty (rhBMP-7) to iliac crest autograft for posterolateral lumbar arthrodesis: a minimum 2-year follow-up pilot study. Spine. 2005;30(24):2709-16.
583. Vaccaro AR, Garfin SR. Internal fixation (pedicle screw fixation) for fusions of the lumbar spine. Spine. 1995;20(24 Suppl):157S-165S.
584. Vaccaro AR, Garfin SR. Degenerative lumbar spondylolisthesis with spinal stenosis, a prospective study comparing decompression with decompression and intertransverse process arthrodesis: a critical analysis. Spine. 1997;22(4):368-9.
585. Vaccaro AR, Lawrence JP, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis: a long-term (>4 years) pivotal study. Spine. 2008;33(26):2850-62.
586. Vaccaro AR, Patel T, Fischgrund J, et al. A pilot safety and efficacy study of OP-1 putty (rhBMP-7) as an adjunct to iliac crest autograft in posterolateral lumbar fusions. Eur Spine J. 2003;12(5):495-500.
587. Vaccaro AR, Patel T, Fischgrund J, et al. A 2-year follow-up pilot study evaluating the safety and efficacy of op-1 putty (rhbmp-7) as an adjunct to iliac crest autograft in posterolateral lumbar fusions. Eur Spine J. 2005;14(7):623-9.
588. Vaccaro AR, Patel T, Fischgrund J, et al. A pilot study evaluating safety and efficacy of OP-1 putty (rhBMP-7) as a replacement for iliac crest autograft in posterolateral lumbar arthrodesis for degenerative spondylolisthesis. Spine 2004;29:1885-92.
589. Vaccaro AR, Stubbs HA, Block JE. Demineralized bone matrix composite grafting for posterolateral spinal fusion. Orthopedics. 2007;30(7):567-70.
590. Vaccaro AR, Whang PG, Patel T, et al. The safety and efficacy of OP-1 (rhBMP-7) as a replacement for iliac crest autograft for posterolateral lumbar arthrodesis: minimum 4-year follow-up of a pilot study. Spine J. 2008;8(3):457-65.
591. Vamvanij V, Ferrara LA, Hai Y, Zhao J, Kolata R, Yuan HA. Quantitative changes in spinal canal dimensions using interbody distraction for spondylolisthesis. Spine. 2001;26(3):E13-8.
592. Van den heuvel R, Hertel M, Gallagher J, Naidoo V. A toddler who refused to stand or walk: lumbar spondylodiscitis. BMJ Case Rep. 2012;2012
593. Van oostrom SH, Driessen MT, De vet HC, et al. Workplace interventions for preventing work disability. Cochrane Database Syst Rev. 2009;(2):CD006955.
594. Vanek P, Saur K. Transforaminal lumbar interbody fusion (TLIF) and instruments. Prospective study with the minimum of 20-month follow-up. Cesk Neurol Neurochir. 2007;70(5):552-557.
595. Verhoof OJ, Bron JL, Wapstra FH, Van royen BJ. High failure rate of the interspinous distraction device (X-Stop) for the treatment of lumbar spinal stenosis caused by degenerative spondylolisthesis. Eur Spine J. 2008;17(2):188-92.
596. Vibert BT, Sliva CD, Herkowitz HN. Treatment of instability and spondylolisthesis: surgical versus nonsurgical treatment. Clin Orthop Relat Res. 2006;443:222-7.
597. Virk S, Sandhu HS, Khan SN. Cost effectiveness analysis of graft options in spinal fusion surgery using a Markov model. J Spinal Disord Tech. 2012;25(7):E204-10.
598. Vital JM, Gille O, Pointillart V, et al. Course of Modic 1 six months after lumbar posterior osteosynthesis. Spine. 2003;28(7):715-20.
599. Vitzthum HE, König A, Seifert V. Dynamic examination of the lumbar spine by using vertical, open magnetic resonance imaging. J Neurosurg. 2000;93(1 Suppl):58-64.
600. Vogt MT, Rubin D, Valentin RS, et al. Lumbar olisthesis and lower back symptoms in elderly white women. The Study of Osteoporotic Fractures. Spine. 1998;23(23):2640-7.
601. Wang HL, Lü FZ, Jiang JY, Ma X, Xia XL, Wang LX. Minimally invasive lumbar interbody fusion via MAST Quadrant retractor versus open surgery: a prospective randomized clinical trial. Chin Med J. 2011;124(23):3868-74.
602. Wang J, Yang X. Age-related changes in the orientation of lumbar facet joints. Spine. 2009;34(17):E596-8.

603. Watters WC. If, when, and how to fuse when treating lumbar degenerative stenosis. Semin Spine Surg. 2011;23(4):218-221.
604. Watters WC, Bono CM, Gilbert TJ, et al. An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2009;9(7):609-14.
605. Weiner BK, Walker M. Efficacy of autologous growth factors in lumbar intertransverse fusions. Spine. 2003;28:1968-1971.
606. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. N Engl J Med. 2007;356(22):2257-70.
607. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. J Bone Joint Surg Am. 2009;91(6):1295-304.
608. Welch WC, Cheng BC, Awad TE, et al. Clinical outcomes of the Dynesys dynamic neutralization system: 1-year preliminary results. Neurosurg Focus. 2007;22(1):E8.
609. Whitecloud TS, Castro FP, Brinker MR, Hartzog CW, Ricciardi JE, Hill C. Degenerative conditions of the lumbar spine treated with intervertebral titanium cages and posterior instrumentation for circumferential fusion. J Spinal Disord. 1998;11(6):479-86.
610. Wildermuth S, Zanetti M, Duewell S, et al. Lumbar spine: quantitative and qualitative assessment of positional (upright flexion and extension) MR imaging and myelography. Radiology. 1998;207(2):391-8.
611. Willems P. Decision making in surgical treatment of chronic low back pain: the performance of prognostic tests to select patients for lumbar spinal fusion. Acta Orthop Suppl. 2013;84(349):1-35.
612. Wiltse LL, Guyer RD, Spencer CW, Glenn WV, Porter IS. Alar transverse process impingement of the L5 spinal nerve: the far-out syndrome. Spine. 1984;9(1):31-41.
613. Wood GW, Boyd RJ, Carothers TA, et al. The effect of pedicle screw/plate fixation on lumbar/lumbosacral autogenous bone graft fusions in patients with degenerative disc disease. Spine. 1995;20(7):819-30.
614. Wood KB, Popp CA, Transfeldt EE, Geissele AE. Radiographic evaluation of instability in spondylolisthesis. Spine. 1994;19(15):1697-1703.
615. Xiao YX, Chen QX, Li FC. Unilateral transforaminal lumbar interbody fusion: a review of the technique, indications and graft materials. J Int Med Res. 2009;37(3):908-17.
616. Xu H, Tang H, Li Z. Surgical treatment of adult degenerative spondylolisthesis by instrumented transforaminal lumbar interbody fusion in the Han nationality: Clinical article. J Neurosurg Spine. 2009;10(5):496-499.
617. Yamashita T, Steinmetz MP, Lieberman IH, Modic MT, Mroz TE. The utility of repeated postoperative radiographs after lumbar instrumented fusion for degenerative lumbar spine. Spine. 2011;36(23):1955-60.
618. Yan DL, Pei FX, Li J, Soo CL. Comparative study of PILF and TLIF treatment in adult degenerative spondylolisthesis. Eur Spine J. 2008;17(10):1311-6.
619. Yao N, Wang W, Liu Y. Percutaneous endoscopic lumbar discectomy and interbody fusion with B-Twin expandable spinal spacer. Arch Orthop Trauma Surg. 2011;131(6):791-6.
620. Yao Q, Wang S, Shin JH, Li G, Wood KB. Lumbar facet joint motion in patients with degenerative spondylolisthesis. J Spinal Disord Tech. 2013;26(1):E19-27.
621. Yee AJ, Yoo JU, Marsolais EB, et al. Use of a postoperative lumbar corset after lumbar spinal arthrodesis for degenerative conditions of the spine. A prospective randomized trial. J Bone Joint Surg Am. 2008;90(10):2062-8.
622. Yone K, Sakou T, Kawauchi Y, Yamaguchi M, Yanase M. Indication of fusion for lumbar spinal stenosis in elderly patients and its significance. Spine. 1996;21(2):242-8.
623. Yong-hing K. Pathophysiology and rationale for treatment in lumbar spondylosis and instability. Chir Organi Mov. 1994;79(1):3-10.
624. Yoshimoto H, Sato S, Nakagawa I, et al. Deep vein thrombosis due to migrated graft bone after posterior lumbosacral interbody fusion. Case report. J Neurosurg Spine. 2007;6(1):47-51.
625. Yue WM, Tan SB. Distant skip level discitis and vertebral osteomyelitis after caudal epidural injection: a case report of a rare complication of epidural injections. Spine. 2003;28(11):E209-11.
626. Zagra A, Giudici F, Minoia L, Corriero AS, Zagra L. Long-term results of pediculo-body fixation and posterolateral fusion for lumbar spondylolisthesis. Eur Spine J. 2009;18 Suppl 1:151-5.
627. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus non-surgical treatment for lumbar spinal stenosis. Cochrane Database Syst Rev. 2012;(12):CD010264.
628. Zdeblick TA. A prospective, randomized study of lumbar fusion. Preliminary results. Spine. 1993;18(8):983-991.
629. Zhang HY, Park JY, Cho BY. The BioFlex System as a Dynamic Stabilization Device : Does It Preserve Lumbar Motion?. J Korean Neurosurg Soc. 2009;46(5):431-6.
630. Zhang YF, Yang HL, Tang TS, Shi Y. Mobilization range of the vertebral bodies after treatment of lumbar instability with titanium-coated fusion cage. Chin J Clin Rehabil. 2005;9(10):204-205.
631. Zhang ZM, Jin DD, Chen JT. [Comparative study of dynamic fixation with rigid fixation in the management of degenerative lumbar spondylosis]. Zhonghua Wai Ke Za Zhi. 2008;46(5):346-9.
632. Zhao J, Hou T, Wang X, Ma S. Posterior lumbar interbody fusion using one diagonal fusion cage with transpedicular screw/rod fixation. Eur Spine J. 2003;12(2):173-7.
633. Zhao J, Wang X, Hou T, He S. One versus two BAK fusion cages in posterior lumbar interbody fusion to L4-L5 degenerative spondylolisthesis: a randomized, controlled prospective study in 25 patients with minimum two-year follow-up. Spine. 2002;27(24):2753-7.
634. Zhao Y, Wang YP, Qiu GX, Zhao H, Zhang JG, Zhou X. Efficacy of the Dynamic Interspinous Assisted Motion system in clinical treatment of degenerative lumbar disease. Chin Med J. 2010;123(21):2974-7.
635. Zhou J, Wang B, Dong J, et al. Instrumented transforaminal lumbar interbody fusion with single cage for the treatment of degenerative lumbar disease. Arch Orthop Trauma Surg. 2011;131(9):1239-45.
636. Zouboulis P, Panagiotis ZE, Karageorgos A, et al. Functional outcome of surgical treatment for multilevel lumbar spinal stenosis. Acta Orthop. 2006;77(4):670-6

7075 Veterans Boulevard
Burr Ridge, IL 60527 USA
(866) SPINE-DR
www.spine.org

ISBN 1-929988-36-2

NASS
NORTH AMERICAN SPINE SOCIETY