

Three-dimensional Morphological Characteristics Of The Fourth And Fifth Lumbar Vertebrae And Lumbar Lordosis In Early-Stage Lumbar Spondylolysis Using Homologous Modeling

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INTRODUCTION: The morphology of the lumbar vertebrae is thought to contribute to the development of lumbar spondylolysis. Our previous study identified a distinct overall shape of the fifth lumbar (L5) vertebra in individuals with early-stage spondylolysis¹⁾. However, the morphological characteristics of other lumbar vertebrae, as well as their alignment, remain unclear. Therefore, this study aimed to investigate the morphological features of the fourth (L4) and fifth (L5) lumbar vertebrae and their alignment in early-stage spondylolysis.

METHODS: This study was approved by the Ethics Committee. A total of 162 adolescent males who presented with low back pain participated in this study. To eliminate the influence of sex-related differences in vertebral morphology, only males were included. Participants were divided into two groups: the SP group (diagnosed with early-stage spondylolysis; $n = 72$; mean age: 14.5 ± 1.6 years) and the CON group (without spondylolysis; $n = 90$; mean age: 14.8 ± 1.6 years). Three-dimensional models of the L4–L5 region were reconstructed from initial CT data in Digital Imaging and Communications in Medicine format using software (Mimics Innovation Suite 26). These models were then processed to create homologous models using other software (mHBM and HBM-Rugle) (Fig.1). Each vertebra was represented by 14,324 anatomically corresponding vertices (Fig. 1C), enabling statistical comparisons of overall shape. Principal component analysis was performed on the vertex coordinates using software (HBS and HBM-Rugle) to extract shape-representative variables. The normality of each principal component (PC) was assessed. To compare PC scores between groups, unpaired *t*-tests were used for PCs with normal distributions, whereas the Mann–Whitney *U* test was applied for those with non-normal distributions.

RESULTS SECTION: Significant differences were observed in PC4, PC7, and PC11 ($P = 0.04, 0.01, \text{ and } 0.02$, respectively). Among these, PC4 accounted for the largest proportion of total shape variation (6.62%). The SP group showed significantly higher PC4 scores than the CON group (9.65 ± 52.95 vs -7.72 ± 52.68 ; mean difference = 17.4). This suggests that the SP group exhibited morphological characteristics corresponding to +3 standard deviations (+3 SD) (Fig. 2), including a more wedge-shaped L5 vertebral body in the sagittal plane with greater L4–L5 lordosis, increased height of the L5 transverse processes, a larger L5 neural arch (height/width), shorter L5 inferior articular processes, more horizontally oriented L4 and L5 spinous processes, and reduced height of the L5 spinous process. PC7 and PC11 represented subtle asymmetries in vertebral morphology.

DISCUSSION: These results suggest that adolescents with early-stage lumbar spondylolysis have a distinct overall vertebral shape, particularly of L5, as well as increased L4–L5 lordosis. The finding of a wedge-shaped L5 vertebral body in this study is consistent with our previous report¹⁾, and the present results further indicate that this wedge-shaped L5 vertebra may contribute to increased lumbar lordosis, which could be a factor influencing the development of spondylolysis. The characteristics of increased height of L5 transverse processes and greater height and width of the L5 neural arch may represent adaptations to this increased lordosis. PC7 and PC11 primarily reflected minor asymmetrical variations in vertebral shape, which are commonly observed in lower PCs and are unlikely to have substantial clinical implications.

SIGNIFICANCE/CLINICAL RELEVANCE: Understanding these morphological features may help clarify the developmental mechanisms of spondylolysis and contribute to the development of early detection and prevention strategies for adolescents.

REFERENCES: 1) Yamane Y, et al. Spine Surgery and Related Research. 2025;9(1):78-86.

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IMAGES AND TABLES:

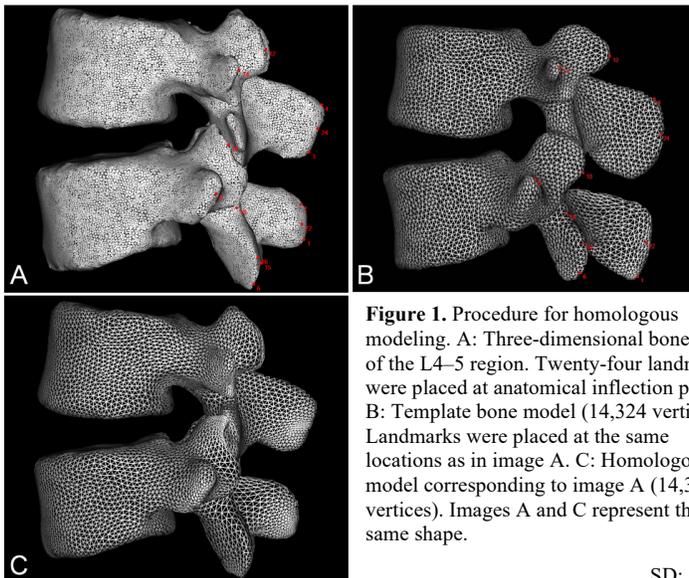


Figure 1. Procedure for homologous modeling. A: Three-dimensional bone model of the L4–5 region. Twenty-four landmarks were placed at anatomical inflection points. B: Template bone model (14,324 vertices). Landmarks were placed at the same locations as in image A. C: Homologous model corresponding to image A (14,324 vertices). Images A and C represent the same shape.

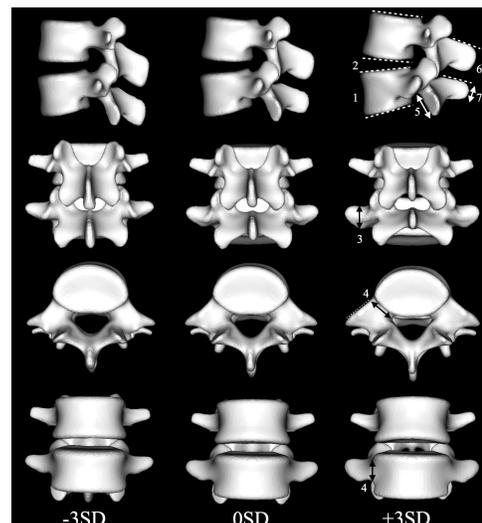


Figure 2. Morphological variation of the fourth principal component (PC4). SD: Standard deviation. 1. wedge-shaped vertebral body, 2. L4–L5 lordosis, 3. transverse processes height, 4. height and width of neural arch, 5. inferior articular processes length, 6. spinous processes orientation, 7. spinous process height.