CLINICAL ARTICLE

Pedicle Length and Degree of Slip in Lumbosacral Isthmic Spondylolisthesis

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Objective: The present retrospective study was performed to assess the anatomical features of the pedicle in isthmic spondylolisthesis and to correlate this with degree of slip.

Methods: Twenty-six patients with isthmic spondylolytic spondylolisthesis were studied. Relevant patient variables, length, width, height of the L₅ pedicle, and the product of height and angle between pedicle and vertebral midline were measured. The length of the posterior compartment of the pedicle was calculated as the product of the pedicle length and angle.

Results: With measurements comparable to those reported in previous publications, the L₅ pedicle was found to be longer, and the height and width of the body shorter, than published values for patients without spondylolysis. The difference between the length of the posterior compartment of the pedicle and height of body is significantly proportional to the degree of slip and may reflect an adaptive response for stabilizing the vertebral body with posterior elements.

Conclusions: The pedicle anatomy was found to be altered in patients with L₅S₁ spondylolytic spondylolisthesis. These anatomical changes have implications for surgeons performing fusion operations in terms of length of screw, landmarks used and entry approach.

Key words: Anatomy; Isthmic spondylolisthesis; Pedicle; Spondylolysis

Introduction

Spondylolisthesis is one of the major causes of low back pain, often manifesting as defects in the pars interarticularis and leading to anterior or posterior slip of the involved vertebra(e)^{1,2}. Defects in the pars interarticularis have several possible causes, including stress, trauma, fatigue fractures, lytic destruction and congenital malformation. Adult isthmic spondylolisthesis most commonly occurs at the L₅S₁ level of the lumbar spine and may be asymptomatic¹. Degeneration of the disc below the pars defect can lead to slip progression, worsening the radiculopathy caused by facet joint arthrosis and foraminal stenosis³. Traditional surgical treatment goals include decompression, fusion and restoration of

disc space height, and sagittal plane alignment, additional options being instrumentation and bone grafts. However, there are still no well-established guidelines outlining the optimal approach for surgical stabilization, which include both anterior and posterior procedures.

Despite the various options available for surgical intervention, including anterior and posterolateral approaches, few studies have focused on the basic anatomical features of the pedicle in patients with spondylolisthesis. The developmental nature of this defect raises the possibility of dynamic pedicle anatomy in response to instability of the vertebral body relative to its posterior elements. Progression of slips of L₅ on S₁ is traditionally thought to elongate the pedicle in an attempt to

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Fig. 1 Technique for measuring spondylolisthesis variables. (A) Axial section through L₅, the pedicle length being determined by the anterior and posterior transverse reference lines. (B) Sagittal section through the left pedicle depicting the degrees of offset attributable to lordosis. (C) and (D) Anatomical variables as described by Srikumaran *et al.*⁷. PL, pedicle length; SPA, sagittal pedicle angle; SPD, sagittal pedicle diameter; TPD, transverse pedicle diameter.

stabilize and bridge the pars interarticularis defect⁴. This notion is supported by sagittal magnetic resonance (MR) images, which demonstrate an increased sagittal diameter following dorsal subluxation of the posterior elements. In an anatomic study of 1072 cadavers, Bajwa *et al.* noted that L₅ pedicle length is increased in subjects with pars interarticularis defects⁵. In another study by Choi *et al.*, the pedicle was noted to be elongated and to have a wider angle in patients with L₅–S₁ spondylolytic spondylolisthesis⁶. However, there is a lack of robust evidence correlating anatomical changes in pedicle features with the degree of slip. Thus, the present retrospective study was performed to assess the anatomical features of the pedicle in patients with isthmic spondylolisthesis and to correlate this with degree of slip.

Materials and Methods

Relevant data on 142 patients in the Northern Sydney Health Network's radiology database who had undergone preoperative CT scans for lumbar disease in this institution from October 2009 to August 2014 were retrospectively reviewed. From all available computed tomography (CT) and magnetic resonance imaging (MRI) scans available, 26 patients

with lumbar spondylolisthesis with bilateral pars defects were identified. Measurements were performed in accordance with a previously published study by Srikumaran *et al.*⁷ (Fig. 1).

In brief, computer software (Vitrea 2, Vital Images, Plymouth, MN, USA) was used to produce transverse axial section images perpendicular to the midline sagittal axis. The criteria of Krag *et al.*⁸ were used to select the transverse axial section, known as the mid-pedicle cut. After the mid-pedicle section had been defined, reference axes, including anteroposterior transverse posterior, transverse anterior reference, superior endplate and pedicle axis reference lines, were drawn. Subsequently pedicle dimensions, including pedicle length, angle, height and width, were measured (Fig. 1).

The percentage of slipping was calculated by the ratio of the distance between a line parallel to the posterior portion of the first sacral vertebral body and a line parallel to the posterior portion of the L₅ body, with the anteroposterior dimension of the L₅ vertebra (Fig. 1).

SPSS version 22.1 and Microsoft Excel were used for all analyses. Descriptive statistics are presented as means $\pm$ standard deviations (SD). Pearson's test was used to assess

TABLE 1 Correlation between radiological features and degree slip

Variable	R value	P value
L ₅ pedicle length (mm)	0.26	0.20
Height (mm)	-0.24	0.24
Width (mm)	-0.32	0.12
L ₅ pedicle length—height (mm)	0.55	0.0044

correlation between two variables. *P* values of <0.05 were considered significant.

Results

In all, 142 patients with lumbar spondylolisthesis with bilateral pars defects were identified by examination of preoperative CT scans from the Northern Sydney Health Network's imaging database. From this group, 26 patients with spondylolytic spondylolisthesis were selected as subjects for the present study. Their mean age was 68 ± 22 years (range, 13–102 years). Of the included patients, 12 (46.2%) were male and 14 (53.8%) female. Most of the cohort had Grade 1 slip (15 patients, 57.7%), followed by Grade 2 slip (nine patients, 34.6%), Grade 3 slip (one patient, 3.8%) and Grade 4 slip (one patient, 3.8%).

Pedicle morphology was assessed radiographically using previously published guidelines^{7,8}. The average L₅ pedicle length was determined to be 24.3 ± 6.7 mm (range, 12.6–35.8 mm) and the average pedicle height 8.7 ± 2.6 mm (range, 4.7–13.1 mm), whereas the average pedicle width was 10.8 ± 4.5 mm (5.9–23.9 mm). The average degree of slip of the 26 patients in this cohort was found to be $25.9\% \pm 13.9\%$.

There was a non-significant trend for pedicle length to be proportional to the degree of slip ($R = 0.26$, $P = 0.20$; Table 1). There was also a non-significant trend for negative correlations between height ($R = -0.24$, $P = 0.24$) and width ($R = -0.32$, $P = 0.12$) with degree of slip. There was a significant positive correlation between the pedicle length subtracted from the height and degree of slip ($R = 0.55$, $P = 0.0044$; Fig. 2).

Discussion

Spondylolysis is thought to develop as a result of microfractures of the pars interarticularis with repetitive hyperextension injuries⁹. In particular, spondylolysis at the fifth vertebrae may allow slippage, thus resulting in L₅–S₁ spondylolisthesis. Although spondylolysis and spondylolisthesis are often asymptomatic, many patients have back pain, leg pain and claudication, which can ultimately reach a stage where surgical intervention is required¹. Typically, anterior and posterior surgical approaches are used to achieve effective fusion and decompression with reduction using pedicle screw fixation^{10–12}. However, it has not been well established whether pedicle screw insertion procedures and screw size selection can be optimized according to changes in the morphology of the pedicle in patients with spondylolytic spondylolisthesis.

Although the pathological anatomy in spondylolisthesis and different surgical approaches utilized have been well characterized, there are very few published reports defining associated changes in pedicle morphology. Few studies have investigated the relationship between pedicle length and other anatomical variables, including height, length and degree of slip. Choi *et al.* studied the CT scans of 70 patients with L₅–S₁ spondylolytic spondylolisthesis and concluded that the L₅ pedicle has a significantly longer posterior compartment pedicle length (24.2 mm vs. 21.9 mm, $P < 0.05$), shorter width (10.8 mm vs. 12 mm) and lower height (11.2 mm vs. 12.4 mm, $P < 0.05$) than in patients with without spondylolisthesis⁶. These authors suggested that longer pedicle screws inserted at wider angles than in patients without spondylolisthesis may be optimal for fusion operations on these patients. In an anatomic study of 1072 cadavers, the L₅ pedicle length in 120 specimens with spondylolysis was compared with that of 952 controls without spondylolysis. It was found that the average pedicle length was greater in subjects with spondylolysis, and that elongation occurred after 40 years of age⁵. However, this study was limited to cadavers, and the results and observations may not be directly applicable to living humans.

In the present study, the length of the posterior compartment of the pedicle was calculated as the product of the pedicle length and cos of the angle, which has been previously suggested to provide a more clinically relevant measurement of the length of the pedicle. In our 26 study subjects, this length was longer than published values for non-spondylolytic patients^{6,13}. In contrast, the width and height of the body were found to be shorter than non-spondylolytic published values^{6,13}. A possible explanation for these findings is that, if the overall volume of the pedicle is to remain unchanged, then an elongation of the pedicle would result in corresponding narrowing and shortening of the pedicle height and width.

Fig. 2 Correlation between L₅ length of the posterior pedicle compartment—height of body and degree of slip.

Overall, these changes are likely due to remodeling processes that occur in subjects with spondylolytic spondylolisthesis in response to repetitive microfractures, mechanical stress and healing^{6,13}. Such remodeling processes may play a role in stabilizing the pedicle against posterior elements and may be responsible for the increased lordotic curvature of the lower lumbar spine observed in patients with spondylolisthesis^{14,15}.

The present study also assessed whether the morphological changes identified in the L₅ pedicles were associated with the degree of slip in the study subjects. Although there was a trend towards pedicle length being proportional to degree of slip, this was not statistically significant, possibly because of the small sample size. However, it was noted that the level of “overhang”, or the difference between the posterior compartment pedicle length and the height of the body, was significantly associated with the degree of slip. This measurement was used because elongation of the posterior compartment of the screw trajectory is attributable to elongation of the pedicle, but is not affected by changes in the anterior and posterior diameters of the L₅ body. No correlation was found between the height and width and degree of slip, supporting the notion that the degree of slip is attributable to changes in pedicle length, whereas body volume defined by height and width remains relatively unchanged.

The results of the present study add to the limited available data on the morphology of the L₅ pedicle in subjects with spondylolytic spondylolisthesis^{5,6}. Anatomic pedicle changes in spondylolytic spondylolisthesis may reflect remodeling, greater changes being associated with a greater degree of slip. These observations have implications in terms of choice of longer pedicle screw sizes, landmarks and trajectory for screw insertion and use of navigation and guidance in surgical interventions for spondylolytic spondylolisthesis. Review of a

greater number of cases would be helpful in better defining the anatomical changes and confirming correlation.

Limitations

The present anatomical study has some limitations. Firstly, it is a retrospective single-cohort analysis and therefore lacked a comparable group of patients without spondylolysis. Thus, direct statistical comparisons could not be made. The retrospective and non-randomized design of the study means that selection bias may have undermined the validity of the presented results¹⁶. Secondly, the small number of study subjects (26) potentially limits the statistical power of the study. Strengths of the present study include it being one of the only studies in patients characterizing anatomical variables of the fifth lumbar vertebra in subjects with L₅-S₁ spondylolytic spondylolisthesis. We have also been able to report a significant correlation between the difference between the length of the posterior compartment of the pedicle and height of body and degree of slip.

Conclusions

We found that the pedicle anatomy is altered in patients with L₅-S₁ spondylolytic spondylolisthesis. With measurements comparable to previous publications, the L₅ pedicle was found to be longer, and the height and width of the body shorter than published values in patients without spondylolysis. The difference between the length of the posterior compartment of the pedicle and height of body is significantly proportional to the degree of slip and may reflect an adaptive response for stabilizing the vertebral body with posterior elements. These anatomical changes have implications for surgeons performing fusion operations in terms of length of screw, landmarks used and entry approach.

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