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ORIGINAL ARTICLE

Quadratus lumborum muscle stiffness in chronic non-specific low back pain: a diagnostic accuracy study

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Abstract

Background Evaluation of muscle tenderness is encouraged in the diagnosis of low back pain (LBP). However, manual palpation is poorly reliable and objective methods to quantify muscle stiffness are needed.

Objectives To investigate quadratus lumborum muscle stiffness differences between individuals with chronic non-specific low back pain (LBP) and pain-free controls, analyze side-to-side stiffness differences, and assess the diagnostic accuracy of shear wave elastography.

Methods A cross-sectional study was conducted recruiting 40 patients with chronic non-specific LBP and 40 asymptomatic controls. Variables assessed included muscle stiffness using shear wave elastography metrics (shear wave speed (SWS) and Young's modulus (YM)), pain chronicity, pain intensity, pain-related disability (using the Oswestry Disability Index) and symptoms associated with central sensitization (using the Central Sensitization Inventory). Diagnostic accuracy was evaluated through sensitivity, specificity, and receiver operating characteristic analysis.

Results No significant side-to-side stiffness differences were observed within either group (both, $p > 0.05$). Quadratus lumborum muscle stiffness was significantly lower in LBP patients compared to controls (SWS $p = 0.010$; YM $p = 0.008$). The receiver operating characteristic analysis for both metrics showed poor discriminatory ability (< 0.7). A modest balance between sensitivity (SWS 70%; YM 75%) and specificity (SWS 97.5%; YM 50%) was found.

Conclusions Although greater stiffness was expected due to the associated prevalence of trigger points in patients with LBP, quadratus lumborum muscle stiffness was significantly lower in patients suffering chronic non-specific LBP compared to controls. Despite significant differences, the diagnostic accuracy of shear wave elastography was poor, requiring further research to improve the diagnostic utility of shear wave elastography.

Keywords Diagnostic accuracy · Low back pain · Pain-related disability · Quadratus lumborum · Shear wave elastography

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Introduction

Low back pain (LBP) is one of the most prevalent musculoskeletal disorders (affecting up to 18.3% of the entire world population) [1], characterized by its high recurrence rate, with up to 76% of patients reporting a history of more than one episode. The duration of LBP can be extensive, with pain and disability persisting for 6 to 24 months in 54% and 47% of patients, respectively [2], both with moderate to extreme severity [2]. LBP affects all age groups and its disability-adjusted life years have increased by up to 54% between 1990 and 2015 [2], underscoring its significant socioeconomic impact worldwide. This impact is further influenced by variations in social norms, healthcare approaches, and legislation, with the annual economic burden of LBP estimated at $100 billion in the United States and £2.8 billion in the United Kingdom [2].

Although LBP can be a symptom of various specific pathoanatomical conditions affecting the lumbar spine, the majority of LBP cases (90–95%) are classified as non-specific LBP, as the pain cannot be attributed to a known cause [3]. However, numerous systematic reviews and meta-analyses have identified various factors (i.e., individual factors, psychological characteristics, biomechanical indicators, nociceptive detection and processing, tissue injury, behaviors, and contextual and social factors are among the most frequently described) contributing to the development of non-specific LBP [4–6]. These factors are associated both within and across categories and are linked to clinical outcomes such as pain, quality of life, disability, function, symptom duration, and physical impairments [7].

Although previous studies focusing on specific muscles showed promising results to discriminate asymptomatic individuals from LBP sufferers [8], evidence assessing the role of the quadratus lumborum (QL) in LBP is lacking, controversial and mostly limited to electromyographic and morphological analyses. From a clinical perspective, this muscle is integral to the understanding of LBP, given its significant functional implications. Electromyographic studies have demonstrated a redistribution of muscle activity in patients with recurrent LBP compared to asymptomatic individuals [9, 10].

However, anatomical findings remain inconclusive [11]; for example, Kamaz et al. [12] reported atrophy of the QL muscle in chronic LBP patients, whereas Sions' research found no impact of LBP on the QL cross-sectional area or fatty infiltration [13]. Despite this controversy, numerous studies are consistent with the high prevalence of active myofascial trigger points (MTrPs) in patients with non-specific LBP [14–18]. These MTrPs are defined as "hyperirritable painful spots located in taut bands which elicit local and referred pain recognized by the patient when mechanically stimulated mechanically [19]". Assessing muscle stiffness may provide clinically significant information, aiding in the early identification of diseases when morphological abnormalities are not evident in grey-scale images.

Sonoelastography is utilized to assess tissue elasticity within this context, functioning as a complementary tool to B-mode ultrasound imaging (US). Although the literature outlines various elastography methods for evaluating musculoskeletal structures [20], shear wave elastography (SWE) is regarded as the most valid technique due to its ability to provide quantitative and reproducible measurements of tissue stiffness. SWE employs mechanical shear waves, which are generated by the compressive acoustic waves used during the acquisition of B-mode images, to measure the velocity of shear wave propagation. This velocity is closely associated with tissue stiffness, offering high precision and reliability in musculoskeletal assessments. Additionally, SWE's capacity to provide operator-independent and absolute measurements (in contrast with strain elastography) further establishes its superiority over other elastography methods.

Current clinical practice guidelines [3, 21] recommends the assessment of pain-related data, functional disability, and psychosocial factors. This includes evaluating pain duration, intensity, nature, distribution and extent, alongside a physical examination focusing on posture, motor control, range of motion, and muscle tenderness. Given the current recommendations that stress the importance of assessing muscle tenderness, particularly in the QL muscle and gluteus medius for patients with LBP, and recognizing the poor reliability in determining the presence, number, and location of MTrPs [16], there is a growing interest in utilizing objective methods to quantify muscle stiffness. This interest extends to examining its correlation with clinical severity indicators, such as pain intensity, pain chronicity, recurrence, pain-related disability, central sensitization, and quality of life. Considering that SWE has been validated as a reliable method for measuring QL stiffness, as demonstrated by Zhou et al., [22] the primary objective of this study is to investigate QL muscle stiffness (assessed with SWE) differences between cases with chronic non-specific LBP and pain-free controls. Additionally, this study aimed to analyze side-to-side stiffness differences in both samples and the diagnostic accuracy of SWE to discriminate patients suffering LBP and asymptomatic individuals.

Methods

Study design

Between February and May 2024, a cross-sectional case-control study with a diagnostic accuracy study design was conducted to determine the QL stiffness differences between a sample of patients suffering chronic non-specific LBP and a sample of pain-free controls. The study was carried out in a university lab. For enhancing the quality of the report, the STROBE checklist for case-control studies [23] and the EQUATOR guidelines [24] were used to provide the necessary details. Additionally, the rights of the participants were respected in accordance with the Declaration of Helsinki and supervised by a Local Ethics Committee prior to data collection (UFV ID:15/2024 Approval date 22/02/2024).

Participants

Two samples were recruited in this study (a sample of patients with chronic non-specific LBP and a sample of asymptomatic controls) by responding to announcements and flyers posted around the campus.

Common inclusion criteria included being aged between 18 and 60 years old and capable of reading and signing the informed consent form. In addition, patients from the cases group had to report bilateral pain and/or numbness (without irradiated pain to the lower limbs) for over six months between the T12 vertebra and the gluteal fold while asymptomatic subjects had to be free from any low back and/or hip pain within the last 12 months.

Exclusion criteria for both groups included: (1) “red flags” or specific underlying pathologies causing LBP (such as cauda equina syndrome, fractures, rheumatological diseases, cancer, stenosis, significant or rapidly progressing neurological deficits, infections, or systemic diseases); (2) history of spinal fractures, spinal surgery, severe degenerative changes, severe scoliosis, or osteoporosis; (3) being pregnant or having given birth within the past year; (4) being under any pharmacological potentially affecting the muscle tone; or (5) current or past participation in a lumbar strengthening rehabilitation program within the previous year. Patients were also asked to refrain from any LBP treatments during the study, except for on-demand analgesics.

The a priori estimation of the minimum sample size needed was calculated based on the guide for sample size estimation in diagnostic accuracy studies described by Akoglu [25]. Using the formula $n = Z^2_{\alpha\,/2} \times \frac{Se(1-Se)}{d^2}$(where $Z^2_{\alpha\,/2}$ is the Z-value corresponding to the 95% confidence level ($Z^2_{\alpha\,/2}$ = 1.96), Se is the expected sensitivity (estimated at 0.75 based on previous ultrasound studies conducted in low back pain populations [26]) and d is the margin of error (estimated at 0.07 since a range of 0.05 to 0.10 is acceptable [27]). This calculation resulted on 32 subjects per group.

Quadratus lumborum muscle stiffness

One experienced examiner (with over a decade of experience in musculoskeletal ultrasonography and clinical management of musculoskeletal disorders) acquired all images. The imaging was performed using a Canon Aplio A device equipped with an 8C1 convex transducer, with standardized parameters across all examinations (Frequency: 5 MHz, Gain: 80 dB, Dynamic Range: 60, Depth: 12 cm).

Participants were positioned in a lateral decubitus posture to ensure spinal and lower limb neutrality. A wedge-shaped cushion was placed posterior to the upper thoracic region to maintain a perpendicular orientation of the torso relative to the examination table. Additionally, a square cushion was positioned between the thighs to ensure hip joint neutrality. If necessary, a towel was used to support and maintain a neutral alignment of the lumbar spine [22]. Participants were instructed to relax their muscles during the procedure to prevent morphological bias due to muscle contractions [28].

The transducer was initially positioned superior to the iliac crest along the mid-axillary line. Subsequently, the cranial aspect of the transducer was pivoted posteriorly by approximately 20° to ensure the L4 vertebra was centered within the imaging field. In this orientation, the quadratus lumborum muscle was identified as the relatively hypoechoic structure overlaying the psoas major muscle, which appeared as the muscle overlying the vertebral bodies. The region of interest was delineated at the center of the quadratus lumborum, encompassing at least 50% of the muscle, using a freely drawn quantification box to exclude the fasciae. Finally, after setting the quantification box the US device calculated automatically both the shear wave speed and Young’s modulus metrics. A pilot secondary intra-examiner reliability analysis was conducted prior to the data collection to confirm the intra-examiner reliability of the procedure, resulting in an excellent intraclass correlation coefficient (ICC $>$ 0.9), with no statistically significant differences between trials ($p > 0.05$).

Clinical severity descriptors

In order to interpretate correctly the stiffness differences attributable to LBP, an analysis of the LBP clinical severity is needed. Therefore, during the data collection the research team collected information about pain chronicity, intensity, related-disability and central sensitization. A clinical history was filled out indicating the time (in months) that they have been suffering LBP.

Pain intensity was evaluated using the Visual Analogue Scale (VAS), a reliable and valid instrument for pain measurement. The VAS comprises a 10 cm straight line with endpoints representing the extremes of pain, where 0 indicates no pain and 10 denotes the worst imaginable pain. The score is determined by measuring the distance in centimeters from the "no pain" endpoint to the patient's mark, resulting in a score ranging from 0 to 10, with higher scores indicating greater pain intensity [29].

Pain-related disability was assessed using the Oswestry Disability Index (ODI), a validated and reliable questionnaire consisting of 10 sections. Each section contains 6 statements scored from 0 to 5, where 0 represents no disability and 5 signifies maximum disability. The final scores classify patients into categories: minimal disability (0–20), moderate disability (21–40), severe disability (41–60), crippling disability (61–80), and complete disability (81–100) [30].

The Central Sensitization Inventory (CSI) is a self-report questionnaire designed to assess symptoms associated with central sensitization. It consists of 25 items, each rated on a 5-point Likert scale ranging from 0 (never) to 4 (always). The total score, which is the sum of all item scores, ranges from 0 to 100, with higher scores indicating a greater degree of central sensitization [31].

Statistical analysis

All data processing and analyses were conducted in the Statistical Package for the Social Sciences (SPSS) v.29.1.1 (Armonk, NY, USA) for Mac OS. All tests were two-tailed, and the significance level cut-off was set at $p < 0.05$. Initially, the distribution of continuous variables was assessed by employing histograms and Shapiro-Wilk tests. Subsequently, the demographic and clinical characteristics of the sample were described using descriptive statistics. Demographic differences between cases and controls and clinical severity differences between males and females within the cases group were assessed by using Student's T-tests for independent samples (providing the mean difference, 95% of Confidence Interval and p value).

Subsequently, SWE scores were described by group and side. Differences were analyzed were calculated using a multivariate general lineal model with analysis of covariance, including the group and side examined as fixed factors. Due to the use of multiple comparisons for shear wave speed and Young's modulus, the Bonferroni correction was applied. Accordingly, group*side p values were assumed to be significant at < 0.0125 (0.05/4). Finally, the effect size was estimated using the partial eta squared if it was significant. An effect size of 0.01 was considered small, 0.06 was considered medium, and 0.14 was considered large [32].

Finally, the capability of SWE to differentiate individuals with LBP was assessed by analyzing the area under the receiver operating characteristic (ROC) curve, considering an under the curve (AUC) of ≥ 0.7 as acceptable discrimination [33]. Shear wave speed and Young's modulus were the index tests (diagnostic test being evaluated for its accuracy in detecting non-specific LBP), while the participants' classification into the cases group in accordance with the eligibility criteria was the reference test (the established benchmark to evaluate the accuracy of the index test). To construct the ROC curve, sensitivity and specificity were calculated at various threshold values based on the true positive, true negative, false positive, and false negative rates derived from the index tests in comparison to the reference test classifications. The optimal cut-off point for each measure ratio was identified using the Youden index. The reported metrics included sensitivity ($sensitivity = \frac{True\ positives}{True\ positives + False\ negatives}$), specificity ($specificity = \frac{True\ negatives}{True\ negatives + False\ positives}$),, positive likelihood ratio ($LR+ = \frac{Sensitivity}{1 - Specificity}$), and negative LR ($LR- = \frac{1 - Sensitivity}{Specificity}$). The validity was deemed acceptable if a sensitivity of at least 70% and a specificity of at least 50% were achieved [34].

Results

During the recruitment period, 80 individuals expressed interest in participating in the study. Since no data was missed and any participant was excluded from the study, all participants were successfully analyzed (cases with LBP $n = 40$, 56,5% females; asymptomatic individuals $n = 40$, 43.5% females). Table 1 summarizes the demographic and clinical characteristics of the samples included in the study, comparing their demographic characteristics. The analysis of demographic characteristics revealed that both samples were comparable in terms of age, weight, height and BMI (all, $p > 0.05$). In addition, the gender distribution in both groups were comparable ($p = 0.523$). Regarding the clinical severity descriptors within the cases group, the sample consisted of individuals with moderate pain intensity [35], mild disability [30], and reported human-assumed central sensitization since the group passed the CSI cut-off value [36]. No significant differences were found between males and females for any of the variables (all, $p > 0.05$).

The QL stiffness metrics and the comparisons between sides and groups are reported in Table 2. For individuals

Table 1 Descriptive analyses of demographic and clinical characteristics of the sample

Variables	Sample ($n=80$)		Difference (95% CI)
	Pain-free controls ($n=40$)	Cases with Low Back Pain ($n=40$)	
Demographics			
Age, years	29.7 ± 13.1	27.5 ± 9.6	2.2 (-5.2;9.7) $p=0.545$
Weight, kg	69.3 ± 16.1	68.7 ± 15.9	0.6 (-9.7;10.8) $p=0.911$
Height, m	1.66 ± 0.07	1.71 ± 0.09	0.05 (0.00;0,10) $p=0.056$
BMI, kg/m^2	24.8 ± 4.9	23.2 ± 4.3	1.6 (-1.3;4.6) $p=0.260$
Pain-Related Characteristics			
Chronicity (months, n)	-	63.8 ± 53.6	-
Pain Intensity (VAS, 0–10)	-	5.0 ± 1.6	-
Related-Disability (ODI, 0-100)	-	12.7 ± 7.5	-
Central Sensitization (CSI, 0-100)	-	40.2 ± 13.8	-

Table 2 Quadratus lumborum muscle stiffness analyses

	Shear Wave Speed (m/s)	Young's Modulus (kPa)
Cases with LBP ($n=40$)		
Mean	2.40 ± 0.60	18.5 ± 8.8
Left side	2.43 ± 0.53	19.4 ± 8.9
Right side	2.38 ± 0.66	17.5 ± 8.6
Between-sides difference	*0.05 (-0.21;0.32)* *$p=0.715$*	*1.9 (-2.0;5.8)* *$p=0.339$*
Pain-free controls ($n=40$)		
Mean	2.67 ± 0.69	23.4 ± 13.9
Left side	2.72 ± 0.79	25.8 ± 16.9
Right side	2.62 ± 0.56	21.0 ± 9.8
Between-sides difference	*0.10 (-0.20;0.41)* *$p=0.131$*	*4.8 (-1.3;10.9)* *$p=0.124$*
Between-Group Differences (ANCOVA)		
Group	F = 6.891; $p=0.010$; $\eta^2_p=0.042$	F = 7.306; $p=0.008$; $\eta^2_p=0.045$
Side	F = 1.916; $p=0.168$; $\eta^2_p=0.012$	F = 3.340; $p=0.070$; $\eta^2_p=0.021$
Group*Side	F = 0.804; $p=0.371$; $\eta^2_p=0.005$	F = 0.636; $p=0.426$; $\eta^2_p=0.004$

with low back pain, the intra-group analysis showed no significant difference between the left and right sides for either shear wave speed ($p=0.715$) or Young's modulus ($p=0.339$). This indicates that within the LBP group, the mechanical properties of the lumbar quadrate muscle are similar on both sides of the body. In pain-free controls, the results similarly revealed no significant difference between the left and right sides for shear wave speed ($p=0.131$) or Young's modulus ($p=0.124$).

Table 3 Validity of quadratus lumborum shear wave elastography for discrimination between patients with non-specific low back pain and asymptomatic individuals

Variables	Shear Wave Speed	Young's Modulus
ROC value	0.347	0.351
95% CI	0.261–0.432	0.266–0.437
Cut-off point	2.05	20.2
Youden Index	0.275	0.275
Sensitivity	70	75
Specificity	97.5	50
Positive LR	28	1.5
Negative LR	0.31	0.5

The ANCOVA analysis comparing both groups indicated significant differences between individuals with LBP and pain-free controls for shear wave speed ($p=0.010$) and Young's modulus ($p=0.008$), which are below the adjusted p-value threshold for multiple comparisons. These results indicate that the mechanical properties of the QL muscle differ significantly between those individuals with LBP and those without, regardless of the side of the body. The interaction between group and side was not significant for either measure, suggesting that the differences between groups are consistent across both sides.

Finally, Table 3; Fig. 1 describe the discriminatory accuracy of SWE. The ROC analysis indicated poor discriminatory ability (AUC = 0.347) since it is well below the threshold of 0.7 for acceptable discrimination. The optimal cut-off point identified was 2.05 m/s, with a Youden Index of 0.275, suggesting a modest balance between sensitivity and specificity at this threshold. In addition, this outcome showed a 70% sensitivity (indicating that 70% of true positives are correctly identified) and 95% specificity (it correctly identifies 97.5% of true negatives). The high positive LR suggests that individuals with a positive result are much more likely to have LBP, making this a strong indicator when the test is positive. Conversely, the negative LR indicates a moderate ability to exclude LBP when the test is negative. Despite these promising likelihood ratios, the overall low ROC value implies that shear wave speed should not be solely relied upon for diagnosing LBP.

The ROC analysis for Young's Modulus also demonstrated poor discriminatory capability (AUC = 0.351). The optimal cut-off point for this metric is determined to be 20.2 kPa, with a Youden Index of 0.275, indicating a similar balance between sensitivity and specificity. Although sensitivity was similar to shear wave speed (75%), specificity was considerably lower (50%). The positive LR suggested a slight increase in the likelihood of having LBP when the test is positive, but this is not strong enough to be considered a reliable indicator. The negative LR of 0.5 indicated a moderate ability to exclude LBP when the test result is negative.

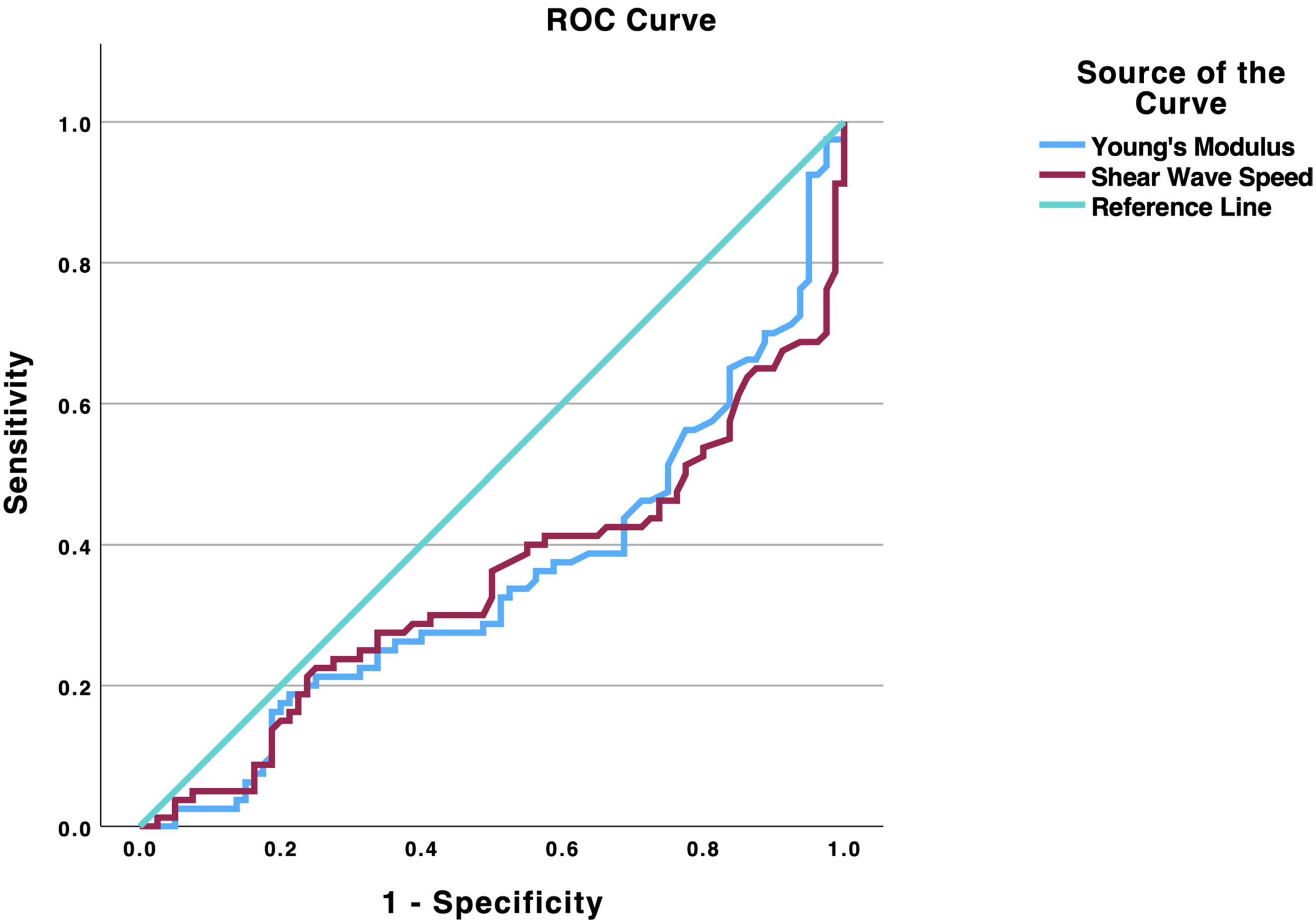

Fig. 1 Receiver operating characteristic (ROC) curves for young's modulus and shear wave speed

Discussion

This is the first study assessing QL muscle stiffness using SWE between cases with non-specific chronic LBP and asymptomatic subjects to evaluate the if objective stiffness measures differ between these groups and to analyze the discriminatory capacity of SWE to differentiate patients and asymptomatic subjects. In general, the results indicated (1) that QL muscle stiffness was significantly lower in patients suffering chronic non-specific LBP compared to pain-free controls, (2) that there are no side-to-side asymmetries in either both groups and (3) that despite the observed differences in muscle stiffness, the diagnostic accuracy of SWE for differentiating between individuals with and without LBP was found to be poor since the ROC analysis for both metrics indicated limited discriminatory capacity. Although the optimal cut-off points provided high specificity for shear wave speed and moderate sensitivity for Young's modulus, the overall performance of SWE as a diagnostic tool in this context is suboptimal. This suggests that while SWE can detect differences in muscle stiffness, it should not be solely relied upon for diagnosing LBP. Further research is needed to enhance the diagnostic utility of SWE, possibly by combining it with other clinical assessments or biomarkers.

While methodological factors such as transducer pressure, angle, and region of interest placement can introduce measurement variability and potentially contribute to the poor discriminatory capacity observed, the strong intra-examiner reliability demonstrated in both Zhou et al. [22] and our pilot study makes this explanation less likely. In our case, these factors were carefully controlled, and high reliability estimates were achieved. Instead, a more plausible explanation lies in the magnitude of the difference in stiffness between the groups. Although the difference is statistically significant, it may be relatively small. A substantial overlap in stiffness values between patients and healthy controls could account for the ROC analysis yielding an AUC below 0.7. This overlap reduces the classifier's ability to distinguish between the groups, which is reflected in the poor discriminability observed.

Perhaps one of the most surprising findings of this study was the softer QL characterization in patients with LBP. Since a high prevalence of MTrPs has been described in this population and considering the tender nature of MTrPs

[37], greater stiffness was hypothesized for the LBP group. Although a previous study conducted with asymptomatic subjects [22] demonstrated that females are characterized by greater stiffness than males (possibly due to variations in muscle composition), the gender representation in both groups were comparable in our case and therefore alternative hypothesis should be formulated.

For instance, non-histological factors such as including muscle recruitment during both rest and functional tasks, play a significant role in influencing muscle stiffness [9, 10, 38]. Colloca and Hinrichs [39] have elucidated the relationship between neuromuscular imbalance and LBP. They describe the flexion-relaxation phenomenon, characterized by myoelectric silence, which reflects increased load distribution to the posterior discoligamentous passive structures during trunk flexion. This indicates that during flexion, the load is transferred to passive spinal structures, such as ligaments and intervertebral discs, contributing to LBP and related disabilities. In LBP patients, there is continuous activation of the lumbar erector spinae muscles, likely an adaptive response to stabilize compromised spinal structures via reflexogenic ligamentomuscular activation, thus preventing further injury and mitigating pain. Conversely, there is a notable myoelectric silencing of the QL. This context supports the hypothesis that reduced stiffness of the QL is associated with more severe clinical manifestations and decreased muscle stiffness in LBP patients compared to asymptomatic individuals.

Another reason explaining these findings could be the clear flaw in diagnostic procedures to determine the presence and location of MTrPs. Since there is an absence of objective procedures, the diagnosis mainly depends on the physical examination and the pain responses reported by the patients [40]. In earlier studies focusing on the cervical region, researchers discovered a notable discrepancy between patients' perceived muscle stiffness and the objective stiffness measurements obtained using SWE [41]. Dieterich et al. [41] compared muscle stiffness across five cervical sites in women with chronic non-specific neck pain and asymptomatic women. Their results indicated that, despite patients' subjective sense of increased stiffness, there was no significant difference in objective muscle stiffness between the two groups across various muscle regions and tasks. In addition, Wolff et al. [42] found that patients with idiopathic chronic neck pain had softer sternocleidomastoid muscles compared to asymptomatic controls during forward reaches. The authors attributed these findings to pain-avoidance movement strategies, noting that contrasting results were observed in the upper trapezius muscle, and that changes in stiffness were independent of muscle activity [42].

Finally, another study [43] examined the stiffness properties of active and latent MTrPs in the upper trapezius muscle, comparing these with pain-free control sites and analyzing the relationship between muscle stiffness and clinical severity outcomes. The study found no significant differences in stiffness among active, latent, and control regions. Additionally, there were no correlations between SWE metrics and pain intensity, pain extent, pain-related disability (consistent with Xie et al.'s findings [44]), or pressure pain thresholds. These results were supported by a clinical trial demonstrating that interventions targeting pain intensity and pain-related disability did not affect muscle stiffness [45].

Limitations

Despite the significant findings of this study, several limitations should be acknowledged. First, although the SWE protocol described by Zhou et al. [22] demonstrated good reliability it was tested in asymptomatic subjects. Specific reliability analyses in patients suffering LBP are needed as minimum detectable changes and accuracy of measurements might be different due to the histological and functional differences reported in the literature between cases with LBP and asymptomatic subjects [46, 47]. Secondly, future studies should include factors which were not considered in this study (i.e., physical activity, pain pressure thresholds or biopsychosocial factors) since the association with muscle stiffness described in other studies [48] may influence on the results' interpretation. Although assessing the QL mechanosensitivity was initially considered, the QL is located beneath other superficial muscles (e.g., erector spinae and the abdominal wall). In this anatomical context, measuring PPTs could introduce bias, as the pressure applied might primarily reflect the sensitivity of the overlying muscles, which are also frequently symptomatic in patients with LBP. Finally, the design of the current study does not allow us to infer a cause-and-effect relationship between decreased muscle stiffness and LBP. Longitudinal studies will help to further elucidate this association.

Conclusion

The primary findings indicate that QL muscle stiffness is significantly lower in patients with chronic non-specific LBP compared to pain-free controls, contrary to expectations given the high prevalence of MTrPs in patients with LBP. This suggests that factors beyond histological changes, such as neuromuscular adaptations and imbalances, may play a significant role in influencing muscle stiffness in LBP. Additionally, the study found no significant side-to-side differences in QL stiffness within either group, indicating consistent mechanical properties bilaterally. However, these differences were of small magnitude and the overlap in stiffness values between cases and asymptomatic controls could account for the ROC analysis yielding an AUC below 0.7 and the poor diagnostic accuracy of SWE in differentiating individuals with and without. While SWE showed high specificity for shear wave speed and moderate sensitivity for Young's modulus, its overall discriminatory capacity fell below acceptable thresholds. These findings highlight the need for further research to enhance the diagnostic utility of SWE, possibly through its integration with other clinical assessments or biomarkers to better manage and diagnose LBP in clinical practice.

Author contribution Mónica López-Redondo: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation, Writing - Review & Editing, Visualization. Davinia Vicente-Campos: Conceptualization, Methodology, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project Administration. Javier Álvarez-González: Investigation, Resources, Data Curation, Writing - Review & Editing, Visualization. Alberto Roldán-Ruiz: Investigation, Resources, Data Curation, Writing - Review & Editing, Visualization. Sandra Sánchez-Jorge: Investigation, Resources, Data Curation, Writing - Review & Editing, Visualization. María José Díaz-Arribas: Investigation, Resources, Data Curation, Writing - Review & Editing, Visualization. Juan Antonio Valera-Calero: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project Administration.

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Data availability All data derived from this study are presented in the text.

Declarations

Institutional review board statement The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Clinical Ethics Committee of Francisco de Vitoria University (ID: UFV 15/2024).

Informed consent Informed consent was obtained from all subjects involved in the study.

Conflict of interest The authors declare no conflict of interest.

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