ORIGINAL

# Distribution of the Spinal Arteries in Adult Patients with Lumbar Spondylolysis

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**Abstract : INTRODUCTION : The pathology of lumbar spondylolysis is generally thought to begin with a stress fracture in adolescence. Stress fractures of the lower extremities occur in watershed areas with a poor vascular supply because of an inability to respond to stress and heal. This pathology has not been well researched in the lumbar spine. The aim of this study was to evaluate the distribution of the spinal arteries in patients with lumbar spondylolysis. METHODS : The extraosseous distribution of the arteries around the pars interarticularis was retrospectively investigated in 14 patients with colon cancer who underwent abdominal contrast-enhanced computed tomography (CE-CT) as part of a preoperative assessment at our hospital and were found to have spondylolysis at L5. RESULTS : All patients were found to have terminal-stage spondylolysis at L5 (1 unilateral, 13 bilateral). L5 segmental artery was absent in all cases. However, separate spinal arteries supplying the pars interarticularis at L5 were found above and below the transverse process at this level. CONCLUSION : All the patients had two separate arteries originating from the cranial and caudal sides that distributed to the superior and inferior articular processes, suggesting that the pars interarticularis is a posterior element containing a vascular watershed area. J. Med. Invest. 67 : 62-66, February, 2020**

***Keywords* :** *Lumbar spondylolysis, stress fracture, pars interarticularis, vascular supply, watershed area*

## INTRODUCTION

Lumbar spondylolysis, a defect of the pars interarticularis, is considered to originate from a stress fracture occurring in childhood (1, 2). It is widely believed that repetitive trunk movements, particularly extension and rotation, increase the risk of concentration of stress at the pars interarticularis (3). However, we often encounter patients with lumbar spondylolysis who have no history of spinal trauma or playing sports as well as patients with a family history of the disease (4-6). Therefore, the etiology of lumbar spondylolysis cannot be explained simply on the basis of "stress fracture theory".

Vascularity is well known to be a determinant of bone healing. Stress fractures in the lower extremities reportedly occur around watershed areas with an inability to respond normally to stress and heal because of a poor blood supply (7-10). However, the relationship between vascularity and stress fractures of the pars interarticularis is not well understood. We hypothesized that the blood supply to the posterior elements of the lumbar spine may affect healing of a stress fracture in patients with lumbar spondylolysis.

The purpose of this study was to evaluate the distribution of the spinal arteries in patients with lumbar spondylolysis at L5, which is the level most frequently involved.

## MATERIALS AND METHODS

Fourteen patients with colon cancer who underwent 0.5-mm slice abdominal contrast-enhanced computed tomography (CE-CT) as part of preoperative surgical planning at our hospital between April 2009 and March 2013 and were noted to have spondylolysis at L5 were retrospectively reviewed. These 14 patients comprised 12 men and 2 women with a mean age of 66.3 (range, 51–85) years (Table 1). Patients with obvious bone metastases or a past medical history of lumbar surgery were excluded. Arterial-phase contrast enhanced-computed tomography (CE-CT) with 0.5 mm slice thickness were obtained with using 16-multi-detector row CT scanner (Aquilion 16, Toshiba Medical Systems, Tokyo, Japan). In staging of lumbar spondylolysis and evaluating vascular structures, oblique axial multi planar reconstruction (MPR) and parasagittal maximum intensity projection (MIP) image with 10.0-mm slab thickness were reconstructed by imaging software (Aquarius NET® Server, TeraRecon, Inc. ; San Mateo, CA) respectively. Their images were evaluated by two orthopedic surgeons and were decided in the agreement of both surgeons.

Table 1. Patient demographics

| Variable | |
|---|---|
| Mean age (range) (y) | 66.3 (51–85) |
| Sex (n) | |
| Female | 2 |
| Male | 12 |

*Lumbar spondylolysis*

Lumbar spondylolysis was diagnosed and staged using reconstructed CT images of the reverse-gantry angles on the plane parallel to the pars interarticularis (11). The spondylolysis was

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staged as early, if there was a hairline crack in the pars interarticularis ; progressive, if there was an obvious gap in the pars interarticularis ; or terminal, if there was a wide defect with sclerotic change at the both edges (i.e., pseudarthrosis). L5 was defined to be the lowest mobile spine.

*Extraosseous arteries around the lumbar spine*

The distribution of the extraosseous arteries around the lumbar spine was confirmed on the reconstructed CE-CT images. We assessed the distribution of the segmental arteries (SAs), iliolumbar arteries (ILAs), and combinations of these arteries providing the vascular supply to the posterior elements using a method we have described previously (12). Using this method, we found that one artery usually originated from the cranial side and ran around the superior articular process and that the other originated from the caudal side and ran around the inferior articular process through the lamina.

*Statistical analysis*

We used CE-CT data from age-matched and sex-matched controls without lumbar spondylolysis (control group), and compared them to those from bilateral L5 spondylolysis patients (spondyloysis group). All statistical analyses were performed using IBM SPSS Statistics for Mac OS X version 21.0 (IBM Corp., Armonk, NY, USA). Fischer's exact test was used to compare differences between control group and spondylolysis group. P value at levels of 0.05 or less were considered significant.

## RESULTS

*Lumbar spondylolysis*

All 14 patients were diagnosed as having terminal-stage spondylolysis. The spondylolysis was bilateral in all cases except one (Table 2). Figure 1 shows a representative case of terminal-stage L5 spondylolysis with bilateral pars defects and sclerotic change at both edges.

Table 2. Stage and laterality of lumbar spondylolysis

| Spondylolysis | n (%) |
|---|---|
| Stage | |
| Early | 0 (0) |
| Progressive | 0 (0) |
| Terminal | 14 (100.0) |
| Laterality | |
| Unilateral | 1 (7.1) |
| Bilateral | 13 (92.9) |

*Extraosseous arteries around L1 to L4*

The SA from L1 to L4 bifurcated from the abdominal aorta and then ran through the lateral aspect of the vertebra and distributed to the posterior elements on both sides (Figure 2A). In the foraminal area, each artery distributed to both the same spinal level and the level immediately below. For example, L3 SA distributed to the inferior articular process and lamina of L3 and to the superior articular process of L4. Thus, the vascular supply to the posterior elements of L3 was derived from branches of the SA at both L2 and L3 (Figure 2B).

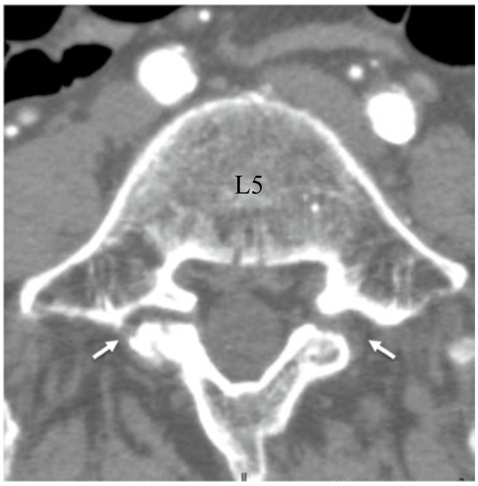


Figure 1 Reconstructed oblique axial MPR image of CE-CT showing terminal-stage spondylolysis at L5. The white arrows show bilateral pars defects with sclerotic change at both edges.

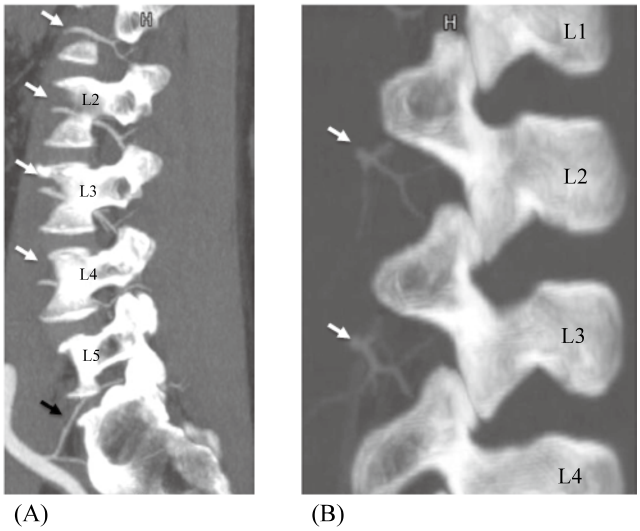


Figure 2 Reconstructed CE-CT images. (A) Parasagittal view showing the anatomical relationship between the arteries and spinal structures. The white arrows show the segmental arteries (L1 to L4) and the black arrow shows the iliolumbar artery. (B) Unilateral oblique view showing that branches of the segmental arteries distribute to the facet joints. The white arrows show the segmental arteries at L2 and L3.

*Extraosseous arteries around the pars defect at L5*

None of the patients in this study had an L5 SA (Figure 3A) ; instead, the posterior elements of L5, including the pars interarticularis, were supplied by a combination of the L4 SA and ILA. Figure 3B shows the arterial distribution in a patient diagnosed with terminal-stage L5 spondylolysis seen from both above and below the transverse process at L5. L4 SA came from above the transverse process as a cranial nutrient and distributed to the superior articular process at L5 while the ILA came from below the transverse process as a caudal nutrient and distributed to the L5 inferior articular process. Table 3 shows the arterial distribution to the posterior elements of L5 in the 13 patients with bilateral spondylolysis at this level. The cranial nutrient was derived from the L4 SA on both sides in all patients except for one, in whom it was derived from the ILA on the right side. However, although we could not detect the caudal nutrient on the right side in two patients, we detected two patterns of arteries at L4 SA (on the right in three patients, on the left in seven) and ILA (on the right in eight patients, on the left in six).

Table 4 shows comparison between age-/sex-matched control group and spondylolysis group in the presence of L5 SA and combinations of arteries around L5. The presence of L5 SA was not significant difference between 2 groups. About the combinations of extraosseous arteries around L5, there was significant difference between 2 groups at only left side ($p = 0.015$). On the other hand, there was not significant difference at right side.

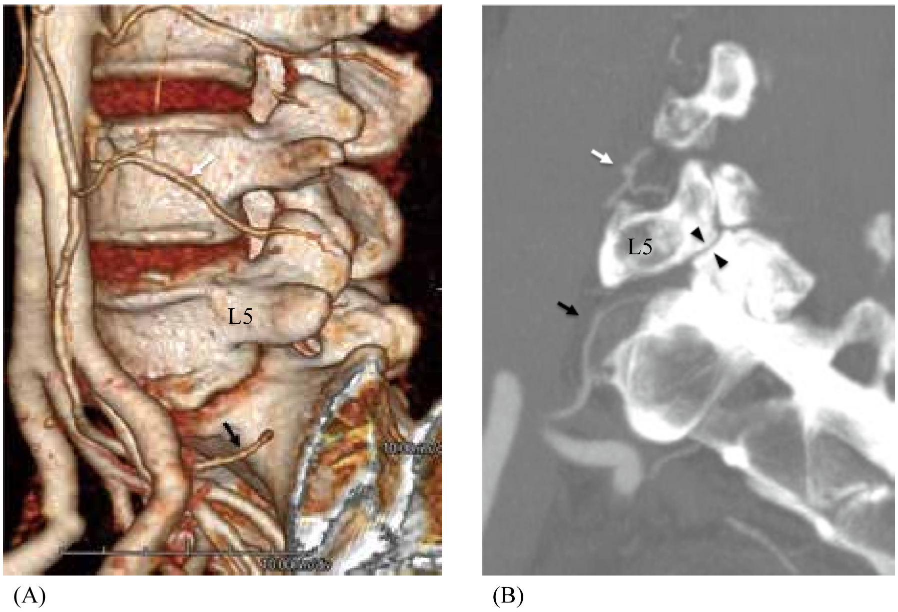


Figure 3 (A) Volume rendering (VR) image obtained from CE-CT of a lumbar spine viewed from the left side in which there is no L5 segmental artery. The white arrow shows the segmental artery at L4 and the black arrow shows the iliolumbar artery. (B) Reconstructed unilateral oblique CE-CT image of a patient diagnosed with terminal-stage L5 spondylolysis. The black arrowheads show a defect at the pars interarticularis.

Table 3. L5 lumbar spondylolysis and the arterial distribution to the posterior element of L5

| Case | | | Right | | | Left | | |
|---|---|---|---|---|---|---|---|---|
| No. | Age (y) | Sex | Spondylolysis | CRN | CAN | Spondylolysis | CRN | CAN |
| 1 | 62 | Male | L5 | L4 SA | ILA | L5 | L4 SA | ILA |
| 2 | 67 | Male | L5 | L4 SA | ILA | L5 | L4 SA | L4 SA |
| 3 | 77 | Male | L5 | L4 SA | ILA | L5 | L4 SA | L4 SA |
| 4 | 53 | Male | L5 | L4 SA | ILA | L5 | L4 SA | ILA |
| 5 | 63 | Male | L5 | L4 SA | L4 SA | L5 | L4 SA | L4 SA |
| 6 | 79 | Female | L5 | L4 SA | ILA | L5 | L4 SA | ILA |
| 7 | 85 | Female | L5 | ILA | ILA | L5 | L4 SA | ILA |
| 8 | 51 | Male | L5 | L4 SA | ILA | L5 | L4 SA | ILA |
| 9 | 61 | Male | L5 | L4 SA | L4 SA | L5 | L4 SA | L4 SA |
| 10 | 79 | Male | L5 | L4 SA | ILA | L5 | L4 SA | L4 SA |
| 11 | 63 | Male | L5 | L4 SA | - | L5 | L4 SA | ILA |
| 12 | 68 | Male | L5 | L4 SA | - | L5 | L4 SA | L4 SA |
| 13 | 59 | Male | L5 | L4 SA | L4 SA | L5 | L4 SA | L4 SA |

CRN : cranial nutrient, CAN : caudal nutrient, SA : segmental artery, ILA : iliolumbar artery

Table 4. Comparison between age-/sex-matched control group and spondylolysis group

| | | Control group (n=13) | Spondylolysis group (n=13) | p value |
|---|---|---|---|---|
| L5 SA | | n (%) | n (%) | |
| Right side | (-) | 12 (92.3) | 13 (100.0) | 1 |
| | (+) | 1 (7.7) | 0 (0.0) | |
| Left side | (-) | 12 (92.3) | 13 (100.0) | 1 |
| | (+) | 1 (7.7) | 0 (0.0) | |
| Combinations of arteries around L5 | | n (%) | n (%) | |
| Right side | L4 SA / ILA | 8 (61.5) | 7 (53.8) | 1 |
| | L4 SA / L4 SA | 2 (15.4) | 3 (23.1) | |
| | L4 SA / L5 SA | 1 (7.7) | 0 (0.0) | |
| | L3 SA / ILA | 0 (0.0) | 0 (0.0) | |
| | Others | 2 (15.4) | 3 (23.1) | |
| Left side | L4 SA / ILA | 6 (46.2) | 6 (46.2) | 0.015 |
| | L4 SA / L4 SA | 1 (7.7) | 7 (53.8) | |
| | L4 SA / L5 SA | 1 (7.7) | 0 (0.0) | |
| | L3 SA / ILA | 1 (7.7) | 0 (0.0) | |
| | Others | 4 (30.8) | 0 (0.0) | |

SA : segmental artery, ILA : iliolumbar artery
Combinations of arteries around L5 are described as cranial artery supply / caudal artery supply (e.g. : L4 SA / ILA).
Others include the combinations of L3 SA / L3 SA, L4 SA / - (invisible), and ILA /ILA.

## DISCUSSION

The etiology of stress fractures is generally thought to be multifactorial. The risk of a stress fracture is influenced by bone composition, vascular supply, surrounding muscle attachments, systemic factors, and type of athletic activity pursued (7). The vascular supply is particularly important. Poorly vascularized areas and relative watershed areas of bone cannot respond normally to stress and heal. Sites in the lower extremities with a poor blood supply, particularly the anterior tibial, navicular, and fifth metatarsal areas, are at increased risk for stress fractures, delayed healing, and nonunion (7-9). These factors, in addition to mechanical stress, make management of stress fractures challenging.

The lowest mobile spinal level, which is usually L5, is the site most prone to lumbar spondylolysis as a result of a stress fracture of the pars interarticularis. Sakai *et al*. reported that lumbar spondylolysis had an incidence of 5.9% in the general adult Japanese population and that all cases of spondylolysis were in the terminal stage as pseudoarthrosis, with 90.3% of cases found at L5 (13). However, recent advances, such as the advent of magnetic resonance imaging, have enabled earlier diagnosis of spondylolysis, including at the start of a stress fracture (14). One research group reported that magnetic resonance images showed signal changes indicating a pending fracture at multiple spinal levels, with only 66.3% of all cases found at L5 (15). In a follow-up study from the same group, the rate of union after conservative treatment was over 95% at L3 and L4, and 85% at L5. The discrepancy between findings on magnetic resonance imaging and those on CT and the difference in union rates at different spinal levels in the early stage of spondylolysis suggest that stress fractures at spinal levels other than L5 can heal spontaneously or be treated easily by conservative methods. As a result, terminal-stage spondylolysis was identified more often than earlier-stage spondylolysis at L5. These reports suggest that L5 spondylolysis as result of a stress fracture of the pars interarticularis is harder to repair and more likely to progress to pseudoarthrosis.

The absence of an L5 SA in all of our patients was not surprising given our previous finding that more than 90% of patients without spondylolysis lacked an L5 SA (12). And also, from our result of comparison between control group and spondylolysis group, there was no statistical difference between 2 groups. About the combinations of extraosseous arteries around L5, although there was not significant difference at right side, there was significant difference between 2 groups at left side. The incidence of L4 SA / L4 SA pattern in spondylolysis group was higher than that in control group at left side. Although these were interesting results, it is difficult to discuss the laterality of the result because the patients had bilateral spondylolysis.

In our previous study, each SA between L1 and L4 was identified and seen to be running from the vertebra through the lamina in 91.0% of cases on the right side and in 90.7% of those on the left side (12). As shown in Figure 2, the posterior elements at lumbar spinal levels other than L5 received their blood supply from two adjacent SAs, one of which distributes to the superior articular process and the other to the inferior articular process ; this is consistent with the watershed theory regarding the posterior elements of the lumbar spine. The L5 level, which usually has no SA, is supplied by two separate arteries distant to each other or sometimes by one artery, such as the L4 SA (L4 SA / L4 SA, L4 SA / none) or the ILA (ILA / ILA) ; this difference between L5 and the other spinal levels could be the reason why L5 has a poor blood supply. Further research will be needed to confirm this theory. Given that we cannot check CE-CT in pediatric patients diagnosed with lumbar spondylolysis, a cadaveric study will be needed to better understand intraosseous blood flow and volume in the lumbar spine.

## LIMITATIONS OF THIS STUDY

This study has some limitations. First, all patients had a previous history of colon cancer. Although the study included patients who did not have spinal metastases, which could lead to angiogenesis around the spine, a young population with otherwise good general health might have been a better cohort. Second, because 0.5-mm slices were obtained, arteries with a diameter < 0.5 mm might not have been detected. Third, intraosseous vascular structures are not easy to detect using a CE-CT imaging protocol.

## CONCLUSION

We retrospectively evaluated the distribution of extraosseous spinal arteries in patients with terminal-stage L5 spondylolysis using reconstructed CE-CT images. All the patients had two separate arteries originating from the cranial and caudal sides that distributed to the superior and inferior articular processes, suggesting that the pars interarticularis is a posterior element containing a vascular watershed area.

## CONFLICT OF INTEREST

All authors confirm that there are no conflicts of interest with people or organizations that could bias this report.

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