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SCIENTIFIC ARTICLE

Effect of sacralization on the success of lumbar transforaminal epidural steroid injection treatment: prospective clinical trial

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Abstract

Objective The aim of this study was to invastigate the effect of the sacralization on the results of transforaminal epidural steroid injection for radicular low back pain.

Materials and methods The study included 64 patients diagnosed with radicular low back pain due to unilateral and single-level lumbar disk herniation. Patients were divided into 2 groups: patients with sacralization (Group S) and patients without lumbosacral transitional vertebrae (Group A). Injection was applied to the relevant level. Patients were evaluated with Numeric Rating Scale and Modified Oswestry Disability Index before, at week 3 and month 3 after the procedure. Sacralization presence was determined by MRI. Sacralization was categorized by anteroposterior lumbar radiography using Castellvi classification. Treatment success was considered as ≥ 50% reduction in NRS scores.

Results Numeric Rating Scale and Modified Oswestry Disability Index scores decreased in both groups on both week 3 and month 3 ($p < 0.05$). Pain scores of Group S (median value 5 (3–6)) were significantly higher than Group A ((median value 3 (0–5)) in the third month follow-up ($p = 0.026$), but no significant difference was observed at other time points. There was no significant difference in Modified Oswestry Disability Index scores between the groups at all follow-ups ($p > 0.05$). Treatment success in the third month was 44.8% in Group S and 65.6% in Group A.

Conclusion Transforaminal epidural steroid injection is an effective and safe method for radicular low back pain. Sacralization presence should be evaluated before treatment considering that it may be a risk factor reducing treatment success.

Keywords Lumbar radicular pain · Low back pain · Transforaminal epidural steroid injection · Sacralization · Lumbosacral transitional vertebrae

Introduction

Lumbar disk herniation (LDH) is a very common condition that can cause radicular low back pain (RLBP) [1]. Pain is attributed to mechanical compression of the spinal nerve root by the herniated disk and/or local inflammation triggered by chemokines and enzymes spread around the nerve root [2]. Transforaminal epidural steroid injection (TFESI) is a common and safe treatment method that is effective in the short term in non-surgical treatment of RLBP [3]. It is target-specific. It is preferred over caudal and interlaminary epidural steroid injection because it allows direct injection to the anterior epidural space where pathological changes caused by LDH on the spinal nerve root are seen [4, 5]. With

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the recent popularity of spinal interventional pain treatment methods, more patients have received these treatments which have led to a significant increase in treatment costs. For that reason, it is important for clinicians to determine the factors that may affect the treatment success of TFESI. [2].

Lumbosacral transitional vertebrae (LSTV) are a common spinal congenital variation. In patients with LSTV, the transverse process of the lowest lumbar vertebrae makes a unilateral or bilateral joint with the sacrum [6]. Its prevalence in the general population is between 7 and 36% [7]. LSTV covers a spectrum of conditions from partial or full L5 sacralization to partial or full S1 lumbarization [8]. According to the Castellvi classification, LSTV is classified into four types according to the relationship of the transverse process with the sacrum [9]. There are numerous studies that report that LSTV is associated with increased lower back pain [7, 10–13]. It is thought that low back pain may be due to the degenerative process caused by altered biomechanics [14].

There are studies in the literature examining various clinical and radiological parameters that may have an impact on the treatment success of lumbar TFESI [2, 4, 15, 16]. However, there are limited studies evaluating the effect of LSTV presence on TFESI treatment outcomes and the results are contradictory [2, 17]. Son et al. reported that lumbarization had no effect on TFESI treatment outcomes while sacralization had a negative affect [17]. In addition, Sencan et al. reported that LSTV had no effect on TFESI treatment success [2].

The aim of the present study was to investigate the effect of sacralization presence on TFESI success in LDH-related RLBP treatment. Our hypothesis is that the presence of sacralization reduces the treatment success of TFESI.

Materials and methods

This prospective randomized assessor blinded study was conducted in the pain medicine department of a tertiary care center. Sixty-four patients diagnosed with L5-S1 level LDH-related RLBP as a result of clinical examination and lumbar magnetic resonance imaging (MRI) evaluations were included in the study. Patients were divided into two groups as those with sacralization (Group S) and those without LSTV (Group A) (Fig. 1).

Inclusion criteria were as follows: (1) between the ages of 18 and 65 years; (2) presence of sacralization of L5 vertebrae in MRI evaluation; (3) presence of type 2, type 3, or type 4 LSTV according to Castellvi classification; (4) symptom duration longer than 3 months; (5) NRS pain score ≥ 4; and (6) presence of paracentrally localized LDH at L5-S1 level and unilateral L5 or S1 spinal nerve root compression in MRI.

Exclusion criteria were as follows: (1) presence of lumbarization of S1 vertebrae in MRI evaluation; (2) presence of type 1 LSTV according to Castellvi classification; (3) bilateral radicular pain; (4) presence of LDH at multiple levels; (5) previous lumbar spinal surgery; (6) presence of lumbar foraminal or central canal stenosis; (7) presence of spondylolysis or spondylolisthesis; (8) having lumbar epidural steroid injection last 6 months; and (9) pregnancy. Son et al. reported that lumbarization had no effect on TFESI treatment outcomes [17]. Therefore, the presence of lumbarization was considered a reason for exclusion in this study.

The decision at which lumbar level to apply TFESI was made by a physiatrist who performed the physical examination of the patients and evaluated lumbar MRI. The same physiatrist also determined the root compression grade in lumbar MRI. The same physiatrist examined the lumbar MRI of the patients to assess the presence of sacralization and categorized the patients according to Castellvi classification in anteroposterior lumbar radiography. Another physiatrist blinded to patient groups recorded demographic data of patients, body mass index (BMI), symptom duration, and the lumbar level applied to TFESI. The second physiatrist was also responsible for the follow-up process after TFESI and the evaluation of treatment outcomes. The procedures were performed under fluoroscopy guidance by a pain medicine specialist with at least 10 years of experience.

Ethics committee approval was obtained from Marmara University Ethics Committee (No:09.2013.0352). Patients were informed about the study and written consent forms were obtained from all patients included in the study. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Outcome measures

Pain severity was evaluated with Numerical Rating Scale (NRS) (0 to 10, verbal) before the procedure as well as 1 h, 3 weeks, and 3 months after the procedure. Functional impairment was assessed with the Modified Oswestry Disability Index (MODI) before the procedure as well as at week 3 and month 3 after the procedure. MODI consists of 10 questions, each scored between 0 and 5. These questions evaluate pain severity, personal care, lifting, walking, sitting, standing, sleeping, social life, pain, and change in pain during travel. Higher scores indicate higher disability [18]. The criterion for treatment success was determined as 50% or more reduction in NRS scores in the 3rd month after TFESI compared to pre-treatment [2].

Radiological assessment

Radiological evaluation was made by a physiatrist. Cervicothoracic sagittal scout images were used as the gold standard method for enumeration of the lumbar vertebrae [19]. All images were acquired with a 3.0 Tesla MR device (Verio, Siemens Healthcare, Erlangen, Germany) using dedicated lumbar

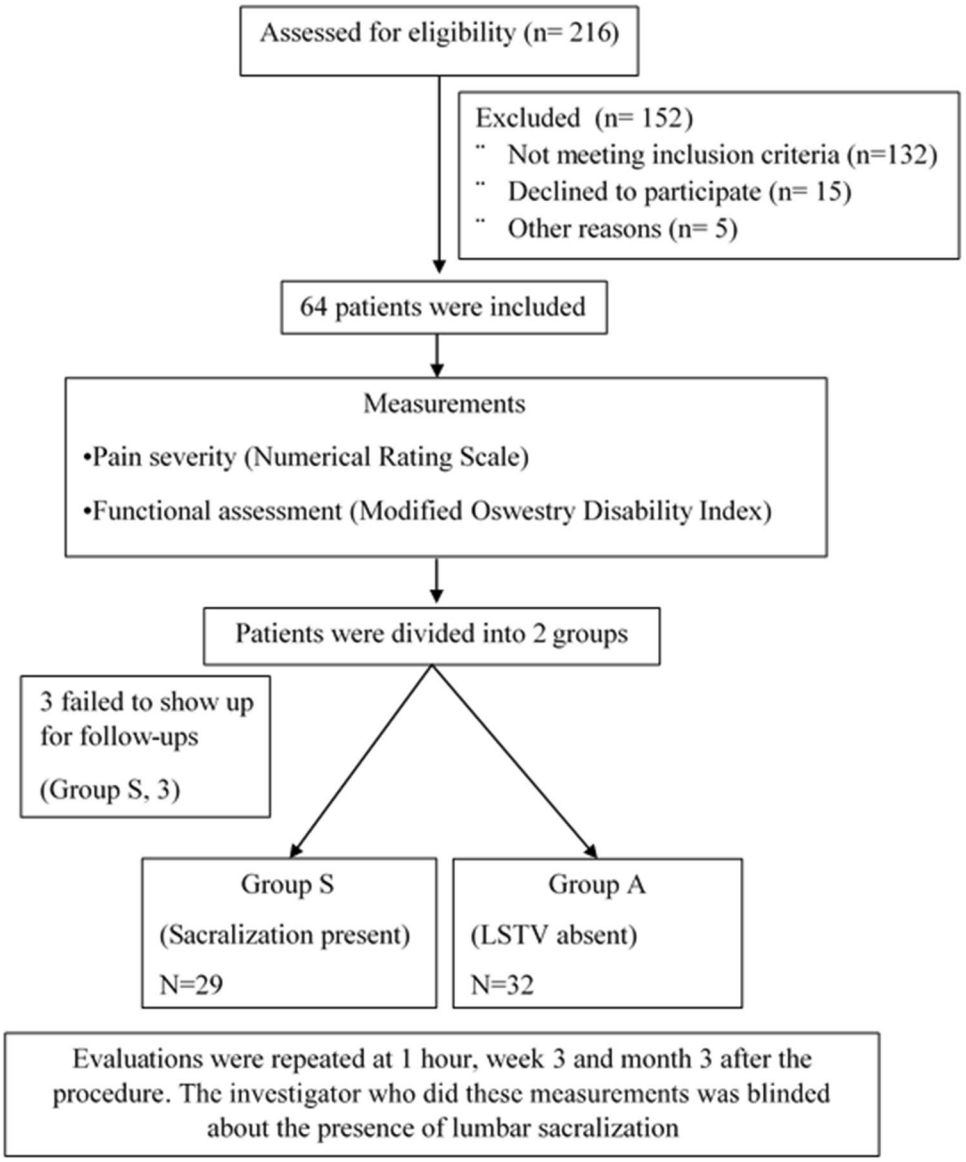

Fig. 1 Flow diagram of the study

spinal coil with standard lumbar MR protocol and without contrast material. All studies included T2-weighted turbo spin echo (TSE) whole spinal column counter images. For the lumbosacral vertebral imaging, sagittal and axial T1-weighted TSE (TR/TE: 380/9.4 ms) and T2-weighted TSE (TR/TE: 3390/106) were obtained. Axial images had a matrix of 256×133 with a slice thickness of 4 mm and a gap of 0.4 mm and sagittal images had a matrix of 256×320 with a slice thickness of 4 mm and a gap of 0.4 mm.Vertebrae were numbered from C2 to caudal with cross-referenced cervicothoracic and lumbar sagittal MRI scans. Sacralization presence was recorded based on the number and enumeration of vertebrae.

LSTV typing was performed using the Castellvi classification in anteroposterior lumbar radiography. According to the Castellvi classification, lumbosacral transitional vertebrae consist of four types. Type 1, dysplastic transverse process with a width of at least 19 mm, unilateral (1A) or bilateral (1B). Type 2, incomplete fusion of the transverse process and sacrum, unilateral (2A) or bilateral (2B). Type 3, complete bone fusion of the transverse process and sacrum, unilateral (3A) or bilateral (3B). Type 4 is the mixed type (Fig. 2) [8].

Nerve root compression grade was evaluated in axial T2-weigheted images and sagittal T1-weighted images. The Pfirrmann grading system, developed and modified for central and subarticular disk herniation, was used for grading spinal nerve root compression. [20].

Procedure

The patient was taken to the operation room and intravenous vascular access was established. Patient was placed

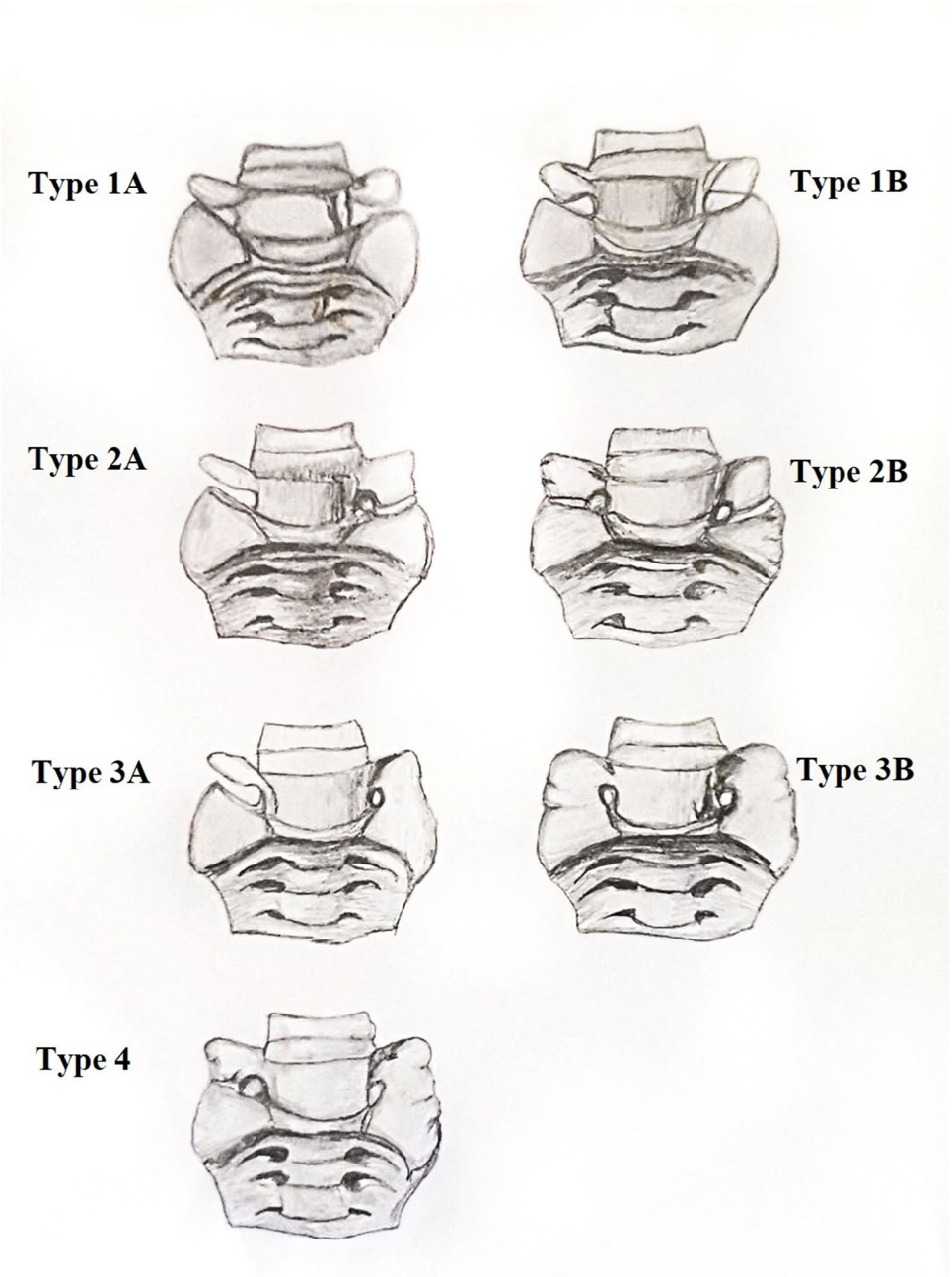

Fig. 2 Schematic representation of the types of lumbosacral transitional vertebrae according to Castellvi classification

in the prone position and monitorized. The injection site was cleaned with povidone iodine and skin antisepsis was provided. Sterile cover was placed. The fluoroscopy was positioned in an oblique and cranial angle and the foramen to be injected was displayed. Anesthesia was provided in skin and subcutaneous tissue with 3 cc (2%) prilocain. With fluoroscopy guidance, the needle entry location was determined under the relevant pedicule at the area called "safe triangle." The 22 G 3.5-inch spinal needle was advanced towards the epidural area with coaxial technique. After progressing the needle to posterior one-third of the relevant foramen in lateral imaging, 1–2 cc contrast medium was injected and epidural spread was checked. Then, the epidural spread of the contrast medium was confirmed for the second time by anteroposterior image (Fig. 3). Afterwards, the mixture of 4 mg betamethasone, 1 cc saline, and 1 cc (0.5%) bupivacaine was injected. Patients who did not have any complications in the 1st hour after the procedure were discharged.

Statistical analysis

Descriptive statistics were presented as median and percentiles. Categorical variables were examined by Pearson's chi

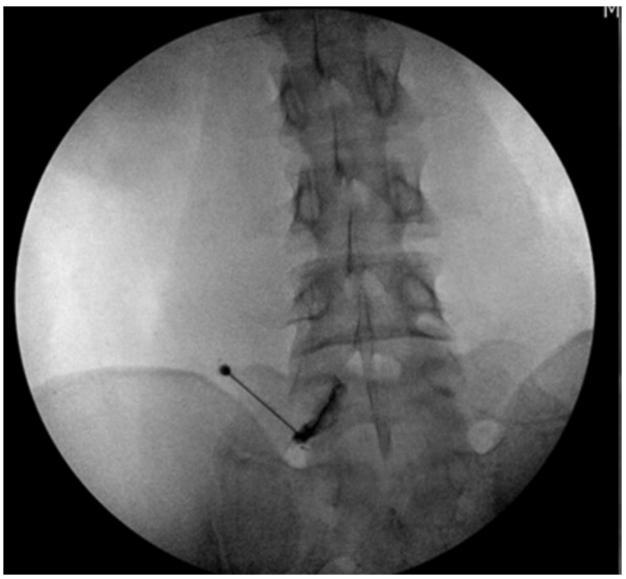

Fig. 3 According to the Castellvi classification, type 2B lumbosacral transitional vertebrae are shown in the figure. Left L5 transforaminal epidural steroid injection. Epidural spread of contrast agent in the left L5 foramen on anteroposterior imaging

square test. Friedman test and post hoc Dunn test were used for periodic comparisons. Scores of patients with and without LSTV were compared with the Mann–Whitney *U* test. $P < 0.05$ was accepted as statistically significant in all analyses. SPSS version 23 program was used for statistical analysis.

G power version 3.1.9.2 was used for statistical power analysis (*t*-test) of variance. Fixed effects, main effects and interactions, and type of power analysis were selected as a priori: the power of the study was calculated as 0.80 with 0.05 error level and a sample size of 29 patients for each group [21].

Results

A total of 64 patients with LDH (32 in Group S and Group A) were included in the study. In Group S, 3 patients were excluded from the study because they did not show up for follow-ups. Group S consisted of 16 female and 13 male patients whereas Group A consisted of 18 female and 14 male patients (Fig. 1). The median age was 42 (35–49) years in group S and 47 (39–50.5) years in group A. No significant difference was found between the groups in terms of demographic data ($P > 0.05$) (Table 1) (Table 2). The median symptom duration was 12 (6–14) months in Group S and 10 (5–15) months in group A. TFESI was performed on L5 and S1 nerve roots in 19 and 10 patients in Group S, respectively. In Group A, TFESI was performed on L5 and S1 nerve roots in 20 and 12 patients, respectively. The groups were similar in terms of symptom duration, BMI, injection levels, and root compression degree due to disk herniation ($P > 0.05$) (Table 1) (Table 2).

Table 1 The descriptive values of the categorical features of the groups

		Group S (Sacralization present)		Group A (LSTV absent)		*P*
		N	%	*N*	%	
Sex	Female	16	55.2	18	56.3	0.933
	Male	13	44.8	14	43.8	
Level of injection	L5	19	65.5	20	62.5	0.806
	S1	10	34.5	12	37.5	
Nerve root compression (grade)	1	15	51.7	16	50.0	0.740
	2	11	37.9	13	40.6	
	3	2	6.9	3	9.4	
	4	1	3.4	0	0.0	

LSTV, lumbosacral transitional vertebrae; *N*, sample size

Table 2 Descriptive values of numerical characteristics in groups

	Group S (sacralization present)				Group A (LSTV absent)				*P*
	N	25th	Median	75th	*N*	25th	Median	75th	
Age (year)	29	35.0	42.0	49.0	32	39.0	47.0	50.5	0.726
BMI	29	25.1	27.8	31.3	32	25.3	27.4	30.2	0.606
Symptom duration (month)	29	6.0	12.0	14.0	32	5.0	10.0	15.0	0.743

LSTV, lumbosacral transitional vertebrae; *BMI*, body mass index; *N*, sample size; *SD*, strandart deviation

NRS and MODI scores improved in all measurement periods in both groups ($P<0.001$) (Table 3) (Fig. 4). Three months after TFESI, NRS scores were significantly higher in Group S (median value 5 (3–6)) compared to Group A ((median value 3 (0–5)) ($P=0.026$). There was no significant difference in NRS and ODI scores between groups in other measurement points ($P>0.05$) (Table 3). Treatment success in the first hour was 96.5% in group S and 96.3% in group A. Treatment success in the third month was 44.8% in group S and 65.6% in Group A.

According to Castellvi classification, LSTV was type 2A in 4 patients, type 2B in 6 patients, type 3A in 5 patients, type 3B in 5 patients, and type 4 in 9 patients in Group S. Subgroup analysis was performed; it was determined that NRS and disability scores were higher in the type 3B LSTV group, and the disability scores were higher in the type 2B LSTV group at the 3rd week ($P<0.05$). In the third month, although NRS and MODI scores were higher in the type 3B LSTV group, there was no significant difference.

During the procedure, the needle was repositioned in one patient in Group S due to intravascular contrast filling pattern and hypotension due to vasovagal reaction developed in two patients in both groups. Nevertheless, the procedure was completed. In addition, lower extremity motor blocks were seen in one patient in group S and two patients in group A. After a short period of monitoring, the motor block disappeared completely. No serious complications associated with the procedure were observed in either group.

Discussion

The aim of the study was to examine the effect of sacralization presence on TFESI treatment success in patients with unilateral RLBP due to LDH. The results showed that both patient groups with sacralization and without LSTV exhibited decreased pain severity and functional

Table 3 Distribution of time-dependent changes in scale scores between groups

	Group S (sacralization present)				Group A (LSTV absent)				
	N	25th	Median	75th	*N*	25th	Median	75th	*P*
NRS before injection	29	7.0	8.0	9.0	32	7.0	8.0	10.0	0.734
NRS at hour 1	29	0	0	2.0	32	0	0	1.5	1.000
NRS week 3	29	0	2.0	4.0	32	0	2.0	3.5	0.739
NRS month 3	29	3.0	5.0	6.0	32	0	3.0	5.0	**0.026**
P	**< 0.001**				**< 0.001**				
MODI before injection	29	42.0	52.0	60.0	32	39.0	50.0	64.0	0.712
MODI week 3	29	8.0	24.0	40.0	32	16.0	20.0	30.0	0.908
MODI month 3	29	12.0	28.0	46.0	32	16.0	22.0	40.0	0.470
P	**< 0.001**				**< 0.001**				

LSTV lumbosacral transitional vertebrae, *NRS* numerical rating scale, *MODI* modified Oswestry Disability Index, *N* sample size; *SD* standart deviation

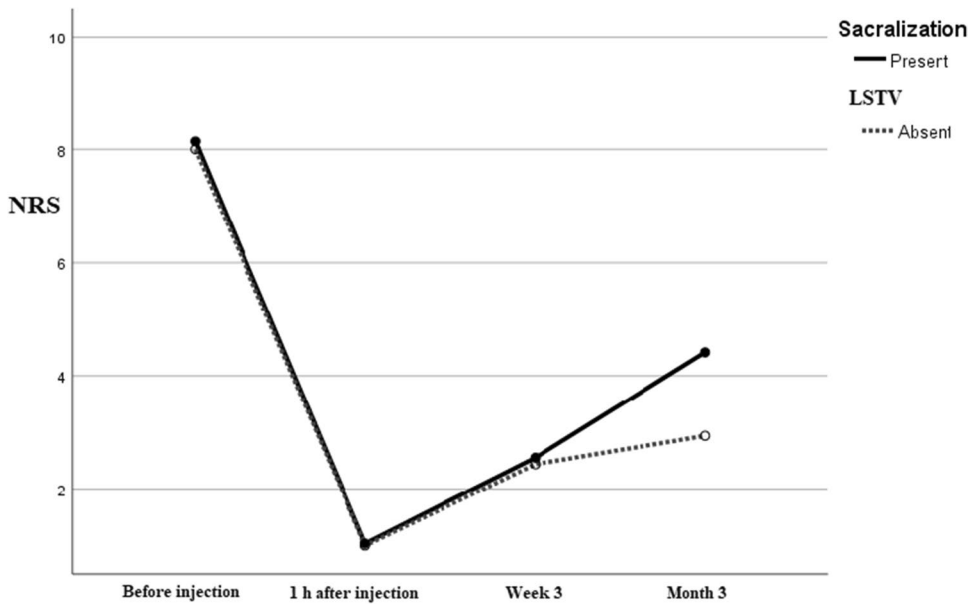

Fig. 4 Change from baseline in Numerical Rating Scale (NRS) scores. LSTV: lumbosacral transitional vertebrae

improvement during the 3-month follow-up after TFESI. There was no significant difference between the groups in terms of demographic characteristics, clinical data, and nerve root compression grade. However, pain scores in the 3rd month were significantly higher in the patient group with sacralization compared to patients without LSTV. Treatment success in the third month was 65.6% in patients without LSTV and 44.8% in patients with sacralization. These results support our hypothesis that the presence of sacralization reduces the treatment success of TFESI.

Although the pathophysiological mechanism associated with LSTV and lower back pain is not fully clarified, numerous studies in the literature have clearly demonstrated the relationship between LSTV and lower back pain [22–26]. Bezuidenhout et al. described the association of LSTV pseudoarthroses with S1 nerve root compression due to degenerative stenosis of the nerve root canal [22]. Otani et al. reported that the presence of LSTV may be a risk factor for the development of nerve root symptoms in patients with lumbar canal stenosis without LDH or spondylolisthesis [23]. Elster likened hypermobility developing in the disk above the level of LSTV to adjacent segment disease, which can be seen after fusion surgery in spinal segments [24]. Hypermobility in the lumbar intervertebral disk and altered torque moments on the disk are thought to expose the disk and facet joints to an increased risk of accelerated degeneration. In a recent study supporting this hypothesis, it was reported that there was more lumbar degeneration in LSTV type 2, 3, and 4 compared with the control group [25]. Luoma et al. reported that the iliolumbar ligaments above the LSTV are thin and weak, thus predisposing this level to hypermobility and early degeneration [26]. In light of the findings above, we believe that these mechanisms played a role in the high pain scores in the 3rd month and the low treatment success in patients with sacralization.

Although there are numerous studies investigating various clinical and radiological parameters that may have an impact on TFESI treatment success, there are only two studies in the literature examining the effect of LSTV on TFESI treatment success [2, 17]. In a recent study conducted by Sencan et al., LSTV was detected in 18 (8.2%) of the 219 patients who underwent TFESI with the diagnosis of unilateral radiculopathy due to LDH. The authors reported that the presence of LSTV had no effect on treatment success in the third month after TFESI [2]. In the present study, however, the presence of sacralization negatively affected treatment success. This difference may be due to the small sample size of patients with LSTV, retrospective study design, and the subtypes of LSTV included in the study. Unlike Sencan et al.'s study, LSTV type 1, which was reported to be not often associated with low back pain, was not included in the present study [12]. In addition, lumbarization, which was reported to have no effect on treatment outcomes, was not included [17]. Furthermore, power analysis result showed that sufficient number of patients was reached in both patient groups. Son et al. detected LSTV in 47 (33 sacralization, 14 lumbarization) of 291 patients who underwent TFESI due to LDH. The authors reported that there was no significant difference in pain and disability scores in the 1st and 3rd months in patients with sacralization compared to the other two groups, whereas pain and disability scores were significantly higher in the 6th month and 1st year [17]. Patients were not followed up for a long period of time in the present study, and we found that pain scores were higher in patients with sacralization in the 3rd month, but there was no significant difference in disability scores. There may be several explanations for the significant difference observed in pain scores in the third month, unlike the results of Son et al. [17]. In the present study, patients with single-level and only paracentrally localized LDH-related root compression were included in the evaluation. In addition, there was no difference between the groups in terms of root compression grades according to the modified Prifman classification [20]. Furthermore, LSTV type 1, whose effect on low back pain is controversial, was not included in the study [12]. Therefore, the study was completed with a more specific and homogeneous patient group.

Although Apazidis et al. reported that the most common type of LSTV is type 1A with a prevalence of 14.7%, type 1 is generally considered to have no clinical significance and does not require further attention in clinical practice [9, 27]. In fact, it is thought to be a potentially protective factor from low back pain with the change in spinal mobility induced by wide transverse processes by preventing bending [12]. Tang et al. similarly reported that the most common type of LSTV was type 1, but type 2 and type 4 were associated with lower back pain and gluteal pain [12]. Therefore, type 1 LSTV was excluded from the present study and the patient group included LSTV type 2, 3, and 4, which are thought to be more associated with lower back pain. Subgroup analysis revealed that NRS and disability scores were higher in type 3B LSTV group and disability scores were higher in type 2B LSTV group on week 3. Similarly, type 3B LSTV group had higher pain and disability scores on month 3, but there was no significant difference. In type 2B and type 3B LSTV, where fusion-related articulation between bilateral transverse processes of the lower lumbar vertebrae and the sacrum is seen, sacrum movement is restricted at a greater rate compared to other types [28]. Worse treatment outcomes in type 2B and type 3B may be associated with this phenomenon.

Determining the correct level in TFESI, which targets the foramen that the nerve root under compression exits, is extremely important for treatment success [29]. Counting

based on 12th level in antero-posterior lumbar X-ray is not a reliable method for enumeration of lumbar vertebrae. For this reason, we used cervicothoracic sagittal scout MRI images, which are considered the gold standard for level determination before TFESI [19]. In the present study, treatment success in the 1st hour after the procedure was 96.5% in patients with sacralization, which supports the role of MRI in level determination in the patient group with sacralization. In addition, pain score decreased and functional improvement was observed in both patient groups 3 months after TFESI. In this respect, the results of the present study are consistent with other studies reporting that TFESI is an effective treatment in the short term for RLBP due to LDH [4, 30].

There are certain limitations of the present study. These include the lack of long-term follow-up, low number of patients in sacralization subgroups, and the use of particulate steroids in TFESI. Although there are studies reporting that the use of particulate or non-particulate steroids in TFESI makes no difference in terms of treatment outcomes while other studies report that the use of particulate steroids can lead to serious neurological complications, this issue is still controversial [31]. Particulate steroids were preferred in the present study based on literature evidence showing that particulate steroids are more effective in the long term [32]. Furthermore, no serious complications other than minor side effects were observed in both patient groups. The prospective design of the study, addressing a specific and homogeneous patient population, and the contributions to a subject with limited literature data are the strengths of the study. Further prospective studies are needed to investigate the biomechanical changes created by LSTV subtypes and their impact on TFESI treatment outcomes.

TFESI is an effective and reliable treatment option for RLBP due to LDH that provides short-term reduction in pain severity and functional improvement. The presence of sacralization, especially type 3B, negatively affects TFESI treatment outcomes and is associated with low treatment success. Sacralization presence should be evaluated before treatment considering that it may be a risk factor reducing TFESI treatment success. In addition, MRI evaluation before TFESI is important not only in diagnosis, but also in determining the correct injection level in the presence of LSTV.

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Declarations

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to participate Written informed consent was obtained from all patients

Conflict of interest The authors declare no competing interests.

References

1. Lee JH, Choi KH, Kang S, Kim DH, Kim DH, Kim BR, et al. Nonsurgical treatments for patients with radicular pain from lumbosacral disc herniation. Spine J. 2019;19(9):1478–89.
2. Şencan S, Çelenlioğlu AE, Asadov R, Gündüz OH. Predictive factors for treatment success of transforaminal epidural steroid injection in lumbar disc herniation-induced sciatica. Turk J Med Sci. 2020;50(1):126–31.
3. Manchikanti L, Buenaventura RM, Manchikanti KN, Ruan X, Gupta S, Smith HS, et al. Effectiveness of therapeutic lumbar transforaminal epidural steroid injections in managing lumbar spinal pain. Pain Physician. 2012;15(3):E199-245.
4. Celenlıoglu AE, Sencan S, Gunduz OH. Does facet tropism negatively affect the response to transforaminal epidural steroid injections? Prospect Clin Study Skeletal Radiol. 2019;48(7):1051–8.
5. Ghai B, Bansal D, Kay JP, Vadaje KS, Wig J. Transforaminal versus parasagittal interlaminar epidural steroid injection in low back pain with radicular pain: a randomized, double-blind, active-control trial. Pain Physician. 2014;17(4):277–90.
6. Jancuska JM, Spivak JM, Bendo JA. A review of symptomatic lumbosacral transitional vertebrae: Bertolotti's syndrome. Int J Spine Surg. 2015;9:42.
7. Farshad-Amacker NA, Herzog RJ, Hughes AP, Aichmair A, Farshad M. Associations between lumbosacral transitional anatomy types and degeneration at the transitional and adjacent segments. Spine J. 2015;15(6):1210–6.
8. Ravikanth R, Majumdar P. Bertolotti's syndrome in low-backache population: classification and imaging findings. Ci Ji Yi Xue Za Zhi. 2019;31(2):90–5.
9. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493–5.
10. Hanhivaara J, Määttä JH, Karppinen J, Niinimäki J, Nevalainen MT. The association of lumbosacral transitional vertebrae with low back pain and lumbar degenerative findings in MRI: a large cohort study. Spine (Phila Pa 1976). 2022;47(2):153–62.
11. Gopalan B, Yerramshetty JS. Lumbosacral transitional vertebra-related low back pain: resolving the controversy. Asian Spine J. 2018;12(3):407–15.
12. Tang M, Yang XF, Yang SW, Han P, Ma YM, Yu H, et al. Lumbosacral transitional vertebra in a population-based study of 5860 individuals: prevalence and relationship to low back pain. Eur J Radiol. 2014;83(9):1679–82.
13. Nardo L, Alizai H, Virayavanich W, Liu F, Hernandez A, Lynch JA, et al. Lumbosacral transitional vertebrae: association with low back pain. Radiology. 2012;265(2):497–503.
14. Bahadir Ulger FE, Illeez OG. The effect of lumbosacral transitional vertebrae (LSTV) on paraspinal muscle volume in patients with low back pain. Acad Radiol. 2020;27(7):944–50.
15. McCormick Z, Cushman D, Caldwell M, Marshall B, Ghannad L, Eng C, et al. Does electrodiagnostic confirmation of radiculopathy predict pain reduction after transforaminal epidural steroid injection? A multicenter study. J Nat Sci. 2015;1(8).
16. Ekedahl H, Jönsson B, Annertz M, Frobell RB. The 1-year results of lumbar transforaminal epidural steroid injection in patients with

chronic unilateral radicular pain: the relation to MRI findings and clinical features. Am J Phys Med Rehabil. 2017;96(9):654–62.
17. Son KM, Lee SM, Lee GW, Ahn MH, Son JH. The impact of lumbosacral transitional vertebrae on therapeutic outcomes of transforaminal epidural injection in patients with lumbar disc herniation. Pain Pract. 2016;16(6):688–95.
18. Fritz JM, Irrgang JJ. A comparison of a modified Oswestry Low Back Pain Disability Questionnaire and the Quebec Back Pain Disability Scale. Phys Ther. 2001;81(2):776–88.
19. Tureli D, Ekinci G, Baltacioglu F. Is any landmark reliable in vertebral enumeration? A study of 3.0-Tesla lumbar MRI comparing skeletal, neural, and vascular markers. Clin Imaging. 2014;38(6):792–6.
20. Pfirrmann CW, Dora C, Schmid MR, Zanetti M, Hodler J, Boos N. MR image-based grading of lumbar nerve root compromise due to disk herniation: reliability study with surgical correlation. Radiology. 2004;230(2):583–8.
21. Chang MC, Lee DG. Outcome of transforaminal epidural steroid injection according to the severity of lumbar foraminal spinal stenosis. Pain Physician. 2018;21(1):67–72.
22. Bezuidenhout AF, Lotz JW. Lotz, Lumbosacral transitional vertebra and S1 radiculopathy: the value of coronal MR imaging. Neuroradiology. 2014;56(6):453–7.
23. Otani K, Konno S, Kikuchi S. Lumbosacral transitional vertebrae and nerve-root symptoms. J Bone Joint Surg Br. 2001;83(8):1137–40.
24. Elster AD. Bertolotti's syndrome revisited. Transitional vertebrae of the lumbar spine. Spine (Phila Pa 1976). 1989;14(12):1373–7.
25. Hanhivaara J, Määttä JH, Niinimäki J, Nevalainen MT. Lumbosacral transitional vertebrae are associated with lumbar degeneration: retrospective evaluation of 3855 consecutive abdominal CT scans. Eur Radiol. 2020;30(6):3409–16.
26. Luoma K, Vehmas T, Raininko R, Luukkonen R, Riihimäki H. Lumbosacral transitional vertebra: relation to disc degeneration and low back pain. Spine (Phila Pa 1976). 2004;29(2):200–5.
27. Apazidis A, Ricart PA, Diefenbach CM, Spivak JM. The prevalence of transitional vertebrae in the lumbar spine. Spine J. 2011;11(9):858–62.
28. Delport EG, Cucuzzella TR, Kim N, Marley J, Pruitt C, Delport AG. Lumbosacral transitional vertebrae: incidence in a consecutive patient series. Pain Physician. 2006;9(1):53–6.
29. Furman MB, Wahlberg B, Cruz EJ. Lumbosacral transitional segments: an interventional spine specialist's practical approach. Phys Med Rehabil Clin N Am. 2018;29(1):35–48.
30. Sencan S, Edipoglu IS, Bilim S, Gunduz OH. Does coadministration of transforaminal epidural steroid injection with sedation improve patient satisfaction? A prospective randomized clinical study. Pain Physician. 2019;22(4):E287–94.
31. Kennedy DJ, Plastaras C, Casey E, Visco CJ, Rittenberg JD, Conrad B, et al. Comparative effectiveness of lumbar transforaminal epidural steroid injections with particulate versus nonparticulate corticosteroids for lumbar radicular pain due to intervertebral disc herniation: a prospective, randomized, double-blind trial. Pain Med. 2014;15(4):548–55.
32. Chatterjee N, Roy C, Das S, Al Ajmi W, Al Sharji NS, Al MA. Comparative efficacy of methylprednisolone acetate and dexamethasone disodium phosphate in lumbosacral transforaminal epidural steroid injections. Turk J Anaesthesiol Reanim. 2019;47(5):414–9.