Original Article

Flexion-extension standing radiographs underestimate instability in patients with single-level lumbar spondylolisthesis: comparing flexion-supine imaging may be more appropriate

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Background: Generally, most spine surgeons agree that increased segmental motion viewed on flexion-extension radiographs is a reliable predictor of instability; however, these views can be limited in several ways and may underestimate the instability at a given lumbar segment.

Methods: Consecutively collected adult (≥18 years old) patients with symptomatic single-level lumbar spondylolisthesis were reviewed from a two-surgeon database from 2015 to 2019. Routine standing lumbar X-rays (neutral, flexion, extension) and supine lumbar MRI (sagittal T2-weighted imaging sequence) were performed. Patients were excluded if they had prior lumbar surgery, missing radiographic data, or if the time between X-rays and MRI was >6 months.

Results: All 39 patients with symptomatic, single-level lumbar spondylolisthesis were identified. The mean age was 57.3±16.7 years and 66% were female. There was good intra- and inter-rater reliability agreement between measured values on the presence of instability. The slip percentage (SP) difference was significantly highest in the flexion-supine (FS) (5.7 mm, 12.3%) and neutral standing-supine (NS) (4.3 mm, 8.7%) groups, both of which were significantly higher compared with the flexion-extension (FE) group (1.8 mm, 4.5%, P<0.001). Ventral instability based on SP >8% was observed more frequently in FS (79.5%) and NS (52.6%) groups compared with FE group (16.7%, P<0.001). No statistically significant correlation was found between SP and disc angle for all radiographic views.

Conclusions: Comparing standing lateral and flexion X-rays with supine MRIs provides higher sensitivity to assess instability than standard flexion-extension radiographs. The FS and NS comparisons also show greater slip percentage differences at higher slip grades, but not at different lumbar levels. These changes are not dependent on age or gender.

Keywords: Spondylolisthesis; ventral instability; anterolisthesis; flexion-extension lumbar (FE lumbar); radiographic lumbar instability

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Introduction

Lumbar spondylolisthesis is a common cause of low back pain and radicular leg pain, which often warrants operative intervention (1). However, there continues to be considerable debate among spine surgeons regarding the optimal surgical management of lumbar stenosis in the presence of spondylolisthesis, namely decompression alone versus decompression and fusion (2-4). The decision regarding whether or not to fuse most often depends on the surgeon's assessment of lumbar segmental stability. In the appropriate patient, fusion has been shown to successfully halt the progression of spondylolisthesis, reduce pain, and improve patient-reported outcomes when compared to decompression alone (4-7). On the other hand, fusion can be associated with complications (e.g., higher risk for longer hospital stay, longer operative time, increased blood loss, adjacent segment disease) and higher costs, and may not be necessary for those without lumbar instability (8-11).

Instability in lumbar spondylolisthesis has been characterized by a number of radiographic findings such as slip displacement, sagittal disc angle, disc height, facet joint orientation, the presence of facet effusion, and severity of degenerative change (12-15). Traditionally, most surgeons rely on flexion-extension radiographs to evaluate for the presence or absence of anterior-posterior lumbar instability as measured by the difference in slip percentage (12,16,17). Many insurers use radiology reports of flexion-extension radiographs to determine eligibility for lumbar fusion. However, the reliability of this method has been called into question due to poor reproducibility of non-standardized radiographic techniques and underestimation of intervertebral motion in symptomatic patients resulting from their often limited ability to extend their trunk while standing (18-20).

In this study, we hypothesize that radiographic extension views will be of little value but that the slip percentage difference will be greater when comparing flexion X-rays with supine sagittal MRI views as part of routine diagnostics for symptomatic patients with single-level lumbar spondylolisthesis. To the author's knowledge, no prior literature has directly compared standing radiographic films to supine MRI.

We present the following manuscript in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/jss-20-631).

Table 1 The differences in slip, slip percentage, and segmental angle for each view

Patient position	Mean slip difference between (SD)		Mean segmental angle difference (SD), angle
	Distance, mm	SP (%)	
Flexion and neutral standing, FN	1.8 (2.0)	4.4 (4.0)	4.1 (4.3)
Neutral and extension, EN	0.9 (1.9)	1.8 (4.2)	3.6 (4.0)
Flexion and extension, FE	1.8 (1.9)	4.5 (3.8)	5.1 (4.6)
Neutral and supine (NS)	4.3 (3.0)	8.7 (6.2)	3.9 (4.1)
Flexion and supine (FS)	5.7 (2.8)	12.3 (6.4)	4.7 (4.4)
P value	<0.001	<0.001	0.214

Methods

Consecutively collected adult (≥18 years old) patients with symptomatic single-level lumbar spondylolisthesis were reviewed from a two-surgeon database from 2015 to 2019. All patients in this study received preoperative routine standing lumbar X-rays (neutral, flexion, extension) and supine lumbar MRI (Sagittal T2-weighted imaging sequence). Patients were excluded if they had prior lumbar surgery, missing radiographic data, or if the time between X-rays and MRI was >6 months. These examinations were part of routine clinical work-up for low back pain and/or leg pain, and were not acquired for the sole purpose of this study. We only reviewed images done at our institution to ensure consistency. This study was deemed exempt from the institution's IRB since only deidentified radiographic data was assessed. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Several parameters were measured for both supine and standing images by two resident orthopedic surgeons. Repeat measurements were taken two weeks apart to assess for intra-observer and inter-observer reliability. *Tables 1*,*2*,*3* include the average measurements taken by the two observers. These measurements included anterior displacement of vertebra relative to caudal vertebra (*Figure 1*), caudal vertebral sagittal width (*Figure 1*), and slip percentage (SP, ×100; *Figure 1*). At the slip level, the disc angle (DA) in the sagittal plane was measured by the formation of two lines (inferior and superior end plates of the cephalad and caudal vertebral bodies, respectively (*Figure 1*). The slip differences (mean displacement in mm and %) were recorded for flexion-neutral standing (FN), extension-neutral (EN), flexion-extension (FE), neutral

Table 2 Ventral instability (slip % difference cut-off >8%) breakdown for each view

Patient positioning	No	Yes
FN	82.1%	17.9%
EN	91.0%	9.0%
FE	83.3%	16.7%
NS	47.4%	52.6%
FS	20.5%	79.5%
P value	<0.001	

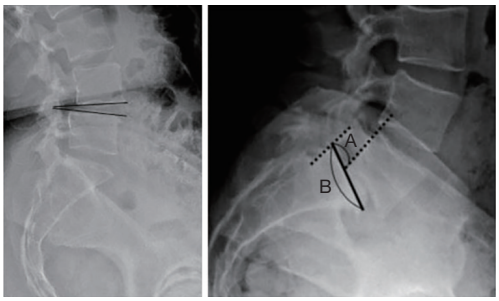

Figure 1 Slip percentage (A/B) on left and segmental slip angle on right.

Table 3 The mean slip percentage differences by standing slip grade and lumbar levels

Mean slip percentage difference	Standing slip grade, %				Level		
	1	2	3	P value	L4–5	L5–S1	P value
FN	5.3 (4.7)	3.4 (2.8)	1.9 (1.9)	0.051	4.8 (4.1)	3.8 (3.9)	0.259
EN	1.8 (4.4)	1.9 (3.8)	1.2 (5.7)	0.935	1.1 (4.2)	2.8 (4.3)	0.085
FE	5.2 (3.8)	3.1 (3.0)	4.5 (5.7)	0.076	5.6 (4.1)	2.8 (2.7)	0.001
NS	5.8 (4.5)	11.7 (4.1)	16.5 (10.4)	<0.001	7.8 (6.1)	10 (6.3)	0.123
FS	10.0 (5.5)	14.8 (4.5)	18.1 (11.1)	<0.001	11.5 (6.4)	13.4 (6.5)	0.206

standing-supine (NS), and flexion-supine (FS). Similarly, the DA differences were measured for each group and compared. The SP grades for standing (neutral) X-ray were recorded as follows (Grade 1: <25%, Grade 2: 25 to <50, Grade 3: 50 to <75). No patient had a grade 4 or higher slip preoperatively in our study sample.

Although current literature provides various definitions for lumbar segmental instability, the most commonly accepted radiologic sign for ventral instability is a sagittal SP difference of ≥8% or a translation ≥3 mm, which appear to have a strong clinical correlate (12,13,21-23).

Statistical analysis

Chi-square or Fisher's exact test (where appropriate) and *t*-tests/ANOVA were used for categorical and continuous variables, respectively. Statistical significance was determined by a P value <0.05. SAS Studio Version 3.4 (SAS Institute Inc., Cary, NC) was used for all statistical analyses.

Results

After exclusion criteria, a total of 39 patients with symptomatic, single-level lumbar degenerative spondylolisthesis from 2015 to 2019 were identified. This cohort had a mean age of 57.3±16.7 years and 66% of them were female. The mean time between X-rays and MRI was 1.7±1.8 months. There was good agreement between measured values on the presence of instability. The intra- and inter-rater reliability kappa coefficients for Neutral-Supine views were 0.53 and 0.74, respectively. The intra- and inter-rater reliability kappa coefficients for Flexion-Supine views were 0.74 and 0.69, respectively.

The average amount of spondylolisthesis by SP was 26.8%±11.8% in the standing, neutral position. The majority of those in the standing neutral position had a slip grade of either 1 or 2 (Grade 1: 57.7%, Grade 2: 33.3%, Grade 3: 9.0%) and at the L4–5 level (L4–5: 60.5%, L5–S1: 39.5%). The magnitude of change in SP was significantly highest in the FS (5.7 mm, 12.3%) and NS (4.3 mm, 8.7%) groups, both of which were significantly higher compared with the traditional FE group (1.8 mm, 4.5%, P<0.001).

Ventral instability based on SP >8% was observed more frequently in FS (79.5%) and NS (52.6%) groups compared with FE group (16.7%, P<0.001). Differences in SP appear to increase significantly at higher slip grades

for NS (P<0.001) and FS parameters (P=0.024), but not for other views. In addition, the NS and FS slip percentages did not vary based on lumbar levels. The exception to this was FE view which show significant differences in mean slip for L4–5 and the L5–S1 level. The SP differences were not statistically significant by gender for FS (male *vs.* female 14.2% *vs.* 11.3%, P=0.061), NS (9.1% *vs.* 8.5%, P=0.681), and FE (3.7% *vs.* 4.9%, P=0.195). Similarly, no statistically significant differences were observed by age for FS (age ≥57 *vs.* <57, 11.6% *vs.* 13.5%, P=0.227), NS (7.8% *vs.* 10.4%, P=0.08), and FE (5.1% *vs.* 3.4%, P=0.06). The mean DA difference was highest in the FE group (5.1 degrees), but this was not statistically significant P=0.214). No statistically significant correlation was found between SP and DA for all radiographic views.

Discussion

Stratifying patients with spondylolisthesis based on stability at a given lumbar segment is important in the surgical decision-making for these patients. Current literature provides a myriad of potential parameters that may predict stability in spondylolisthesis. Generally, most spine surgeons agree that increased segmental motion viewed on flexion-extension radiographs is a reliable predictor of instability; however, these views can be limited in several ways and may underestimate the instability at a given lumbar segment. It is possible that an extension standing X-ray may achieve the same result as an MRI (supine); however, the former depends heavily on patient effort and those with significant pain may be less willing or able to fully participate in extending their trunk (24,25). A lack of consistency from the radiology technician during X-rays may introduce measurement errors due to patient positioning. Unfortunately, insurance companies often use radiology reports of flexion-extension radiographs to determine eligibility for lumbar fusion and often refuse appropriate care based on obsolete criteria.

In this study, we demonstrate that the neutral standing-supine and flexion-supine views evoke the greatest mean slip differences (4.3 mm, 5.7 mm, P<0.001) as well as slip percentage differences (8.7%, 12.3%, P<0.001) compared with flexion-extension views (1.8 mm, 4.5%). Furthermore, ventral instability was identified more frequently using these two views (supine-standing 52.6%, flexion-supine 79.5%) when compared with flexion-extension positions (16.7%). In other words, flexion-extension missed nearly 65% of patients with segmental instability. Comparing supine views to either standing or flexion views provides a more sensitive indicator for segmental lumbar instability.

Of note, differences in disc angle did not vary significantly across different positions and this parameter is not a reliable measure of instability. This may be related to degenerative changes in the facet joint possibly hindering angular motion, which is consistent with prior literature (14,15,26).

A number of prior comparative studies agree that dynamic radiographs are important in the preoperative workup for instability at a given spinal segment and that flexion-extension radiographs in the standing position are not ideal. In a consecutive series of 50 patients, Wood *et al.* recommended that flexion-extension radiographs should be performed in the lateral decubitus position (27). In the standing position, patients are forced to support themselves against gravity and the increased tension of the paraspinal muscles may reduce the allowable spinal motion. In the lateral decubitus position, they were able to identify an additional 36% of patients with unstable spondylolisthesis compared to standing views. A lateral decubitus position is a useful alternative when a patient is not able to actively flex or extend their back or has significant difficult with standing. However, lateral decubitus posture does not provide a weight bearing view, and therefore may underestimate maximal vertebral subluxation seen with physiologic axial loads. Furthermore, this posture may be associated with potential bias based on how the patient is positioned and the degree to which they are flexed/extended by the radiology technician.

In a study of 37 patients, Luk *et al.* suggested that erect flexion and prone traction X-rays are the most clinically relevant views since they showed maximum subluxations and reductions of the spondylolisthesis, respectively (28). These authors surmised that traction allows for restoration of the disc height which increases the surrounding ligamentous tension necessary for spontaneous reduction. Unfortunately, traction views require special tools and positioning that can be uncomfortable for patients and may be difficult to integrate into clinical practice.

A flexion radiograph made with the patient in the sitting position has been described in literature as well (23,29). It has been reported to increase the diagnostic rate of sagittal spinal instability by up to 40% compared with conventional standing forward bending methods (30). In a survey of 60 patients performed by Hey *et al.*, patients in the sitting position felt less pain and were less apprehensive when attempting flexion views. However, the radiology

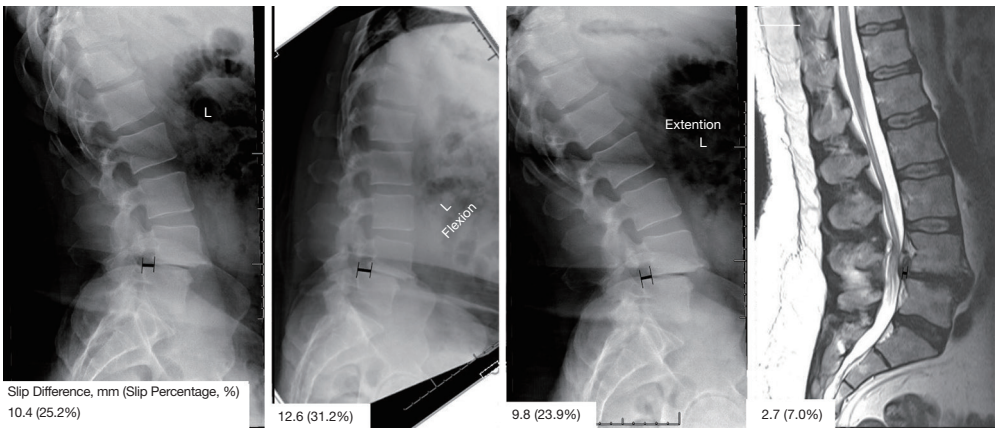

Figure 2 Example of patient with standing-neutral, flexion, extension, supine/MRI views (from left to right). slip differences FN (2.2 mm), FE (2.8 mm), NS (7.7 mm), FS (9.9 mm). Slip percentage differences FN (6.0%), FE (7.3%), NS (18.2%), FS (24.2%).

technicians felt this positioning was logistically demanding and more difficult to explain to patients than the positioning required for standardized views.

In comparison with these other stress views, the standing-supine and flexion-supine views provide a safe, reproducible method that can be readily integrated into the routine clinical work-up for these patients. MRI scans were used to assess supine parameters since they are already available for almost every patient that undergoes surgery for spinal stenosis and spondylolisthesis. Imaging in the supine position requires minimal effort from the patient, relaxes muscles and soft tissues which may otherwise block true lumbar instability from the patient, and excludes potential examiner and patient bias (31).

There are a number of limitations to this study. First, degenerative changes may reduce measurement precision. The use of percentage measurements and two independent raters helps to limit these inaccuracies. Theoretically, the slip distances for FN and EN should sum to FE but this was not true for our data. There are a number of factors including patient effort and measurement error that are difficult to control. However, our inter- and intra-rater scores were acceptable. Flexion views still require adequate patient cooperation; however, significant differences between views were still observed. Furthermore, we acknowledge the relatively small sample size; however, we were powered to detect significant differences in our primary outcome between various radiographic positions. In future work, larger sample sizes would allow for potential multivariate analyses which could explore other factors such as the impact of spinal pathology (e.g., degenerative versus isthmic disease), specific disc levels (L4/5 versus L5/S1), and number of disc levels involved,

Conclusions

Standing flexion-extension views have long been the standard technique used to assess instability in lumbar spondylolisthesis. This study demonstrates that assessment of this instability is more accurately identified by comparing standing lateral radiographs with supine sagittal MRI images. An example of this is illustrated in *Figure 2*. Ventral instability based on SP >8% was observed more frequently in FS (79.5%) and NS (52.6%) groups compared with FE group (16.7%, P<0.001). These FS and NS comparisons also show greater slip percentage differences at higher slip grades, but these two view did not demonstrate significant changes based on lumbar levels. These changes are not dependent on age or gender.

Comparing standing lateral and flexion X-rays with supine MRIs provides higher sensitivity to assess instability than standard flexion-extension radiographs. In addition, this method can reduce radiation and cost by decreasing the need for extension radiographs.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was deemed exempt from the institution's IRB since only deidentified radiographic data was assessed. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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