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SCIENTIFIC ARTICLE

Sonoelastographic evaluation of the sciatic nerve in patients with unilateral lumbar disc herniation

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Abstract

Objective The aim of this study was to compare strain elastography (SE) and shear wave elastography (SWE) findings of the sciatic nerve in patients with unilateral lumbar disc herniation (LDH) and healthy control subjects.

Materials and methods The study group included patients with complaints of unilateral sciatica for 3–12 months, with foraminal stenosis due to one level of LDH (L4-L5 or L5-S1). An age- and gender-matched control group was formed of healthy subjects. Evaluations were performed on both the axial and longitudinal planes from the bilateral gluteal region using a 5–9 MHz multifrequency convex probe.

Results There were 40 patients (20 male, 20 female) with a mean age of 43.1 ± 12.7 years in the study group, and 40 healthy subjects (22 male, 18 female) with a mean age of 42.9 ± 10.7 years in the control group ($p > 0.05$). The sciatic nerve stiffness assessed on both the axial (12.3 ± 3.7 kPA) and longitudinal (14.3 ± 3.8 kPA) planes of the involved side was significantly higher than non-involved side (axial: 6.8 ± 2.1 and longitudinal: 8.3 ± 2.3 kPA) in the patient group ($p < 0.001$).

Conclusions Patients with unilateral LDH have increased stiffness of the sciatic nerve compared to healthy control subjects. Although the findings in this preliminary study show that shear wave elastography can detect a change in sciatic nerve stiffness in patients with unilateral LDH, larger studies are required to determine the clinical utility of this technique.

Keywords Sciatic nerve · Ultrasound · Peripheral nerve · Strain elastography · Shear wave elastography · Low back pain

Introduction

Approximately 80% of adults experience an attack of low back pain (LBP) at least once during their lifetime, and up to 40% of those patients have radiating pain along the sciatic nerve distribution [1, 2]. Degenerative disc disease or lumbar disc herniation (LDH) compressing the lumbosacral nerve roots rank first in respect of the etiology of sciatic nerve irritation [1]. Magnetic resonance imaging (MRI) could be used to image the extraspinal sciatic nerve. The sciatic nerve can be evaluated using standard fat-saturated and anatomic MRI sequences [2–6]. The role of peripheral nerve ultrasound (US) has been well established in imaging sciatic nerves due to several advantages (ease of application, inexpensive, repeatable, lack of ionizing radiation, providing real-time imaging, high spatial resolution) [7–11]. Kara et al. [2] have shown the enlarged sciatic nerve on the side of sciatica in patients with LBP [2]. However, to the best of our knowledge, sonoelastographic findings of the sciatic nerve have not been studied in patients with sciatica or LDH.

Therefore, the aim of this study was to evaluate the strain elastography (SE) and shear wave elastography (SWE) findings of the sciatic nerve in patients with unilateral LDH. It was hypothesized that there will be an increase in the stiffness of the sciatic nerve due to the compression of nerve roots and inflammatory changes in patients with LDH.

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Materials and methods

Study design and participants

This study was designed as cross-sectional and case-control. Patients suffering from unilateral sciatica for 3–12 months, and with foraminal stenosis due to one level of LDH (L4-L5 or L5-S1), were included in the study group. An age- and gender-matched control group was formed of healthy subjects (without herniation). All patients were aged 18–50 years and were selected from those with MRI results in the neurosurgery department of a tertiary center university hospital. Patients who met any of the following criteria were excluded; diabetes mellitus, polyneuropathy, trauma, previous history of lumbar surgery, or sciatica due to tumor, cyst, or piriformis syndrome. Patients with conditions that reduce image quality on US imaging (thick gluteal subcutaneous fat tissue, hip joint prosthesis and/or degeneration) or professional athletes were also excluded. Socio-demographic data such as age and gender of the patients were noted. Sciatic nerve diameter, SE and SWE values, and Wildermuth staging were used as the outcome measures.

The current study protocol was approved by the Local Ethics Committee of Kırıkkale University Medical School (date 24.02.2017 and no: 03/02). Informed consent was obtained from all the participants.

Diagnosis of lumbar disc herniation and foraminal stenosis

In this study, LDH was diagnosed and foraminal level assessment was based on the MRI-based description recommended by the North American Spine Society, the American Society of Spine Radiology, and the American Society of Neurology [12, 13]. In this study, a 1.5-Tesla MRI unit (Philips MRI Systems®, Achieva Release 3.2 Level 2013–10-21, Philips Medical Systems, The Netherlands) was used to visualize nerve roots and herniation. The protocol used in routine lumbar MRI evaluation is as follows: axial T2-weighted imaging (T2AG) (repetition time [TR]/echo time [TE]: 2867 ms/100 ms, NEX: 2, slice thickness/gap: 4 mm/150 × 150 mm, acquisition matrix: 152 × 104 mm); sagittal T2-weighted imaging (T2AG) (TR/TE: 3862 ms/100 ms, NEX: 2, slice thickness/gap: 4 mm/1 mm, FOV 160 × 331 mm, acquisition matrix: 176 × 260 mm, sagittal T1-weighted imaging (T1AG) (554 ms/7 ms, NEX: 2, slice thickness/gap: 4 mm/1 mm, FOV 160 × 332 mm, acquisition matrix: 160 × 245 mm).

The foraminal stenosis was assessed according to the Wildermuth staging, which was established in 1998 by Wildermuth et al. [14]. Thereafter, this staging was revised in 2013 by Park et al. [15]. This classification is summarized below;

- Stage 0: Normal foramen
- Stage 1: Mild foraminal stenosis (< 50% obliteration)
- Stage 2: Moderate foraminal stenosis (> 50% obliteration)
- Stage 3: Severe foraminal stenosis (full pressure or morphological changes of the nerve root)

B-mode ultrasonographic and elastographic evaluation of the sciatic nerve

A digital sonography instrument with real-time tissue elastography software (LOGIQ E9, GE Healthcare, 2014, 9900 Innovation Drive, Wauwatosa, WI, USA) was used for US evaluations. Evaluations were performed on both the axial and longitudinal planes from the bilateral gluteal region using a 5–9-MHz multifrequency convex probe.

The sciatic nerve elastography was performed as described by Chan et al. [16] from the gluteal region [16]. The patient was placed in the lateral decubitus position with the knees and hips were in flexion. The anatomic orientation of the probe and anatomic structures are shown in Fig. 1. Once the nerve is visualized on the axial plane, all US and elastographic measurements were obtained from the same level. Thereafter, the

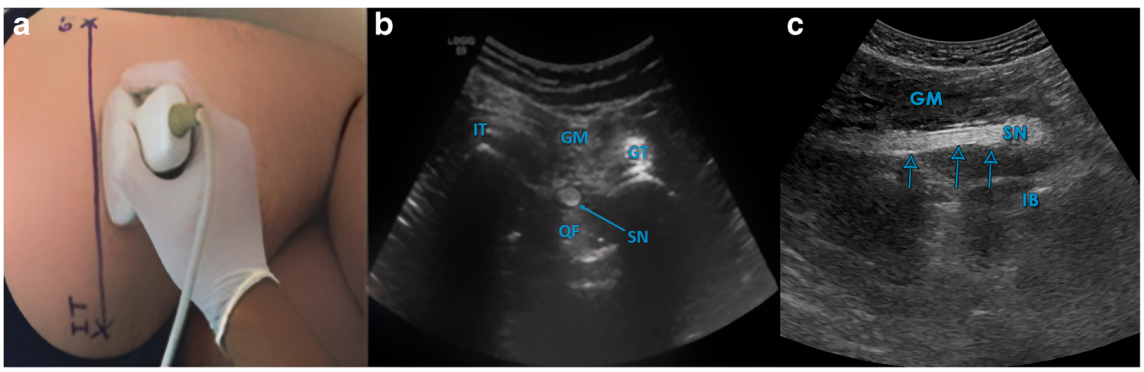

Fig. 1 **a** Image showing the probe position and anatomic orientation. B-Mode ultrasound image shows the sciatic nerve. **b** Gluteal approach sonographic appearance in axial plane. **c** Gluteal approach sonographic appearance in longitudinal plane. (GT: Great trochanter, IT: Ischial tuberosity, GM: Gluteus maximus, QF: Quadriceps femoris, SN: Sciatic nerve (*arrows*), IB: Ischial bone)

nerve was visualized on the longitudinal view at the same level, and measurements were made.

Strain elastography was performed from the gluteal region with light and rhythmic compression of the probe. On the monitor, color coding of SE, which was superimposed on B-mode images, was obtained. According to the compression bar scale of 1–7 in the device, screen images showing ideal compression (5–7 bar pressure) were evaluated. The SE examination was digitally recorded in the instrument memory for analysis in both axial and longitudinal video format. In the analysis of color codes varying from red to blue, red refers to the softest texture, green refers to medium hard texture, and blue refers to the hardest texture [17]. In addition, color coding was classified as red only, yellow-red, green-yellow, green only, blue-green, and blue only, depending on the distribution of patient data from the side of the patient as a semi-quantitative characterization.

The shear wave elastography examination of each patient was performed without compression in both the axial and longitudinal planes. B-mode and SWE images were demonstrated simultaneously on the same screen. SWE evaluation was recorded in a digital video format in the device memory for further analysis. Quantitative measurement of the sciatic nerve hardness was analyzed in kilo Pascal (kPA). Measurements in a circular region of interest area at 2–4-mm intervals of each sciatic nerve were repeated three times, and the mean values were obtained for statistical analysis. Sonoelastography examination of all participants was carried out by one of two radiologists. Sonoelastography features were decided in consensus by two radiologists.

The elastography patterns were classified into three main groups. Each group was divided into subcategories as the follows;

- Type 1 (stiff tissue); a: blue, b: blue-green
- Type 2 (moderate); a: green, b: green-yellow
- Type 3 (soft tissue); a: red-yellow, b: red

Statistical analysis

Statistical analyses were performed using SPSS (SPSS version 20.0, IBM®, USA) packet software. Descriptive statistics were summarized as number, percentage, mean, and standard deviation. The normal distribution of the variables was examined using visual (histogram and probability plots) and analytical methods (Kolmogorov–Smirnov, Shapiro–Wilk tests). Between-group comparisons were made using the Student's *t* test or the Mann–Whitney *U* test after checking the normal distribution. The Kruskal–Wallis test was used to compare three or more groups. Categorical variables were compared using the Chi-square test. A value of $p < 0.05$ was accepted as statistically significant.

Results

The study group comprised 40 patients (20 male, 20 female) with a mean age of 43.1 ± 12.7 years, and the control group comprised 40 healthy subjects (22 male, 18 female) with a mean age of 42.9 ± 10.7 years. Clinical and demographic features are summarized in Table 1**.** No significant difference was observed between the groups in respect of age ($p = 0.0955$), gender ($p = 0.654$), and diameter of the sciatic nerve (all $p > 0.05$). No significant difference was observed within the study group when the sciatic nerve diameter of the involved (5.8 ± 0.8 mm) and non-involved (6.0 ± 0.9 mm) sides was compared ($p = 0.261$) (Table 2).

Strain elastography values of the study and control groups are shown in Table 3. While blue (32.5%) and blue-green (47.5%) color codes were the most commonly observed in the involved side of LDH patients (Fig. 2), green-yellow color codes were the most commonly observed in the non-involved side of LDH patients and both sides of healthy control subjects (Fig. 3) ($p < 0.05$). No significant difference was observed between the non-involved sides of the LDH patients and both sides of healthy control group ($p > 0.05$).

The shear wave elastography findings of the groups are presented in Table 4. The sciatic nerve stiffness assessed on both the axial and longitudinal sides of the involved side was significantly higher than that of non-involved side in the patient group ($p < 0.001$). The stiffness of the involved side in the patient group was also higher than that of right and left sides of the control group ($p < 0.001$). Elasticity values in the axial plan were correlated with those of in the longitudinal planes ($p < 0.001$).

Table 1 Clinical and demographical features

Variables	Study group ($N = 40$)	Control group ($N = 40$)	P value
Age (years)	43.1 ± 12.7	42.9 ± 10.7	0.955
Gender			
Male	20 (50)	22 (55)	0.654
Female	20 (50)	18 (45)	
Involved Side			
Right	13 (32.5)	–	
Left	27 (67.5)	–	
Wildermuth grading			
Grade 0	–	40	
Grade 1	12 (30)	–	
Grade 2	17 (42.5)	–	
Grade 3	11 (27.5)	–	
Sciatic nerve diameter (mm)			
Right	5.8 ± 0.8	5.9 ± 0.4	0.494
Left	5.9 ± 0.9	5.8 ± 0.4	0.714

The data are shown as mean ± standard deviation or *n*, (%)

Table 2 Diameter of the sciatic nerve and shear wave elastography findings according to the Wildermuth staging

Wildermuth grading	Grade 1 ($N = 12$)	Grade 2 ($N = 17$)	Grade 3 (N = 11)	P value
Diameter (mm)	5.3 ± 0.6	5.9 ± 0.9	6.0 ± 0.9	0.082
Elasticity (axial)	10.8 ± 3.2	13.1 ± 3.8	12.6 ± 3.7	0.208
Elasticity (longitudinal)	12.7 ± 3.5	15.1 ± 3.8	14.7 ± 4.2	0.225

Discussion

In this cross-sectional and controlled study, it was aimed to evaluate the elastographic findings of the sciatic nerves in patients with foraminal stenosis due to unilateral LDH, using SE and SWE. To the best of our knowledge, this is the first such study in literature. The first notable finding of the study was that the sciatic nerve stiffness in the involved side was significantly increased compared to the non-involved side in patients with unilateral LDH, and both sides of the healthy control group. In addition, blue (32.5%) and blue-green (47.5%) color codes were the most commonly observed in the sciatic nerve SE of patients with LDH. In contrast, the green-yellow color codes were the most commonly observed in the normal sciatic nerves.

There have been only two studies in the literature evaluating the sciatic nerve with elastography [18, 19]. Santos et al. [18] reported in an meeting abstract that the sciatic nerve can be evaluated by US elastography, and it is visualized as a hard structure, blue according to the color mapping in healthy control subjects. However, there was no mention of the MRI findings of the study population or physical examination findings. In 2016, Andrade et al. [19] assessed the change of sciatic nerve elasticity with ankle movements in 90 healthy volunteers, using SWE. It was highlighted that the sciatic nerve stiffness can be assessed accurately using elastography, and the stiffness of the sciatic nerve is affected by the lower limb movements. Compared to the study by Santos et al. different findings were observed in the current study [18]. In the present study, while blue or blue-green color mappings were observed the most frequently in the involved side of LDH patients, green-yellow was the most frequently observed color

Table 3 Strain elastography findings of the groups

Color coding	Study group		Control group	
	Involved side	Noninvolved side	Right side	Left side
Blue	13 (32.5)	0	0	0
Blue-green	19 (47.5)	4 (10)	3 (7.5)	0
Green	4 (10)	8 (20)	4 (10)	5 (12.5)
Green-yellow	2 (5)	20 (50)	25 (62.5)	28 (70)
Yellow-red	1 (2.5)	6 (15)	1 (2.5)	0
Red	1 (2.5)	2 (5)	7 (17.5)	7 (17.5)

The data are shown as *n*, (%)

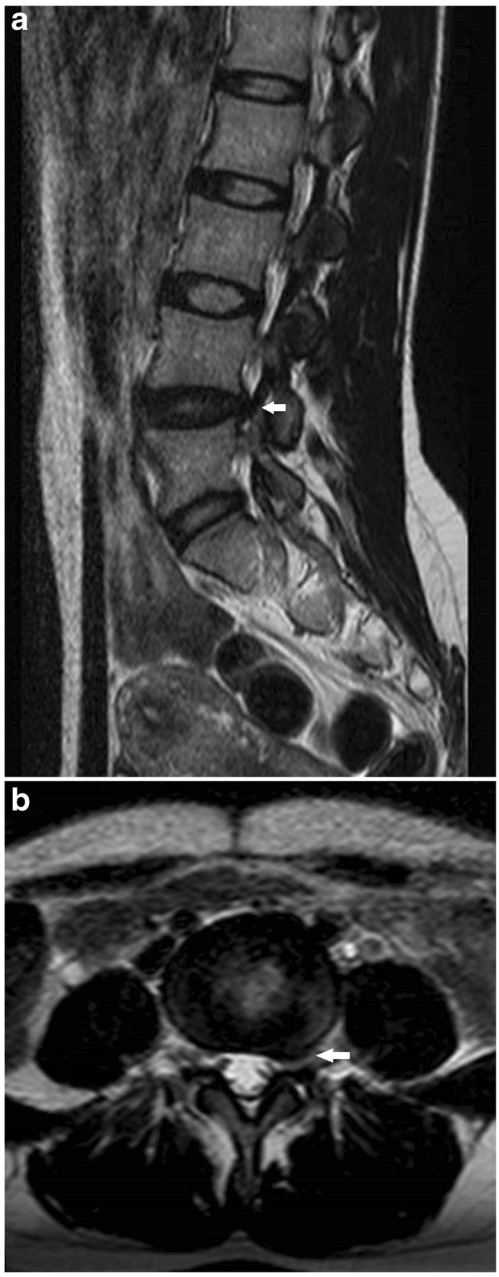

Fig. 2 A 36-year-old female patient with complaints of sciatalgia for 6 months magnetic resonance imaging (**a** T2A sagittal, **b** axial view) illustrates a foraminal disc protrusion. The left L4 neural foramen (*white arrow*) is consistent with stage 2 narrowing according to the Wildermuth grading (**a**, **b**). The left sciatic nerve (*white arrows*) shows a type 1a pattern on the axial (**c**) and longitudinal (**d**) planes with strain elastography. The shear wave elasticity value is measured as 9.89 kPa in the axial plane (**e**), and 12.25 kPa in the longitudinal plane (**f**)

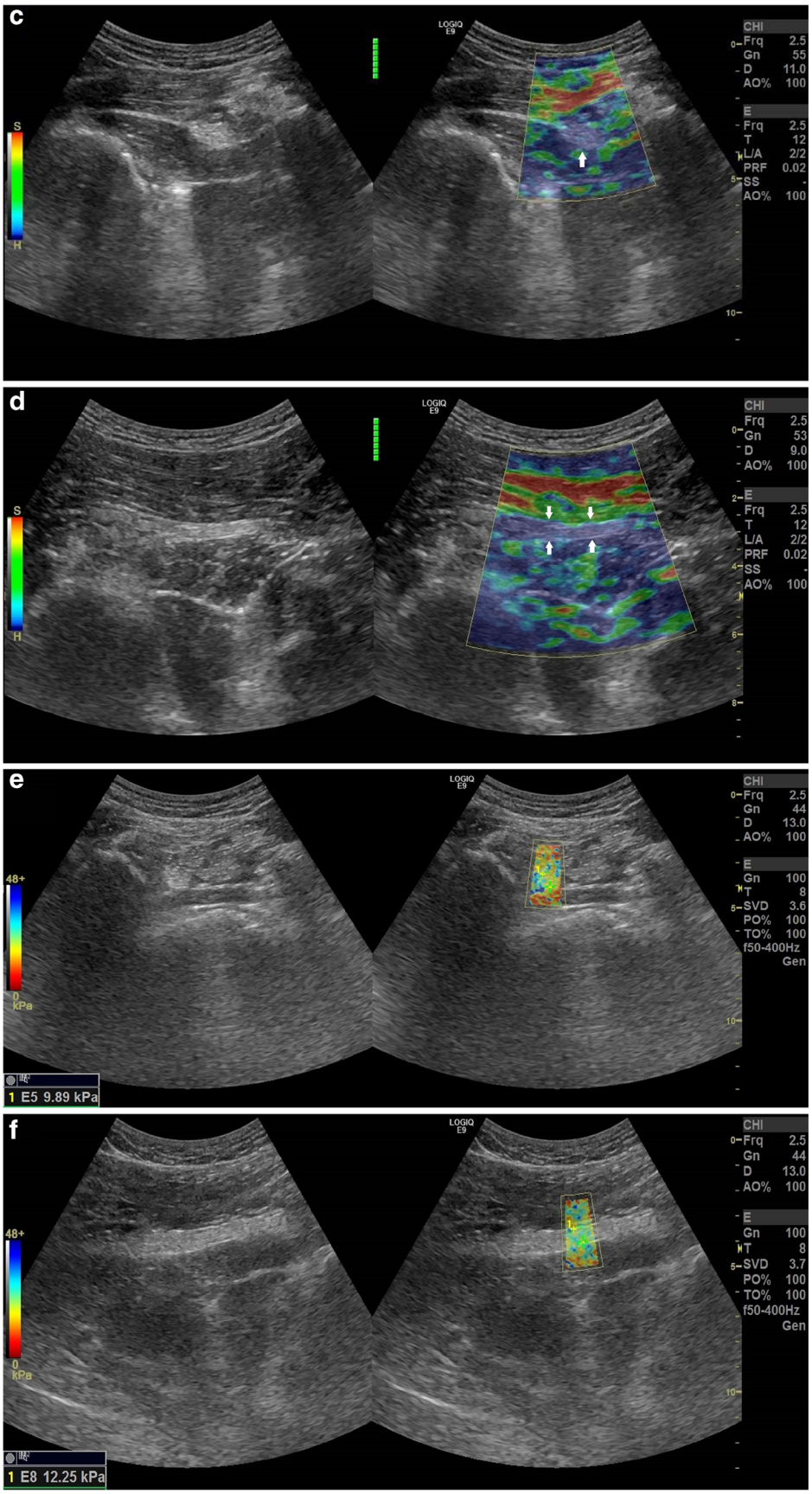

Fig. 2 (continued)

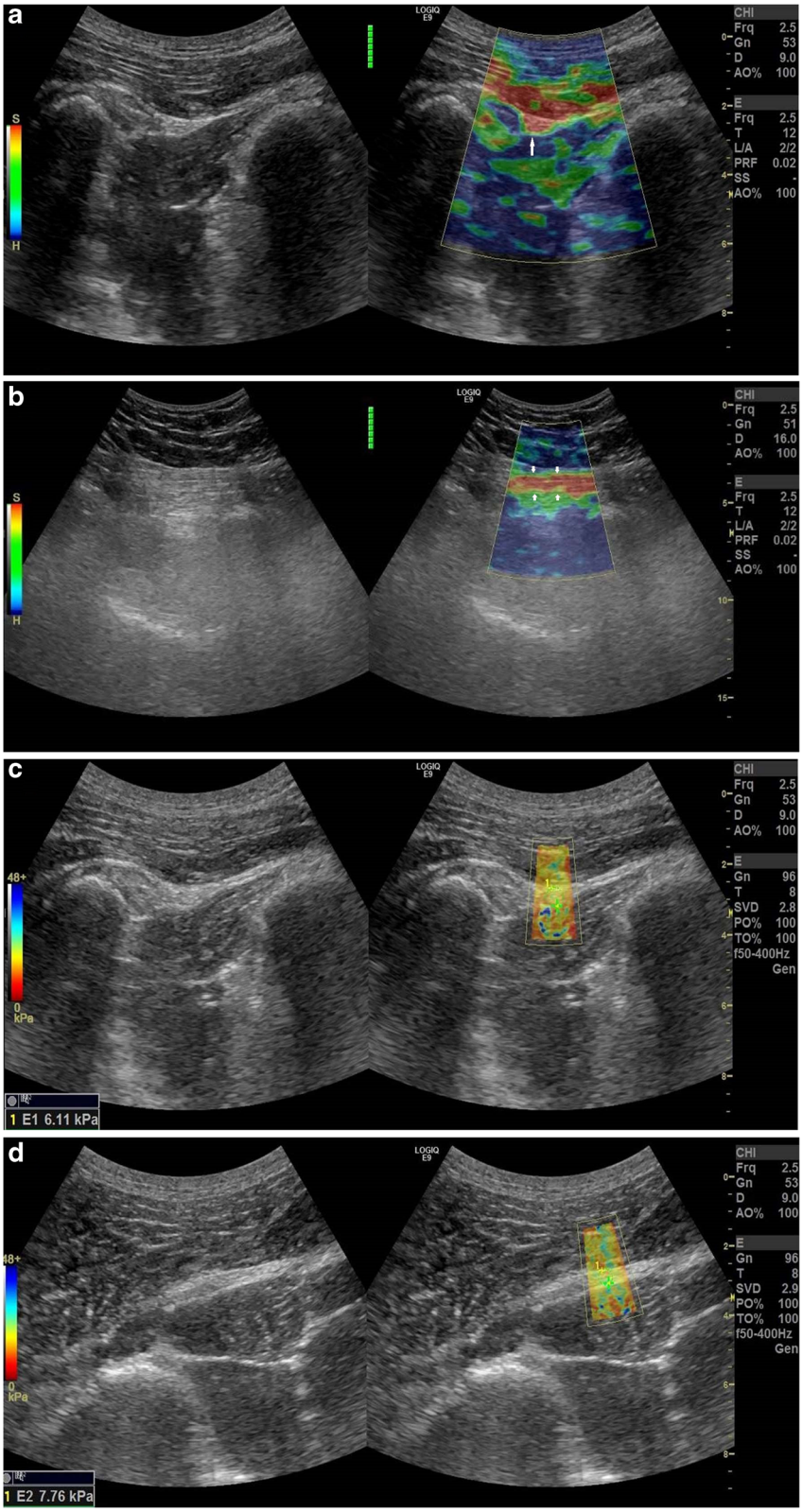

Fig. 3 A 22-year-old female healthy subjects. Magnetic resonance imaging designates the right and left neural foramens as normal. The left sciatic nerve (*white arrows*) shows pattern 3a on the axial (**a**) and longitudinal (**b**) planes with strain elastography. Shear wave elasticity value is measured as 6.11 kPa in the axial plane (**c**) and 6.53 kPa in the longitudinal plane (**d**)

Table 4 Shear wave elastography findings of the groups (kPa)

Study group ($N = 40$)	Mean ± SD	Median	Min-max	P value
Involved side (axial)	12.3 ± 3.7	11.6	6.8–19.9	< 0.001
Noninvolved side (axial)	6.8 ± 2.1	6.1	4.1–11.3	
Involved side (longitudinal)	14.3 ± 3.8	13.6	6.2–22.8	< 0.001
Noninvolved side (longitudinal)	8.3 ± 2.3	7.8	4.3–12.8	
Control group ($N = 40$)				
Right side (axial)	7.9 ± 2.2	7.8	4.3–14.5	0.090
Left side (axial)	7.0 ± 1.8	7.1	4.3–12.3	
Right side (longitudinal)	8.8 ± 2.4	8.6	5–15.6	0.082
Left side (longitudinal)	7.9 ± 1.8	7.4	4.6–12.3	

mapping in the non-involved side or healthy control subjects. This difference might be due to the different machines used, different clinical or demographical features (age, BMI) or technique in the study done by Santos et al. However, they did not mention the name of the machine, technique or clinical parameters clearly in their study. Symptom duration (acute/chronic) might have affected the results as well. Persistent inflammation can result in demyelinization and change the connective tissue of the nerve which eventually changes the nerve structure [20]. We believe that our results can be considered more reliable since the study comprised a control group and MRI results.

In the current study, the sciatic nerve was evaluated both quantitatively and qualitatively using both elastographic methods, i.e., shear wave and SE. SWE has some advantages over SE, as it enables reproducible and quantitative features to be obtained. At the same time, the physical equations that are preferred in the shear wave method are different from the strain method. It provides a direct and quantitative assessment of the Young's modulus (hardness), allowing the localized evaluation of the desired area of the assessed tissue. While SE measures tissue with compression applied by the examiner, in SWE the waves are produced by the transducer [20]. Minimal transducer pressure is recommended when obtaining SWE values [21]. SWE measurements are not interchangeable across different ultrasound machine models, even in those from the same company. Therefore, both elastographic methods were used in the current study to achieve more reliable results.

According to the results obtained, there is no linear correlation between the severity of foraminal stenosis and nerve stiffness or diameter in contrast to the median nerve entrapment, which has been previously reported in literature [20]. This fact might be due to the etiological and pathophysiological differences between the median nerve entrapments and foraminal stenosis of the nerve roots. Despite being effective in grading, it should be kept in mind that the Wildermuth grading is a semiquantitative classification of stenosis, which does not involve the characteristic morphological nerve pressure findings [14, 15]. When we allocated the patients according to the Wildermuth staging; although the nerve diameter was higher in the stage 3 compared to the 1, it was not significant. The small sample sizes of the subgroups might have affected the results. On the other hand, it should also be considered that different scales are used in different machines. It is important to note that these diagnostic values are only valid for measurement taken with the LOGIQ E9 ultrasound system by GE. Also, the small sample size is a limitation of our study, and our results should be verified by the studies done in larger sample size. Another important issue should be considered was the fact that the importance and clarity of the results may be further improved if historical knowledge of occupation, prior physical therapy, pain medications and/or prior steroid injections were utilized. These factors may have a potential role in altering the results of elastography.

Limitations

There are some important drawbacks to this study. Kara et al. [2] evaluated the cross-sectional area of the sciatic nerves with tracing method and found that sciatic nerves were enlarged and edematous in patients with unilateral sciatica. In contrast, no significant difference was observed between the involved and non-involved sides in respect of the sciatic nerve diameter in the current study. This could be attributed to the different measurement methods and should be stated as a limitation. The tracing method is more sensitive and accurate than other methods to measure nerve size [22]. Anthropometric measurements such as body mass index, weight, or height could have been considered. The sciatic nerve was evaluated only from the gluteal region, not from the level of the thigh or above the popliteus. The sample size was small, and the method was not be applicable in patients with thick gluteal subcutaneous fat tissue, hip joint prosthesis, and/or degeneration. Finally, the lack of intra-rater and inter-rater reliability assessment should be stated as a limitation.

Conclusions

In the light of the current study results, patients with unilateral LDH have increased stiffness of the sciatic nerve compared to

healthy control subjects or non-involved sides. Although the findings in this preliminary study show that shear wave elastography can detect a change in sciatic nerve stiffness in patients with unilateral LDH, larger studies are required to determine the clinical utility of this technique.

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Compliance with ethical standards

Ethical approval Local Ethics Committee of Kırıkkale University Medical School (Date 24.02.2017 and No: 03/02). Informed consent was obtained from all the participants.

Conflict of interest Author Umut Orkun Çelebi declares that he has no conflict of interest.

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References

1. Amin RM, Andrade NS, Neuman BJ. Lumbar disc herniation. Curr Rev Musculoskelet Med. 2017. https://doi.org/10.1007/s12178-017-9441-4.
2. Kara M, Özçakar L, Tiftik T, Kaymak B, Özel S, Akkuş S, et al. Sonographic evaluation of sciatic nerves in patients with unilateral sciatica. Arch Phys Med Rehabil. 2012;93(9):1598–602.
3. Alsaleh K, Ho D, Rosas-Arellano MP, Stewart TC, Gurr KR, Bailey CS. Radiographic assessment of degenerative lumbar spinal stenosis: is MRI superior to CT? Eur Spine J. 2017;26(2):362–7.
4. Carrino JA, Lurie JD, Tosteson AN, Tosteson TD, Carragee EJ, Kaiser J, et al. Lumbar spine: reliability of MR imaging findings. Radiology. 2009;250(1):161–70.
5. Pfirrmann CW, Dora C, Schmid MR, Zanetti M, Hodler J, Boos N. MR image-based grading of lumbar nerve root compromise due to herniation: reliability study with surgical correlation. Radiology. 2004;230(2):583–8.
6. Milano C, Lotti G, Mariconda M. Comparison of CT scan diagnosis and surgical findings in lumbar disk herniation. Ital J Orthop Traumatol. 1991;17(3):401–5.
7. Kara M, Ekiz T, Öztürk GT, Onat ŞŞ, Özçakar L. Heterotopic ossification and peripheral nerve entrapment: ultrasound is a must-use imaging modality. Pain Med. 2015;16(8):1643–4.
8. Kara M, Özçakar L, Tan E, Akıncı A. Ultrasonographic imaging of the sciatic nerve in a patient with knife injury. Muscle Nerve. 2015;51(2):303–4.
9. Tiftik T, Öztürk GT, Kara M, Türkkan C, Ersöz M, Özçakar L. Ultrasonographic evaluation of sciatic nerves in patients with spinal cord injury. Spinal Cord. 2015;53(1):75–7.
10. Uğurlu FG, Tiftik T, Kara M, Türkkan C, Ersöz M, Akkuş S, et al. Ultrasonographic evaluation of the median and sciatic nerves in hemiplegic patients after stroke. Am J Phys Med Rehabil. 2015;94(6):429–35.
11. Göktepe AS, Ozçakar L, Kömürcü E, Safaz I, Yazicioğlu K. Sonographic evaluation of the sciatic nerve in patients with lower-limb amputations. Muscle Nerve. 2010;41(6):763–6.
12. Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze GK. Lumbar disc nomenclature: version 2.0: recommendations of the combined task forces of the North American Spine Society, the American Society of Spine Radiology and the American Society of Neuroradiology. Spine J. 2014;14(11):2525–45.
13. Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze GK. Lumbar disc nomenclature: version 2.0: recommendations of the combined task forces of the North American Spine Society, the American Society of Spine Radiology, and the American Society of Neuroradiology. Spine (Phila Pa 1976). 2014;39(24):E1448–65.
14. Wildermuth S, Zanetti M, Duewell S, Schmid MR, Romanowski B, Benini A, et al. Lumbar spine: quantitative and qualitative assessment of positional (upright flexion and extension) MR imaging and myelography. Radiology. 1998;207(2):391–8. Erratum in: Radiology 1998;208(3):834
15. Park HJ, Kim SS, Lee SY, Park NH, Chung EC, Rho MH, et al. A practical MRI grading system for cervical foraminal stenosis based on oblique sagittal images. Br J Radiol. 2013;86(1025):20120515.
16. Chan VW, Nova H, Abbas S, McCartney CJ, Perlas A, Xu DQ. Ultrasound examination and localization of the sciatic nerve: a volunteer study. Anesthesiology. 2006;104(2):309–14. discussion 5A
17. Çıracı S, Tan S, Özcan AŞ, Aslan A, Keskin HL, Ateş ÖF, et al. Contribution of real-time elastography in diagnosis of polycystic ovary syndrome. Diagn Interv Radiol. 2015;21(2):118–22.
18. Santos R, Armada P. Sciatic nerve hardness measurement by using ultrasound elastography. Ultrasound Med Biol. 2013;39(5):S57.
19. Andrade RJ, Nordez A, Hug F, et al. Non-invasive assessment of sciatic nerve stiffness during human ankle motion using ultrasound shear wave elastography. J Biomech. 2016;49(3):326–31.
20. Kantarci F, Ustabasioglu FE, Delil S, Olgun DC, Korkmazer B, Dikici AS, et al. Median nerve stiffness measurement by shear wave elastography: a potential sonographic method in the diagnosis of carpal tunnel syndrome. Eur Radiol. 2014;24(2):434–40.
21. Kot BC, Zhang ZJ, Lee AW, Leung VY, Fu SN. Elastic modulus of muscle and tendon with shear wave ultrasound elastography: variations with different technical settings. PLoS One. 2012;7(8):e44348.
22. Ekiz T, Kara M, Özçakar K. Median nerve area measurements using ultrasound: importance of proper technique and interpretation. Am J Phys Med Rehabil. 2017. https://doi.org/10.1097/PHM.0000000000000854.