L5 Pedicle Length Is Increased in Subjects With Spondylolysis: An Anatomic Study of 1072 Cadavers

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Abstract

Background In spondylolisthesis, it is believed that as L5 slips on S1, the pedicle may become elongated in response to the instability in an attempt to bridge the defect. Whether patients with spondylolysis, which is largely developmental, also develop elongation of the pedicles is unknown.

Questions/purposes The purpose of this study is to evaluate and quantify the increase in L5 pedicle length in

subjects with spondylolysis as compared with normal healthy subjects.

Methods Nine hundred fifty-two human cadaveric specimens without spondylolysis and 120 specimens with spondylolysis from the Hamann-Todd Osteological Collection were examined by a single examiner. Baseline data, including age, sex, and race of specimens, were collected. Digital calipers were used to measure the pedicle lengths at the L5 level. Linear regression analysis was performed to compare the L5 pedicle lengths in healthy patients and patients with spondylolysis.

Results Linear regression showed a significant association of increased L5 pedicle length in subjects with spondylolysis. The average L5 pedicle length in subjects with spondylolysis was greater compared with subjects without spondylolysis. In spondylolytic specimens, pedicles start to elongate after the age of 40 years. The pedicle lengths increase progressively from 5.6 mm at 40 years to 6.7 mm at 80 years with a 1% to 3% increment every decade. The pedicle lengths showed little variation in specimens from healthy subjects.

Conclusions In spondylolytic specimens, there is progressive elongation of L5 pedicle length after the third decade. An increase in L5 pedicle length in all age groups compared with the specimens from healthy subjects suggests that pathologic changes occur in bony anatomy of L5 vertebrae as early as adolescence when the condition develops.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Spondylolysis is an osseous defect of the pars interarticularis and is largely believed to be developmental. It can also be an acquired stress fracture secondary to chronic

low-grade trauma occurring most frequently in adolescents, most commonly involving the lower lumbar levels. Lumbar spondylolysis is two to four times more common in men than in women. The biomechanics and pathophysiology of spondylolysis result from musculoskeletal strain, foraminal stenosis, facet degeneration, associated disc degeneration or herniation, and occasionally stenosis of the spinal canal [1, 9, 13, 16, 22–24].

There are major anterior shear forces acting on the vertebral body created by gravity, trunk musculature, and lumbosacral curvature [5, 7]. When these shear forces are unopposed, as in the case with spondylolysis, dorsal subluxation of the posterior elements occurs causing an increase in sagittal diameter [20, 21], which is readily apparent on sagittal MR images [6, 10, 11, 16, 19].

Logically, the increase in sagittal diameter cannot be an isolated process and should be accompanied by changes in morphologic features of the pedicle. An increase in anterior subluxation of the vertebral body accompanied by posterior subluxation of the posterior elements results in repeated microfractures followed by osseous healing [18]. Repeated cycles of microfractures and healing with time should result in an increase of pedicle length. To our knowledge, as of this writing, no study has examined the anatomic changes of the L5 pedicle with advancing age in patients with spondylolysis. Thus, the purpose of this study is to evaluate if L5 pedicle length is increased in patients with spondylolysis and to quantify the increase in L5 pedicle length occurring with age by dividing the specimens into various decades of life.

Materials and Methods

The Hamann-Todd Osteological Collection in Cleveland, OH, contains more than 3300 treated and dried specimens of which 120 spondylolytic specimens and 952 normal human cadaveric specimens were randomly chosen for examination in no particular order. All of the 120 spondylolytic specimens showed isolated, bilateral pars interarticularis defects in the L5 vertebral body. Healed specimens were not examined in this study. The specimens in the collection were from individuals who died in Cleveland, OH, between 1893 and 1938. The current study included specimens from 882 males and 190 females ranging in age from 17 to 105 years. Four hundred twenty-one specimens were of African American ancestry; the remainder were white.

The gross specimens were measured subjectively by one examiner (BNS). The flat surface of the table edge was used to align the vertebrae in the axial plane and the measurements were taken from the superior aspect of the vertebrae. A digital caliper with precision of one-hundredth

Fig. 1 Pedicle length is measured from the superior aspect of the lumbar vertebrae. The average of both pedicles was used in the study.

of a millimeter was used for all the measurements. Pedicle length was measured starting from the origin of the pedicle at the vertebral body until the beginning of the superior articular facet on both sides (Fig. 1). The length of each pedicle on either side was measured twice. In the few specimens that had osteophytes and hypertrophic facet joints on the superior surface, the pedicle length also was measured twice from the inferior surface using the inner pincers of the digital caliper. The values from the superior and inferior surfaces were then correlated to minimize the error in measurements. The average of both sides was used as the pedicle length. The reliability and accuracy of these measurements were verified by comparing these with Image J measurements on a sample of 20 random lumbar vertebrae. In addition, for each specimen, we also recorded the age, sex, and race of the specimen. Stepwise multiple linear regression models then were used to analyze the relationship between age and L5 pedicle length in spondylolytic specimens. We used the standard *p* value cutoff ($p < 0.05$) in the study. Spondylolytic specimens were further divided into age subsets of a decade each to analyze the progression of L5 pedicle elongation.

Results

A total of 1072 specimens were examined with more than 85% specimens in the age range of 25 to 75 years (Table 1). Our measurements were comparable to Image J measurements on all the 20 lumbar vertebrae specimens (Table 2). A stepwise linear regression analysis revealed that in all the specimens, there was a significant association ($p < 0.01$) of increased L5 pedicle length in subjects with spondylolysis. The average L5 pedicle length in subjects with spondylolysis was 6.02 mm (1 SD = 1.43 mm) as compared to 4.31 mm (1 SD = 0.87 mm) in healthy

subjects. At all age groups, the L5 pedicle length was smaller in normal specimens as compared with spondylolytic specimens. As a result of such a small number of spondylolytic specimens from black subjects, we were unable to detect any racial difference in the population with spondylolysis. No other differences were found in the bony anatomy of L5 vertebrae in the population with spondylolysis versus the population without spondylolysis. In spondylolytic specimens, the pedicle length did not show any elongation until after the age of 40 years. The pedicle lengths increased progressively from 5.6 mm at 40 years to 6.7 mm at 80 years with a 1% to 3% increment in pedicle length every decade (Fig. 2). Thereafter, the pedicle length showed a decline to 5.5 mm. In the normal skeletal specimens, there was little variation in pedicle length with progressive age, with length being constant at 4.4 mm until the sixth decade and then declining to 4.1 mm in the specimens older than 80 years.

Discussion

Lumbar spondylolysis occurs in approximately 3% to 7% of the adult population [1, 2, 13, 23, 24], mainly at the L5

Table 1. Age, sex, and racial breakdown of all the sampled specimens

Age (years)	Number of specimens	Females	Males	White	Black
15–24	58	18	40	8	50
25–34	129	42	87	46	83
35–44	233	44	189	120	113
45–54	260	35	225	163	97
55–64	191	15	176	146	45
65–74	127	18	109	107	20
75–84	60	12	48	53	7
85–94	12	6	6	7	5
95–104	1	0	1	1	0
105–114	1	0	1	0	1
Total	1072	190	882	651	421

level, characterized by bony defects of the pars interarticularis. Repeated microfractures and bony healing of congenitally weakened vertebral segments cause dorsal subluxation of posterior elements resulting in an increased sagittal diameter of the lumbar canal [2, 16, 17, 23]. It is not known whether this increase in sagittal diameter in patients with spondylolysis also causes elongation of the pedicles. The purpose of this study was to evaluate if L5 pedicle length was increased in patients with spondylolysis and to assess the relationship between age and the average degree of elongation of the L5 pedicles. We found that the average L5 pedicle length in subjects with spondylolysis was increased as compared with that of healthy subjects (6.02 mm and 4.31 mm, respectively). In spondylolytic specimens alone, the pedicle length increased after the age of 40 years from 5.6 mm to 6.7 mm at 80 years.

The various studies previously done on pedicle lengths in patients with spondylolysis had small sample sizes with major emphasis on the axis and alignment of the vertebral column. However, in our study, we examined the bony anatomy of L5 vertebrae and objectively defined the changes in L5 spondylolytic pedicles with age and compared them with specimens from a population of individuals without spondylolysis.

This retrospective, cadaveric study has some inherent limitations. Ideally we would require a prospective cohort study following a large group of patients with serial imaging studies and autopsy analysis after death. Such a study would provide the most satisfactory answers to our questions. However, such a study would be logistically difficult, financially prohibitive, and carry the possible risk of radiation exposure to a live population. As far as the anatomic parameters are concerned, a cadaveric study provides the most viable answers. Also, the cadavers contain a significantly greater number of specimens from black subjects, proportionately, compared with the general population and the preservation techniques used to dry bones in cadavers make it impossible to deduce if there was fibrous tissue, cartilage, and/or bone in these defects.

Masharawi [12], in a skeletal study of 115 spondylolytic specimens, concluded that the L5 is manifested with a longer

Table 2. The Image J and actual measurements of pedicle lengths in 20 lumbar vertebrae

Lumbar vertebra	Specimen 1		Specimen 2		Specimen 3		Specimen 4	
	Image J	Actual measurement	Image J	Actual measurement	Image J	Actual measurement	Image J	Actual measurement
L1	8.367	8.51	9.334	9.14	8.43	8.58	7.623	7.84
L2	6.88	6.66	8.856	8.84	8.127	8.09	7.86	7.7
L3	6.411	6.54	8.647	8.51	7.719	7.85	6.756	6.86
L4	5.434	5.21	8.584	8.61	7.689	7.66	6.854	6.99
L5	4.132	4.23	5.985	6.13	5.344	5.51	4.964	4.98

Fig. 2 The increase in L5 pedicle length through decades in spondylolytic specimens as compared with normal specimens is shown.

lamina (1.85–2.18 mm), longer isthmus (3.24–4.69 mm), and longer and wider vertebral canal (3.64 mm and 1.13 mm). Another study [4], in which CT images of 30 patients with L5-S1 level spondylolysis were analyzed retrospectively, concluded multiple factors including L5 pedicle width, height of the iliac crest, and L5 vertebra sagittal index in lumbosacropelvic morphology affect the defect development in pars interarticularis. Belfi et al. [2] reported that as many as 67% of patients with unilateral spondylolysis have sclerosis of the contralateral pedicle. Although these studies indicate that bone remodeling occurs in L5 pedicles, no study has objectively quantified the pedicle length changes at the L5 level. In our study, we observed an average increase of 1.7 mm in the pedicle length of subjects with spondylolysis as compared with subjects without spondylolysis, which seems in accordance with the reported studies.

Marrow changes occurring in L5 pedicles have been reported. Hajek et al. [8] and de Roos et al. [3] first noted MR signal changes of vertebral body end plates in response to degenerative disc disease. Modic et al. [14, 15] concluded that pathological changes such as the extent of vertebral body sclerosis correlate well with MR signal intensity changes in vertebrae. They classified MR signal intensity changes in vertebral bodies into three categories. This classification was used in another study by Ulmer et al. [19] who reported that reactive marrow changes, ie, bone sclerosis, in the pedicles were seen in 40% of spines adjacent to a spondylolytic defect as a result of increased mechanical stresses. Thus, the bone is constantly remodeling itself in the pedicles and whether this bone remodeling leads to an increase in pedicle length has not been examined. We found an average increase of 29% in pedicle length in spondylolytic specimens as compared with specimens from subjects without spondylolysis.

We objectively quantified the age changes in L5 pedicle length during various decades of life. Through a post-mortem, cadaveric analysis, it appears that spondylolysis is associated with increased L5 pedicle lengths. An increase of approximately 29% in pedicle length of subjects with spondylolysis in all age groups (from as early as 18 years) compared with subjects without spondylolysis suggests that pathologic changes occur in the bony anatomy of L5 vertebrae in spondylolysis, in adolescence when the condition develops.

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