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Original Article

Clinical value of flexion-extension radiographs with bracket support for lumbar stability assessment

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Abstract: Objectives: This study proposes a novel standardized technique to evaluate lumbar stability in lumbar lateral flexion-extension radiographs and determine whether the most reliable intraoperative reference level of extension can be attained. Methods: A total of 104 patients undergoing surgical treatment for lumbar degenerative disease were included in the study. Radiographs in the conventional extension position (CE) and the extension position with bracket support (CEB) and intraoperative prone fluoroscopic radiographs of patients were included in this study. The slip angle (SA) and slip percentage (SP) were compared for these three radiographic methods. Furthermore, the correlation of differences in the SA and SP were examined among different spinal segments. Results: Among 104 patients (mean age 58 years, 54% women) with a total of 147 operated segments examined, the average SA (10.65°±3.65°) and SP (12.18%±4.91%) with bracket support and SA (10.62°±3.67°) and SP (12.19%±4.90%) during intraoperative muscle relaxation were not significantly different (P=0.54; 0.91). However, the SA and SP in the CEB and intraoperative muscle relaxation conditions were significantly increased compared with the SA (6.46°±3.23°) and SP (7.87%±4.26%) obtained in the CE condition (all P<0.001). Both surgeons demonstrated high reliability, with intraclass correlation coefficient values ranging from 0.8 to 1.0 (P<0.001) for SP and SA measurements. Conclusions: CE radiographs underestimate the degree of displacement of lumbar instability. The CEB position reduces patient back pain and increases the feeling of safety, leading to a greater level of extension. This outcome aligns with the intraoperative muscle relaxation findings.

Keywords: Lumbar degenerative disease, extension, lumbar stability, bracket, intraoperative fluoroscopy

Introduction

Lumbar instability refers to an abnormal range of motion or joint dislocation among the lumbar spinal segments [1]. The main cause of lumbar instability is degeneration, often accompanied by degenerative lumbar spondylolisthesis and lumbar spinal stenosis [2]. When patients present with neurologic symptoms, surgical treatment should be considered [3], with options including decompression alone or decompression combined with interbody fusion [4]. It is crucial to identify the presence of lumbar instability before performing surgery for lumbar degenerative disease to devise the most suitable surgical approach [5]. Therefore, accurate assessment of lumbar stability is essential to evaluate the status of lumbar spine disease, plan preoperative procedures, and make intraoperative decisions.

Lumbar flexion and extension X-ray radiographs are frequently utilized for pre-surgical examinations in clinical settings [6, 7]. However, the diagnostic criteria are subject to controversy due to significant individual variations, diverse imaging positions, and limitations of the examination process [8]. The dynamic translation of flexion-extension radiographs was shown to vary from >3 mm to >5 mm, and the angulation varied from >10° to >22° [9-14]. As research on lumbar instability has progressed, advancements have been made in detection methods and diagnostic criteria to assess lumbar stability [14-17]. Nevertheless, these new detection methods have primarily been compared with conventional flexion-extension radiographs, which may not provide a comprehensive evaluation of sensitivity and specificity.

In the absence of a gold standard for lumbar instability, intraoperative fluoroscopic images

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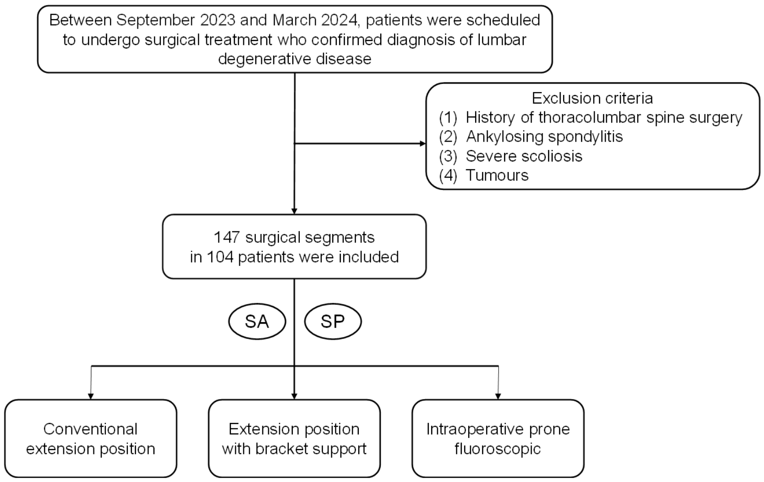

Figure 1. This flow diagram shows the study design.

are commonly regarded as the most reliable evidence for its assessment [5, 18]. All lumbar instability detection methods should be consistent with these results. Accordingly, we assessed lumbar lateral flexion-extension radiographs using self-developed brackets to determine whether they could achieve a reliable degree of lumbar extension compared with conventional extension position and intraoperative prone fluoroscopic radiographs. Although intraoperative images cannot be used in preoperative discussions, they can underscore the limitations of conventional extension position radiographs in depicting true instability.

Materials and methods

Study design and setting

This study was approved by the Ethics Committee of the Second Affiliated Hospital of Soochow University (JD-LK-2021-028-02) and was conducted retrospectively on patients admitted from September 2023 to March 2024. The study focused on patients recommended for surgical treatment. Criteria for inclusion in this study were computed tomography and magnetic resonance imaging findings indicative of lumbar degenerative disease and persistent lower back pain with accompanying lower extremity symptoms unresponsive to 6 weeks of conservative therapy. Patients with a history of thoracolumbar spine surgery, ankylosing spondylitis, severe scoliosis, or tumors were excluded. Flexion-extension position X-ray images using an auxiliary bracket were obtained in addition to conventional flexion-extension position X-ray imaging. These extension images were then compared with intraoperative fluoroscopy radiographs (**Figure 1**).

Composition of the bracket

The bracket was composed of three parts connected by bolts, facilitating disassembly and transfer. The arc-shaped bracket had a height of 30 cm and a width of 40 cm, with a 15-cm distance from the bottom edge to the center of the arc and an arc radius of 15 cm. The bracket height could be adjusted to align with the patient's iliac crests, allowing the patient to hold the handrails on both sides for maximum flexion and extension. These handrails assisted the patient in supporting their body during the examination, thus reducing fear and preventing falls (**Figure 2**).

Radiographic assessment

All preoperative X-ray and intraoperative fluoroscopic images were obtained by non-surgeons with radiology training. Intraoperative fluoroscopic images at the surgical incision were captured following induction of anesthesia and before internal fixation with screws. Sagittal images were acquired with the patient in the prone position on the operating table. After the surgeon viewed the fluoroscopic images in real time, the images were stored for subsequent analysis specifically for this study. The measurement data included the lumbar slip percentage (SP), the length of the translation of the adjacent vertebral endplates divided by the width of the lower lumbar vertebrae, and slip angle (SA), the angle formed by the adjacent vertebral endplates, to minimize errors resulting from varying equipment and X-ray magnification factors. Preoperative X-ray data were analyzed using Neusoft PACS/RIS software, and intraoperative fluoroscopic radiograph data were analyzed using MicroDicom software. Measurements were independently performed by two spine surgeons with over 10 years of clinical experience who were unaware of the method used to obtain preoperative

Figure 2. Composition of the bracket (A, B) and inspection method of flexion-extension radiographs (C, D). The bracket is positioned at the level of the patient's iliac crest during the film, enabling the patient to hold the handrails for optimal lumbar flexion and extension.

X-ray images during the measurement process.

Statistical analysis

SPSS 27.0 (IBM SPSS Inc., Chicago, IL, USA) statistical software was utilized for data analysis. Continuous variables are presented as the mean ± standard deviation. Paired t-tests were employed to compare differences in the SP and SA between preoperative conventional extension position radiographs, bracket-assisted extension radiographs, and intraoperative fluoroscopy radiographs obtained under anesthesia. A *P* value of <0.05 was deemed statistically significant. The agreement between the measurements obtained by the two surgeons was evaluated using the intraclass correlation coefficient (ICC), which ranged from 0 (inconsistent) to 1 (perfect agreement). It is commonly understood that an ICC less than 0.4 indicates poor reliability, and an ICC greater than 0.75 indicates high reliability.

Results

A total of 104 patients, consisting of 48 male and 56 female patients with a mean age of 58 years, were included in this observational study. All participants had preoperative flexion-extension radiographs and flexion-extension radiographs while supported by an auxiliary bracket, as well as intraoperative prone fluoroscopy radiographs. The study involved a total of 147 operated segments, with 7 from L2/3, 27 from L3/4, 80 from L4/5, and 33 from L5/S1. Surgical approaches included decompression alone and decompression combined with a fusion procedure.

The intervertebral lumbar SP and SA were assessed in all operated segments. Both surgeons demonstrated high reliability, with ICC values ranging from 0.8 to 1.0 for SP and SA measurements (**Figure 3**). Specifically, the SA (6.46°±3.23°) and SP (7.87%±4.26%) values in the conventional extension position, SA (10.65°±3.65°) and SP (12.18%±4.91%) values in extension with auxiliary bracket support, and SA (10.62°±3.67°) and SP (12.19%±4.90%) values obtained during intraoperative anesthetic muscle relaxation were compared. For both the SA and SP, a statistically significant difference was found between the conventional extension and extension with auxiliary bracket support conditions, as well as between the conventional extension and intraoperative anesthesia conditions (P<0.001). There was no significant difference between the extension position under auxiliary bracket support and intraoperative anesthesia conditions (P>0.05) (**Table 1**). In addition, 20 participants had an SP of <5% preoperatively in conventional extension radiographs, which was redefined as lumbar degenerative spondylolisthesis with an SP of >5% under the intraoperative anesthesia and auxiliary bracket support conditions [19].

A comparison of imaging data from the three groups revealed that in the extended position,

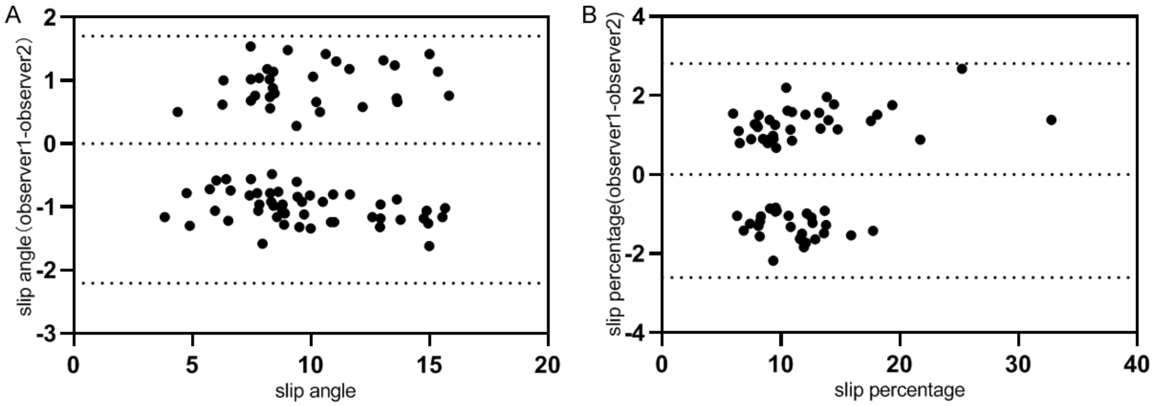

Figure 3. Inter-observer Bland Altman plots of intraoperative L4-5 segmental slip angle (A) and slip percentage (B) measurements.

Table 1. The measurement of slip angle (SA) and slip percentage (SP) using three radiographic methods

Group	Segments	Extension	Bracket-assisted extension	Intraoperative	P1	P2	P3
SA (°)	L2-L3 (n=7)	6.14±3.02	9.72±3.55	9.69±3.70	*	*	*
	L3-L4 (n=27)	4.71±2.42	8.76±2.87	8.82±2.99	<0.001	<0.001	0.396
	L4-L5 (n=80)	5.77±2.65	9.85±2.99	9.78±2.99	<0.001	<0.001	0.107
	L5-S1 (n=33)	9.65±3.10	14.36±3.25	14.38±3.21	<0.001	<0.001	0.650
	All (n=147)	6.46±3.23	10.65±3.65	10.62±3.67	<0.001	<0.001	0.541
SP (%)	L2-L3 (n=5)	6.33±2.50	10.51±3.15	10.63±3.04	*	*	*
	L3-L4 (n=22)	8.46±4.42	12.75±4.99	12.83±4.90	<0.001	<0.001	0.186
	L4-L5 (n=63)	7.44±3.85	11.72±4.61	11.70±4.66	<0.001	<0.001	0.700
	L5-S1 (n=24)	8.80±5.29	13.24±5.83	13.19±5.77	<0.001	<0.001	0.384
	All (n=114)	7.87±4.26	12.18±4.91	12.19±4.90	<0.001	<0.001	0.911

*: sample size less than 10; P1: extension vs bracket-assisted extension; P2: extension vs intraoperative; P3: bracket-assisted extension vs intraoperative.

where muscle factors play a more substantial role, the SP and SA in the bracket-assisted extension position and during muscle relaxation under intraoperative anesthesia were higher than those in the traditional extension position. Additionally, the results obtained with bracket assistance and intraoperative anesthesia were more similar to each other than to those obtained in the conventional extension position (**Figure 4**). The findings from the intergroup correlation analysis of different spinal segments may not only be relevant to the commonly studied L4-L5 segment [20, 21] but also to other lumbar spine segments when using an assisted frame.

A 78-year-old woman with degenerative lumbar spondylolisthesis underwent lumbar fusion. Images obtained using bracket-assisted extension (SA=12.90°; SP=19.83%) and intraoperative anesthesia (SA=12.79°; SP=19.62%) showed an increased SP and SA. The bracket-assisted extension results more closely matched the intraoperative results than those of conventional extension radiographs (SA=7.54°; SP=14.36%) (**Figure 5**).

Discussion

Anteroposterior instability of lumbar segments is regarded as an important biomechanical aspect in the clinical evaluation of lumbar degenerative disease [22]. Existing diagnostic tools have limited reliability and do not provide methods to measure intraoperative stability. The objective of this study was to develop and validate a bracket that could enhance the detection of lumbar instability and achieve a relatively high level of intraoperative reliability. Our study of 147 surgical segments found that

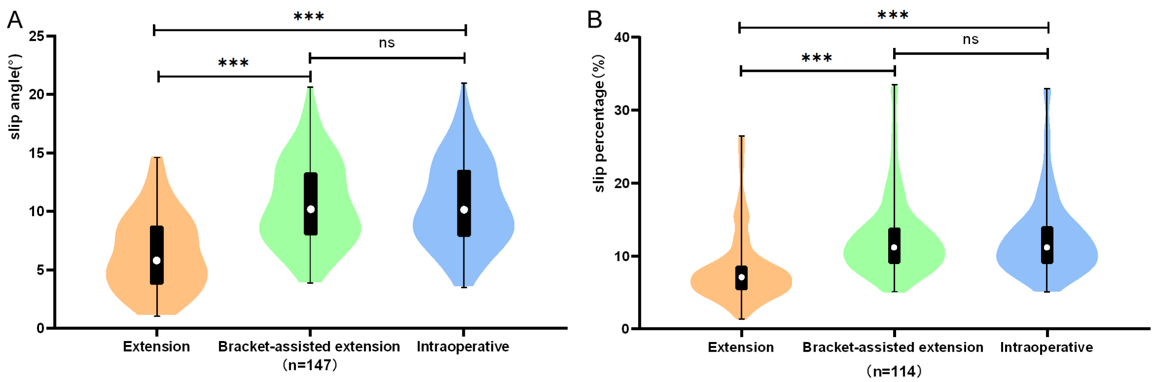

Figure 4. There was no significant difference between the bracket-assisted extension and the intraoperative anesthetized state in the slip angle (A) and slip percentage (B) in all surgical compartments (*** denotes P<0.001, ns denotes P>0.05).

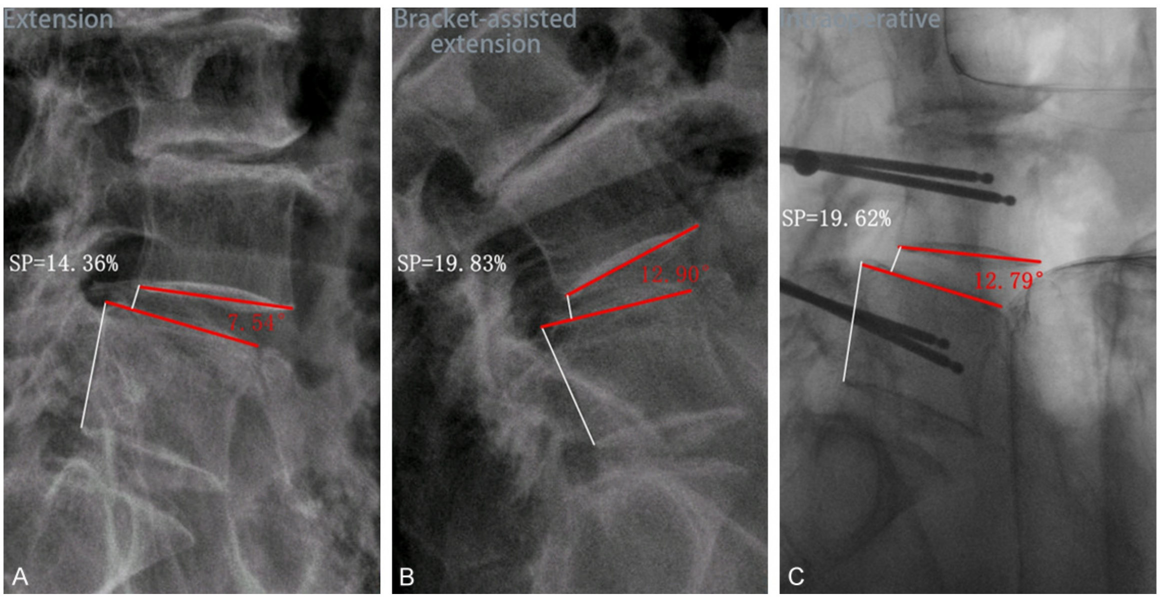

Figure 5. A 78-year-old female with degenerative lumbar spondylolisthesis. Compared to the conventional extension radiograph (A), the bracket-assisted extension (B) and intraoperative anesthesia (C) in the sagittal position demonstrated a significantly higher slip percentage and slip angle. The bracket-assisted extension is closer to the intraoperative results.

higher SA and SP values were achieved in the extension position with bracket support and under intraoperative anesthesia than those obtained in conventional extension radiographs. There was no significant difference in the SA and SP between the extension position with bracket support and the intraoperative anesthesia conditions (P>0.05). This finding indicates that greater extension can be attained with bracket support, potentially improving the detection rate of lumbar instability. These results also align with intraoperative observations, suggesting that redefined lumbar instability could lead to an increased likelihood of fusion surgery.

During routine standing flexion-extension imaging, patients experience aggravated lumbar pain. Additionally, the fear of falling hinders their ability to fully participate in lumbar flexion and extension examinations [23, 24]. However, when utilizing an auxiliary bracket for imaging, the support alleviates muscle and ligament strain, improving patient comfort and reducing symptoms of lumbar pain. Additionally, this method can help avoid missed diagnoses of lumbar instability caused by patients being unable to cooperate with examinations due to low back pain. Previous research has shown that pain-induced muscle tension can lead to an underestimation of lumbar stability on conventional flexion-extension radiographs and may increase lumbar instability during surgery or in a state of muscle relaxation. A comprehensive observational study with 382 patients found that 15 patients were initially identified as having lumbar instability based on preoperative conventional flexion-extension X-rays, and an additional 63 patients were later reclassified as having lumbar instability after comparing intraoperative fluoroscopic images in the supine and prone positions [5]. Cornaz demonstrated "moderate" to "excellent" reliability in measuring anterior-posterior displacement of spinal segments in five fresh cadaveric torsos under simulated surgical conditions [22]. Furthermore, Bendnar proposed that the gold standard for diagnosing spinal instability involves measuring vertebral stiffness, either intraoperatively or with external fixation [18].

Mellin G. found a stronger correlation with low back pain in the extension position than in the flexion position, suggesting that extension X-rays are less effective for evaluation [25]. To minimize intraoperative radiation exposure, only fluoroscopic images of patients in the prone position were obtained during surgery, with no additional supine position images. Therefore, this study focused on comparing differences between conventional extension radiographs, bracket-assisted extension radiographs, and prone position radiographs obtained under intraoperative anesthesia.

Since 1997, Hasegawa [26] has developed parametric devices for intraoperative evaluation of vertebral biomechanics based on Panjabi's [27] definition of the neutral zone (NZ). The redefined NZ is the inverse of the load value required for vertebral spinous processes to shift from -5 mm (flexion) to 5 mm (extension). An NZ value >2 mm indicates lumbar instability. Making impromptu surgical decisions during surgery is not ideal, and future research should focus on developing more specific and sensitive clinical tools, as well as standardized radiographic assessment criteria, to predict dynamic features during surgery and improve diagnostic and treatment options for lumbar instability.

Numerous recent domestic and international studies have examined radiographic diagnostic methods for lumbar instability [12, 16, 17, 28, 29]. The focus has been on identifying an easy-to-operate tool that can be widely utilized to diagnose lumbar instability. However, these studies have primarily concentrated on intervertebral translation instability, overlooking intervertebral segmental angular instability. This oversight may lead to missed diagnoses of intervertebral instability characterized by abnormal changes in intervertebral angularity. To address this issue, we developed a flexion-extension position-assisted bracket. This bracket enables the attainment of maximum lumbar flexion and extension, while a standardized operational procedure helps minimize errors, making it suitable for clinical application [30]. The patient is positioned so that the highest point of the bracket aligns with the level of the bilateral iliac crests. Holding the handles with both hands enhances the patient's sense of security during the imaging process. This positioning reduces strain on the muscles and ligaments responsible for maintaining the flexion and extension of the lower back, allowing the patient to fully relax. This relaxation aligns with the desired state of muscular relaxation achieved during intraoperative anesthesia. This result was validated by our high concordance of measurement data for two surgeons. Our study highlights the importance of using flexion-extension X-rays with assisted bracket support to accurately diagnose lumbar instability, as conventional methodologies may miss a substantial number of patients with this condition. The consistency of data under auxiliary bracket support with the intraoperative anesthetized muscle relaxation state is clinically significant as it can impact the surgeon's fusion plan, which is not solely determined by routine flexion-extension position X-rays.

There are several limitations of this study. First, the sample size was small, and the study was conducted at a single center, indicating the need for verification with a larger sample size in future studies. Second, a unique feature of our study was the use of intraoperative fluoroscopy radiographs to aid in diagnosing lumbar instability. However, only prone fluoroscopy was used without the addition of a supine fluoroscopy radiograph. Furthermore, there were no established diagnostic criteria for fluoroscopy and lumbar instability. Lastly, future studies should include testing on a normal population to establish diagnostic criteria for lumbar instability on flexion-extension X-ray images using an assisted bracket.

Conclusions

Our study provides evidence that flexion-extension radiographs underreport the dynamic extent of lumbar instability, and lumbar lateral flexion-extension radiographs with self-developed brackets can better assess the SA and SP, resulting in values closer to the intraoperative "gold standard". These findings have implications for how instability should be established and the indicated surgical procedure.

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Disclosure of conflict of interest

None.

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