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Congenitally Short Pedicles; as an Underlying Cause of Lumbar Spinal Stenosis

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Abstract

Objective: A major element of developmental anatomical abnormalities associated with congenital lumbar spinal stenosis is congenitally shortened pedicles. We analyzed the role of congenitally shortened pedicles in LSS by quantitatively analyzing the antero-posterior midsagittal diameter of the spinal canal and the pedicle lengths on lumbar magnetic resonance imaging (MRI).

Methods: The lumbar MRI database of our hospital was retrospectively searched for terms' lumbar spinal stenosis, spinal stenosis and stenosis' in patients older than 18 years between January 2020 and January 2021. Midsagittal AP diameters of the lumbar spinal canal were measured at L2, L3, L4, and L5 levels on sagittal T2w images. Patients having at least one level of AP diameter equal to or less than 12 mm were considered as having LSS and included in the study group. After exclusions, 19 patients met the criteria and additional measurements were made for the pedicle lenght. They were compared with 76 control subjects.

Results: The rate of AP diameter being 12 mm or less at all levels was statistically significantly higher in the LSS group. The mean length of pedicles at the L2, L3, L4 and L5 levels in the LSS group was significantly shorter. The cut-off value for the pedicle length at the L2 level in the diagnosis of LSS was ≤8.7 mm. This was ≤9.7 for L3 level, ≤9.5 for L4 level and ≤10.1 for L5 level.

Conclusion: Decrease in pedicle length is proportionally associated with reduced diameter of the spinal canal resulting in CCS. Furthermore, the congenitally shortened pedicles give the canal a flattened appearance. The other-discriminating feature is that narrowing of the spinal canal is usually distributed throughout the lumbar spine. We found greater threshold values for shortened pedicles associated with decreased spinal canal AP diameter than found in other studies in the literature. In conclusion, the congenitally shortened pedicle plays an important role by increasing the likelihood of symptomatic presentations in LSS patients.

Keywords: Short pedicle, lumbar spinal stenosis, congenital stenosis

INTRODUCTION

Spinal stenosis is characterized by the narrowing of the spaces for the neural and vascular elements in the spinal canal to the point where it can exert pressure on the nerves running through the spine. It is subdivided based the relevant anatomical regions into central canal stenosis (CCS), lateral (recess) stenosis (LS) and foraminal stenosis (FS). The most commonly affected region is the lumbar spine followed by the cervical spine (1). CCS in the lumbar spine can cause impingement on the nerves of the cauda equina or on the thecal sac itself, resulting in debilitating buttock or lower extremity pain, with or without accompanying low back pain. Symptoms of lumbar radiculopathy may also be present when the lateral recess and neural foramen are stenosed. Lumbar spinal stenosis (LSS) is the most common cause for lumbar spinal surgery in elderly patients older than 65 years (2,3). However, because of the lack of universally accepted radiological diagnostic criteria, the exact epidemiology is difficult to determine. Nonetheless, radiological examinations are the key non-invasive tests for the diagnosis (2,4). Magnetic resonance imaging (MRI) is the most commonly preferred modality of choice with its excellent soft tissue resolution that demonstrates

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the thecal sac and the neural elements in the neuroforamina. On lumbar MRIs, absent fluid around the cauda equine and osseous/soft tissue hypertrophic degenerative changes, including degenerative disc disease, facet joint hypertrophy and ligamentum flavum hypertrophy are qualitative indicators of CCS. These degenerative changes are prominent imaging findings responsible for the acquired, degenerative form of LSS (DLSS). However, the presence of developmental anatomical abnormalities of the spinal canal can increase the likelihood of LSS with minimal, less severe degenerative changes. This type of LSS, which is less common than its degenerative form, is named as congenital LSS (CLSS) (5,6). Therefore, patients with DLSS may have a preexisting developmentally narrowed canal when they are treated at later ages (7,8). A major element of these developmental anatomical abnormalities is congenitally shortened pedicles (9). In this study, we analyzed the role of congenitally shortened pedicles in LSS by quantitatively analyzing the antero-posterior (AP) midsagittal diameter of the spinal canal and the pedicle lengths on lumbar MRIs.

METHODS

Study Population

The lumbar MRI database of our hospital was retrospectively searched for the terms' LSS, spinal stenosis and stenosis' in the reports of adult patients (older than 18 years) in one year period between January 2020 and January 2021, until a study group of 19 patients and a control group of 76 patients were formed. Patients with severe degenerative changes, lumbar spondylolisthesis, history of trauma, infection, and tumor interfering with the central canal diameter, and patients with achondroplasia and lumbar spinal surgery for any reason were not included. Ethics approval was obtained from the University of Health Sciences Turkey, Prof. Dr. Cemil Tascioglu City Hospital Local Institutional Review Board (no: E-48670771-514.99, date: 18.04.2022). Two radiologists with more than 20 years (H.Ö.) and 7 (B.E.) years of radiology experience, respectively, evaluated the examinations in consensus. All were examined on 1.5 T or 3.0 T MR scanners and included sagittal T1w and T2w images, and axial T2w images of the lumbar spine.

Midsagittal AP diameters of the lumbar spinal canal were measured at the L2, L3, L4, and L5 levels on sagittal T2w images. Patients having at least one level of AP diameter equal to or less than 12 mm were considered as having LSS and included in the study group. Among the study patients, the values smaller than 10 mm were accepted as absolute LSS and the values between 10 and 12 were accepted as relative LSS. Nineteen patients met the criteria in whom additional measurements were made for the pedicle length on the sagittal T2w images. They were compared with 76 control subjects between the ages of 20-40 with normal AP diameters (>12 mm) of the lumbar spine at all four levels.

Statistical Analysis

While evaluating the findings obtained in the study, IBM SPSS Statistics 22 program was used for statistical analysis. The conformity of the parameters to the normal distribution was evaluated with the Shapiro-Wilks test. While evaluating the study data, in addition to descriptive statistical methods (mean, standard deviation, frequency), Student's t-test was used for comparisons of normally distributed parameters between two groups, and Mann-Whitney U test was used for comparisons between groups of parameters that did not show normal distribution. Continuity (Yates) correction and Fisher's Exact test were used to compare qualitative data. The most appropriate cut-off point was chosen on the basis of the ROC curve analysis. Statistical significance was defined at $p<0.05$.

RESULTS

The study was conducted with 95 subjects, 53 (55.8%) men and 42 (44.2%) women, whose ages ranged from 20 to 79, with a mean age of 37.19±13.95 years. The subjects were evaluated under two groups as "LSS" (n=19) and "control" (n=76). The mean age of the LSS group was statistically significantly higher than that of the control group (p=0.000; $p<0.05$). There was no statistically significant difference between the groups in terms of gender distribution ($p>0.05$) (Table 1).

The mean AP diameter at the L2 level of the control group was 20.04±2.74, and 12.93±2.03 in the LSS group. The rate of AP diameter being 12 mm or less at the L2 level in the LSS group (31.6%) was statistically significantly higher than that in the control group (0%) (p=0.000; $p<0.05$). The rate of having AP diameter of 10 mm or less at the L2 level was higher than in the LSS group (5.3%) than in the control group (0%) but, this was not statistically significant ($p>0.05$). The mean AP diameter at the L3 level of the control group was 18.61±2.93 mm and it was

Table 1. Evaluation of groups in terms of age and gender

	LSS	Control	p
Age mean ± SD (median)	58.74±16.01 (62)	31.80±5.96 (35)	[1]0.000*
Gender n (%)			
Male	10 (52.6%)	43 (56.6%)	[2]0.959
Female	9 (47.4%)	33 (43.4%)	

[1]Mann-Whitney U test, [2]Continuity (Yates) correction, *p<0.05, SD: Standard deviation, LSS: Lumbar spinal stenosis

11.48±2.10 mm in the LSS group. The rate of having AP diameter of 12 or less at L3 level in the LSS group (63.2%) was statistically significantly higher than that in the control group (0%) (p=0.000; p<0.05). The rate of having AP diameter of 10 mm or less at the L3 level in the LSS group (31.6%) was statistically significantly higher than that in the control group (0%) (p=0.000; p<0.05). The mean AP diameter at the L4 level of the control group was 17.62±2.48, and 11.09±2.04 in the LSS group. The rate of having AP diameter of 12 mm or less at the L4 level in the LSS group (57.9%) was statistically significantly higher than the control group (0%) (p=0.000; p<0.05). The rate of having AP diameter of 10 mm or less at the L4 level in the LSS group (47.4%) was statistically significantly higher than the control group (0%) (p=0.000; p<0.05). The mean AP diameter at the L5 level of the control group was 17.10±2.48, and 12.51±2.33 for the LSS group. The rate of having AP diameter of 12 mm or less at the L5 level in the LSS group (36.8%) was statistically significantly higher than the control group (2.6%) (p=0.000; p<0.05). The AP diameter in these 2 patients was 11.99 mm. The rate of having AP diameter of 10 mm or less at the L5 level in the LSS group (21.1%) was statistically significantly higher than that in the control group (0%) (p=0.000; p<0.05) (Table 2).

The mean length of pedicles at the L2, L3, L4, and L5 levels of the cases in the LSS group were statistically significantly shorter than that in the control group (p=0.000; p<0.05) (Table 3). In the diagnosis of LSS, the ROC curve was drawn for the pedicle length at the L2 level (Figure 1). The area under the curve was 0.961 and its standard error was 0.01. The area under the ROC curve was found to be significantly higher than 0.5 (p=0.001; p<0.05). The cut-off point determined for the pedicle length at the L2 level in the diagnosis of LSS was ≤8.7 mm. The sensitivity of this value was 89.5% and the specificity was 92.1%. The rate of having pedicle length of 8.7 mm or less at the L2 level in the LSS group (89.5%) was statistically significantly higher than that in the control group (7.9%) (p=0.000; p<0.05) In the diagnosis of LSS, the ROC curve was drawn for the pedicle length at the L3 level (Figure 2). The area under the curve was 0.917 and its standard error was 0.02. The area under the ROC curve was found to be significantly higher than 0.5 (p=0.001; p<0.05). The cut-off point determined for the pedicle length at the L3 level in the diagnosis of LSS was ≤9.7 mm. The sensitivity of this value was 94.7% and the specificity was 77%. The rate of having pedicle length of 9.7 mm or less at the L3 level in the LSS group (94.7%) was statistically significantly higher than that in the control group (23%) (p=0.000; p<0.05). In the diagnosis of LSS, the ROC curve was drawn for the pedicle length at the L4 level (Figure 3). The area under the curve was 0.919 and its standard error was 0.02. The area under the ROC curve was found to be significantly higher than 0.5 (p=0.001; p<0.05). The cut-off point determined for the pedicle length at the L4 level in the diagnosis of LSS was ≤9.5 mm. The sensitivity of this value was 84.2% and the specificity

Table 2. Evaluation of groups in terms of AP diameter measurements being shorter than 10 and 12 mm

		Control (n=76)	LSS (n=19)	Total (n=95)	
Spinal AP diameter		n (%)	n (%)	n (%)	p
L2	<12	0 (0%)	6 (31.6%)	6 (6.3%)	0.000*
L2	<10	0 (0%)	1 (5.3%)	1 (1.1%)	0.200
L3	<12	0 (0%)	12 (63.2%)	12 (12.6%)	0.000*
L3	<10	0 (0%)	6 (31.6%)	6 (6.3%)	0.000*
L4	<12	0 (0%)	11 (57.9%)	11 (11.6%)	0.000*
L4	<10	0 (0%)	9 (47.4%)	9 (9.5%)	0.000*
L5	<12	2 (2.6%)	7 (36.8%)	9 (9.5%)	0.000*
L5	<10	0 (0%)	4 (21.1%)	4 (4.2%)	0.000*

Fisher's Exact test, *p<0.05, LSS: Lumbar spinal stenosis, AP: Antero-posterior

Table 3. Evaluation of groups in terms of pedicle length measurements

	LSS	Control	
Pedicle	Mean ± SD	Mean ± SD	p
L2	7.64±0.92	10.14±1.27	0.000*
L3	8.22±1.05	10.64±1.55	0.000*
L4	8.52±1.15	11.09±1.56	0.000*
L5	8.82±1.41	11.92±1.86	0.000*

Student t-test, *p<0.05, LSS: Lumbar spinal stenosis, SD: Standard deviation

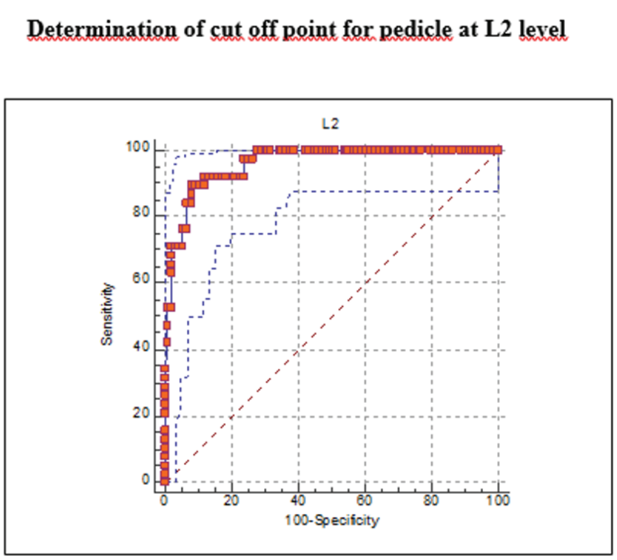

Figure 1. ROC curve for the pedicle length at L2 level in the diagnosis of LSS

LSS: Lumbar spinal stenosis, ROC: Receiver operating characteristic was 87.5%. The rate of having pedicle length of 9.5 mm or less at the L4 level in the LSS group (84.2%) was statistically significantly higher than that in the control group (12.5%) (p=0.000; p<0.05). In the diagnosis of LSS, the ROC curve was drawn for the pedicle length at the L5 level (Figure 4). The area under the curve was 0.921 and its standard error was 0.02. The area under the ROC curve was found to be significantly higher than 0.5 (p=0.001; p<0.05). The cut-off point determined for the pedicle level at the L5 level in the diagnosis of LSS was ≤10.1 mm (Table 4). The sensitivity of this value was 86.8% and the specificity was 82.9%. The rate of having pedicle length of 10.1 mm or less at the L5 level in the LSS group (86.8%) was statistically significantly higher than the control group (17.1%) (p=0.000; p<0.05).

Determination of cut off point for pedicle at L3 level

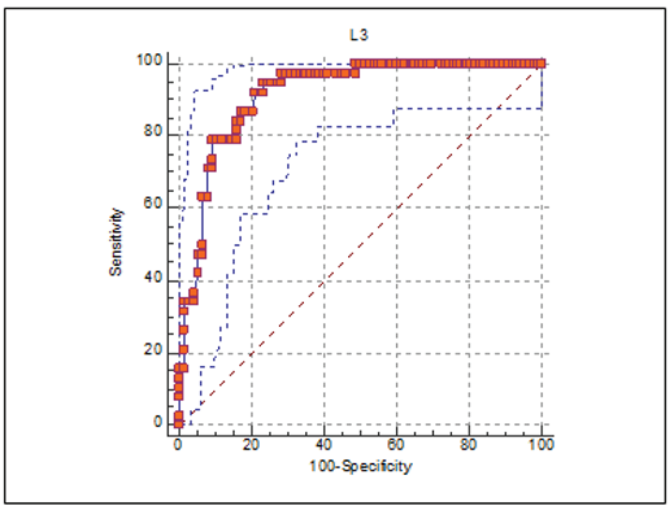

Figure 2. ROC curve for the pedicle length at the L3 level in the diagnosis of LSS

LSS: Lumbar spinal stenosis, ROC: Receiver operating characteristic

Determination of cut off point for pedicle at L4 level

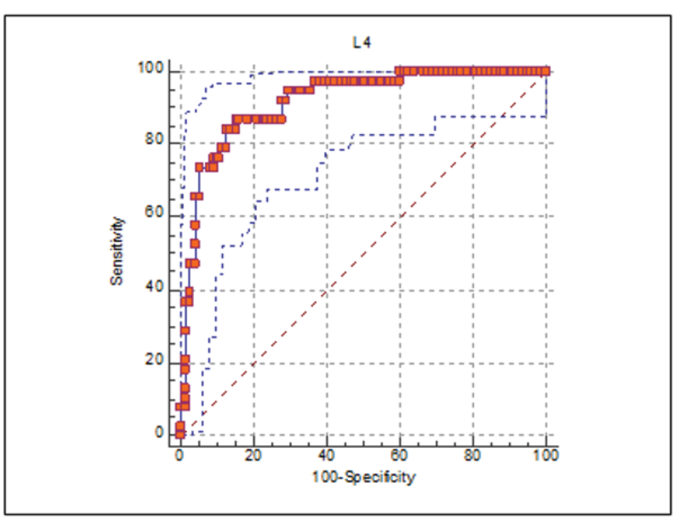

Figure 3. ROC curve for the pedicle length at the L4 level in the diagnosis of LSS

LSS: Lumbar spinal stenosis, ROC: Receiver operating characteristic

DISCUSSION

LSS is a common cause of lumbar spinal surgery in patients with leg and low back pain. However, there is a lack of universally accepted radiological diagnostic criteria for LSS due to significant variability regarding the relationship between the imaging findings and the clinical symptoms. Fourteen different semiquantitative or qualitative radiologic criteria that were identified in a systematic review [according to the involved anatomic spaces including criteria for CCS, lateral (recess) stenosis, and FS] showed remarkable variability based on the subjectivity of the evaluation of the interpreter (10). Quantitative measurements of LSS also showed great variability among the results of different studies in the literature. AP and transverse diameters of the spinal canal with regard to its shape were reported as a reliable indicator for CCS (11,12). In the Delphi survey, the highest rated quantitative criterion for CCS was the AP diameter of the osseous canal (13). Epstein et al. (14) found the lower limit of normal for a sagittal canal diameter of approximately 15 mm. A mean AP canal diameter of 14.1 mm was identified by Schonstrom et al. (15) on computed tomography scans. Sortland et al. (16) determined that 10.5 mm in extension was the lower value of the normal by describing

Determination of cut off point for pedicle at L5 level

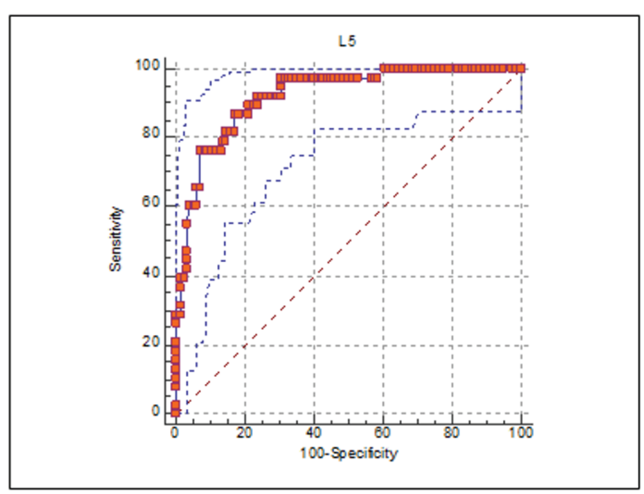

Figure 4. ROC curve for the pedicle length at the L5 level in the diagnosis of LSS

LSS: Lumbar spinal stenosis, ROC: Receiver operating characteristic improved myelographic techniques with flexion-extension views. In a systematic review which identified 10 different quantitative parameters to measure LSS, the AP mid-sagittal diameter <10 mm was found to be one of the most frequently reported criteria (17). Verbiest divided LSS into two subgroups as absolute stenosis having an AP diameter <10 mm and relative stenosis as AP diameter between 10 and 12 mm (18,19). We also measured the midsagittal AP diameter in lumbar MRI to define CCS, and we accepted a central canal diameter of <10 mm as absolute LSS and diameters between 10 and 12 mm as relative LSS (Figure 5). It is well known that evidence of lumbar spondylosis (LS) usually accompanies LSS in varying degrees. However, in congenitally stenotic patients, the spinal canal is primarily narrowed by an anatomical abnormalities that increase the likelihood of neural compression with fewer, less severe degenerative spondylotic changes. These patients are at a disadvantage because a small disc bulge may convert them from asymptomatic to severely symptomatic LSS, which is probably present at earlier ages than the degenerative form. The most common cause of the congenital narrowing of the spinal canal is short pedicles. The decrease in pedicle length is proportionally associated with reduced diameter and cross-sectional area of the spinal canal resulting in CCS, which is the pertinent feature in CLSS due to short pedicles. Furthermore, there are additional unique features of the spinal canal in these congenitally stenotic patients with short pedicles that differentiate them from their primarily degenerative counterparts. First, the congenitally shortened pedicles give the canal a flattened (compressed) appearance compared to the more round shape of the spinal canal in healthy patients (Figure 6). This is referred to as trefoil-shaped bony spinal canal, particularly when the lateral recesses are also stenosed (12,20). The other-discriminating feature of CLSS is that narrowing of the spinal canal is usually distributed throughout the lumbar spine as opposed to the DLSS in which the stenosis is often limited to a single level, reported much more frequently at L4-5 level (Figure 7) (19,21). In their comparative study of 15 patients with CLSS, Singh et al. (9) reported a shorter pedicle length with a critical cutoff value of 6.5 mm and proportionally decreased cross-sectional area of the spinal

Table 4. Evaluation of the pedicle measurements of the groups in terms of the rate of being shorter than the cut-off values

		Control (n=152)	LSS (n=38)	Total (n=190)	
Pedicle		**n (%)**	**n (%)**	**n (%)**	**p**
L2	≤8.7	12 (7.9%)	34 (89.5%)	46 (24.2%)	0.000*
L3	≤9.7	35 (23%)	36 (94.7%)	71 (37.4%)	0.000*
L4	≤9.5	19 (12.5%)	32 (84.2%)	51 (26.8%)	0.000*
L5	≤10.1	26 (17.1%)	33 (86.8%)	59 (31.1%)	0.000*

Continuity (Yates) correction, *p<0.05, LSS: Lumbar spinal stenosis

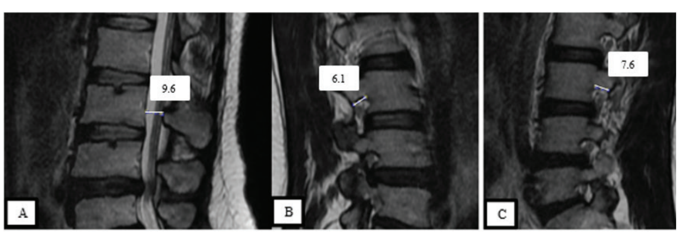

Figure 5. A-C) Sagittal T2w MR images of a 32-year-old female demonstrating the decreased AP diameter of the lumbar spinal canal at the L3 level (A) and associated short pedicle lengths in both the right (B) and the left (C) side

MR: Magnetic resonance, AP: Antero-posterior

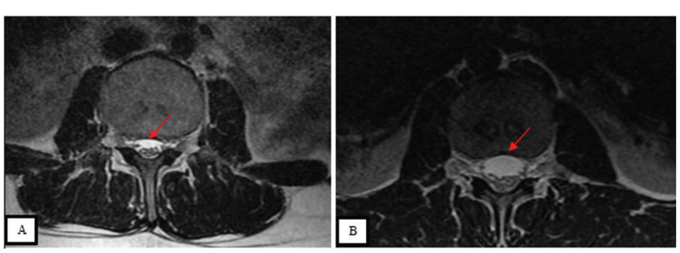

Figure 6. A) Axial lumbar T2w MR image of a 32-year-old female with short pedicles shows a compressed appearance of the lumbar spinal canal (A, arrow) B) axial lumbar T2w MR image of a 22-year-old female with normal pedicle lengths shows a more rounded (non-compressed) appearance of the lumbar spinal canal (B, arrow)

MR: Magnetic resonance

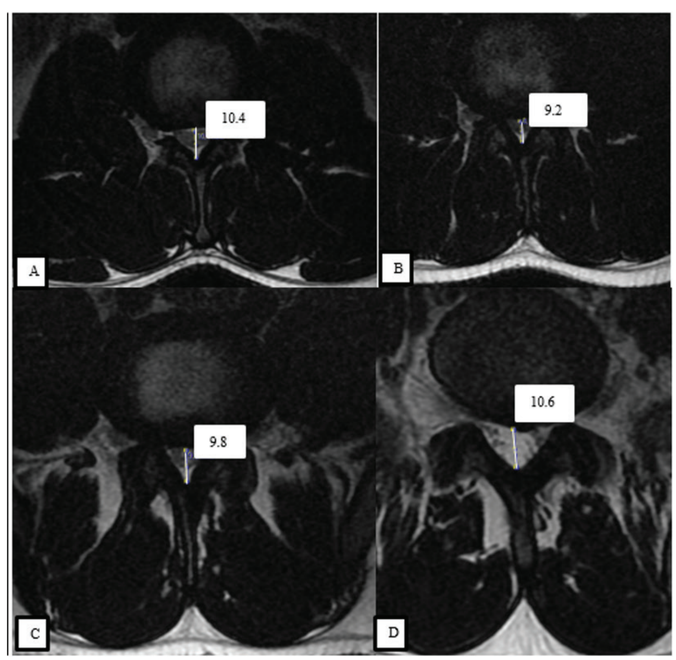

Figure 7. Axial T2w MR images of a 20-year-old male with short pedicles showing the long segment of narrowing of the central spinal canal at all four levels; L2-L3 (A), L3-L4 (B), L4-L5 (C) and L5-S1 (D). The associated compressed appearance of the central spinal canal is noted

MR: Magnetic resonance

canal in congenitally stenotic patients in contrast to the control group subjects with pedicle lengths closer to 9 mm. Although, the preoperative MRI and plain radiographs of the congenitally stenotic patients were evaluated, the major limitation of this study was that all congenitally stenotic patients in this study were treated surgically, i.e. these patients aforementioned in this study represent severely symptomatic patients. However, congenital stenosis does not correspond only to the extreme end of the narrowing requiring surgical treatment, but includes a spectrum of changes with increasing clinical severity. We found greater threshold values for shortened pedicles associated with decreased spinal canal AP diameter than found in this study. We think that this is because our study group consisted of patients with lumbar spinal canal diameter less than 12 mm, who were considered stenotic, but did not require surgical management because to the lack of significant degenerative changes made them not significantly symptomatic. However, less severe degenerative hypertrophic changes may convert them into severely symptomatic states than expected.

Our study stands out with its following features; first, we included congenitally stenotic patients who were not surgically treated to obtain the cut values associated with decreased midsagittal AP diameter at the lumbar spine. However, as one of the shortcomings of this study, we did not compare patients with symptomatic CLSS to asymptomatic CLSS to determine the phenotypic differences that may result in/or correlate with the symptoms. Additionally, we did immeasure the transverse diameter of the spinal canal in our study. In this regard, Singh et al. (9) found no notable difference in the transverse diameter of the canal and concluded that the reduction in cross-sectional area is mainly due to the reduced AP diameter of the lumbar spinal canal. Another shortcoming is that we did immeasure the diameters of the lumbar vertebral bodies to evaluate if the congenitally shortened pedicles are also associated with smaller vertebral bodies. We believe that our results will contribute to the understanding of CLSS and conducting further studies regarding the limitations of our study.

CONCLUSION

LSS is an important cause of low back and leg pain. In patients suffering from LSS, the congenitally shortened pedicle plays an important role by increasing the likelihood of symptomatic presentations in less severe degenerative changes compared to with normal individuals. Additionally, since it is more often multilevel pathology defining this subgroup of stenotic patients is also important in the management approaches.

Ethics

Ethics Committee Approval: Ethics approval was obtained from the University of Health Sciences Turkey, Prof. Dr. Cemil Tascioglu City Hospital Local Institutional Review Board (no: E-48670771-514.99, date: 18.04.2022).

Informed Consent: Retrospective study.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: H.Ö., Design: H.Ö., B.E., Data Collection or Processing: H.Ö., B.E., T.K., E.K., Analysis or Interpretation: H.Ö., B.E., Literature Search: B.E., T.K., E.K., Writing: B.E.

Conflict of Interest: No conflict of interest was declared by the authors.

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