Evaluating Instability in Degenerative Lumbar Spondylolisthesis

Objective Variables Versus Surgeon Impressions

Mark A. MacLean, MD, MSc, Chris Bailey, MD, MS, FRCS, Charles Fisher, MD, MHSc, FRCS, Yoga Raja Rampersaud, MD, MSc, FRCS, Ryan Greene, MSc, Edward Abraham, MD, FRCS, Nicholas Dea, MD, MSc, FRCS, Hamilton Hall, MD, FRCS, Neil Manson, MD, FRCS, and Raymond Andrew Glennie, MD, MSc, FRCS

**Background:** The subjective degenerative spondylolisthesis instability classification (S-DSIC) system attempts to define preoperative instability associated with degenerative lumbar spondylolisthesis (DLS). The system guides surgical decision-making based on numerous indicators of instability that surgeons subjectively assess and incorporate. A more objective classification is warranted in order to decrease variation among surgeons. In this study, our objectives included (1) proposing an objective version of the DSIC system (O-DSIC) based on the best available clinical and biomechanical data and (2) comparing subjective surgeon perceptions (S-DSIC) with an objective measure (O-DSIC) of instability related to DLS.

**Methods:** In this multicenter cohort study, we prospectively enrolled 408 consecutive adult patients who received surgery for symptomatic DLS. Surgeons prospectively categorized preoperative instability using the existing S-DSIC system. Subsequently, an O-DSIC system was created. Variables selected for inclusion were assigned point values based on previously determined evidence quality. DSIC types were derived by point summation: 0 to 2 points was considered stable, Type I; 3 points, potentially unstable, Type II; and 4 to 5 points, unstable, Type III. Surgeons’ subjective perceptions of instability (S-DSIC) were retrospectively compared with O-DSIC types.

**Results:** The O-DSIC system includes 5 variables: presence of facet effusion, disc height preservation (≥6.5 mm), translation (≥4 mm), kyphotic or neutral disc angle in flexion, and low back pain (≥5 of 10 intensity). Type I (n = 176, 57.0%) and Type II (n = 164, 53.0%) were the most common DSIC types according to the O-DSIC and S-DSIC systems, respectively. Surgeons categorized higher degrees of instability with the O-DSIC than the S-DSIC system in 130 patients (42%) (p < 0.001). The assignment of DSIC types was not influenced by demographic variables with either system.

**Conclusions:** The O-DSIC system facilitates objective assessment of preoperative instability related to DLS. Surgeons assigned higher degrees of instability with the S-DSIC than the O-DSIC system in 42% of cases.

**Level of Evidence:** Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Degenerative lumbar spondylolisthesis (DLS) is an acquired anterior translation of 2 adjacent vertebrae. Patients with DLS may develop radiculopathy or neurogenic claudication, with or without low back pain (LBP). Current evidence supports the role of surgery, primarily for the decompression of neural elements. Instability is a common indication for surgical stabilization. Decompression and fusion have been suggested to improve clinical outcomes for symptomatic DLS when compared with decompression alone. Three recent randomized controlled trials found no major advantage for either laminectomy alone or laminectomy plus fusion in patients with spinal stenosis; however, none of the studies captured patients with traditional horizontal translational instability. Notably, there has been an exponential increase in the rates of fusion surgery in the United States. Instability or translation that exists between 2 (or 3) vertebrae drives the decision to perform fusion in many instances. Many clinical and radiographic variables may contribute to spinal instability, adding complexity and variation to surgical decision-making. Other reported structural variables include facet joint orientation, facet effusion, sagittal disc angle, and stabilization signs, including loss of disc height, osteophytes, vertebral end-plate sclerosis, and posterior ligament ossification. Inconsistent and subjective consideration of numerous parameters associated with instability naturally introduces variability in the decision-making process.
In an effort to reduce such variation, the Canadian Spine Outcomes Research Network (CSORN) systematically reviewed the literature and described the subjective degenerative spondylolisthesis instability classification (S-DSIC) system for categorizing DLS-related stability7 (Table I). The S-DSIC includes 1 clinical (back pain) and 3 radiographic variables (evidence of segmental restabilization, disc translation or angulation, and presence of joint effusion) supported by the best available clinical and biomechanical data. Surgeons categorize stability as Type I (stable), Type II (potentially unstable), or Type III (unstable).7 The system suggests decompression alone, instrumented posterolateral fusion (IPLF), or IPLF with an interbody device, depending on the degree of instability. However, the S-DSIC lacks specific cutoff values for each of the clinical and radiographic variables. An objective DSIC (O-DSIC) system is warranted.

The recently validated French10 and CARDS (clinical and radiographic degenerative spondylolisthesis)11 classification systems for DLS incorporate a variety of pertinent radiographic indices to improve the recognition of distinct DLS subtypes. These systems, however, do not make explicit recommendations about specific surgical procedures or account for potential overutilization of fusion surgery.

We enrolled 408 consecutive adult patients receiving surgery for DLS with symptomatic spinal stenosis in a prospective cohort study. Our study objectives included (1) proposing an objective version of the DSIC system (O-DSIC) based on the best available clinical and biomechanical data and (2) comparing subjective surgeon perceptions (S-DSIC) with the objective measure (O-DSIC) of instability secondary to DLS. Validation of the preliminary O-DSIC system requires future work, which should be conducted prior to its use in clinical and research settings.

| 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 radiographs | Neutral disc angle on flexion radiographs or 3-5 mm of translation on dynamic radiographs | Kyphotic disc angle on flexion radiographs or >5 mm of translation on dynamic radiographs |
| Joint effusion     | No facet joint effusion on MRI                      | Facet joint effusion on MRI without joint distraction | Large facet joint effusion on MRI                        |

*MRI = magnetic resonance imaging.

In an effort to reduce such variation, the Canadian Spine Outcomes Research Network (CSORN) systematically reviewed the literature and described the subjective degenerative spondylolisthesis instability classification (S-DSIC) system for categorizing DLS-related stability7 (Table I). The S-DSIC includes 1 clinical (back pain) and 3 radiographic variables (evidence of segmental restabilization, disc translation or angulation, and presence of joint effusion) supported by the best available clinical and biomechanical data. Surgeons categorize stability as Type I (stable), Type II (potentially unstable), or Type III (unstable).7 The system suggests decompression alone, instrumented posterolateral fusion (IPLF), or IPLF with an interbody device, depending on the degree of instability. However, the S-DSIC lacks specific cutoff values for each of the clinical and radiographic variables. An objective DSIC (O-DSIC) system is warranted.

The recently validated French10 and CARDS (clinical and radiographic degenerative spondylolisthesis)11 classification systems for DLS incorporate a variety of pertinent radiographic indices to improve the recognition of distinct DLS subtypes. These systems, however, do not make explicit recommendations about specific surgical procedures or account for potential overutilization of fusion surgery.

We enrolled 408 consecutive adult patients receiving surgery for DLS with symptomatic spinal stenosis in a prospective cohort study. Our study objectives included (1) proposing an objective version of the DSIC system (O-DSIC) based on the best available clinical and biomechanical data and (2) comparing subjective surgeon perceptions (S-DSIC) with the objective measure (O-DSIC) of instability secondary to DLS. Validation of the preliminary O-DSIC system requires future work, which should be conducted prior to its use in clinical and research settings.

**Materials and Methods**

**Study Design and Population**

Consecutive adult patients scheduled for surgery for 1- or 2-level DLS-related symptomatic spinal stenosis were enrolled by 16 surgeons across 8 sites as part of an ongoing multicenter prospective CSORN study. Patients undergoing decompression or fusion surgery for lumbar disc herniation, degenerative scoliosis of >10°, or static spinal stenosis were excluded. Patients with nondegenerative spondylolisthesis (i.e., isthmic or congenital), DLS without stenosis, trauma, infection, or malignancy were also excluded.

**Data Collection**

Patient data collection and privacy procedures that were employed in this study have been described previously12. All of the participants provided written informed consent. All of the sites obtained Research Ethics Board approval prior to data collection. The use and handling of data were independent of commercial interests.

Radiographic measurements were performed preoperatively by the surgeons. Clinical variables were recorded by trained research coordinators using patient-completed assessment forms.

**Creating the O-DSIC System**

The CSORN group previously summarized and published levels of evidence (i.e., very low, low, medium, or high quality) supporting common DLS-related clinical and radiographic variables and their association with instability, and Simmonds et al. provided a full summary of the evidence assignment8. For the purpose of creating the O-DSIC system, we retained the variables that CSORN had previously determined as being supported by low-quality evidence, and assigned a value of 1 point to each; variables with “very low-quality” evidence supporting their association with instability were excluded (see Appendix A). We chose this approach for several reasons: (1) we sought to include only variables supported by the best available evidence, (2) based on the aforementioned review of the literature, there are no variables supported by medium- and high-quality evidence, (3) the best available literature is not sufficient to correlate the quality of evidence with the magnitude of impact for each variable, (4) it allowed assigning a value of a single point to each of the variables of equal evidence quality included in the (O-DSIC) scoring system, and (5) it facilitated the calculation of O-DSIC scores by means of straightforward summation.

Surgeons who assigned S-DSIC types prospectively were not involved with the retrospective derivation and application of the O-DSIC system.
Calculation of DSIC Scores and Conversion to DSIC Types

For each patient, the presence of instability variables included in the O-DSIC system was summed in order to yield DSIC scores. O-DSIC scores were converted to O-DSIC Types I, II, and III using an a priori conversion method that was determined following the creation of the O-DSIC system (as described in the Results section).

Comparing S-DSIC and O-DSIC Types

S-DSIC and O-DSIC types for the overall cohort and for each patient were presented as frequencies. In our analysis of the degree of difference among DSIC types, when surgeons assigned an S-DSIC type that was lower than the corresponding O-DSIC type, it was considered an underestimate of instability. When S-DSIC and O-DSIC types were the same, it was considered a similar estimate of instability. When the S-DSIC type was higher than the corresponding O-DSIC type, it was considered an overestimate of instability.

Patient Characteristics Stratified by Differences Between the O-DSIC and S-DSIC Types

The patient demographics of age, gender, body mass index (BMI), marital status, living arrangement, education, smoking status, and employment status were compared among the DSIC types for both the S-DSIC and O-DSIC systems. Demographic data were also stratified according to the degree of difference between the S-DSIC and O-DSIC types.

Statistical Analysis

Statistical analyses were conducted using the IBM Statistical Package for the Social Sciences (SPSS version 25). Baseline and demographic variables were tabulated and presented as frequency distributions or the mean ± standard deviation for the 2 groups, stratified by either S-DSIC or O-DSIC types. Analysis was performed using Pearson chi-square or 1-way analysis of variance (ANOVA) testing, as appropriate. For example, chi-square testing was used to compare the actual surgical procedures that had been performed with the procedures proposed on the basis of the O-DSIC and S-DSIC systems, respectively. Bonferroni correction was performed for multiple comparisons as needed, and p < 0.05 was considered significant.

Source of Funding

No external funding was provided for this study.

TABLE II The Preliminary O-DSIC System

| Clinical/Radiographic Variables | Proposed Point Value | Quality of Evidence* |
|---------------------------------|-----------------------|----------------------|
| Disc height on lateral radiograph | Low                   |
| Preserved, ≥6.5 mm               | 1                     |
| Narrowed, <6.5 mm                | 0                     |
| Degree of translation on dynamic lateral radiographs | Low |
| ≥4 mm                           | 1                     |
| <4 mm                           | 0                     |
| Disc angle on flexion radiograph | Low                   |
| Kyphotic or neutral              | 1                     |
| Lordotic                        | 0                     |
| Low back pain on visual analog scale | Low |
| ≥5 of 10                        | 1                     |
| <5 of 10                        | 0                     |
| Facet effusion†                  | Low                   |
| Present                         | 1                     |
| Absent                          | 0                     |

*As previously determined by Simmonds et al. 8. †As observed on T2-weighted magnetic resonance imaging.

TABLE III Number of Patients with Each Instability Parameter Included in the O-DSIC System (N = 309)*

| Translation | Disc Angle | Disc Height | Facet Effusion | Low Back Pain |
|-------------|------------|-------------|----------------|---------------|
| No.         | 47         | 88          | 174            | 148           | 272           |
| %           | 15         | 29          | 56             | 47            | 88            |

*In the O-DSIC system, 1 point is assigned for each of the following: translation of ≥4 mm, kyphotic or neutral disc angle on flexion radiographs, disc height of ≥6.5 mm, facet effusion present, and low back pain with intensity of ≥5 of 10 on the visual analog scale.
Results

Demographic Data
The mean patient age and BMI were 65.8 ± 9.0 years and 29.3 ± 6.0 kg/m², respectively. The mean DLS-related translation at the index level on supine and standing lateral radiographs was 6.1 ± 4.1 and 7.4 ± 3.8 mm, respectively; the mean dynamic translation was 2.0 ± 3.4 mm. The mean disc height was 10.0 ± 14.7 mm on lateral radiographs. The mean preoperative LBP intensity on a visual analog scale (VAS) for pain was 7.0 ± 2.1. Additional demographic data are detailed in Appendix B.

Creating the O-DSIC System
Five evidence-based variables were retained and assigned a single point value, constituting the O-DSIC system (Table II). They include the presence of facet effusion on T2-weighted magnetic resonance imaging (MRI), preservation of absolute disc height on lateral radiographs (≥6.5 mm), translation on dynamic lateral radiographs (≥4 mm), a kyphotic or neutral disc angle on flexion radiographs, and presence of LBP (≥5 of 10 intensity on the VAS). The following variables supported by very low-quality evidence were excluded from the O-DSIC system: patient-specific factors (age, gender, occupation, and BMI), select restabilization signs (osteoophyte formation, vertebral end-plate sclerosis, and ligament ossification), and facet joint orientation⁶.

Calculation of DSIC Scores and Conversion to DSIC Types
There were 408 consecutive adult patients who were eligible; 99 (24%) of these lacked at least 1 of the 5 variables required to calculate the O-DSIC score and therefore were excluded. Presence of LBP (≥5 of 10 intensity) was the most frequent (n = 272 patients; 88%) instability variable, and translation of ≥4 mm was the least frequent (n = 47 patients; 15%) instability variable (Table III). DSIC types were derived from the O-DSIC scores (see Appendix C): 0 to 2 points was considered stable, Type I; 3 points, potentially unstable, Type II; and 4 to 5 points, unstable, Type III (Table IV).

Comparing O-DSIC and S-DSIC Types
The frequencies of O-DSIC and S-DSIC types are presented for the overall cohort in Table V. According to the O-DSIC system, Type I was the most common (n = 176; 57%). According to the S-DSIC system, Type II was the most common.

S-DSIC and O-DSIC types differed for more than half of the patients (p < 0.001; Table VI); surgeons assigned a higher S-DSIC type than what was objectively determined using the O-DSIC system (overestimate of instability) in 130 patients (42%) (see Appendix D). Surgeons assigned a lower S-DSIC type than what was objectively determined (underestimate of instability) using the O-DSIC system in only 34 patients (11%).

Patient Characteristics Stratified by Differences Between the O-DSIC and S-DSIC Types
Patients categorized as DSIC Type III were younger than DSIC Type I and Type II for both the S-DSIC and O-DSIC systems (see Appendix E). Using the O-DSIC system, we found that DSIC Type III was associated with a higher BMI. S-DSIC and O-DSIC types both were independent of gender, marital status, living arrangement, education, smoking status, or employment status.

Data were stratified according to whether surgeons assigned a lower, the same, or a higher S-DSIC type compared with that based on the O-DSIC system. No differences were identified for age, BMI, gender, marital status, living arrangement, education, smoking status, or employment status across the stratified groups (Table VII).

Discussion
The S-DSIC system was developed as an attempt to assess preoperative instability related to DLS⁷. The system captures the heterogeneity of DLS and subjectively facilitates the selection of a surgical technique⁸. An objective classification is warranted to further reduce variation among surgeons’ interpretations of instability and tailor surgical procedures based on the best available evidence. In our study, we enrolled 408 consecutive adult patients who received surgery for
symptomatic spinal stenosis related to DLS. Surgeons prospectively categorized DLS-related instability using the previously reported S-DSIC system. Our group subsequently proposed a preliminary O-DSIC system with clearly defined criteria. O-DSIC scores were retrospectively calculated for the same cohort of patients. Surgeons assigned more instability with the S-DSIC system than was determined based on the O-DSIC system. The inter- and intra-rater reliability of the O-DSIC system should be determined prior to its use in future clinical or research settings.

**Interpretation**

Only a small percentage of patients in this study had a degree of translation consistent with substantial instability, challenging the belief that any translation plays a significant role. Loss of absolute disc height (using a height cutoff of 6.5 mm) was the only restabilization sign with evidence supporting an association with instability. As such, preservation of disc height was included in the O-DSIC system. Many studies report on facet effusion measured via the facet fluid index; these studies use nonstandardized measurement and calculation techniques. The best available evidence supports the association between DLS-related instability and the presence or absence of facet effusion, which also facilitates ease of scoring. Kanayama et al. demonstrated that the disc angle on flexion radiographs impacts segmental stability; only a lordotic disc angle was considered stable in flexion. Distraction stiffness and sagittal alignment in flexion were similar for both kyphotic and neutral alignments. The best

| TABLE VII Patient Demographics Stratified by the Degree of Difference Between O-DSIC and S-DSIC Types* (As Presented in Appendix D) |
|---------------------------------------------------------------|
| ** Degree of Difference Between O-DSIC and S-DSIC Types†        |
| **Variable**                          | Surgeon Underestimate | Similar Estimate | Surgeon Overestimate | P Value |
| Age, mean ± SD (yr)    | 64.4 ± 8.7            | 66.7 ± 9.0       | 65.3 ± 9.0           | 0.25    |
| BMI, mean ± SD (kg/m²) | 30.3 ± 6.4            | 29.5 ± 4.8       | 28.8 ± 6.9           | 0.32    |
| Gender
| Male                  | 17                    | 58               | 51                   | 0.50    |
| Female                | 17                    | 87               | 79                   |         |
| Marital status
| Married               | 25                    | 102              | 83                   | 0.62    |
| Not married           | 9                     | 42               | 42                   |         |
| Living arrangement
| Living with someone   | 27                    | 113              | 95                   | 0.77    |
| Living alone          | 7                     | 32               | 32                   |         |
| Education
| ≤High school          | 12                    | 75               | 53                   | 0.11    |
| >High school          | 22                    | 70               | 73                   |         |
| Smoking status
| Smoker                | 1                     | 25               | 22                   | 0.10    |
| Nonsmoker             | 32                    | 119              | 105                  |         |
| Employment status
| Not working           | 6                     | 14               | 19                   | 0.54    |
| Working               | 9                     | 41               | 30                   |         |
| Retiree               | 14                    | 80               | 69                   |         |
| Other                 | 12                    | 9                | 2                    |         |
| Procedure
| Decompression only†   | 7                     | 39               | 17                   | 0.059   |
| Decompression and IPLF§ | 8                   | 35               | 39                   |         |
| Decompression with IPLF and interbody device# | 12 | 49 | 57 |

*SD = standard deviation, BMI = body mass index, and IPLF = instrumented posterolateral fusion. †See Methods section and/or Appendix D for a detailed explanation regarding terminology. ‡Laminectomy alone. §Laminectomy and posterior pedicle screw and rod instrumentation for the purpose of arthrodesis. #Laminectomy, unilateral facetectomy, interbody device insertion, and posterior pedicle screw and rod instrumentation for the purpose of fusion.
evidence suggests that neither disc nor facet angles in the neutral position (nor the disc angle in extension) are significantly correlated with distraction stiffness\(^a\).\(^b\).\(^c\)\(^d\)\(^e\).\(^f\). Regarding LBP, only its presence or absence has been associated with DLS-related instability; since the cutoff threshold for intensity as a sign of instability has not been previously defined, we define substantial LBP as \(\geq 5\) of 10 on the VAS.

Type I in the S-DSIC system is associated with restabilization signs, while patients with Type II exhibit fewer of these signs, and patients with Type III have no signs of restabilization. These vague categories provide an opportunity for inconsistency in a surgeon’s interpretation and categorization. The majority of these variables (osteophyte formation, posterior ligamentous ossification, and vertebral end-plate sclerosis) are supported by “very low-quality” evidence and were excluded\(^g\).\(^h\)\(^i\).\(^j\). Moderate-quality evidence supports measurable in vivo biomechanical markers of instability in DLS, including flexion stiffness, absorption energy, and the neutral zone\(^k\).\(^l\). Given that measurement requires a novel intraoperative system that includes spinous process holders, a motion generator, and a personal computer, these variables were considered impractical and not included in the O-DSIC system. Most studies have failed to demonstrate a significant correlation of age, symptom duration, BMI, and multiple comorbidities with instability in patients with DLS\(^m\).\(^n\). Comorbidities may be considered during surgical decision-making when assessing fitness to tolerate a procedure; however, the contribution of these variables to stability is supported by very low-quality evidence\(^o\).\(^p\). These variables may have marked impacts, however, on the type of surgery performed. We found that O-DSIC Type III was associated with younger age and higher BMI. However, there was no association between 7 other demographic variables and DSIC types. Lastly, while facet joint orientation and tropism are associated with DLS, their role in the development of the disease and segmental stability is controversial based on current very low-quality evidence\(^q\).

Surgical technique may vary based on surgeon bias toward the anticipated degree of instability and the number of clinical and radiographic variables that are considered. The O-DSIC and S-DSIC systems have been developed in an effort to decrease such bias. There may be a “regression to the mean” in which surgeons consider 1 or 2 variables and then, in the face of uncertainty, choose a more rigid construct in the belief that doing so would make early reoperation less likely.

Future Work

Historically, translation has been considered a key contributor to the definition of DLS-related instability; we believe that our study emphasizes a more heterogeneous view of DLS-related instability in the context of numerous parameters beyond translation. At one extreme, the facet joints may be virtually ankylosed and there may be 4 mm of translation between 2 vertebrae. At the other extreme, the facet joints may be distracted such that there may be no apparent slippage between the 2 vertebrae when the patient is supine, but then translation of >12 mm on standing as the disc space becomes kyphotic. Expanding the definition of instability beyond translation may facilitate the tailoring of specific surgical plans\(^r\).\(^s\).\(^t\). Assigning objective criteria to the decision-making process represents an important first step in recognizing the heterogeneity of DLS.

Although we have proposed a preliminary O-DSIC system, this was not a validation study. The validity and magnitude of each parameter’s contribution to the O-DSIC system should be determined through future study. Analysis of intra- and inter-rater reliability based on the input of each participating surgeon should be assessed. Following validation, the O-DSIC system should be assessed in the context of patient-reported outcomes stratified by the surgical procedure that is performed.

Limitations

It is possible that the S-DSIC and O-DSIC systems both underestimate instability compared with surgeon judgment. Their derivation is based on the best available evidence, although the evidence quality is low. One in 4 patients was excluded from the O-DSIC analysis for missing data for at least 1 of the 5 variables required to calculate the O-DSIC score. Although the derivation of the preliminary O-DSIC system represents an exhaustive evaluation of DLS instability, there are likely other factors that influence surgical decision-making that were not considered as part of this study (coexistent foraminal stenosis, spinopelvic parameters, coronal listhesis, etc.). Future research efforts will be directed toward determining the contribution of such parameters toward DLS-related instability. Lastly, the O-DSIC is a tool for assessing preoperative DLS-related instability in order to guide surgical management—it does not account for potential iatrogenic intraoperative instability.

Conclusions

The O-DSIC system allows for the objective assessment of preoperative instability related to DLS. This system was developed by assigning clearly defined values to previously reported instability variables. Comparing the O-DSIC and S-DSIC systems revealed that the latter may overestimate instability. The validity and magnitude of the contribution of each parameter should be determined through future study. Inter- and intra-rater reliability should be determined prior to the use of the O-DSIC system in clinical and research settings.

Appendix

Supporting material provided by the authors is posted with the online version of this article as a data supplement at ibjs.org (http://links.lww.com/JBJSOA/A436).
Evaluating Instability in Degenerative Lumbar Spondylolisthesis

Neil Manson, MD, FRCSC3
Raymond Andrew Glennie, MD, MSc, FRCSC
1Division of Neurosurgery, Dalhousie University, Halifax, Nova Scotia, Canada
2Division of Orthopedic Surgery, Western University, London, Ontario, Canada
3Division of Orthopedic Surgery, University of British Columbia, Vancouver, British Columbia, Canada
4Division of Orthopedic Surgery, University of Toronto, Toronto, Ontario, Canada
5Division of Orthopedic Surgery, Dalhousie University, Saint John, New Brunswick, Canada
6Division of Orthopedic Surgery, Dalhousie University, Halifax, Nova Scotia, Canada

Email for corresponding author: andrew.glennie@nshealth.ca

References

1. Dupuis PR, Yong-Hing K, Cassidy JD, Kirkaldy-Willis WH. Radiologic diagnosis of degenerative lumbar spinal instability. Spine (Phila Pa 1976). 1985 Apr;10(3):262-76.
2. Matz PG, Meagher RJ, Lamer T, Tontz WL Jr, Annaswamy TM, Cassidy RC, Cho CH, Doughearty P, Easa JE, Enz DE, Gunnoe BA, Jallo J, Julien TD, Maseraer MT, Nucci RC, O’Toole JE, Rosolow K, Sembrano JN, Villavicencio AT, Witt JP. Guideline summary review: An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2016 Mar;16(3):439-48.
3. Resnick DK, Watters WC 3rd, Sharan A, Mummmaneni PV, Bailey AT, Wang JC, Choudhri TF, Eck J, Gogawala Z, Groff MW, Dhali SS, Kaiser MG. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 9: lumbar fusion for stenosis with spondylolisthesis. J Neurosurg Spine. 2014 Jul;21(1):54-61.
4. Forst G, Olafsson G, Carlsson T, Frost A, Bergstrom F, Fritzell P, Ohagen P, Michaelsson K, Sandén B. Randomized Controlled Trial of Fusion Surgery for lumbar spondylolisthesis: cohort of 670 patients, and proposal of a new classification. Global Spine J. 2022 Aug 10:21925682221118845.
5. Schlenker F, Ólafsson G, Carlsson T, Frost A, Borgström F, Fritzell P, Ohagen P, Persad ARL, Sader N, Alant J, Christie SD. Work-up and management of asymptomatic extracranial traumatic vertebral artery injury. Can J Neurol Sci. 2022 Aug 6:1-11.
6. Lattig F, Fekete TF, Grob D, Kleinstück FS, Jezenszko D, Mannion AF. Lumbar facet joint fusion in MRI: a sign of instability in degenerative spondylolisthesis? Eur Spine J. 2012 Feb;21(2):276-81.
7. Oishi Y, Murase M, Hayashi Y, Ogawa T, Hamawaki J. Smaller facet fusion in association with restabilization at the time of operation in Japanese patients with lumbar degenerative spondylolisthesis. J Neurosurg Spine. 2010 Jan;12(1):88-95.
8. 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 Nov;11(5):614-9.
9. Kanayama M, Hashimoto T, Shigenobu K, Koga F, Ishida Y, Tawara S. Intraoperative biomechanical assessment of lumbar spinal instability: validation of radiographic parameters indicating anterior column support in lumbar spinal fusion. Spine (Phila Pa 1976). 2003 Oct 15;28(20):2368-72.
10. Kirkaldy-Willis WH, Farfan HF. Instability of the lumbar spine. Clin Orthop Relat Res. 1982 May;(165):110-23.
11. Matsunaga S, Sakou T, Morizono Y, Masuda A, Demirtas AM. Natural history of degenerative spondylolisthesis. Pathogenesis and natural course of the slippage. Spine (Phila Pa 1976). 1990 Nov;15(20):2036-42.
12. Hasegawa K, Kitahara K, Haneda T, Takanoue M, Shimoda H. Biomechanical evaluation of segmental instability in degenerative lumbar spondylolisthesis. Eur Spine J. 2009 Apr;18(4):465-70.
13. Karim SM, Fisher C, Glennie A, Rampersaud R, Stewart J, Dvorak M, Paquette S, Kwon BK, Charest-Morin R, Alton I, Manson N, Abraham E, Thomas K, Urquhart J, Bailey CS. Preoperative Patient-reported Outcomes are not Associated With Sagittal and Spinopelvic Alignment in Degenerative Lumbar Spondylolisthesis. Spine (Phila Pa 1976). 2022 Aug 15;47(16):1128-36.
14. Alahmari A, Thorlsey P, Glennie A, Urquhart JC, Al-Jahdali F, Rampersaud R, Fisher C, Siddiqi F, Rasoulinejad P, Bailey CS. Preoperative Disc Angle is an Important Predictor of Segmental Lordosis After Degenerative Spondylolisthesis Fusion. Global Spine J. 2022 Aug 10:21925682221118845.