Paradoxical motion in L5-S1 adult spondylolytic spondylolisthesis

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Abstract

Introduction In patients with spondylolisthesis, it is assumed that flexion accentuates anterior displacement, whereas extension causes some reduction. Paradoxical movement—where flexion causes reduction of spondylolisthesis and extension increases the anterior translation, is rarely described. In this study, we investigate the prevalence of paradoxical motion in patients with L5-S1 spondylolytic spondylolisthesis and why this abnormal motion occurs.

Materials and methods Flexion and extension radiographs of 41 patients with grade I and II spondylolytic spondylolisthesis of the L5-S1 segment were analysed. Patients who had previous lumbar spine surgery, recent lumbar spine trauma, those more than 50 years of age and those with poor quality radiographs were excluded.

Results There were 24 male and 17 female patients. The average age was 32.7 years. Of the 41 patients, 29 (70.7%) showed no significant instability. Six (15%) patients showed anterolisthesis, where flexion accentuated the forward

displacement, while further six (15%) patients showed paradoxical motion. Statistical analyses found that patients with paradoxical motion had a significantly higher slip angle.

Conclusion In this study, we have demonstrated that: (1) paradoxical motion in spondylolytic spondylolisthesis is more common than previously thought. (2) Patients without anterolisthesis during flexion in dynamic radiographs may still have (paradoxical) instability. (3) Paradoxical motion may be more common in patients with a low sacral slope and increased lumbosacral lordosis.

Keywords Paradoxical motion · Spondylolytic spondylolisthesis · Spondylolysis · Spinal instability

Introduction

Flexion and extension radiographs are commonly used to assess the instability in patients with spondylolysis [1, 2]. In patients where spondylolisthesis is found, it is assumed that flexion accentuates anterior displacement, whereas extension causes some reduction.

Paradoxical motion—where flexion causes reduction of spondylolisthesis and extension increases the anterior translation, has rarely been described [3, 4]. In this study, we attempt to determine the prevalence of paradoxical movement in patients with spondylolytic spondylolisthesis of the L5-S1 lumbo-sacral segment during dynamic flexion and extension, and why this abnormal motion occurs.

Materials and methods

A multi-centred, retrospective study was conducted. From 2005–2009, patients who had a diagnosis of spondylolisthesis

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Fig. 1 Method of calculating sagittal translation. A baseline parallel to the S1 superior endplate is drawn. The posterior superior edge of S1 and posterior inferior edge of L5 are identified two perpendicular lines are extrapolated with reference to the S1 endplate. The difference measured is the sagittal translation = (b – a) mm

Table 1 Summary of patients with instability (translation >3 mm) in L5-S1 spondylolisthesis

Group	Number	Mean translation (flexion–extension) (mm)
Paradoxical motion	6 (15%)	–5.9
No instability (<3 mm)	29 (70%)	0.2
Anterolisthesis	6 (15%)	5.1

Table 2 Patients with instability (translation >3 mm) demonstrating paradoxical motion

Group 1	Flexion (mm)	Extension (mm)	Translation (flexion–extension) (mm)
1	5.6	12.3	–6.7
2	–4.8	4.1	–8.9
3	2.3	5.7	–3.4
4	5.0	9.9	–4.9
5	4.0	10.2	–6.2
6	2.2	7.6	–5.4

were reviewed. Among these, only those who had L5/S1 spondylolytic spondylolisthesis were recruited. Patients more than 50 years old, those who had recent lumbar spine trauma, previous lumbar spine surgery and those with poor quality radiographs (inadequate exposure, rotated films) were excluded. Flexion and extension radiographs were taken using conventional standing radiography. In total, there were 41 patients with Meyerding grade I and grade II spondylolytic spondylolisthesis at the L5/S1 segment. The clinical symptoms and signs of the patients were recorded.

Radiographs were digitally processed by computerised software (Centricity Web, General Electric, USA) adjusting for scale and magnification. Through this, calculations for sagittal translation and angulation could be made in a

Table 3 Patients with instability (translation >3 mm) demonstrating anterolisthesis in flexion

Group 3	Flexion (mm)	Extension (mm)	Translation (flexion–extension) (mm)
1	8.2	4.8	3.5
2	3.3	–2.7	6.0
3	19.4	14.1	5.3
4	12.5	9.2	3.3
5	10.5	7.2	3.2
6	15.6	6.0	9.6

consistent manner. Analysis of radiographs was performed by two orthopaedic spine specialists independently. The results were then collated and averaged. Significant instability was considered as sagittal translation of >3 mm between flexion and extension radiographs. Additional radiographic parameters such as the lumbar index, sacral slope, sacral inclination and slip angle (or lumbo-sacral angle) among the patients were also measured using the techniques as described by Labelle and Bozell [5, 6].

Calculation of sagittal displacement between the L5 and S1 vertebrae was carried out using the methods as described by White and Panjabi [7]. This involved drawing a baseline parallel to the S1 endplate and extrapolating two perpendicular lines by locating the postero-inferior point of L5 and postero-superior point of S1 (Fig. 1). The difference between flexion and extension is the measured sagittal translation.

All analyses were performed using SPSS v17. Patient demographic and clinical parameters were summarised descriptively. The patients were then divided into three groups:

1. Instability >3 mm translation with paradoxical motion
2. Patients with no instability (translation <3 mm)
3. Instability >3 mm translation with anterolisthesis

Fig. 2 Radiographs of a lady who had spondylolytic spondylolisthesis with paradoxical motion. *Left* indicates extension accentuates sagittal translation (10.18 mm) more than flexion (4.01 mm)

Fig. 3 Forty-five-year-old male also showed spondylolytic spondylolisthesis with paradoxical motion. *Left* indicates extension increases displacement (9.91 mm) while flexion causes some reduction (4.99 mm)

Fig. 4 An example of the radiographic parameters used for analysis in a lateral (neutral) radiograph

A Chi-square test was used to compare the distribution of grade and gender among the three groups, while a Kruskal–Wallis test was used to compare other radiographic parameters (lumbar index, sacral slope, sacral inclination and slip angle) and to determine if there was any significant correlation with paradoxical motion. Multiple comparisons were performed using Mann–Whitney *U* test. All *p* values were adjusted using the Bonferroni technique.

Results

There were 24 male and 17 female patients with L5–S1 spondylolytic spondylolisthesis. The average age was 32.7 years. Twenty-six patients had grade 1, while 15 patients had grade 2 spondylolisthesis. Twenty-two (53.7%) patients presented with isolated low back pain, 8 (19.5%) with radicular leg symptoms and 11 (26.8%) had a combination of both.

Table 4 Summary of radiographic outcomes

	Paradoxical motion (<i>n</i> = 6)	No instability (<i>n</i> = 29)	Anterolisthesis (<i>n</i> = 6)
Lumbar index (C/D)			
Mean	0.8	0.8	0.8
Min	0.7	0.2	0.7
Max	0.9	0.9	0.9
Std deviation	0.08	0.05	0.06
Sacral slope (°)			
Mean	39.3	44.8	36.5
Min	30.5	17.9	31.4
Max	44.1	67.8	38.6
Range	13.6	49.9	7.2
Std deviation	5.2	11.8	2.8
Sacral inclination (°)			
Mean	36.1	41.6	38.6
Min	30	21	23
Max	47	67	55
Range	17	47	32
Std deviation	6.9	10.4	11.5
Slip angle (°)			
Mean	9.5	5.7	0.9
Min	5	−24	−5
Max	16	19	5
Range	11	43	10
Std deviation	4.1	8.5	3.3

The White and Panjabi classification was used to classify spinal instability, defined as displacements >3 mm between flexion and extension radiographs. Of the 41 patients, 29 (70.7%) showed no significant instability. Six (15%) patients showed anterolisthesis, where flexion accentuated the forward displacement (range 3.2–9.6 mm). Interestingly, 6 (15%) patients also showed paradoxical motion, where flexion caused a reduction in the listhesis (range 3.4–8.9 mm). Thus, the prevalence of paradoxical motion among patients with instability was 6 out of 12 (50%) (Tables 1, 2, 3 and Figs. 2, 3).

Statistical analyses were performed to identify any associations among the three groups with radiographic parameters such as the lumbar index, sacral slope, sacral inclination and slip angle (See Fig. 4; Table 4).

The Kruskal–Wallis test showed that there was a significant difference among the three groups for the slip angle ($p = 0.02$). Patients in the paradoxical group (Table 5) tend to have a higher slip angle (9.49) compared with patients with no instability (5.72) and with

Table 5 Kruskal–Wallis test comparing all three groups

	Paradoxical motion	No instability	Anterolisthesis	Significance (<i>p</i> value)
Lumbar index	0.8	0.8	0.8	0.798
Sacral slope	39.3	44.8	36.5	0.078
Sacral inclination	36.1	41.6	38.6	0.359
Slip angle	9.5	5.7	0.9	<0.021*

Asterisk represents significant *p* value

Table 6 Mann Whitney *U* test comparing paradoxical motion versus anterolisthesis

	Paradoxical motion	Anterolisthesis	Significance (<i>p</i> value)
Lumbar index	0.8	0.8	1
Sacral slope	39.3	36.5	0.93
Sacral inclination	36.1	38.6	1
Slip angle	9.5	0.9	<0.006*

Asterisk represents significant *p* value

Table 7 Chi-square test comparing three groups with grade and gender

	Paradoxical motion	No instability	Anterolisthesis	Chi-square test
Grade				
I	6 (100%)	18 (62.1%)	2 (33.3%)	<i>p</i> = 0.054
II	0 (0%)	11 (37.9%)	4 (66.7%)	
Gender				
Female	1 (16.7%)	13 (44.8%)	3 (50%)	<i>p</i> = 0.399
Male	5 (83.3%)	16 (55.2%)	3 (50%)	

Bold represents value expressed as overall percentage within groups

anterolisthesis (0.93), suggesting that the sagittal spinal alignment at the lumbo-sacral junction may be more lordotic in the paradoxical group.

Multiple comparisons using the Mann–Whitney *U* test showed that there was again a significant difference in the slip angle between group 1 and group 3 (paradoxical motion and anterolisthesis), respectively. Patients in the paradoxical group had a significantly greater slip angle (more lordotic at L5–S1) compared with patients who had instability with anterolisthesis (9.49–0.93, $p = 0.006$). Other variables, however, showed no significant association between the groups (Table 6).

While it was observed that all the patients who had paradoxical motion had a grade 1 slip, but only 33% with anterolisthesis had a grade 1 slip (Table 7), the difference was not statistically significant (0.054). There was also no significant association with regards to gender among the three groups ($p = 0.399$).

Fig. 5 Schematic diagram of the lumbar spine during extension (a) and flexion (b): during extension, there is a posterior compressive force with impingement, displacing the L5 vertebra forward, causing paradoxical motion. During flexion, this compression force becomes a distractive force, and the anterolisthesis is less pronounced

Discussion

In patients with unstable spondylolysis, spondylolisthesis results because the pars defect disconnects the vertebral body from the inferior articular process. The loss of this posterior stabilising element causes the vertebra to be susceptible to excessive forward translation during spinal flexion [8]. This, however, does not explain why paradoxical movement of the L5/S1 segment occurs. Similarly, other factors that play a role in spondylolisthesis such as pelvic incidence, sacral slope, pelvic tilt and lumbar lordosis also do not explain this phenomenon [9].

The first case of paradoxical motion was described by Knutsson [3]. In his study, he analysed radiographic features of instability in degenerative disc disease. From his cohort of 140 patients, he noticed that four cases had a

“displacement in the direction opposite to flexion” of the L5 vertebrae. Unfortunately, more details on the patients’ age, type of listhesis or the amount of translation were not available.

More recently, Ehara and Shimamura reported a case of paradoxical motion in a 27-year-old male with L5/S1 spondylolytic spondylolisthesis [4]. Here, flexion was seen to cause an anterolisthesis of 4 mm, whereas extension accentuated this to 8 mm. Schneider et al. [8] performed a kinematic study on the lumbar spine in patients with spondylolytic spondylolisthesis. He used the ICR (instantaneous centre of rotation) to analyse motion differences across the affected segments during flexion and extension. Interestingly, 6 of the 13 patients studied displayed paradoxical motion, with displacements ranging from 0.5 to 4.5 mm.

In our series, 6 out of 12 patients with instability displayed paradoxical motion. We chose to study only translational motion as this had a greater influence on symptoms than angulation [2]. The “nutcracker” theory explains this observation. During extension, the anterior column is subjected to a distractive force, while the posterior column is subjected to a compressive force. This compression causes impingement of the posterior elements which, when coupled with a pars defect, displaces the L5 vertebra forward and accentuates the anterolisthesis (Fig. 5).

This impingement theory is not a new concept. Roussouly et al. [9] postulated that the development of spondylolysis was due to two variations in the sagittal alignment of the spine. In some individuals, the horizontal orientation of the lumbar–sacral junction (*low sacral slope*) results in the L5 vertebra being pushed out after *impingement* by the L4 and sacrum. Conversely, individuals with a vertically aligned lumbar–sacral junction (*high sacral slope*)

Fig. 6 Two possible aetiologies of spondylolysis: **a** horizontal orientation of L5–S1 junction with low sacral slope resulting in *impingement* effect. **b** Vertical orientation of L5–S1 with high sacral slope causing excessive *traction* on pars—adapted and modified from Roussouly [9]

slope) developed spondylolysis from excessive forward *traction* on the pars of the L5 vertebra, instead of the nutcracker effect (Fig. 6).

In keeping with Roussouly's aetiology of spondylolysis, we believe that patients from the "impingement" group will show paradoxical motion during dynamic motion—as extension will accentuate the compression of L4 on the sacrum and cause forward displacement of the L5 vertebral body. On the other hand, those with a "traction" type listhesis will show displacements similar to the direction of flexion or extension, as is conventional belief.

The positive correlation between the slip angle and paradoxical motion ($p < 0.006$) reinforces our theory of posterior impingement. In these patients, the lordosis at the lumbo–sacral junction is more pronounced, and in turn, may result in impingement of the L4 spinous process on the sacrum in a neutral or upright posture (Fig. 5).

While our statistical analyses do not show any significant correlation between the sacral slope and paradoxical motion, we believe our hypothesis is still valid. This is because the measurement of the sacral slope is dependent on the *orientation* of the pelvis, i.e., the measurement varies with posture. For a more precise measurement, the pelvic incidence should be taken into account as this reflects the true *morphology* of the pelvis at the lumbo–sacral junction. Unfortunately, not all radiographs were able to visualise the centre of the femoral head, making it difficult to calculate the pelvic incidence, and in turn an accurate sacral slope measurement.

Conclusion

In this study, we have demonstrated that: (1) paradoxical motion in spondylolytic spondylolisthesis is more common

than previously thought. (2) Patients without anterolisthesis during flexion in dynamic radiographs may still have instability (paradoxical). (3) Paradoxical motion may be more common in patients with a low sacral slope and increased lumbosacral lordosis.

Conflict of interest None.

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