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LITERATURE REVIEW

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# Defining the inherent stability of degenerative spondylolisthesis: a systematic review

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**OBJECT** A range of surgical options exists for the treatment of degenerative lumbar spondylolisthesis (DLS). The chosen technique inherently depends on the stability of the DLS. Despite a substantial body of literature dedicated to the outcome analysis of numerous DLS procedures, no consensus has been reached on defining or classifying the disorder with respect to stability or the role that instability should play in a treatment algorithm. The purpose of this study was to define grades of stability and to develop a guide for deciding on the optimal approach in surgically managing patients with DLS.

**METHODS** The authors conducted a qualitative systematic review of clinical or biomechanical analyses evaluating the stability of and surgical outcomes for DLS for the period from 1990 to 2013. Research focused on nondegenerative forms of spondylolisthesis or spinal stenosis without associated DLS was excluded. The primary extracted results were clinical and radiographic parameters indicative of DLS instability.

**RESULTS** The following preoperative parameters are predictors of stability in DLS: restabilization signs (disc height loss, osteophyte formation, vertebral endplate sclerosis, and ligament ossification), no disc angle change or less than 3 mm of translation on dynamic radiographs, and the absence of low-back pain. The validity and magnitude of each parameter's contribution can only be determined through appropriately powered prospective evaluation in the future. Identifying these parameters has allowed for the creation of a preliminary DLS instability classification (DSIC) scheme based on the preoperative assessment of DLS stability.

**CONCLUSIONS** Spinal stability is an important factor to consider in the evaluation and treatment of patients with DLS. Qualitative assessment of the best available evidence revealed clinical and radiographic parameters for the creation of the DSIC, a decision aid to help surgeons develop a method of preoperative evaluation to better stratify DLS treatment options.

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**KEY WORDS** degenerative lumbar spondylolisthesis; stability; qualitative systematic review; restabilization; surgical technique

Degenerative lumbar spondylolisthesis (DLS) is a common condition that usually occurs at the L4–5 level, seldom presents before the 5th decade, predominates in women, and often presents with spinal stenosis and an anterior translation up to 30% of the vertebral body width. Its pathology differs widely among patients; diverse clinical and radiographic presentations exist. Patients may have back pain or leg pain or both. Radiographically,

**ABBREVIATIONS** DLS = degenerative lumbar spondylolisthesis; DSIC = degenerative spondylolisthesis instability classification; MeSH = Medical Subject Headings.

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DLS varies in the magnitude of slip, disc and facet degeneration, and motion at the segment on dynamic views.[2,11,25,53,56]

Dupuis et al. described instability in DLS as abnormal movement exhibited by a lumbar motion segment.[19] The radiographic findings of disc height, sagittal disc angle, slip magnitude, facet joint orientation, severity of degenerative change, and presence of facet effusion are well described in the literature. However, no consensus has been reached on the value of these parameters in determining segmental stability, despite a large volume of studies dedicated to the preoperative assessment of patients presenting with DLS.

Degenerative lumbar spondylolisthesis has been investigated extensively from a management perspective,[41,56,58] and there is strong evidence to support surgical intervention.[47,58,59] However, it is not clear which surgery should be used to treat DLS, and there is no agreement on the role that instability should play in the treatment algorithm. It seems prudent to define symptomatic DLS in terms of stability to better target the optimal surgical technique and implant construct from an outcome and cost perspective.

No systematic review of the best available evidence has been completed as regards the treatment of stable and unstable DLS. The ability to quantify stability using clinically relevant parameters would allow surgeons to determine an individualized, patient-specific surgical approach. Moreover, greater treatment and outcome consistency using comprehensive terminology would optimize prospective research.

Our primary objective in the present study was to identify measurable preoperative clinical and radiographic variables that would define instability in DLS. A secondary objective was to evaluate clinical studies for factors that would help determine which levels of unstable pathology would benefit from decompression alone, decompression with posterolateral fusion, or decompression with posterolateral fusion and interbody fusion. Lastly, we developed a guide for choosing the optimal surgical technique in managing DLS.

## Methods

### Search Strategy

A systematic search of the English literature pertaining to DLS was undertaken in consultation with a professional librarian. MEDLINE and EMBASE databases were searched for data published from 1990 to 2013. The subject headings (MeSH [Medical Subject Headings]) in both databases were used in conjunction with key word variants to build gold-standard search strategies, which were then run on March 7, 2013. Variant terms used in the search included "spondylolisthesis" [MeSH], "spondylolisthesis" [keyword search], "lumbar vertebrae" [MeSH] (and their key word variants), "degenerative," and spinal stenosis" [MeSH]. Important references from each paper were reviewed for related studies and for gray literature not found initially in MEDLINE or EMBASE. All the papers found in both databases were then imported into a reference management program (RefWorks), and duplicate studies were examined and placed into exclusion files. Additional articles that may have been initially missed in the MEDLINE and EMBASE searches were subsequently added.

### Inclusion and Exclusion Criteria

We included biomechanical studies investigating possible factors associated with the stability of DLS and/or randomized controlled trials, comparative observational studies, or large case series investigating the surgical management of DLS by comparing 1) fusion to decompression and/or 2) instrumented to noninstrumented fusion and/or 3) posterolateral fusion to posterolateral fusion augmented with interbody fusion. To be included in our review, comparative studies had to have at least 5 patients in each study group, retrospective case series had to have 100 or more patients, and prospective case series had to have 40 or more patients. These inclusion parameters were chosen to safeguard objectivity, based on the quality of the literature available and previously used criteria.[38,41]

Studies were excluded if they investigated spinal stenosis in the absence of DLS or if it was impossible to separately analyze patients with DLS from another patient population. Comparative studies were excluded if they contained patients with tumors, isthmic spondylolisthesis, scoliosis, spinal fractures, or previous spine surgery. Degenerative spondylolisthesis in the cervical or thoracic spine was excluded as well.

### Evidence Categorization

Included studies were divided into 2 categories: biomechanical and clinical/radiographic. Clinical studies were critically evaluated by 2 independent reviewers (A.M.S. and C.G.F.) according to the Grades of Recommendation, Assessment, Development, and Evaluation (GRADE) criteria proposed by Schünemann et al.[54] Biomechanical studies were reviewed by a biomedical engineer (A.D.M.) and also graded according to their quality of evidence.

To facilitate defining DLS in terms of stability, results from the literature were categorized under the headings of patient factors, dynamic radiographs, facet joint orientation and tropism, facet joint effusion, restabilization signs, and disc height (Table 1). The findings were used to generate a quantitative scheme based on stability (Table 2). Examples of each stability type are illustrated in Figs. 1–3.

Our secondary objective was aided by the evaluation of clinical studies for factors that might help to determine which disease types, based on stability grading, would benefit from decompression alone, decompression with posterolateral fusion, or decompression with posterolateral fusion and interbody fusion. These findings were used to create a provisional surgical decision guide for the recommended surgical technique (Table 3).

## Results

### Degenerative Lumbar Spondylolisthesis Stability

A total of 696 abstracts were identified through MEDLINE and EMBASE searches. All abstracts were reviewed, and the complete text of each potentially relevant article was obtained. Another 9 potential articles were identified from a hand search of bibliographies. Five biomechanical[10,16,27,28,31] and 40 clinical and/or radiographic

**TABLE 1. Parameters used to assess stability in the included biomechanical and clinical studies evaluating patients with DLS**

| Parameter | Definition | Comments |
|---|---|---|
| Patient factors | Age, sex, occupation, & BMI | These variables assessed in several papers for correlation w/ stability at a given segment; none were found to have a strong association w/ instability |
| Dynamic radiographs | Change in disc angle or translation w/ flexion or extension radiographs, compared to neutral radiographs | Various measurement criteria used to define instability, including change in angle >8°–10°, change from lordotic angle to kyphotic angle, and translation >1.25 mm |
| Facet joint orientation | Angle btwn coronal plane & plane of the facet joint | Sagittally orientated facet joints have been shown to be associated w/ DLS; their role in the disease & particularly in the stability of a diseased segment is controversial |
| Facet joint effusion | T2-weighted MRI assessed for presence & amount of facet joint fluid; measured as a facet fluid index | Several calculation techniques exist for facet joint fluid effusion measurement; effusion size appears to have a linear correlation w/ instability |
| Restabilization signs | Osteophyte formation, vertebral endplate sclerosis, & ligament ossification have been described as signs of restabilization | Several parameters exist that may indicate restabilization of a given segment |
| Disc height | Disc height as a percentage of either disc width or vertebral body height | Assessed in several studies as a potential indicator of stability |

BMI = body mass index.

papers[1,3–5,7,9,11–13,15,18,20,22–24,29,30,32–34,36,37,39,40,42–47,49,52,53,57] were selected for study inclusion and graded for quality of evidence (Tables 4 and 5 list studies with evidence graded as low or higher). Twenty-two studies had very low quality evidence, 15 had low quality evidence, 3 had moderate quality evidence, and none had high quality evidence.

## Patient Factors

Most of the identified studies failed to demonstrate a significant correlation between stability in DLS and patient age, sex, occupation, or body mass index.[3,22,30,42–46,49] Pearson et al. found that a significantly smaller number of women with DLS showed radiographic instability, as compared with their male counterparts.[47] Matsunaga et al. found that patients with occupations demanding repetitive anterior flexion of the lumbar spine showed a significant increase in the likelihood of slip progression when they were managed nonoperatively.[44] Several studies used the presence of leg-dominant symptoms as a predictor of stability, with low-back pain as the dominant or secondary presenting feature being a marker of instability.[32,49] None of the identified patient factors showed a strong association with instability. All studies (11) that investigated the relationship between patient factors and stability in DLS had a very low to low quality of evidence.

## Dynamic Radiographs

Most studies indicated that dynamic radiographs are an important part of a preoperative workup and offer insight into stability at a given segment. Traditionally, authors use a disc angle change > 10° or change in translation > 3 mm, from standing or supine radiographs to dynamic radiographs, as a sign of instability.[3,7–9,13,15,17,25,26,31,48] In a study with low quality evidence, Kanayama et al. showed that dynamic flexion radiographs may be the most important images for determining instability.[31] These authors proposed that lordosis on flexion radiographs (compared with neutral position radiographs) is a sign of a stable segment, whereas change from lordosis to kyphosis with forward bending shows instability at a given level. In Blumenthal et al.'s study with low quality evidence, a translation > 1.25 mm of a DLS segment on dynamic radiographs was a significant risk factor for instability.[7] Several other studies that did not meet our inclusion criteria also described translation as a marker of instability.[8,25,48,58] Dynamic radiographs appear to be an important tool for assessing sta-

**TABLE 2. Degenerative spondylolisthesis instability classification scheme: a qualitative guide for the preoperative assessment of stability in patients with DLS**

| Parameter | Type I, Stable | Type II, Potentially Unstable | Type III, Unstable |
|---|---|---|---|
| Low-back pain | None or very mild | Primary or secondary complaint | Primary or secondary complaint |
| Restabilization | Restabilization signs, grossly narrowed disc height | Some restabilization signs, reduced disc height | No restabilization signs, normal to slightly reduced disc height |
| Disc angle | Lordotic disc angle on flexion radiographs or <3 mm of translation on dynamic films* | Neutral disc angle on flexion radiographs or 3–5 mm of translation on dynamic films* | Kyphotic disc angle on flexion radiographs or >5 mm of translation on dynamic films* |
| Joint effusion | No facet joint effusions on MRI | Facet joint effusion on MRI w/o joint distraction | Large facet joint effusion on MRI |

* Dynamic films include flexion and extension radiographs or supine to standing radiographs.

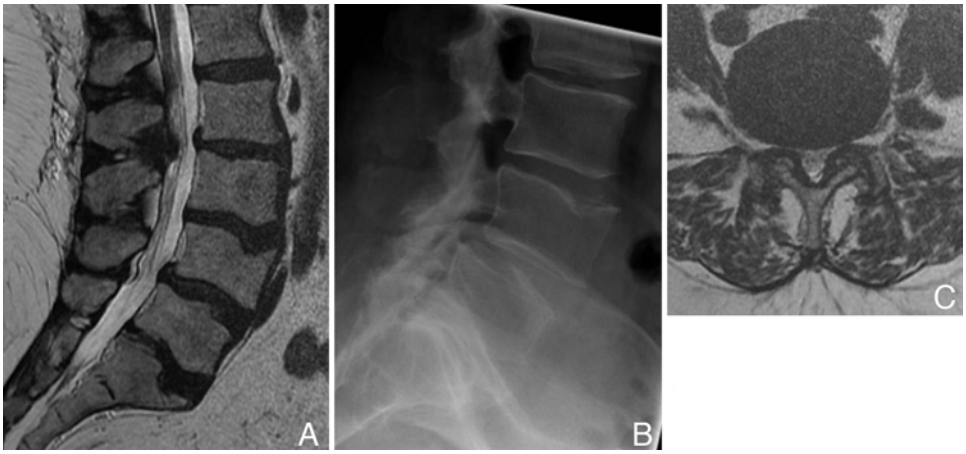

**FIG. 1.** Imaging samples of a patient with Type I (stable) L4–5 DLS. Note the restabilization signs, disc height loss, stable slip translation on standing radiographs **(A and B)**, as well as the lack of facet joint effusion **(C)** on MRI.

bility. Several parameters exist for measurement, including change in disc angle and translation. Kanayama et al. proposed a simplified measurement tool that categorizes the segmental angle as lordotic, neutral, or kyphotic.[31]

## Facet Joint Orientation and Tropism

Studies with very low quality evidence have suggested that increased sagittal orientation of the facet joints is associated with DLS.[4,6,15,23,31,57] However, there is disagreement among the authors of these papers regarding the significance of facet joint orientation and tropism as they relate to the stability of a DLS segment. Kanayama et al. did not find that facet orientation correlated with angular instability.[31] Cinotti et al. found an inverse relationship between the degree of sagittal orientation of the facet joints and the hypermobility of the spondylolisthetic vertebra.[15] Grobler et al. found an association between higher sagittal orientation at L4–5 and DLS; they concluded that this association represents a developmental predisposition for DLS.[23] Dai also suggested that facet joint tropism is a predisposing factor in DLS.[18] However, Berlemann et al. contend that a sagittal orientation is unlikely to be a causative factor in DLS given the lack of correlation between facet orientation and advancing patient age;[4] instead, they suggest that a remodeling of the joint due to hypertrophic degeneration is more likely. Furthermore, they did not find an association between facet joint tropism and the development of DLS. However, they did find a significant positive association between listhesis grade and more sagittally oriented facet joints.[6] While sagittally oriented facet joints have been associated with DLS, their role in the development of the disease and especially in the stability of a diseased segment is controversial, based on current evidence.

## Facet Joint Effusion

Facet joint effusion appears to have a linear correlation with the degree of instability at a given segment.[13,39,46] To measure this entity, Cho et al. used the facet fluid index,[13]

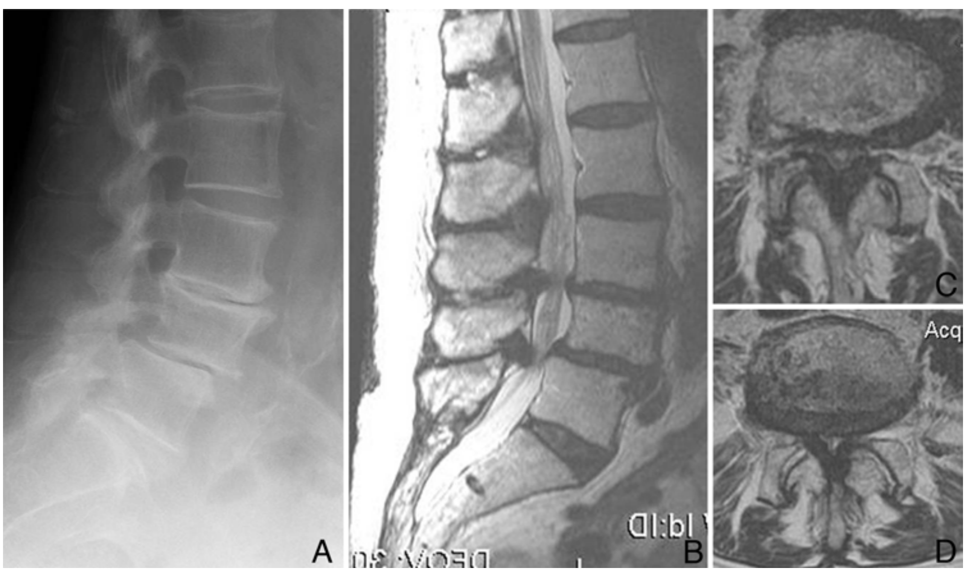

**FIG. 2.** Imaging samples of a patient with a Type II (potentially unstable) L4–5 DLS. Note the increase in slip translation on standing radiographs **(A and B)**, moderate facet joint effusion on MRI **(C and D)**, and presence of restabilization signs **(A and B)**.

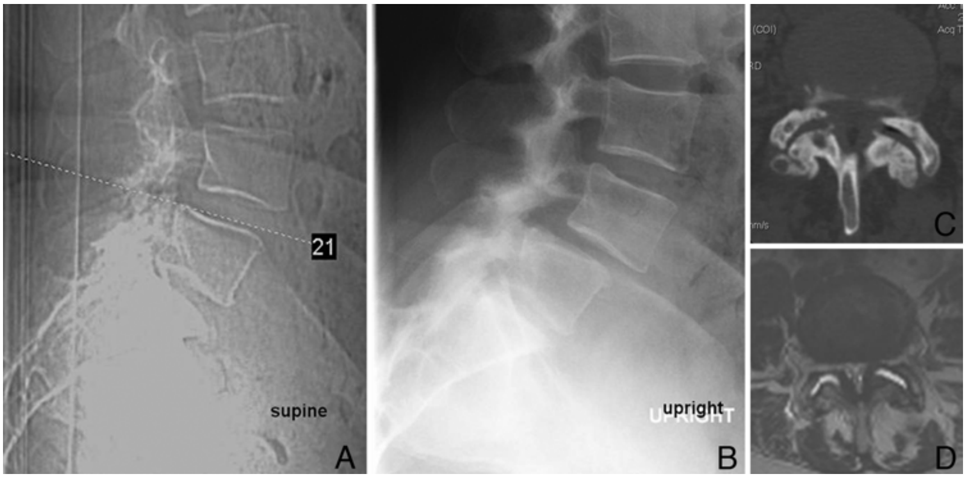


**FIG. 3.** Imaging samples of a patient with a Type III (unstable) L4–5 DLS. Note the increase in slip translation **(A and B)** on standing radiographs, large facet joint effusion **(C and D)** on MRI, and subtle restabilization signs **(A–C)**.

which was defined as the sum of the facet fluid distance on the right and left sides divided by the sum of their average facet width on the right and left sides. Lattig et al.[39] and Oishi et al.[46] measured the greatest distance between the apparent articular surfaces to determine facet effusion size. Lattig et al. found that, in general, mean effusions over 1.77 mm on either side were associated with instability, whereas Oishi et al. found unstable motion in patients with effusion sizes over 1.3 mm. Several proposed but unvalidated calculation techniques exist for measuring facet joint fluid effusion. Although all studies (3) included in this analysis of facet joint effusion have a low to very low quality of evidence, they have indicated that the presence of a facet joint effusion, best seen on a supine axial MR image, appears to have a linear correlation with instability.

### Restabilization Signs

Kirkaldy-Willis and Farfan described secondary changes in the affected segments leading to the restabilization of spondylolisthesis.[35] Several other authors have echoed the concept of segmental stabilization from osteophyte formation, vertebral endplate sclerosis, and ligament ossification. Lattig et al.[39] and Matsunaga et al.[44] associated osteophytes with increased stability at the affected segments. However, Anderson et al. found that osteophyte size, when evaluated both categorically or as a continuous variable, was not correlated with either translational or angular motion on flexion and extension radiographs.[3] The majority of studies have showed that restabilization can occur at a diseased segment, and thus increasing stability in DLS. There is no firm agreement on what parameters indicate a restabilized segment, but osteophyte formation, vertebral endplate sclerosis, and ligament ossification have been implicated in this process by very low quality evidence.

### Disc Height

Controversy exists regarding the association between narrowed disc height and stability of the affected DLS segment. While several clinical and biomechanical studies have failed to show a significant correlation between the two,[6,31,44] some studies with low quality evidence have showed decreased slip progression or have inferred stability with narrowed disc height.[16,21] Despite the absence of conclusive evidence that disc space narrowing is directly associated with increased stability, there is enough evidence for it to be considered in the determination of stability at a given segment.

### Surgical Technique

#### Decompression Versus Decompression and Fusion

Low to moderate quality evidence supports the historical understanding that decompression and fusion lead to better outcomes than decompression alone.[23,30,37] However, as our understanding evolves, DLS is viewed as a more complex disease than previously assumed. More recent studies with low quality evidence have challenged the belief that all patients with DLS should be placed in a single study group. Several authors have stratified patients based on presumed stability and reevaluated the need for fusion.[32,42,49,53] In these studies, it would appear that the 2 main selection criteria for selecting decompression alone in the DLS population were 1) leg-dominant symptoms and 2) Grade 1 DLS with < 3–5 mm of movement on loading or dynamic radiographs.[32,42,52] Furthermore, Kim et al. found that in stable patients with leg-dominant symptoms, decompression alone is significantly more cost effective.[33] While the literature is not conclusive at this point, there is some low quality evidence that decompression alone may be the optimal treatment in carefully selected patients with so-called stable DLS.

#### Instrumented Versus Noninstrumented Fusion

While instrumentation has been shown to increase fu-

**TABLE 3. Proposed treatment guideline with stratification by stability grade**

| Type of Stability Grade | Treatment |
|---|---|
| I, stable | Decompression alone |
| II, potentially unstable | Decompression & posterior fusion |
| III, unstable | Decompression & posterior fusion + interbody fusion |

**TABLE 4. Summary on the 5 biomechanical articles included in the study, with the grade of evidence determined by an independent biomechanical engineer**

| Authors & Year | Article Title | No. of Patients or Motion Segments | Study Type | Outcomes | Critique of Evidence | Grade of Evidence |
|---|---|---|---|---|---|---|
| Crawford et al., 2001 | Biomechanics of Grade I degenerative lumbar spondylolisthesis. Part 1: in vitro model | 3 cadaveric spines, 13 segments | Cross-sectional cadaveric (ex vivo) | Effect of tissue sectioning on spinal motion (rotation & shear translation) | Nonphysiological shear loads, questionable statistics | Low |
| Cagli et al., 2001 | Biomechanics of Grade I degenerative lumbar spondylolisthesis. Part 2: treatment with threaded interbody cages/dowels and pedicle screws | 7 cadaveric spines, 33 segments | Cross-sectional cadaveric (ex vivo) | Effect of spine hardware on ROM & translation | Low no. of specimens, nonphysiological shear loads, questionable statistics | Low |
| Hasegewa et al., 2009 | Biomechanical evaluation of segmental instability in degenerative lumbar spondylolisthesis | 41 subjects, 6 controls | Case-control (in vivo) | Difference in in vivo biomechanical parameters btwn case & control: stiffness, neutral zone, absorption energy | Actual motion/force applied & measured is not clear, but comparisons btwn groups should still be valid | Moderate |
| Hasegawa et al., 2010 | Facet joint opening in lumbar degenerative diseases indicating segmental instability | 17 DLS subjects, 12 stenosis subjects | Case-control (in vivo) | Difference in in vivo biomechanical parameters btwn case & control: stiffness, neutral zone, energy; correlations w/ facet joint degeneration | Small no. of subjects | Moderate |
| Kanayama et al., 2003 | Intraoperative biomechanical assessment of lumbar spinal instability: validation of radiographic parameters indicating anterior column support in lumbar spinal fusion | 19 patients | Prospective cohort (in vivo) | In vivo spinal distraction stiffness correlation w/ radiographic measures of instability | Low no. of patients, calibration of force-strain spreader to measure main outcome (stiffness) was not adequately described | Low |

ROM = range of motion.

sion rates, 2-year follow-up results in most of the identified studies consistently showed no difference in clinical outcomes between patients treated with instrumented fusion and those treated with noninstrumented fusion.[14,20] Kimura et al. did find that postoperative low-back pain was significantly less in the instrumented fusion group and that the use of pedicle screws resulted in a lordotic angulation at the L4–5 level.[34] Chen et al. found that instrumentation led to better clinical outcomes at an average of 58 months.[12] Unfortunately, there is limited long-term follow-up among the studies. At this time, the studies (4) investigating instrumented versus noninstrumented fusion are low quality and suggest that there is no definite benefit to instrumented fusion.

### Posterolateral Fusion Versus Posterolateral and Interbody Fusion

A limited amount of literature evaluates the role of interbody fusion as an adjunct to decompression and posterolateral fusion in patients with DLS.[24,53] Ha et al. highlighted the need for the stratification of patients based on stability and showed that interbody fusion could be a worthwhile adjunctive procedure in those with unstable DLS.[24]

## Discussion

In 2005, Resnick et al. published an extensive set of guidelines for the performance of fusion procedures for degenerative diseases of the lumbar spine, including stenosis and spondylolisthesis.[50] These guidelines were updated in 2014,[51] and decompression plus posterolateral fusion was recommended in this patient population, but the authors noted that there was insufficient evidence to recommend a treatment guideline. Surgeons' understanding of DLS is evolving; thus, conventional evidence-based treatments are being challenged with less invasive and lower cost procedures. The controversy that exists regarding the treatment of patients with stable DLS is exemplified by a Web survey posted by the North American Spine Society in 2008. In this survey, Scioscia et al. noted that, for patients with stable DLS, the majority of respondents (41.7%) still recommended decompression and fusion.[55] However, the second most common recommendation (33.4% of respondents) was for decompression alone. If spine surgeons are to obtain higher quality evidence to guide the treatment of DLS, we must first establish a baseline of best available evidence around critical parameters and move forward with carefully planned prospective research.

While several authors have noted the importance of determining stability in a preoperative workup, there is no consensus on what constitutes the variables indicating stability or their specific weight or contribution to the magnitude of DLS stability. In addition, recent literature

TABLE 5. Summary on radiographic and clinical articles included in the study, with the grade of evidence judged according to the GRADE criteria

| Authors & Year | Article Title | Type of Study | Study Size | Synopsis | Conclusions | Outcomes, Comments, & Statistics | Quality of Evidence Rating |
|---|---|---|---|---|---|---|---|
| Blumenthal et al., 2013 | Radiographic predictors of delayed instability following decompression without fusion for degenerative Grade I lumbar spondylolisthesis | Prospective case series | 40 patients | Review of radiographic parameters in patents treated w/ laminectomy (w/o fusion) for DLS w/ spinal stenosis to determine predictors of instability | DLS patients w/ >1.25 mm motion at the spondylolisthesis, >6.5 mm disc height, & >50° facet angle are more likely to have instability following decompressive surgery for Grade I DLS | SF-36 & ODI scores used in clinical evaluation; chi-square test, Student t-test, & repeated-measures ANOVA used; multivariate stepwise logistic regression w/ a threshold p value of 0.35 | Low |
| Bridwell et al., 1993 | The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis | Prospective randomized study | 44 patients | 2-yr outcome comparison of patients w/ DLS managed w/ decompression alone, decompression & noninstrumented fusion, or decompression & instrumented fusion | DLS patients who underwent instrumented fusion had a higher union rate than those who underwent noninstrumented fusion; those who underwent decompression alone or noninstrumented fusion had a higher rate of slip progression | Uneven groups & not randomized properly; demographic differences btwn groups | Low |
| Cinotti et al., 1997 | Predisposing factors in degenerative spondylolisthesis: a radiographic and CT study | Radiographic case control analysis | 52 patients | Flexion/extension views & CT scans of patients w/ DLS compared w/ those of controls | Facet joint orientation & vertebral motion at the spondylolisthetic level were significantly different in patients w/ DLS compared w/ controls | Prospective study; analysis of variance, t-test, & linear regression analysis used | Low |
| Dai, 2001 | Orientation and tropism of lumbar facet joints in degenerative spondylolisthesis | Radiographic analysis | 106 patients | Comparison of lat radiographs & MRIs of patients w/ DLS compared w/ controls | Patients w/ DLS had more sagittally oriented facet joints & more significant facet joint tropism than controls; this was significantly correlated w/ degree of disc degeneration | Student t-test & linear correlation tests used to compare subjects to age- & sex-matched controls | Low |
| Fischgrund et al., 1997 | Degenerative lumbar spondylolisthesis with spinal stenosis: A prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation | Prospective, randomized study | 76 patients | Comparison of outcomes & fusion rates in DLS patients managed w/ instrumented or noninstrumented posterior decompression & fusion | In patients undergoing single-level posterolat fusion for DLS w/ spinal stenosis, the use of pedicle screws may lead to a higher fusion rate, but clinical outcome shows no improvement in pain in the back & lower limbs | Outcome measured as excellent, good, fair, & poor; 88% FU at 2 yrs | Moderate |
| Ghogawala et al., 2004 | Prospective outcomes evaluation after decompression with or without instrumented fusion for lumbar stenosis and degenerative Grade I spondylolisthesis | Prospective cohort study | 34 patients | Comparison of outcomes & fusion rates in patients w/ spinal stenosis & Grade I DLS managed w/ decompression alone, or decompression w/ posterolat instrumented fusion | Surgery substantially improved 1-yr outcomes in patients w/ Grade I DLS & stenosis; fusion was associated w/ greater functional improvement | Patients not randomized; validated outcome scores used | Low |

*(continued)*

**TABLE 5. Summary on radiographic and clinical articles included in the study, with the grade of evidence judged according to the GRADE criteria *(continued)***

| Authors & Year | Article Title | Type of Study | Study Size | Synopsis | Conclusions | Outcomes, Comments, & Statistics | Quality of Evidence Rating |
|---|---|---|---|---|---|---|---|
| Ha et al., 2008 | Comparison of posterolateral fusion with and without additional posterior lumbar interbody fusion for degenerative lumbar spondylolisthesis | Retrospective cohort study | 40 patients | DLS patients all underwent decompression & posterolat fusion; patients divided into 4 groups: stable no TLIF, unstable no TLIF, stable w/ TLIF, unstable w/ TLIF | Preop segmental instability may be a criterion determining whether an additional PLIF would be beneficial in the treatment of lumbar DLS | Well-done retrospective cohort analysis w/ validated outcome measures but small nos. (<10) in each group | Low |
| Herkowitz & Kurz, 1991 | Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective study comparing decompression with decompression and intertransverse process arthrodesis | Prospective cohort study | 50 patients | 3-yr outcomes compared in patients w/ DLS to evaluate decompression alone vs decompression & inter-transverse process arthrodesis | In patients w/ DLS & spinal stenosis, those treated w/ decompression & inter-transverse process arthrodesis did better w/ respect to pain relief in the back & lower limbs than those treated w/ decompression alone | Patients not randomized appropriately, vague clinical outcome measures | Moderate |
| Jacobsen et al., 2007 | Degenerative lumbar spondylolisthesis: an epidemiological perspective: the Copenhagen Osteoarthritis Study | Cross-sectional epidemiological survey | 4151 patients | Statistical correlations were made btwn degenerative spondylolisthesis, & physical, occupational, & general epidemiological data | BMI longitudinally & at index evaluations, age, & angle of lordosis were significantly associated w/ DLS in women; in men, only increased age was a risk factor for DLS | Chi-square, Student t-test, & multivariate logistic regression analyses used | Low |
| Kim et al., 2012 | Cost-utility of lumbar decompression with or without fusion for patients with symptomatic degenerative lumbar spondylolisthesis | Comparative cost-effectiveness study | 115 patients | Incremental cost/utility ratio analysis of decompression vs decompression & fusion for selected patients w/ DLS, identified retrospectively from a single-surgeon cohort | For a select subgroup of patients w/ DLS (leg-dominant pain w/ a stable Grade I spondylolisthesis), decompression w/o fusion is significantly more cost effective than instrumented fusion & provides an opportunity for increased service delivery &/or cost savings | Markov state-transition model generated w/ cost data obtained from the authors' hospital records | Low |
| Kimura et al., 2001 | Lumbar posterolateral fusion alone or with transpedicular instrumentation in L4–L5 degenerative spondylolisthesis | Retrospective cohort study | 57 patients | 2-yr outcomes comparing decompression & fusion w/ or w/o instrumentation in patients w/ DLS | Radiologically excessive preop segmental motion may affect postop slip angle in patients w/ L4–5 DLS; validity of the general addition of screw instrumentation to L4–5 fusion for DLS is low | JOA clinical outcomes; Wilcoxon rank-sum test was conducted for 2- group comparison | Low |
| Kleinstueck et al., 2012 | To fuse or not to fuse in lumbar degenerative spondylolisthesis: do baseline symptoms help provide the answer? | Retrospective cohort study | 213 patients | Preop & 12-mo postop clinical outcomes compared in patients w/ DLS treated w/ decompression alone or w/ fusion | DLS patients showed better patient-based outcome w/ instrumented fusion & decompression than w/ decompression alone, regardless of baseline symptoms | Multidimensional Core Outcome Measures Index including leg pain & low-back pain compared btwn groups | Low |
| Matsudaira et al., 2005 | Spinal stenosis in Grade I degenerative lumbar spondylolisthesis: a comparative study of outcomes following laminoplasty and laminectomy with instrumented spinal fusion | Retrospective cohort study | 53 patients | Outcome comparison of patients w/ DLS & spinal stenosis, treated w/ laminectomy, laminectomy & instrumented posterolat fusion, or nonoperatively | No significant difference in degree of clinical improvement btwn surgical groups; decompressing the spinal canal w/ preservation of the posterior elements of its roof can be useful for treating patients w/ Grade I DLS w/ symptoms of spinal stenosis | Well-done retrospective study; JOA clinical outcome measurement | Low |

*(continued)*

**TABLE 5. Summary on radiographic and clinical articles included in the study, with the grade of evidence judged according to the GRADE criteria** ***(continued)***

| Authors & Year | Article Title | Type of Study | Study Size | Synopsis | Conclusions | Outcomes, Comments, & Statistics | Quality of Evidence Rating |
|---|---|---|---|---|---|---|---|
| Oishi et al., 2010 | Smaller facet effusion in association with restabilization at the time of operation in Japanese patients with lumbar degenerative spondylolisthesis | Retrospective cohort study | 195 patients | Compared preop imaging & patient factors of surgically managed patients w/ DLS who were deemed stable or unstable based on preop dynamic radiographs | Facet effusion size associated w/ determination of whether the affected disc was stabilized or remained unstable at the time of operation; in particular, a smaller facet effusion strongly suggested that the affected disc had been restabilized in DLS patients | Pearson regression coefficients or kappa coefficients were calculated | Low |
| Pearson et al., 2008 | Spine patient outcomes research trial: radiographic predictors of clinical outcomes after operative or nonoperative treatment of degenerative spondylolisthesis | Subgroup analysis of a combined randomized & observational cohort study | 222 patients | Described baseline characteristics of DLS patients stratified by listhesis grade, disc height, & hypermobility; determined if surgical & nonop outcomes were associated w/ these baseline radiographic findings | Regardless of listhesis grade, disc height or mobility, patients who had surgery improved more than those treated nonoperatively; these differences were due, in part, to differences in nonop outcomes, which were better in patients classified as Grade I or hypermobile | Chi-square & t-tests used to compare data, w/ adjustments for potential confounding, baseline variables associated w/ missing data or treatment received | Moderate |
| Rampersaud et al., 2014 | Health-related quality of life following decompression compared to decompression and fusion for degenerative lumbar spondylolisthesis: a Canadian multicentre study | Ambispective cohort study | 179 patients | Compared HRQOL in patients w/ stable DLS managed w/ either decompression alone or decompression & fusion | Anatomy-preserving decompression alone in selected patients w/ leg-dominant pain & a stable (<5 mm motion) Grade I DLS achieved patient-reported outcomes similar to those in an unselected group of patients w/ decompression & fusion at a minimum of 2 yrs postoperatively | Multicenter study; SF-36 outcome measure; proportion of patients achieving minimal clinically important difference & substantial clinical benefit used; multivariate analysis | Low |
| Sasai et al., 2008 | Microsurgical bilateral decompression via a unilateral approach for lumbar spinal canal stenosis including degenerative spondylolisthesis | Retrospective cohort study | 48 patients | Surgical outcomes at 24–71 mos following microsurgical bilat decompression via a unilat approach were evaluated in patients w/ DLS & degenerative stenosis | Satisfactory outcome of microsurgical bilat decompression via a unilat approach persisted for a period longer than 2 yrs for patients w/ DLS w/ stenosis as well as for those w/ degenerative stenosis | NCOS & ODI scores & the back pain score w/in the NCOS were used | Low |
| Toyone et al., 2009 | Facet joint orientation difference between cephalad and caudad portions: a possible cause of degenerative spondylolisthesis | Radiographic case-control analysis | 60 patients | Cephalad & caudad facet measurements compared btwn patients w/ DLS & spinal stenosis w/o spondylolisthesis | Cephalad portions of facet joints were more sagittally oriented, & the caudad portions were more coronally oriented in patients w/ DLS | The t-test, Mann-Whitney U-test, & Wilcoxon signed-rank test were used | Low |

FU = follow-up; HRQOL = health-related quality of life; JOA = Japanese Orthopaedic Association; NCOS = Neurogenic Claudication Outcome Score; ODI = Oswestry Disability Index; PLIF = posterior lumbar interbody fusion; SF-36 = 36-Item Short-Form Health Survey; TLIF = transforaminal lumbar interbody fusion.

has suggested that stratifying patients based on stability is an important factor in treatment algorithms, and thus the importance of answering the above questions is amplified.

Our qualitative systematic review demonstrated only moderate to very low quality evidence related to these questions. However, we believe that the results are strong enough to adopt a qualitative method of defining DLS stability. Doing so supports our ideal of adopting an evidence-based medicine approach to treatment. Using clinical experience and the best available evidence, we must build decision aids or guidelines with which to move forward and obtain higher quality evidence.

The following parameters are probably predictors of stability in DLS: facet effusion, restabilization signs including disc height loss, disc angle change on dynamic radiographs, and the absence of low-back pain. The magnitude of their contribution can only be determined with appropriately powered prospective evaluation.

The segmental motion on dynamic radiographs is considered by most to be a reliable predictor of instability, yet there is little evidence or consensus on how this would best be assessed. Some studies that are clinically used and often cited did not meet our inclusion criteria. They used translation on dynamic radiographs as a marker of instability. Hanley described an unstable segment as one with > 4 mm of translation or > 10° of angular change on motion radiographs.[26] Boden and Wiesel described ranges of normal translation on dynamic radiographs as 0% to 8%–9% and normal rotation as 0° to 16°–27°.[8] White and Panjabi developed a checklist for clinical instability in the lumbar spine that included sagittal plane translation > 4.5 mm or 15% and sagittal plane rotation of 20° at L4–5 or 25° at L5–S1 on dynamic radiographs.[60] Additionally, Posner et al. introduced the concept of threshold of stability on dynamic views as anterior translation ≤ 8%, posterior translation ≤ 9%, or angular rotation ≤ –9° from L-1 to L-5 or 1° at L5–S1.[48] Working through this maze of parameters is futile if a high-level evidence-based conclusion is the goal. A qualitative proposal with face and content validity to be evaluated prospectively is the best we can do.

Identification of these parameters has allowed us to propose a preliminary degenerative spondylolisthesis instability classification (DSIC) scheme based on the preoperative assessment of stability. Facet joint effusion (very low to low quality evidence), restabilization signs and disc height loss (very low quality evidence), change in disc angle on flexion radiographs (low quality evidence), and leg-dominant versus back-dominant pain (very low to low quality evidence) were included in the proposed classification (Table 2). Other patient factors and sagittal orientation of the facets were not included, as their role in stability remains quite controversial based on current evidence. The DSIC should be used as a qualitative decision aid for surgeons to better evaluate DLS. The next phase for the classification scheme is reliability testing and criterion validity evaluation with future iterations to evolve into a quantitative decision aid.

There are inherent limitations to this study. Primarily, the quality of a systematic review is restricted by the quality of available literature. Much of the available evidence was low to very low quality, with a few studies graded as moderate quality evidence. This certainly lowers the strength of the recommendations, but it is the first systematic literature review regarding this question; therefore, it represents the highest-level evidence to date on grading DLS stability. Our results represent a starting point for studying these findings prospectively, so we can obtain higher-level research to quantify clinically relevant DLS stability.

Many clinical outcomes are measured up to 2 years posttreatment, but a paucity of long-term follow-up data appears in comparative studies on the surgical management of DLS. The answer to some specific outcomes, such as adjacent segment disease related to treatment choice, will not be seen until long-term outcome data become available.[7,41,42,49]

Finally, as a qualitative review, this study is naturally limited by researcher bias. To minimize this, we enlisted the expertise of 3 experienced spine surgeons and a biomedical engineer to evaluate the quality of the literature and reach a consensus on the recommendations.

Our surgical treatment recommendations are founded primarily on the theoretical and biomechanical demands of the surgical construct and the evidence from clinical studies. The surgical technique or construct used in DLS treatment should be established based on stability patterns and patient factors. Very stable DLS should not require fusion. A moderate degree of instability requires instrumented or noninstrumented fusion, and a highly unstable DLS would probably be best treated with a 360° fusion—the construct offering the most stability. We have not discussed specific instrumentation types, nor have we explored more novel techniques such as minimally invasive surgery or interbody fusion as a stand-alone procedure.

While determining stability is critical in the evaluation and treatment of DLS, several other parameters deserve further appraisal for their roles in DLS pathology and treatment choices. Adjacent segment degeneration and proximal junctional kyphosis are not addressed in this study. Similarly, the utility of dynamic stabilization with interspinous stabilizers was outside the scope of our focused research and thus has not been explored in this review. Outcomes with segmental lordosis, reduction of translation, and instrumentation related to these pathologies and to health-related quality of life should be investigated further.

## Conclusions

Spinal stability is an important factor to consider in the evaluation of patients with DLS. Facet effusion, restabilization signs including disc height loss, and disc angle change on dynamic radiographs are important parameters in the assessment of stability. In addition, clinical presentation with leg-dominant pain may be an important parameter to consider. Once the stability of a given segment is determined, the operative plan can be better gauged.

The proposed classification scheme in this study uses these parameters to help surgeons develop a method of preoperative evaluation to better stratify treatment options. From this assessment, preliminary surgical recommendations are based on stability type. These recommendations will be refined as reliability, validity, and prospective studies guide our understanding of this complex disease.

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Conception and design: Fisher, Simmonds. Acquisition of data: Simmonds, Melnyk. Analysis and interpretation of data: Fisher, Simmonds, Rampersaud, Dvorak. Drafting the article: Simmonds, Melnyk. Critically revising the article: all authors. Reviewed submitted version of manuscript: Simmonds, Rampersaud, Dvorak, Dea, Melnyk. Approved the final version of the manuscript on behalf of all authors: Fisher. Study supervision: Fisher.

## Supplemental Information

### Previous Presentation

Portions of this work were presented in a podium presentation at the Annual Meeting of the Canadian Spine Society held in Mont Tremblant, QC, Canada, on March 1, 2013.


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