

# Lumbar lordosis and pars interarticularis fractures: a case–control study

William G. Bugg · Mark Lewis · Arne Juette ·  
John G. Cahir · Andoni P. Toms

Received: 22 May 2011 / Revised: 12 September 2011 / Accepted: 23 September 2011 / Published online: 19 October 2011  
© ISS 2011

## Abstract

**Objective** The aim of this study is to examine the relationship between lumbar lordosis and pars interarticularis fractures.

**Materials and methods** In this retrospective case–control study we compare the angle of lumbar lordosis and the angle of the S1 vertebral endplate (as a measure of pelvic tilt) in patients with bilateral L5 pars interarticularis fractures with age- and sex-matched control cases with normal MRI examinations of the lumbar spine. Twenty-nine cases of bilateral L5 pars interarticularis fractures with matched control–cases were identified on MRI (16 male, 13 female, age 9–63 years). The angle of lordosis was measured between the inferior L4 and superior S1 vertebral endplates on a standing lateral lumbar spine radiograph for both groups.

**Results** The mean angle of lordosis about the L5 vertebra was  $36.9^\circ$  (SD= $6.5^\circ$ ) in the pars interarticularis fracture group, and  $30.1^\circ$  (SD= $6.4^\circ$ ) in the control group. The difference between the two groups was significant (mean difference  $6.8^\circ$ , Student's *t* test:  $P < 0.001$ ). The mean angle of sacral tilt measured was  $122.2^\circ$  (SD= $10.16^\circ$ ) for controls and  $136.4^\circ$  (SD= $10.86^\circ$ ) for patients with pars defects. The difference in the means of  $14.2^\circ$  was statistically significantly different ( $P < 0.0001$ ).

**Conclusion** Sacral tilt represented by a steeply angled superior endplate of S1 is associated with a significantly increased angle of lordosis, between L4 and S1, and pars fractures at L5. Steep angulation of the first sacral vertebral segment maybe the predisposing biomechanical factor that

leads to pincer-like impingement of the pars interarticularis and then spondylolysis.

**Keywords** Lordosis · Lumbar vertebrae · Spondylolysis · MRI

## Introduction

Spondylolysis is defined as a fracture of the pars interarticularis without vertebral slipping [1]. This fracture occurs most commonly at L5 and is generally bilateral [2]. Lumbar spondylolysis is a condition specific to humans because of our unique anatomical characteristic of lumbar lordosis, facilitating upright posture [3]. Clinical presentation with chronic lower back pain exacerbated by hyperlordosis and/or twisting motions is typical [4], but spondylolysis may also develop without symptoms [5].

The precise cause of lumbar spondylolysis is not fully understood. While the aetiology is probably multifactorial it is thought that repetitive microtrauma and stress resulting in a fatigue fracture is the likely mechanism, rather than a single acute traumatic episode [1]. Mechanical studies have shown that during flexion and extension of the normal lumbar spine the loading forces are maximal in the L5 neural arch, with the greatest mechanical stresses found within the pars interarticularis [6]. It is proposed that during hyperlordosis the L4 inferior facets and the S1 superior facets impinge upon the L5 pars interarticularis resulting in bone lysis and/or the accumulation of stress fractures leading to spondylolysis [3]. Repetitive lumbar hyperextension in athletes has been linked with pars interarticularis fractures [7]. Gymnasts, who were also included in the athletes sampled in the previously mentioned study, have an increased incidence of pars interarticularis fractures [8].

W. G. Bugg (✉) · M. Lewis · A. Juette · J. G. Cahir · A. P. Toms  
Norwich Radiology Academy, Cotman Centre,  
Colney Lane,  
Norwich, Norfolk NR4 7UB, United Kingdom  
e-mail: william.bugg@nnuh.nhs.uk

Morphological differences of the neural arch, relating to the configuration of the L4 and L5 inter-facet region, have been described and associated with L5 pars interarticularis fractures. These anatomical differences enhance the forces applied to the pars interarticularis, during torsional spinal motion and also during hyperextension of the lumbar spine, to increase the risk of fracture [3, 9, 10].

The repetitive action of lumbar hyperextension is widely accepted as an important factor in the genesis of pars interarticularis fractures. The suggestion is that an increased native angle of standing lumbar lordosis at rest may be associated with an increased incidence of pars interarticularis fracture, but as yet there is no strong evidence to support this. The aim of this study is to test the hypothesis that there is an association between the angle of lumbar lordosis and the presence of a L5 pars interarticularis fracture.

### Materials and methods

This is a retrospective case–control study. At our institution this study did not require ethical approval, but was carried out according to Good Clinical Practice in Research guidelines as part of the Department of Radiology research governance framework. Patients with pars interarticularis fractures demonstrated on MRI (Fig. 1) were identified from radiologists' databases and from free text searches in the Radiology Information System. Data were collected from our PACS archive for the years 2002 to 2009.



**Fig. 1** Sagittal T2W MR demonstrating an undisplaced pars interarticularis fracture at L5 (*arrow*) in the absence of any other abnormality that might account for a change in the angle of lordosis

Inclusion criteria included all cases with bilateral L5 pars interarticularis fractures with an accompanying standing lateral radiograph of the lumbar spine. All examinations were reviewed independently by two musculoskeletal consultant radiologists. MR examinations were excluded if there were any abnormalities, other than the pars fracture. These included segmentation anomalies, degenerative disc disease, facet joint osteoarthritis and spondylolisthesis greater than grade 1. Any cases with signal loss in the nucleus pulposus on T2W sagittal images were excluded.

Age- and sex-matched controls were found from PACS for each case. The control cases were assessed independently by the same two musculoskeletal consultant radiologists. Cases were again excluded if evidence of segmentation anomalies, or other MRI changes, were identified that could affect the angle of lordosis. If a concern was raised over the suitability of a pars interarticularis fracture case or a control case by either observer it was excluded from the study.

Standing lateral lumbar spine radiographs for both the pars interarticularis fracture cases and the control cases were assessed for the angle of lumbar lordosis about the L5 vertebra. The lumbar spine radiograph most recent to the lumbar MRI was selected for inclusion. A constrained modified Cobb angle measurement was taken between the inferior endplate of the L4 vertebra and the superior endplate of the S1 vertebra using the 2-line technique [11, 12] on a high resolution 2 K PACS workstation (Barco, Kortrijk, Belgium; Fig. 2). The angle of the superior endplate of S1 to a vertical line, measured along the vertical edge of the radiograph, was also recorded as a



**Fig. 2** Lateral radiograph demonstrating a Cobb angle measurement taken from the inferior endplate of L4 and the superior endplate of S1

measure of sacral tilt. Line placement was performed manually by two independent observers on two occasions, separated by a considerable interval of 3 months.

Descriptive statistics of the angles of lordosis and a Student's *t* test for the difference in the means between the two groups were calculated. Inter-observer and intra-observer reliability were measured using intraclass correlation coefficients (SPSS version 16.0, SPSS Inc., Chicago, IL, USA)

## Results

Twenty-nine cases with bilateral L5 pars interarticularis fractures that satisfied the study's inclusion and exclusion criteria were identified. This group contained 16 male and 13 female patients with a median age at diagnosis of 36 years (range 9 to 63 years).

The median interval between the lumbar spine radiographs and the lumbar MRI for the pars interarticularis fracture cases was 3 months (range 0 to 25 months), and 5 months (range 0 to 38 months) for the control cases.

The mean angle of lordosis about the L5 vertebra measured for the group with bilateral L5 pars interarticularis fractures was 36.9° (SD=6.5°). This was found to be 6.8° greater than the mean angle of lordosis found in the control group (mean=30.1°, SD=6.4°; Fig. 3). This difference in the means was statistically significant (Student's *t* test,  $P<0.001$ ). The reliability of the data was

very good, as demonstrated by an intraclass correlation coefficient of 0.91 (95% confidence interval 0.87–0.94) for inter-observer reliability (Fig. 4), and 0.93 (95% confidence interval 0.88–0.95) for intra-observer reliability (Fig. 5).

The mean angle of sacral tilt measured 122.2° (SD=10.16°) for controls and 136.4° (SD=10.86°) for patients with pars defects. The difference in the means of 14.2° was statistically significantly different ( $P<0.001$ ); Fig. 6, Table 1).

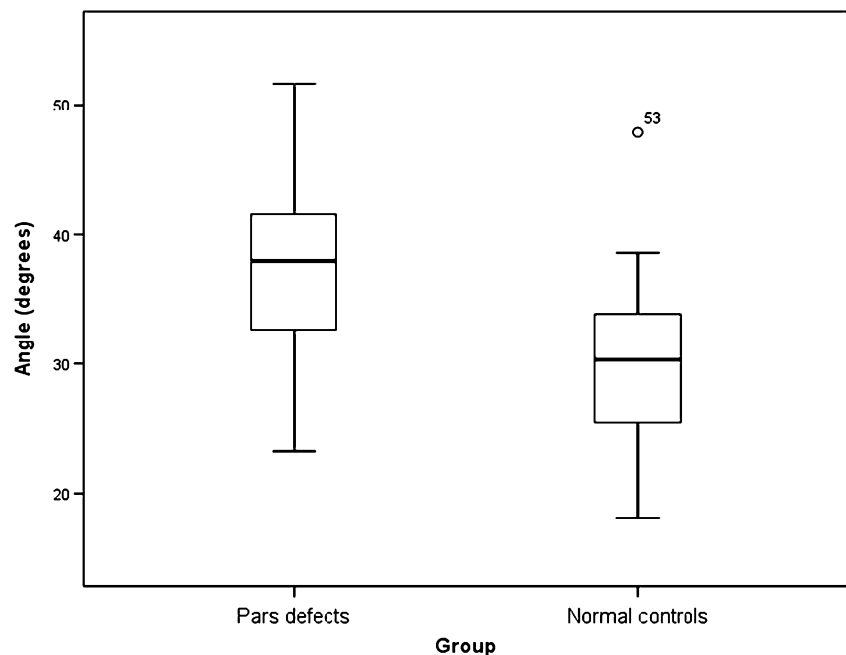
## Discussion

The results of this study support an association between increased lumbar lordosis at about L5, and sacral tilt, with pars interarticularis fracture at L5. Although there is clearly a statistical association this does not necessarily imply causation.

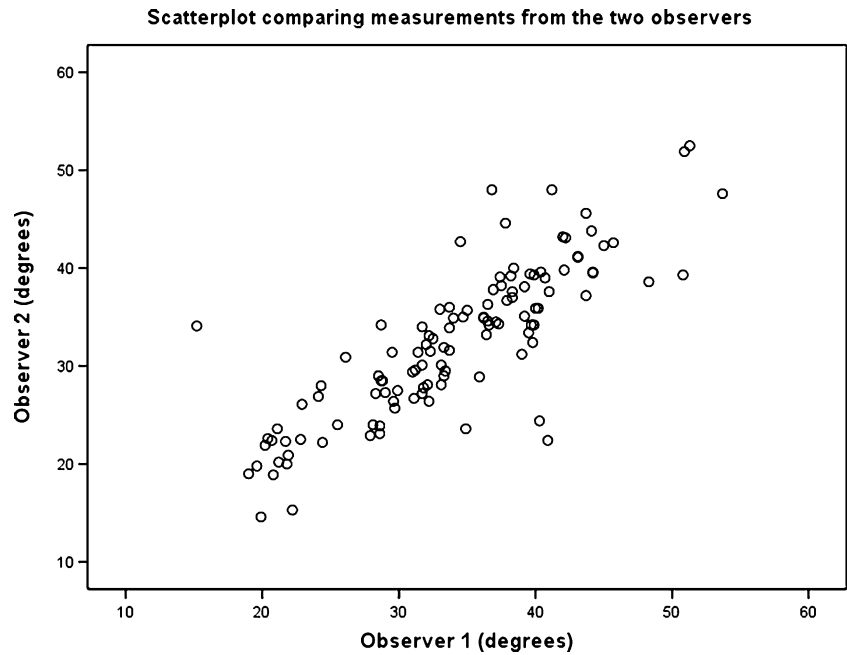
A unifying factor of the mechanical and morphological theories associated with the genesis of spondylolysis is the need for a repetitive motion, such as hyperlordosis, to develop increased mechanical stresses and impingement of the pars interarticularis by the surrounding lumbar facets [3, 6, 13]. It could therefore be argued that an increased standing lumbar lordosis at rest may increase the risk of developing spondylolysis by creating an environment in which these factors are more likely to occur. The results of this study suggest that there is a strong association between

**Fig. 3** Box and whisker plot comparing the frequency distributions of the observed angles of lordosis for patients with pars defects and normal controls

**Box and whisker plot comparing the frequency distributions of observed angles of lordosis for patients with pars defects and normal controls**



**Fig. 4** Scatterplot comparing measurements from the two observers (inter-rater reliability)



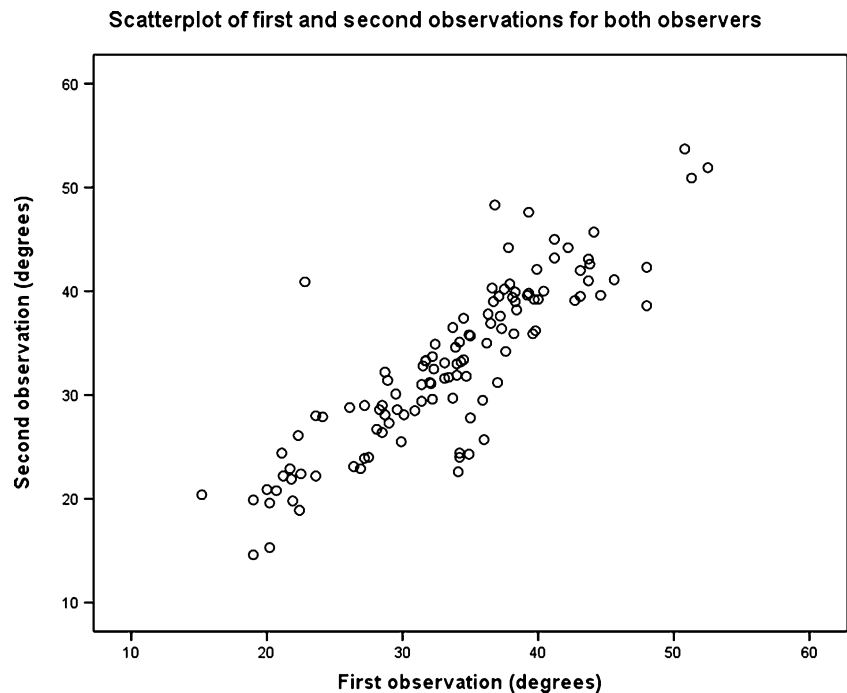
the angle of lordosis, sacral tilt, and the presence of spondylolysis.

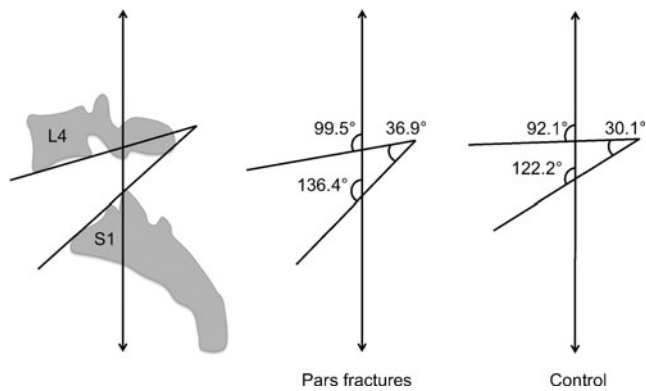
We assessed the angle of lordosis around the L5 vertebra by measuring a constrained modified Cobb angle from the interior endplate of L4 and the superior endplate of S1. The constrained measure was chosen to focus the data on anatomical measures likely to reflect changes associated with a pincer mechanism causing L5 pars interarticularis impingement. A non-constrained measurement of lumbar

lordosis, which would have included more lumbar segments, could be open to compensatory postural changes in the upper lumbar spine, thus diluting the significance of the measurement with respect to the assessment of this specific L5 pathological condition.

Although pelvic tilt is recognised as a likely contributive factor in the aetiology of pars defects [14], it is not possible to measure this on a standard lateral radiograph of the lumbar spine where the pubic symphysis is not included.

**Fig. 5** Scatterplot of first and second observations for both observers (intra-rater reliability)





**Fig. 6** Diagram illustrating the mean angular measurements of the superior endplate of S1 and the inferior endplate of L4 with respect to the vertical, and the intervening angle of lordosis, in controls and patients with pars fractures

However, measuring the angle subtended by the superior endplate of S1 to the vertical gives a measure of sacral tilt. Sacral tilt may of course be independent of pelvic tilt, and therefore not a valid surrogate measure of pelvic tilt, but sacral tilt is arguably a more important measure than pelvic tilt in terms of the biomechanical aetiology of pars fractures. It is the angle of the slope of the superior endplate of S1 that determines how much dorsal curvature is required in the lumbar spine to render axial loading through the spine perpendicular to the endplates and intervertebral discs.

It is clear that the group of patients with L5 pars fractures had a significantly steeper S1 endplate than the control group and despite having a larger L4–S1 angle of lordosis this is unable to compensate for the S1 endplate angulation. The inferior endplate of L4 is still significantly closer to the perpendicular of the axial loading forces through the spine in controls than in the patients with pars fractures.

The clinical implications of these findings are that it may be possible to identify subjects who are at risk of developing pars fractures. Clearly the condition is multifactorial with well recognised associations with certain sporting endeavours, but other genetic and lifestyle factors may contribute to symptoms and disease in patients

mechanically predisposed to pars impingement. Recognising this mechanical predisposition in patients with early symptoms, or subjects embarking on high-risk physical activity, may allow intervention that prevents completion of the spondylolysis and the complications associated with spondylolisthesis.

Line placement for the measurement of the constrained modified Cobb angle was performed manually on a PACS workstation, a technique that is open to observer error. Another potential limitation of this study is that the observers performing the measurements could not be blinded to the pars defects on the radiographs, providing a potential source of bias. However, the excellent inter-observer and intra-observer reliability measures indicate that the method and results gained are reliable.

In a paper similar to our own, Roussouly et al. [14] reviewed the sagittal alignment of the spine and pelvis radiographically in cases with L5 spondylolysis and spondylolisthesis of less than 50% displacement (grade 2 or less). These cases were compared with radiographs obtained from a cohort of asymptomatic adults (average age 27, range 18–48 years) who were assessed as normal on the basis of clinical history and plain radiograph examinations. The pars interarticularis fracture group contained adolescents and adults (average age 19 years; range 15–44 years) about whom no gender statistics were provided. They found that the average angle of lumbar lordosis within the pars interarticularis fracture group was significantly greater than that in the control group. While these results agree with our own, our study aims to remove the variables of age and gender through matched controls as we feel that these might be independent factors that could influence the angle of lordosis in the two groups.

It has been demonstrated that there is a significant difference in the angle of lumbar lordosis between the genders in the normal population, with women having greater lordosis [15]. The same study did not find a significant relationship between the angle of lumbar lordosis and age in the adult population reviewed. However, it has been shown that the angle of lumbar lordosis increases with age during childhood [16]. As our study includes

**Table 1** Results table summarising the angle of lordosis and endplate measurements with statistical analysis

Angle	Controls <sup>a</sup>	Pars fractures <sup>a</sup>	Difference <sup>b</sup>	<i>t</i> test <sup>c</sup>
L4 inferior endplate	92.1° ±17.0° (88.9–95.3)	99.5°±17.7° (96.2–102.9)	7.4° (2.9–12.0°)	<i>P</i> <0.001
Lordosis	30.1°±12.8° (27.7–32.5)	36.9°±13.1° (34.4–39.4)	6.8° (3.4–10.2°)	<i>P</i> <0.001
L5 superior endplate	122.2°±20.3° (118.3–126.1)	136.4°±21.7° (132.3–140.6)	14.2° (8.7–19.8°)	<i>P</i> <0.001

<sup>a</sup> Mean angle±2 standard deviations (95% confidence interval for the mean)

<sup>b</sup> Difference in means (95% confidence intervals for the difference in means)

<sup>c</sup> Independent samples assuming unequal variances

children and adults, age- and sex-matched normal control cases were necessary for rigorous comparison.

During the case selection process for this study, great care was taken to exclude all cases with any additional abnormality seen on the MR examination, other than the bilateral L5 pars interarticularis fracture needed for inclusion. This study therefore contains a highly selected cohort of patients with pars defects that do not represent the normal spectrum of associated findings. The advantage of this is that any confounding causes of back pain that might influence the lumbar lordosis have been kept to a minimum. However, there may be other confounding factors that influence the angle of lumbar lordosis, such as body mass index, which it was not possible to control for or perform subset analysis.

The control group in this study were not clinically normal controls. Although the MRI examinations were independently considered to be normal, the control group had presented with symptoms attributed to their lumbar spine. Therefore, the angle of lordosis in the case controls may not reflect a normal range. However, a previously reported study comparing the angle of lumbar lordosis in those with back pain and an asymptomatic control group found no significant difference between the groups [15]. This suggests that this limitation in the design of the study is probably not significant.

## Conclusion

Sacral tilt represented by a steeply angled superior endplate of S1 is associated with a significantly increased angle of lordosis, between L4 and S1, and pars fractures at L5. Steep angulation of the first sacral vertebral segment maybe the predisposing biomechanical factor that leads to pincer-like impingement of the pars interarticularis and then spondylolysis.

**Funding and grants** Nil.

## References

1. Wiltse LL, Widell EH, Jackson DW. Fatigue fracture: the basic lesion in isthmic spondylolisthesis. *J Bone Joint Surg Am.* 1975;57:17–22.
2. Cyron BM, Hutton WC, Troup JDG. Spondylolytic fractures. *J Bone Joint Surg.* 1976;58:462–6.
3. Ward CV, Latimer B. Human evolution and the development of spondylolysis. *Spine.* 2005;16:1808–14.
4. Jackson DW, Wiltse LL, Dingeman RD, et al. Stress reactions involving the pars interarticularis in young athletes. *Am J Sport Med.* 1981;9:304–12.
5. Fredrickson BE, Baker D, McHolick WJ, et al. The natural history of spondylolysis and spondylolisthesis. *J Bone Joint Surg.* 1984;66:699–707.
6. Dietrich M, Kurowski P. The importance of mechanical factors in the etiology of spondylolysis: a model analysis of loads and stresses in human lumbar spine. *Spine.* 1985;10:532–42.
7. Gerbino PG, Micheli LJ. Back injuries in the young athlete. *Clin Sport Med.* 1995;14:571–90.
8. Jackson DW, Wiltse LL, Cirincione RJ. Spondylolysis in the female gymnast. *Clin Orthop.* 1976;117:658–73.
9. Grobler L, Robertson P, Novotny J, Pope M. Etiology of spondylolisthesis. Assessment of the role played by lumbar facet joint morphology. *Spine.* 1993;18:80–91.
10. Masharawi YM, Dar G, Peleg S, et al. Lumbar facet anatomy changes in spondylolysis: a comparative skeletal study. *Eur Spine J.* 2007;16:993–9.
11. Mac-Thiong J-M, Pinel-Giroux F-M, de Guise JA, Labelle H. Comparison between constrained and non-constrained Cobb techniques for the assessment of thoracic kyphosis and lumbar lordosis. *Eur Spine J.* 2007;16:1325–31.
12. Harrison DE, Harrison DD, Caillet R, Janik TJ, Holland B. Radiographic analysis of lumbar lordosis: centroid, Cobb, TRALL, and Harrison posterior tangent methods. *Spine.* 2001;26:E235–42.
13. Standaert CJ, Herring SA. Spondylolysis: A critical review. *Br J Sport Med.* 2000;34:415–22.
14. Roussouly P, Gollogly S, Berthonnaud E, Labelle H, Weidenbaum M. Sagittal alignment of the spine and pelvis in the presence of L5–S1 isthmic lysis and low-grade spondylolisthesis. *Spine.* 2006;31:2484–90.
15. Murrie VL, Dixon AK, Hollingworth W, Wilson H, Doyle TAC. Lumbar lordosis: Study of patients with and without low back pain. *Clin Anat.* 2003;16:144–7.
16. Giglio CA, Volpon JB. Development and evaluation of thoracic kyphosis and lumbar lordosis during growth. *J Child Orthop.* 2007;1:187–93.