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Research Article

Symptomatic and morphometric analysis of lumbosacral transitional vertebrae: assessments by age and gender

Lumbosakral geçiş vertebralarının semptomatik ve morfometrik analizi: yaş ve cinsiyete göre değerlendirmeler

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Abstract

Aim: Lumbosakral transitional vertebrae (LSTV) are anatomical variations where a vertebra exhibits characteristics of both lumbar and sacral vertebrae. This study aims to assess anatomical changes in LSTV patients by measuring intervertebral disc height (IVDh), vertebral foramen anteroposterior diameter (FVAPd), and intervertebral foramen height (FIVh), with consideration of age and gender differences.

Material and Methods: This retrospective study included 274 patients diagnosed with LSTV. All images were acquired with a 1.5T magnetic resonance imaging device and a 32-channel lumbar coil. The presence of LSTV, forming the morphological data, was identified from coronal and sagittal reformat images and was classified as either lumbarization or sacralization. Morphometric data (IVDh, FIVh and FVAPd) were acquired from axial, sagittal, and coronal planes using both soft tissue and bone window settings.

Results: The mean age of patient was 41.6±13.0 years, and most of them were female (55.8%). LSTV was predominantly lumbarization (96.4%), with sacralization in the remaining cases. The overall mean FVAPd was 11.2±2.4 mm, mean IVDh was 9.1±1.8 mm, and mean FIVh was 18.8±2.4 mm on the right and 19.1±2.4 mm on the left. IVDh levels were consistent across age groups, while FVAPd values were similar between genders. Patients aged 40 and under had higher FVAPd and FIVh levels, and male patients had higher IVDh and FIVh levels compared to females.

Conclusions: The morphometric characteristics of LSTV may vary according to age and gender. Considering these factors in accurately identifying the anatomical variations of LSTV may play a significant role in determining appropriate treatment and management strategies.

Keywords: lumbalisation, lumbar canal, lumbasacral transitional vertebra, sacralisation, sacral canal

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Öz

Amaç: Lumbosakral geçiş vertebraları (LSTV), bir omurun hem lumbal hem de sakral vertebra özelliklerini gösterdiği anatomik varyasyonlardır. Bu çalışma, LSTV'li hastalarda yaş ve cinsiyet farklılıklarını dikkate alarak, intervertebral disk yüksekliği (IVDh), vertebral foramenin anteroposterior çapı (FVAPd) ve intervertebral foramen yüksekliğini (FIVh) ölçerek anatomik değişiklikleri değerlendirmeyi amaçlamaktadır.

Gereç ve Yöntemler: Bu retrospektif çalışmaya LSTV tanısı almış 274 hasta dahil edilmiştir. Tüm MR görüntüleri 1.5T manyetik rezonans görüntüleme cihazı ve 32 kanallı lumbar coil ile elde edilmiştir. Morfolojik veriler oluşturan LSTV'nin varlığı, koronal ve sagittal reformat görüntülerden tespit edilerek lumbalizasyon veya sakralizasyon olarak sınıflandırılmıştır. Morfometrik veriler (IVDh, FIVh ve FVAPd), hem yumuşak doku hem de kemik pencere ayarları kullanılarak aksiyal, sagittal ve koronal düzlemlerden elde edilmiştir.

Bulgular: Hastaların ortalama yaşı 41.6±13.0 yıl olup, çoğunluğu (%55.8) kadındı. LSTV vakalarının büyük çoğunluğu (%96.4) lumbalizasyon, geri kalan vakalar ise sakralizasyon şeklinde görülmüştür. Genel olarak ortalama FVAPd 11.2±2.4 mm, ortalama IVDh 9.1±1.8 mm, ortalama FIVh sağda 18.8±2.4 mm ve solda 19.1±2.4 mm olarak bulunmuştur. IVDh düzeyleri yaş grupları arasında tutarlılık gösterirken, FVAPd değerleri cinsiyet açısından benzerdi. 40 yaş ve altındaki hastalarda FVAPd ve FIVh düzeyleri daha yüksek, erkek hastalarda ise kadınlara kıyasla IVDh ve FIVh düzeyleri daha yüksek bulunmuştur.

Sonuç: LSTV'nin morfometrik özellikleri yaş ve cinsiyete göre farklılık gösterebilir. Bu faktörlerin dikkate alınarak LSTV'nin anatomik varyasyonlarının doğru bir şekilde tanımlanması, uygun tedavi ve yönetim stratejilerinin belirlenmesinde önemli bir rol oynayabilir.

Anahtar Kelimeler: lumbalizasyon, lomber kanal, lumbosakral geçiş vertebrası, sakralizasyon, sakral kanal

Introduction

Lumbosacral transitional vertebraes (LSTVs) are congenital anomalies of the spine, characterized by the sacralization of the lowest lumbar vertebra or the lumbarization of the highest sacral vertebra [1]. LSTVs can lead to nerve root inflammation, which may result in "sciatica" or radicular pain patterns [2]. Although LSTVs are more commonly observed in older age and males, the prevalence in the general population has been reported to range from 4% to 35% [3]. This variation underscores the importance of precise morphometric analysis and standardized diagnostic approaches to accurately identify and classify LSTVs.

LSTVs presents a range of variations, from partial or complete sacralization of the L5 vertebra to partial or complete lumbarization of the S1 vertebra [4]. When L5 is entirely fused with the sacrum, four lumbar vertebrae are present. Conversely, if S1 is fully separated from the sacrum, the spine contains six lumbar vertebrae, which leads to an increased lordotic curvature [5]. Transitional vertebrae can modify the spine's normal load distribution and movement patterns, potentially causing a range of symptoms from chronic low back pain to radiculopathy, depending on the degree and type of vertebral transition [6]. Morphometric measurements, including intervertebral disc height (IVDh), anteroposterior diameter of the vertebral foramen (FVAPd), and height of the intervertebral foramen (FIVh), offer valuable information about altered biomechanics, disc degeneration, and nerve compression [7, 8].

Due to the higher prevalence of LSTVs in older age and males, we assumed that morphometric measurements might differ by age and gender. Additionally, these measurements may vary between patients with pain and those without. Therefore, this study aimed to investigate the relationship morphometric measurements (IVDh, FVAPd, FIVh) derived from magnetic resonance imaging (MRI) of patients with transitional vertebral anomalies and their age, gender, and pain status.

Material and Methods

Following the principles set forth in the Declaration of Helsinki, this retrospective study was conducted at the Erzincan Binali Yıldırım University, Mengücek Gazi Training and Research Hospital, Radiodiagnostics Department between January 2022 and July 2022. The study received approval from the Binali Yıldırım University Clinical Research Ethics Committee (Approval Date: 30.03.2023, Number: 2023-07/4). The local ethics committee waived the requirement of informed consent due to the retrospective nature of the research.

Study population

A total of 1164 patients who visited the Radiodiagnostic Department and underwent MRI of the lumbosacral region during the aforementioned dates were retrospectively examined in this study. Due to the possibility of altered normal anatomy, patients with disk degeneration, those over 69 years old, those with scoliosis, spondylolisthesis, pelvic or spinal trauma, and those who had previously undergone lumbar surgery were not included in the study. After this exclusion process, 274 patients with LSTVs were enrolled in this study.

Patient files and electronic records were used to obtain demographic and clinical information, including age, gender, pain status, and MRI findings.

Acquisition and Processing of Images

MRI images were obtained using a 1.5T MRI device equipped with a 32-channel lumbar coil (Magnetom Aera, Siemens, Erlangen, Germany). The images were acquired with the patient in the supine position. Sagittal T2-weighted images (time of repetition [TR]: 4120 ms, time of echo [TE]: 104 ms, average: 2, field of view: 280 mm, slice thickness: 4 mm, voxel size: 0.9 × 0.9 × 4 mm), sagittal T1-weighted images (TR: 646 ms, TE: 9 ms, average: 2, field of view: 280 mm, slice thickness: 4 mm, voxel size: 0.9 × 0.9 × 4 mm), and axial T2-weighted images (TR: 5070 ms, TE: 88 ms, average: 1, field of view: 190 mm, slice thickness: 4 mm, voxel size: 0.7 × 0.7 × 4 mm) were obtained and processed in multiplanar reconstruction and volume rendering technique formats. Three-dimensional images in the axial, sagittal, and coronal planes were used to obtain morphometric and morphological data in both soft tissue and bone window settings.

All MRI images were re-evaluated by a radiologist with 10 years of experience. The images were transferred to a Picture Archiving and Communication System (Akgün PACS Viewer v7.5, Akgün Software, Ankara, Turkey) workstation for analysis and to perform measurements in standard digital imaging and medical formats.

Assessment of Images

The presence of LSTV, forming the morphological data, was identified from coronal and sagittal reformat images and was classified as either lumbarization or sacralization. Morphometric data (IVDh, FIVh and FVAPd) were acquired from axial, sagittal, and coronal planes using both soft tissue and bone window settings.

The measurement of the intervertebral disc space was conducted in the sagittal plane by measuring the distance between the upper and lower concave points of the L4-5 lumbar vertebral bodies, using the bone window setting. In the axial plane, FVAPd was measured at the widest distance at the relevant level using the bone window setting. At the L4-5 level, the height between the superior vertebral notch of the lower vertebra and the inferior vertebral notch of the upper vertebra was measured as the intervertebral foramen height using the bone window setting.

Statistical analysis

All of the data were analyzed with IBM SPSS Statistics for Windows 22.0 (IBM Corp., Armonk, NY, USA). The normality distribution of the numerical variables was evaluated with the Kolmogorov-Smirnov test. All numerical data showed a normal distribution and were reported as mean ± standard deviation (SD). Student's T-test was used for comparisons of numerical variables between two groups, while ANOVA (post hoc: Bonferroni test) was used for comparisons involving more than two groups. Categorical variables were given as numbers and percentages, and inter-group comparisons were conducted with the Chi-square and Fisher exact tests. Pearson correlation analyses were applied to evaluate the relationships between the numerical variables. Significance was accepted at $P < 0.05$ (*) for all of the statistical analyses.

Results

The patients included in the study had a man age of 41.6 ± 13.0 years (range: 12-64), and most of them were female (n = 153, 55.8%). There was no significant difference in the mean age between female and male patients (42.2 ± 13.1 vs. 41.8 ± 13.0, p = 0.386). LSTV appeared as lumbarization in 96.4% of the patients (n = 264), while in the remaining patients, it was in the form of sacralization (n = 10, 3.6%). Pain was present in 61.7% of the patients (n = 169). The distribution of age, gender, and pain were similar between the lumbarization and sacralization groups. The mean IVDh (9.5 ± 2.1 mm vs. 9.1 ± 1.7 mm, p = 0.541) and mean FVAPd (11.2 ± 2.8 mm vs. 11.2 ± 2.4 mm, p = 0.996) were not significantly different between the lumbarization and sacralization groups, while the mean FIVh values for both the right and left sides were higher in the lumbarization group compared to the sacralization group (18.8 ± 2.4 mm vs. 16.9 ± 1.6 mm, p = 0.004 for right FIVh; 19.2 ± 2.3 mm vs. 17.0 ± 2.4 mm, p = 0.011 for left FIVh). Their basic characteristics are shown in Table 1.

Table 1. Demographic and clinical characteristics of the patients.

Variables	All population n = 274	LSGV Sacralization n = 10	LSGV Lumbarization n = 264	p
Age, years	41.6 ± 13.0	41.8 ± 15.5	41.6 ± 13.0	0.984
Gender, n (%)				
Female	153 (55.8)	5 (50.0)	148 (56.1)	0.705
Male	121 (44.2)	5 (50.0)	116 (43.9)	
Pain, n (%)				
No	105 (38.3)	4 (40.0)	101 (38.3)	0.999
Yes	169 (61.7)	6 (60.0)	163 (61.7)	
Morphometric findings				
IVDh, mm	9.1 ± 1.8	9.5 ± 2.1	9.1 ± 1.7	0.541
FVAPd, mm	11.2 ± 2.4	11.2 ± 2.8	11.2 ± 2.4	0.996
FIVh, mm				
Right	18.8 ± 2.4	16.9 ± 1.6	18.8 ± 2.4	0.004*
Left	19.1 ± 2.4	17.0 ± 2.4	19.2 ± 2.3	0.011*

Data are shown as mean ±SD or number and percentage (%). * indicates a statistically significant difference at p<0.05. Abbreviations: FIVh, height of the intervertebral foramen; FVAPd, anteroposterior diameter of the vertebral foramen; IVDh, height of the intervertebral disc.

The mean IVDh levels did not significantly differ across age groups. The mean FVAPd levels were higher in the 40 and under age group compared to the other age groups, but were lower in the 60-69 age group (≤ 40 years: 11.8 ± 2.4 mm vs. 40-59 years: 10.9 ± 2.2 mm vs. 60-69 years: 9.7 ± 2.2 mm, p < 0.001). Similarly, both right and left mean FIVh levels were higher in the 40 and under age group and lower in the 60-69 age group compared to the other age groups (≤ 40 years: 19.3 ± 2.1 mm vs. 40-59 years: 18.6 ± 2.3 mm vs. 60-69 years: 17.4 ± 2.2 mm, p < 0.001 for right FIVh; ≤ 40 years: 19.7 ± 2.2 mm vs. 40-59 years: 18.9 ± 2.4 mm vs. 60-69 years: 17.9 ± 2.3 mm, p < 0.001 for left FIVh) (Table 2).

The mean IVDh (9.7 ± 1.8 mm vs. 8.6 ± 1.5 mm, p < 0.001), mean right FIVh (19.1 ± 2.6 mm vs. 18.5 ± 2.2 mm, p = 0.001), and mean left FIVh levels (19.7 ± 2.6 mm vs. 18.6 ± 2.1 mm, p < 0.001) were higher in male patients compared to female patients, while mean FVAPd levels did not differ between genders (11.3 ± 2.5 mm vs. 11.2 ± 2.4 mm, p = 0.714). Patients with pain had a higher mean IVDh level compared to those without pain (9.3 ± 1.7 vs. 8.7 ± 1.8, p = 0.011), while the other morphometric measurements showed no significant differences between patients with and without pain (Table 2).

Age exhibited a negative correlation with FVAPd levels (r = -0.262, p < 0.001), right FIVh levels (r = -0.210, p < 0.001), and left FIVh levels (r = -0.209, p = 0.001). A positive correlation was found between IVDh levels and both right and left FIVh levels (r = 0.286, p < 0.001; r = 0.264, p < 0.001; respectively). No significant correlation was observed between FVAPd levels and the other morphometric data (Table 3).

Table 2. The relationship between morphometric data and demographic characteristics.

Variables	n	IVDh	p	FVAPd	p	Right FIVh	p	Left FIVh	p
Age, years									
≤ 40	123	9.0 ± 1.6	0.430	11.8 ± 2.4 ^{b,c}	<0.001*	19.3 ± 2.1 ^{b,c}	0.001*	19.7 ± 2.2 ^{b,c}	<0.001*
41-59	126	9.2 ± 1.8		10.9 ± 2.2 ^{a,c}		18.6 ± 2.3 ^{a,c}		18.9 ± 2.4 ^{a,c}	
60-69	25	8.8 ± 2.0		9.7 ± 2.2 ^{a,b}		17.4 ± 2.2 ^{a,b}		17.9 ± 2.3 ^{a,b}	
Gender									
Female	153	8.6 ± 1.5	<0.001*	11.3 ± 2.5	0.714	18.5 ± 2.2	0.003*	18.6 ± 2.1	<0.001*
Male	121	9.7 ± 1.8		11.2 ± 2.4		19.1 ± 2.6		19.7 ± 2.6	
Pain									
No	105	8.7 ± 1.8	0.011*	10.9 ± 2.5	0.097	18.6 ± 2.4	0.345	18.9 ± 2.3	0.200
Yes	169	9.3 ± 1.7		11.4 ± 2.3		18.9 ± 2.3		19.3 ± 2.4	

Data are shown as mean ±SD. n, sample size. * indicates a statistically significant difference at p<0.05. a vs. ≤ 40 years group, b vs. ≤ 41-59 years group, c vs. ≤ 60-69 years group. Abbreviations: FIVh, height of the intervertebral foramen; FVAPd, anteroposterior diameter of the vertebral foramen; IVDh, height of the intervertebral disc.

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Table 3. The correlation between age and morphometric data.

Variables	Correlation	IVDh	FVAPd	Right FIVh	Left FIVh
Age	r	0.013	-0.262	-0.210	-0.209
	p	0.835	<0.001*	<0.001*	0.001*
IVDh	r	-	-0.054	0.286	0.264
	p	-	0.371	<0.001*	<0.001*
FVAPd	r	-	-	0.026	0.069
	p	-	-	0.667	0.256
Right FIVh	r	-	-	-	0.843
	p	-	-	-	<0.001*

* indicates a statistically significant difference at $p<0.05$. Abbreviations: FIVh, height of the intervertebral foramen; FVAPd, anteroposterior diameter of the vertebral foramen; IVDh, height of the intervertebral disc.

Discussion

In this study, we found that lumbarization group was more prevalent than sacralization group among LSTV patients, with significant differences in FIVh values between these groups. Age was negatively correlated with FVAPd and FIVh levels, while pain presence was associated with higher IVDh levels. Additionally, male patients exhibited higher IVDh and FIVh values compared to female patients. These findings highlight the morphological variations in LSTV based on age, gender, and pain, providing important insights into its clinical implications.

Despite being a frequently observed congenital anatomical variation in the lumbosacral region, the pathophysiology and biomechanical effects of LSTV are still not fully understood. Previous studies have reported that the prevalence of LSTV varies between 4% and 35% [3]. This variation could be attributed to evaluation and interpretation errors, differences in individual diagnostic and classification criteria, and factors that may cause confusion among the study group data in various research studies across different studies [9-12]. In addition to these factors, age and gender differences play a significant role in the prevalence and manifestation of LSTV [13]. Studies have indicated that the frequency of LSTV can vary according to age, with certain age groups potentially more susceptible to the symptomatic effects of this anatomical variant [14]. Moreover, gender differences may also influence the presentation and severity of symptoms associated with LSTV, as well as the structural characteristics of the vertebrae involved [15, 16].

Morphometric analysis, which involves precise measurements of anatomical structures such as intervertebral disc height, the anteroposterior diameter of the vertebral foramen, and the height of the intervertebral foramen, is crucial in diagnosing LSTV accurately [17, 18]. The integration of detailed morphometric analysis into the evaluation of LSTV not only aids in the correct classification of the anatomical variation but also enhances the understanding of its biomechanical consequences [18]. By incorporating age and gender considerations into morphometric analysis, clinicians can achieve a more personalized and accurate diagnosis, which is essential for developing appropriate treatment plans. This, in turn, can lead to better management of symptoms and improved outcomes for patients affected by this condition.

A previous study reported that the mean L4-5 IVDh measurements in the sagittal plane were 9.4±2.9 mm, with men showing higher values than female (10.0±2.9 mm vs. 8.6±2.7 mm) [17]. Studies have indicated that the mean L4-5 IVDh levels in young healthy adults are approximately 12 mm [19]. Our study found that IVDh measurements were consistent with the literature and were higher in men than in female. A sagittal diameter below 12 mm is regarded as pathological, with measurements under 10 mm being indicative of severe spinal stenosis [20]. Several factors can contribute to the narrowing of the vertebral canal's diameter, which can result in the spinal cord being compressed and the onset of a clinical condition with neurological symptoms.

The literature contains very few studies on spinal canal diameter in patients with LSTV. FVAPd measurements did not show any gender differences. However, there was a negative correlation between FVAPd measurements and age, with significantly lower levels observed in patients over 60 years old. A negative correlation between increasing age and spinal canal diameter has also been reported in a previous study [21]. Changes in the aging spine generally occur in the discs and facet joints, but the bony lumbar vertebrae also undergo significant changes, typically decreasing in height and widening, with the vertebral body increasingly wedging posteriorly at L4-L5 as aging occurs [22, 23].

Spinal nerves pass through the intervertebral foramina. As a result, the ratio between FIVh and the space occupied by the nerve roots within these foramina influences the probability of root compression [24]. The spinal nerves and vessels that exit through the FIV are one of the potential sources of pain in the lumbosacral region [25]. In the presence of LSTV, the altered anatomy of the region requires careful consideration during any surgical procedures or interventions in this area. Studies have shown that LSTV is correlated with an increase in nerve root symptoms and a higher incidence of foraminal stenosis [26, 27]. FIVh levels showed a decrease with age, in line with the literature [28]. Also, FIVh levels were higher in males than in females [29].

This study had certain limitations. Firstly, the study was conducted at a single center. The patient population in the study might have been confined to a particular geographical region or clinical environment, potentially limiting the generalizability of the findings. Secondly, the study did not include healthy individuals without LSTV, which could complicate the determination of LSTV's specific effects. Controlled studies would provide clearer insights into the impact of LSTV on spinal biomechanics and symptomatology. Thirdly, while the study focused on specific morphometric parameters (IVDh, FIVh, FVAPd), it did not account for other potentially relevant factors, such as body mass index, physical activity levels, or comorbidities that might influence spinal morphology and LSTV's clinical presentation. Including these variables in future research could help identify additional factors that interact with LSTV to affect spinal health. Lastly, long-term follow-up data for the patients were not available. This might provide more meaningful insights into whether LSTV, which may be mild or asymptomatic in the early stages, eventually leads to more noticeable symptoms or how its effects on spinal biomechanics change over time.

Conclusions

LSTV are the most commonly encountered benign anatomical variations in the lumbosacral spine by spine surgeons. The biomechanical changes caused by LSTV can differ based on the patient's age and gender. Thus, morphometric analyses that consider factors such as age and gender are of critical importance in the diagnosis and treatment of LSTV. These analyses can play a key role in accurate diagnosis, symptom management, and the formulation of treatment plans, enabling the development of more personalized approaches tailored to the individual needs of patients.

Ethics Approval

The study was performed in accordance with the Declaration of Helsinki, and was approved by the Binali Yıldırım University Clinical Research Ethics Committee (Approval Date: 30.03.2023, Number: 2023-07/4).

Informed Consent

The need for informed consent was waived under the approval of the Local Ethics Committee due to the retrospective design.

Conflicts of Interest Statement

The authors declare they have no conflicts of interest.

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Availability of Data and Material

The data that support the findings of this study are available on request from the corresponding author.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

References

1. Konin G P and Walz D M. Lumbosacral transitional vertebrae: classification, imaging findings, and clinical relevance. AJNR Am J Neuroradiol. 2010;31(10):1778-86. DOI: 10.3174/ajnr.A2036.
2. Jain A, Agarwal A, Jain S, and Shamshery C. Bertolotti syndrome: a diagnostic and management dilemma for pain physicians. Korean J Pain. 2013;26(4):368-73. DOI: 10.3344/kjp.2013.26.4.368.
3. Byvaltsev V A, Kalinin A A, Shepelev V V, et al. Prevalence of lumbosacral transitional vertebra among 4816 consecutive patients with low back pain: A computed tomography, magnetic resonance imaging, and plain radiographic study with novel classification schema. J Craniovertebr Junction Spine. 2023;14(1):35-43. DOI: 10.4103/jcvjs.jcvjs_149_22.
4. Mahato N K. Redefining lumbosacral transitional vertebrae (LSTV) classification: integrating the full spectrum of morphological alterations in a biomechanical continuum. Med Hypotheses. 2013;81(1):76-81. DOI: 10.1016/j.mehy.2013.02.026.
5. Mahato N K. Complexity of neutral zones, lumbar stability and subsystem adaptations: probable alterations in lumbosacral transitional vertebrae (LSTV) subtypes. Med Hypotheses. 2013;80(1):61-4. DOI: 10.1016/j.mehy.2012.10.013.
6. Bezuidenhout A F and Lotz J W. Lumbosacral transitional vertebra and S1 radiculopathy: the value of coronal MR imaging. Neuroradiology. 2014;56(6):453-7. DOI: 10.1007/s00234-014-1361-z.
7. Coskun Benlidayi I and Tirasci E. The effect of lumbosacral transitional vertebra on lumbar spine degeneration and spondylolisthesis among patients with low back pain. Pain Pract. 2024;24(1):52-61. DOI: 10.1111/papr.13280.

8. Yusof M I, Hassan M N, and Abdullah M S. The Relationship amongst Intervertebral Disc Vertical Diameter, Lateral Foramen Diameter and Nerve Root Impingement in Lumbar Vertebra. Malays Orthop J. 2018;12(1):21-25. DOI: 10.5704/MOJ.1803.004.
9. Jat S K, Srivastava A, Malhotra R, Chadha M, Tandon A, and Jain A K. Prevalence of lumbosacral transitional vertebra in patients with chronic low back pain: a descriptive cross-sectional study. Am J Neurodegener Dis. 2023;12(3):89-96.
10. Verhaegen J C F, Alves Batista N, Horton I, et al. Prevalence of Lumbosacral Transitional Vertebral Anomalies Among Healthy Volunteers and Patients with Hip Pathology: Association with Spinopelvic Characteristics. JB JS Open Access. 2023;8(1) DOI: 10.2106/JBJS.OA.22.00095.
11. Chiu C K, Chin T F, Chung W H, Chan C Y W, and Kwan M K. Variations in the Number of Vertebrae, Prevalence of Lumbosacral Transitional Vertebra and Prevalence of Cervical Rib Among Surgical Patients With Adolescent Idiopathic Scoliosis: An Analysis of 998 Radiographs. Spine (Phila Pa 1976). 2024;49(1):64-70. DOI: 10.1097/BRS.0000000000004711.
12. French H D, Somasundaram A J, Schaefer N R, and Laherty R W. Lumbosacral transitional vertebrae and its prevalence in the Australian population. Global Spine J. 2014;4(4):229-32. DOI: 10.1055/s-0034-1387808.
13. Tatara Y, Niimura T, Sekiya T, and Mihara H. Changes in Lumbosacral Anatomy and Vertebral Numbering in Patients with Thoracolumbar and/or Lumbosacral Transitional Vertebrae. JB JS Open Access. 2021;6(3) DOI: 10.2106/JBJS.OA.20.00167.
14. Shaikh A, Khan S A, Hussain M, et al. Prevalence of Lumbosacral Transitional Vertebra in Individuals with Low Back Pain: Evaluation Using Plain Radiography and Magnetic Resonance Imaging. Asian Spine J. 2017;11(6):892-97. DOI: 10.4184/asj.2017.11.6.892.
15. Nardo L, Alizai H, Virayavanich W, et al. Lumbosacral transitional vertebrae: association with low back pain. Radiology. 2012;265(2):497-503. DOI: 10.1148/radiol.12112747.
16. Ucar D, Ucar B Y, Cosar Y, et al. Retrospective cohort study of the prevalence of lumbosacral transitional vertebra in a wide and well-represented population. Arthritis. 2013;2013:461425. DOI: 10.1155/2013/461425.
17. Kot A, Polak J, Klepinowski T, et al. Morphometric analysis of the lumbar vertebrae and intervertebral discs in relation to abdominal aorta: CT-based study. Surg Radiol Anat. 2022;44(3):431-41. DOI: 10.1007/s00276-021-02865-9.
18. Daniel P, Joel J J, and Rana P K. Lumbosacral transitional vertebrae in patients with low back pain: Radiological classification and morphometric analysis. Journal of the Anatomical Society of India. 2019;68(2):123-28.
19. Demir M, Atay E, Seringeç N, et al. Intervertebral disc heights and concavity index of the lumbar spine in young healthy adults. Anatomy. 2018;12(1):34-37.
20. Gopinathan P. Lumbar spinal canal stenosis-special features. J Orthop. 2015;12(3):123-5. DOI: 10.1016/j.jor.2015.06.001.
21. Kim K H, Park J Y, Kuh S U, Chin D K, Kim K S, and Cho Y E. Changes in spinal canal diameter and vertebral body height with age. Yonsei Med J. 2013;54(6):1498-504. DOI: 10.3349/ymj.2013.54.6.1498.
22. Ericksen M F. Aging in the lumbar spine. II. L1 and L2. Am J Phys Anthropol. 1978;48(2):241-5. DOI: 10.1002/ajpa.1330480219.
23. Masharawi Y, Salame K, Mirovsky Y, et al. Vertebral body shape variation in the thoracic and lumbar spine: characterization of its asymmetry and wedging. Clin Anat. 2008;21(1):46-54. DOI: 10.1002/ca.20532.
24. Devi R and Rajagopalan N. Morphometry of lumbar intervertebral foramen. Indian J Orthop. 2005;39(3):145-7.
25. Adams M A, Bogduk N, Burton K, and Dolan P, The Biomechanics of Back Pain-E-Book. 2012: Elsevier health sciences.
26. Jancuska J M, Spivak J M, and Bendo J A. A Review of Symptomatic Lumbosacral Transitional Vertebrae: Bertolotti's Syndrome. Int J Spine Surg. 2015;9:42. DOI: 10.14444/2042.
27. Türk G, Bilgili M, Acan A, and Koç A. Lumbosacral transitional vertebrae: An overlooked cause of back pain on MRI. Journal of Experimental and Clinical Medicine. 2023;40(1):62-65.
28. Yan S, Wang K, Zhang Y, Guo S, Zhang Y, and Tan J. Changes in L4/5 intervertebral foramen bony morphology with age. Scientific reports. 2018;8(1):7722.
29. Al-Hadidi M T, Abu-Ghaida J H, Badran D H, Al-Hadidi A M, Ramadan H N, and Massad D F. Magnetic resonance imaging of normal lumbar intervertebral foraminal height. Neurosciences (Riyadh). 2003;8(3):165-70.