The analysis of segmental mobility with different lumbar radiographs in symptomatic patients with a spondylolisthesis

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Abstract

Purpose Lumbar flexion–extension radiographs in standing position (SFE) are the most commonly used imaging method to evaluate segmental mobility. Many surgeons use SFE to disclose abnormal vertebral motion and base their decision for surgical fusion on its results. We tested the hypothesis that imaging in standing and recumbent position (SRP) reveals a higher sagittal translation (ST) and sagittal rotation (SR) in symptomatic patients than with SFE.

Materials and methods We analysed images of 100 symptomatic patients with a low-grade spondylolisthesis that underwent surgical fusion. To determine the ST and SR in SRP, we compared the images taken in the recumbent position in the CT with images taken in the standing position during the routine plain radiography.

Results The measurement of ST revealed an absolute value of 2.3 ± 1.5 mm in SFE and 4.0 ± 2.0 mm in SRP and differed significantly ($p = 0.001$). The analysis of the relative value showed an ST of $5.9 \pm 3.9\%$ in SFE and $7.8 \pm 5.4\%$ in SRP ($p = 0.008$). The assessment of ST in flexion and in a recumbent position (FRP) revealed the highest ST (4.6 ± 2.5 mm or $9.2 \pm 5.7\%$). Comparison of SR showed the highest rotation in SFE ($6.1^\circ \pm 3.8^\circ$), however, compared to SRP ($5.4^\circ \pm 3.3^\circ$), it missed the level of significance ($p = 0.051$).

Conclusions For evaluation of ST in symptomatic patients with spondylolisthesis SRP appears to be more suitable than SFE, while a pathological SR is better

revealed in SFE. The analysis of SRP might offer a complementary method to detect or exclude pathological mobility in more cases.

Keywords Lumbar surgery · Back pain · Radiography

Introduction

Lumbar flexion–extension radiographs taken in a standing position (SFE) are the most commonly used imaging method to detect abnormal segmental mobility. Many surgeons use SFE to detect abnormal vertebral motion or to base their decision for surgical fusion on its results [1–4]. The range of lumbar segmental mobility is wide, but a sagittal translation (ST) of ≥ 4 mm or $\geq 8\%$ and sagittal rotation (SR) of $\geq 10^\circ$ in L1–5 and $\geq 2^\circ$ in L5–S1, respectively, are commonly accepted as a radiologic sign of pathologic mobility and seem to have a strong clinical impact [3, 5–7].

Nonetheless, the use of SFE to determine pathologic lumbar mobility has been questioned due to its lack of routine reference standard, inaccurate reproducibility and non-standardized techniques. The optimal choice of patient's position to reveal the maximal ST has been critically discussed as well. While many authors claim that the measurements taken in a sitting position demonstrate the overall best performance and the least interference by concomitant motions [5, 8], other authors prefer the lateral decubitus position, traction or compression to maximize the degree of slip [9, 10].

However, due to the fact that the standing position evokes a greater slip than the recumbent position [9, 11, 12], and due to its simple usage and low cost SFE is routinely applied in most spinal centres.

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A low-grade spondylolisthesis with an ST of less than 5 mm, compared with SFE no longer seems to represent a criterion for fusion surgery [13, 14]. Therefore, many patients with a “stable” spondylolisthesis undergo spinal decompression surgery without instrumentation [13, 14], however in symptomatic patients pain may prevent an adequate bending of the trunk and lead to an underestimation of the intervertebral motion. Furthermore, even small differences in measurements shown by the various methods could reveal a substantial vertebral slip especially in low-grade spondylolisthesis. A substantial vertebral slip would be an important criterion to base the decision for or against fusion surgery.

There are no recent comparative studies about radiography of low-grade spondylolisthesis [15, 16]. The multitude of possible positions for functional radiography and complicated manoeuvres that might cause the maximal ST makes it difficult to choose the proper diagnostic modality. Yet, plain and flexion–extension radiographs taken in a standing position and CT or MRI-scans taken in a recumbent supine position are available for almost every patient undergoing spinal surgery.

We tested the hypothesis, that imaging in standing and recumbent position (SRP) that is done as part of the routine diagnostics with CT and radiography reveals a higher ST- and SR-value than SFE in symptomatic patients.

Materials and methods

Patients

We compared and analysed the plain anterior–posterior and lateral radiographs (APL), SFE-radiographs and CT scans of 100 symptomatic patients with a low-grade spondylolisthesis that have undergone surgical fusion in our department.

Radiographs

Preoperative APL and SFE as well as CT scans were available in all cases. We only analysed images of patients who received the radiographs in our hospital to ensure a constant distance between the patient and the X-ray source. The distance between the X-ray source and the patient during plain and functional radiography was 1.15 m. These images were available as part of the preoperative routine diagnostics. No extra radiography was performed to avoid unnecessary radiation exposure. All radiographs were digitally available in our hospital archives.

ST and SR were analyzed according to Dupuis et al. [3] (Fig. 1). The determination of translational displacement

Fig. 1 Sagittal CT reconstruction of the lumbar spine to demonstrate the measurement technique of Dupuis et al. [3]: The ST was defined as the perpendicular distance between parallel lines *L* and *R*. The intersection line *I* is drawn along the endplate of the superior vertebral body to determine the exact intersection between *R* and *U*. To obviate inaccuracies due to magnification, ST was also assessed as percentage of the upper vertebral body width (*W*). SR was measured as the angle between the posterior body lines *L* and *U*

was measured in absolute values and percentage of the upper vertebral body width.

To validate the assessed data the measurement was performed independently by two examiners.

Data analysis

SR and ST were measured on the dynamic radiographs by subtraction from flexion to extension (SFE), on the plain radiographs (standing position) and on the CT (recumbent supine position) by subtraction from plain standing position and supine recumbent position (SRP), respectively.

We preferred to use the scout view in the CT to determine vertebral angulation and sagittal motion, however due to the lower resolution, we additionally validated the measurement with the aid of the sagittal CT reconstruction. The SFE radiographs were performed in a standing position (Fig. 2).

The measurement was performed with the aid of the Osirix Imaging Software (Pixmeo Sarl, Switzerland). The values were expressed as mean with standard deviation. The statistical analysis was performed using the Wilcoxon test for dependent, non-parametric values, Pearson's Chi square test and *t* test for dependent values.

Besides comparison of absolute and relative values we analysed the ability of the various positions in SFE and SRP

Fig. 2 Radiographs of a female patient in recumbent supine position in CT scout view (a) and plain standing position (b). The sagittal vertebral slip increases in standing position (b) compared to recumbent supine position (a), while it does not substantially change when comparing standing flexion (c) and extension (d) radiographs

to detect a pathologic ST and SR as defined by previous studies (i.e. ST of ≥ 4 mm or $\geq 8\%$ at L1-5 and $\geq 6\%$ at L5-S1; and SR of $\geq 10^\circ$ at L1-5 and $\geq 2^\circ$ at L5-S1) [7, 17].

Results

100 patients were included (65 females and 35 males). The patients' age ranged from 24 to 85 years (mean age 62.1 years) at time of surgery. Spondylolisthesis was present in all cases and it involved grade I in 72 cases and grade II in 28 cases. Most patients ($n = 83$) had a degenerative spondylolisthesis and suffered from a claudicatio spinalis, back pain and sciatica. 17 patients presented an isthmic spondylolisthesis and suffered from back pain only.

The patients with a degenerative spondylolisthesis were significantly older than the patients with an isthmic spondylolisthesis (70.1 ± 5.7 and 39.5 ± 8.1 years, respectively, $p = 0.001$). The majority of patients had a level L4-5 spondylolisthesis (Table 1).

The average spondylolisthesis was $25.2 \pm 8.5\%$ in the standing position.

Table 1 Type, level and grade of spondylolisthesis

	N
Type of spondylolisthesis	
Degenerative	83
Isthmic	17
Level of interest	
L1-2	1
L2-3	5
L3-4	15
L4-5	58
L5-S1	21
Grade of spondylolisthesis	
Grade I	72
Grade II	28

Presentation of type, level and grade of spondylolisthesis

Sagittal translation (ST)

The measurement of ST revealed an absolute value of 2.3 ± 1.5 mm in SFE and 4.0 ± 2.0 mm in SRP and differed significantly ($p = 0.001$) (Table 2A).

The analysis of the relative value showed an ST of $5.9 \pm 3.9\%$ in SFE and $7.8 \pm 5.4\%$ in SRP and differed significantly ($p = 0.008$) as well (Table 2B). The vertebral anterior translation was highest during flexion and lowest during recumbent supine position (FRP). The measurement of ST in FRP showed an absolute value of 4.6 ± 2.5 mm and differed significantly from ST in SFE ($p = 0.001$) and SRP ($p = 0.045$).

The analysis of the relative value showed an ST of $9.2 \pm 5.7\%$ in FRP (Table 2). This differed significantly from SFE ($p = 0.0062$), but did not reach the level of significance when comparing the relative values with SRP ($p = 0.062$).

An ST at levels L1-5 of ≥ 4 mm and $\geq 8\%$ could be detected significantly more often in SRP and FRP than in SFE ($p < 0.001$ and $p < 0.03$, respectively) (Table 2C). However, it is important to note that in 11 of these patients, SFE revealed a pathologic ST of $\geq 8\%$ (in L1-5), while SRP did not. FRP revealed a pathologic ST in only 6 of these 11 cases and missed 5 of them being pathologic as well. The interobserver error was 1.4 mm assessing ST and did not affect statistical analysis.

Sagittal rotation (SR)

The measurement of SR revealed no significant differences between SFE, SRP and FRP (Table 3), however there was at least a trend that SFE evokes a greater SR than SRP ($p = 0.051$). In 51 cases a higher SR could be assessed in

Table 2 Sagittal translation values Sagittal translation presented with mean and standard deviation in absolute (A) and relative values (B) and subdivided into absolute and relative values defined as pathologic [7, 17] (C)

(A)			
SFE (mm)	2.3 ± 1.5		
SRP (mm)	4.0 ± 2.0**		
FRP (mm)	4.6 ± 2.5**		
(B)			
SFE (%)	5.9 ± 3.9		
SRP (%)	7.8 ± 5.4*		
FRP (%)	9.2 ± 5.7*		
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	≥4 mm in L1-S1 (n = 100)	≥8% in L1-5 (n = 79)	≥6% in L5-S1 (n = 21)
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(C)			
SFE (n)	12	19	12
SRP (n)	47**	42*	11
FRP (n)	60**	44*	13

The statistical analysis was performed using the Wilcoxon test for dependent, non-parametric values, Pearson's Chi-square test and *t* test for dependent values

SFE Flexion–Extension radiography in standing position, *SRP* radiography in standing and recumbent position, *FRP* radiography in flexion and recumbent supine position

** *p* = 0.001, * *p* = 0.01–0.049, only statistical comparison of SRP and FRP with SFE indicated

SFE compared to SRP. SR in SFE revealed the most cases with a pathological segmental mobility (21%) (Table 3D). Only 13 of these 21 cases showed a pathological ST of ≥8% in SFE.

Regarding a rotation of ≥10° at L1-5 and ≥2° at L5-S1 as a sign of pathologic mobility, SFE, SRP and FRP did not differ either (*p* > 0.86). The interobserver error was 2.6° assessing SR and did not influence the statistical results.

Discussion

The study of 100 symptomatic patients with a low-grade spondylolisthesis showed that the radiography in SRP evokes a greater ST than the standard SFE in most of the patients. SR might be better achieved with SFE than with SRP. Nevertheless, SFE revealed a pathologic ST in 11% of cases that had not been apparent in SRP.

The number of comparative studies analysing different positions and movements to reveal maximal slip of the vertebral body is limited, and recent studies are rare [16]. The abnormal translation appears to be increased in standing position compared to recumbent position [9, 11, 12, 18–20]. Thus, dynamic flexion extension radiographs

Table 3 Sagittal rotation presented with mean and standard deviation for L1-S1 (A), L1-5 (B) and L5-S1 (C) and subdivided into values defined as pathologic [7, 17] (D)

(A)		
SFE (L1-S1)		$6.1^{\circ} \pm 3.8^{\circ}$
SRP (L1-S1)		$5.4^{\circ} \pm 3.3^{\circ}$
FRP (L1-S1)		$6.0^{\circ} \pm 3.5^{\circ}$
(B)		
SFE (L1-5)		$7.7^{\circ} \pm 2.9^{\circ}$
SRP (L1-5)		$7.2^{\circ} \pm 2.6^{\circ}$
FRP (L1-5)		$7.5^{\circ} \pm 2.7^{\circ}$
(C)		
SFE (L5-S1)		$4.2^{\circ} \pm 3.1^{\circ}$
SRP (L5-S1)		$3.6^{\circ} \pm 2.5^{\circ}$
FRP (L5-S1)		$3.4^{\circ} \pm 2.7^{\circ}$
<hr/>		
	$\geq 10^{\circ}$ in L1-5 ($n = 79$)	$\geq 2^{\circ}$ in L5-S1 ($n = 21$)
(D)		
SFE (n)	15	6
SRP (n)	9	5
FRP (n)	10	6

The statistical analysis was performed using the Wilcoxon test for dependent, non-parametric values, Pearson's Chi square test and *t* test for dependent values

SFE flexion–extension radiography in standing position, *SRP* radiography in standing and recumbent position, *FRP* radiography in flexion and recumbent supine position

became the standard imaging technique to reveal maximal segmental motion [1, 2, 21]. Our study confirms the finding that the vertebral sagittal slip is higher in standing position than in recumbent supine position in most of our patients [10]. This may be related to axial compressing forces.

While static radiographs seem to show the greatest slip in standing position, in cases of hypermobile spondylolisthesis the lateral decubitus position may reveal an even higher abnormal translation, because the stiffness of the splinting muscles is reduced as shown by Wood et al. [9]. Nevertheless, the study of Wood et al. [9] involved only 50 subjects and 6 of them were asymptomatic. Four of the patients (8%) patients did not reveal any abnormal motion in decubitus position. Furthermore, the majority of the patients (52%) had an isthmic spondylolisthesis and were younger than 40 years, which may result in a better physical condition and lumbar mobility [22].

Pain leads to decreased intervertebral motion in symptomatic patients with spondylolisthesis [23]. Adequate functional radiographs depend on the patient's effort and cooperation, on the examiner's proper control and motivation, and can lead to different results from test to test [24]. Imaging in a recumbent supine position with a relatively relaxed state of muscles and in a standing position with activation of the muscles excludes this bias as far as

possible and still reveals a vertebral motion. Nevertheless, SFE identified 11% of patients with a pathologic segmental mobility that had not been apparent in SRP. These patients might have been better motivated by the examiner or adapted to pain, but it also shows the value of SFE. While studies exist that reveal the maximum slip of the vertebral bodies in various positions, they lack considerable patient numbers and symptomatic subjects with substantial pain and demand special manoeuvres and tools that complicate practical clinical application [10].

Greater values of SR could be assessed in SFE, however it was a comparably poor method to reveal pathological values in any position. Interestingly, increased SR did not accompany pathological ST in all cases. This could be explained by degenerative changes of the intervertebral space and the facet joint that may hinder an adequate angular motion. An abnormal ST was the most common sign of pathologic segmental mobility. A pathological SR in SFE was only detected in 21% of cases. This is consistent with other studies that showed a high variation and limited clinical value of sagittal rotation [9, 19, 25]. The comparatively high SR at level L5-S1 in our series can probably be explained by the high share of young patients with an isthmic spondylolisthesis who have a better physical condition than the older patients with a protracted degeneration [22]. The pathogenesis of an isthmic and a degenerative spondylolisthesis is different, as are often age, physical condition and symptoms of the patients. Therefore, the mixture of both patient groups presents a potential bias in such a study. We have previously emphasized such a bias in the study of Wood et al. [9]. While the difference between standing and recumbent position affected both entities in a similar way in our collective, the differences between the two groups must be carefully considered.

While the assessment of absolute ST in FRP reached the level of statistical significance compared to SFE and SRP, it did not do so when comparing with the relative values. This might be related to measurement inaccuracies resulting from different magnification, although the distance between patients and X-ray source was constant. The measurement of structures without a visible calibration represents a substantial source of error. Vertebral bodies of irregular shapes that might be seen in degenerative spinal diseases can complicate a precise comparison as well [25]. Nevertheless, the measurement method of Dupuis et al. is accepted as a valid technique to determine translational and angular displacement and similar to techniques used by other authors [7, 10]. The measurement of the percentage of vertebral body width avoids inaccuracies resulting from magnification [21]. Our interobserver error is comparable with other studies and it did not affect the statistical result [9, 18].

CT and MRI are considered as the gold standard to assess the level of stenosis, but it must be considered that

clinical symptoms of a stenosis impair in standing position when compared to a recumbent position. Our study could show that the vertebral slip significantly increases from supine to standing position. Thus, the presence of at least standing X-ray images represent a necessity in spinal degenerative pathology as the availability of standing MRI or CT images are technically challenging and, from a financial point of view, probably not useful.

Taking a ST of 4 mm or 8% or more in SFE as a sole criterion for pathologic segmental mobility would have meant that only a minority of our patients would have been properly selected for fusion surgery, at least according to recent studies [13, 14]. The overestimate of ST in radiographs can lead to fusion surgery as well, however, deciding for surgery and choosing a specific surgical procedure depends on many factors that involve the patient's history, the clinical symptoms and the radiologic findings. Based on these criteria, we decided to perform fusion surgery in all of these 100 symptomatic patients with low-grade spondylolisthesis.

Nevertheless, considering the value of 4 mm and 8% ST in SFE would have meant that the majority of our patients with a degenerative spondylolisthesis could have undergone surgery without instrumentation, although a pathologic condition could be revealed regarding ST in SRP or FRP. This could have caused later problems in these patients due to secondary hypermobility. Thus, SFE alone is not sufficient to disclose pathologic segmental motion. Fusion surgery was recommended as two important conditions could be observed in our study collective: the presence of pain and of a spinal pathology, spondylolisthesis. It is debatable whether the patients with a pathological ST of more than 4 mm or 8% in SRP would have found benefit for a longer period, if decompression alone had been performed.

Conclusions

SFE represents a common and proper method to reveal pathologic segmental mobility, however it shows a lower ST than SRP in most patients. Adequate functional radiographs depend on the patient's pain status, effort and cooperation and can lead to different results from test to test. The imaging in a recumbent supine position with a relatively relaxed state of the muscles and in a standing position with an activation of the muscles acting as a splinter against gravity excludes this bias as far as possible.

Therefore, to disclose a pathologic segmental mobility SFE alone is not sufficient and should be complemented by the analysis of radiographs in SRP that are commonly available in most patients before surgery.

As CT scans and plain and functional radiographs are commonly available in symptomatic patients and are often

performed routinely in most of the spine centres, the evaluation of ST in SRP might offer an easily available complementary diagnostic modality.

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Conflict of interest None.

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