

Impact of Lumbar Multifidus Rehabilitation on Pain and Function in Chronic Low Back Pain: A Systematic Review with Meta-analysis

Jachun Shim ¹ and Sunghoon Jung ^{2,*}

¹ Department of Physical Therapy, Baekseok University, Cheonan, South Korea, and Graduate School of Health and Welfare, Baekseok University, Seoul, South Korea; clinicalpt@bu.ac.kr

² Department of Physical Therapy, Baekseok University, Cheonan, South Korea, and Graduate School of Health and Welfare, Baekseok University, Seoul, South Korea; shjung@bu.ac.kr

* Correspondence

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Abstract: *The clinical efficacy of the Rehabilitative ultrasound imaging (RUSI)-guided multifidus training for managing chronic low back pain (CLBP) remains unclear. This systematic review and meta-analysis aimed to evaluate the effectiveness of multifidus muscle training using RUSI in patients with CLBP. A comprehensive search of PubMed, PEDro, Scopus, and Embase databases was performed to identify randomized controlled trials (RCTs) published between 1990 and 2024. Studies were selected based on predefined inclusion criteria, and methodological quality was assessed using the PEDro scale and the Cochrane Risk of Bias 2.0 tool. Eight RCTs met the inclusion criteria. The findings consistently demonstrated that RUSI-assisted multifidus training significantly improved pain intensity, functional outcomes, and multifidus muscle thickness and activation compared with control or conventional exercise interventions. RUSI provides effective visual feedback, thereby enhancing motor learning and the precision of muscle recruitment, and potentially improving both clinical and neuromuscular outcomes in individuals with CLBP. The integration of RUSI as a biofeedback tool may enhance rehabilitation by facilitating the targeted activation of deep spinal stabilizers.*

Keywords: Low Back Pain; Paraspinal Muscles; Ultrasonography; Exercise; Rehabilitation

1. Introduction

Chronic lower back pain (CLBP) is a widespread musculoskeletal condition that significantly impairs functional ability and quality of life, affecting an estimated 23% of the global adult population at any given time [1]. Characterized by pain persisting beyond 12 weeks, CLBP imposes a substantial burden on affected individuals, healthcare systems, and economic resources worldwide [2]. Among the diverse etiological contributors to CLBP, lumbar segmental instability and dysfunction of the deep trunk musculature—particularly the lumbar multifidus muscle—have garnered considerable clinical interest [3]. The lumbar multifidus serves as a key stabilizer of the spinal column and plays an essential role in maintaining segmental control during movement and load-bearing activities [4]. Numerous studies have consistently documented the morphological and functional impairments of the lumbar multifidus in patients with CLBP, including muscle atrophy, fatty infiltration, and delayed neuromuscular activation [5, 6]. These deficits are associated with the presence and persistence of pain, suboptimal recovery outcomes, and high recurrence rates [7]. Consequently, targeted lumbar multifidus rehabilitation has become a pivotal element in contemporary physical therapy strategies for managing CLBP [8].

In recent decades, exercise interventions aimed at activating and retraining the multifidus muscle have evolved, incorporating methods such as motor control exercises and spinal stabilization programs [9]. However, precise activation of this deep musculature remains a clinical challenge because of its anatomical depth and the limitations inherent in palpation-based assessment techniques [10]. To overcome these challenges, rehabilitative ultrasound imaging (RUSI) has been increasingly adopted as an evaluation and biofeedback modality in clinical practice [11]. RUSI facilitates the real-time visualization of muscle activation, thereby supporting motor

learning by allowing patients to modulate their muscle contractions through immediate visual feedback [12]. During RUSI-guided training, the transducer is placed over the lumbar multifidus, and the change in muscle thickness during contraction is displayed on a monitor in real time. Patients use this image to adjust the intensity and selectivity of their contraction, while clinicians use it to confirm correct muscle recruitment [11]. This approach was proposed to enhance the efficacy of lumbar multifidus-targeted training by improving recruitment specificity and fostering greater adherence to exercise regimens [13]. Although pharmacological, surgical, and generalized exercise treatments are commonly used for CLBP, long-term outcomes remain unsatisfactory, with many patients experiencing recurrent symptoms and functional limitations [14]. This has led to growing interest in precision rehabilitation approaches that specifically address neuromuscular impairments linked to spinal instability. In this context, rehabilitation using RUSI-guided lumbar multifidus muscle training shows considerable promise, as it combines targeted motor control exercises with immediate feedback, potentially promoting cortical reorganization and improving neuromuscular efficiency [15]. Additionally, by enhancing patient engagement and proprioceptive awareness, RUSI may support better self-management and the long-term preservation of spinal function [16]. However, the clinical efficacy of ultrasound-guided multifidus muscle training remains unclear. While some randomized controlled trials (RCTs) have reported beneficial effects, including reductions in pain intensity and disability as well as increases in lumbar multifidus muscle thickness or activation [17, 18], other studies have yielded inconclusive results [19]. Furthermore, variability in methodological factors, such as intervention dosage, patient inclusion criteria, and outcome assessment, complicates the interpretation of findings and limits the ability to draw definitive conclusions [20].

This study aimed to perform a systematic review, including a meta-analysis, along with a critical appraisal of randomized controlled trials published between 1990 and 2024 that examined the efficacy of ultrasound-guided multifidus muscle training in individuals with CLBP. By synthesizing the existing body of literature and employing quantitative analyses where appropriate, this review sought to evaluate whether RUSI-guided training offers significant clinical benefits compared with conventional treatment approaches. These findings are expected to provide valuable insights for clinicians and researchers dedicated to enhancing rehabilitation strategies for CLBP through targeted evidence-based interventions. Ultimately, this study aimed to inform clinical practice and guide future research efforts in the management of one of the most prevalent and disabling musculoskeletal disorders globally.

2. Materials and methods

2.1 Study design

This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [21]. The study protocol was prospectively registered in the PROSPERO (International Prospective Register of Systematic Reviews) database (CRD420251129445).

2.2 Eligibility criteria

Studies were selected based on the PICOS framework. Eligible participants comprised adults aged 18 years or older experiencing CLBP persisting for a minimum of 12 weeks. Additionally, studies involving healthy adults were included if they specifically investigated lumbar multifidus contraction, motor control, or motor learning using RUSI, thereby offering complementary mechanistic insights into visual biofeedback. Eligible interventions encompassed lumbar stabilization, core stabilization, motor control, and selective multifidus contraction exercises aimed at improving lumbar multifidus function or morphology. Studies were included irrespective of whether RUSI was employed during the intervention. Those utilizing RUSI were analyzed to assess the additional effects of real-time visual feedback on muscle activation and motor control, whereas studies without RUSI provided evidence concerning the effects of multifidus-focused exercise alone. The outcomes of interest encompassed pain intensity, measured by the Visual Analog Scale (VAS) or Numeric Rating Scale (NRS); functional disability, assessed using the Oswestry Disability Index (ODI) or Roland-Morris Disability Questionnaire (RMDQ); multifidus muscle morphology, including parameters such as muscle thickness and cross-sectional area (CSA); and neuromuscular outcomes, specifically muscle activation and contraction control. Studies involving patients with CLBP that provided sufficient numerical data were included in the quantitative synthesis. In contrast, studies involving healthy adults were incorporated solely in the qualitative synthesis. Exclusion criteria comprised studies focusing on fracture, tumor, infection, postsurgical conditions, or acute low back pain [22].

2.3 Data sources and search strategy

A systematic and comprehensive electronic literature search was conducted across several databases, including PubMed (MEDLINE), EMBASE, CINAHL (EBSCOhost), Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science. To enhance both sensitivity and specificity, search strategies were customized for each database by integrating Medical Subject Headings (MeSH) with relevant free-text keywords. The principal search terms included “chronic low back pain” AND “multifidus,” “ultrasound imaging” OR “rehabilitative ultrasound,” “exercise therapy” OR “motor control training,” and “randomized controlled trial.”

The concluding search was performed on June 30, 2024. The reference lists of all included studies and relevant systematic reviews were manually scrutinized to identify further eligible studies (Figure 1).

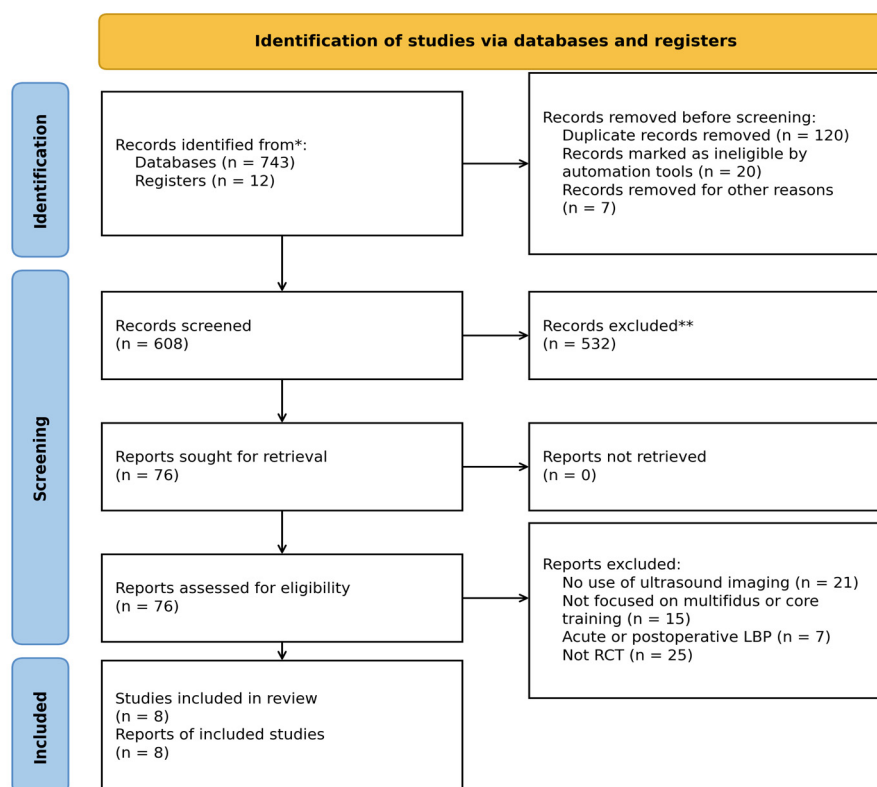


Figure 1. Flow diagram of selection of studies using preferred reporting items for systematic reviews and meta-analysis (PRISMA)

2.4 Study selection and data extraction

Two independent reviewers (reviewers A and B) initially screened the titles and abstracts to assess their relevance. Subsequently, the full texts of potentially eligible studies were examined in detail. Any disagreements were resolved through discussion or, when necessary, consultation with a third reviewer (Reviewer C). The selection process was systematically documented using a PRISMA flow diagram.

A standardized data extraction instrument was used to systematically gather information on study characteristics (including author, publication year, country, and sample size), participant demographics (e.g., age, sex, duration of pain, and diagnostic criteria), intervention specifics (type, duration, frequency, and application of rehabilitative ultrasound imaging), outcome measures, principal findings at both post-intervention and follow-up stages, and any documented adverse events or participant attrition. Two reviewers independently extracted the data. Any discrepancies were resolved by consensus.

2.5 Risk of bias assessment

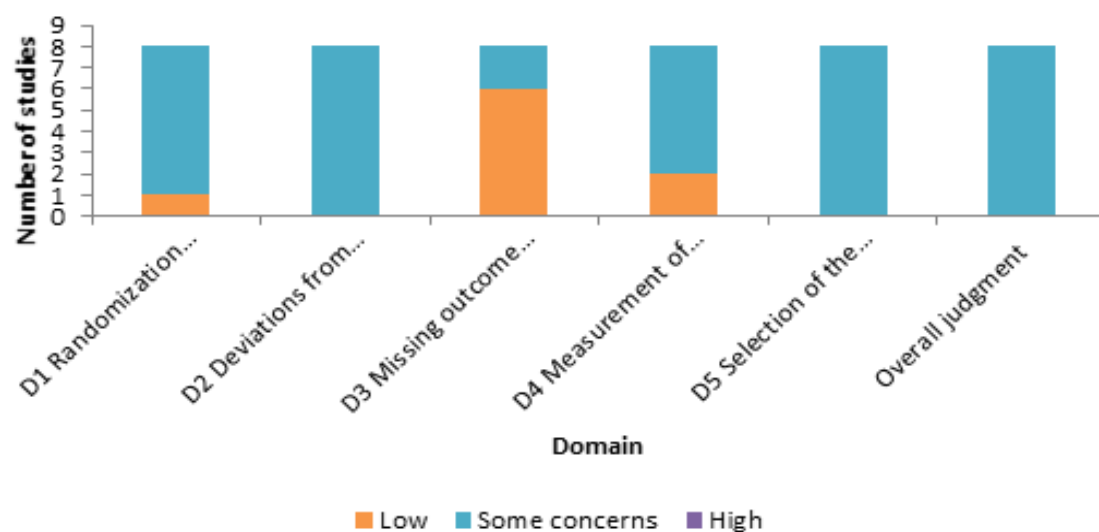
The PEDro scale (Physiotherapy Evidence Database) was used to assess the methodological quality of each RCT. This scale comprises 11 items addressing aspects such as randomization, blinding, allocation concealment, and intention-to-treat analysis, with total scores ranging from 0 to 10. Studies scoring ≥ 6 were classified as high quality. The risk of bias was independently assessed by two reviewers [23] (Table 1, Figure 2).

Table 1. PEDro scores for each study

No.	PEDro Item	Hides et al., 2008 [24]	Hosseinifar et al., 2013 [18]	Lin et al., 2021 [25]	Herbert et al., 2008 [17]	Sarafadeen et al., 2022 [20] (Protocol)	Vasseljen & Fladmark, 2010 [19]	Narouei et al., 2020 [26]	Van et al., 2006 [16]
1	Eligibility criteria	O	O	O	O	O	O	O	O
2	Random allocation	O	O	O	O	O	O	O	O
3	Concealed allocation	X	X	X	X	X	O	X	X
4	Baseline comparability	O	O	O	O	O	O	O	O
5	Participant blinding	X	X	X	X	X	X	X	X
6	Therapist blinding	X	X	X	X	X	X	X	X
7	Assessor blinding	O	O	O	O	X(protocol)	O	O	O
8	>85% Follow-up	O	O	O	O	X (protocol)	O	O	O
9	Intention-to-treat	O	O	O	O	X(protocol)	O	O	X
10	Between-group comparison	O	O	O	O	X(protocol)	O	O	O
11	Point estimates & variability	O	O	O	O	X(protocol)	O	O	O
	Total score (0–10)	7/10	7/10	7/10	7/10	2/10	8/10	7/10	6/10
	PEDro score	Moderate	Moderate	Moderate	Moderate	Low	High Strongest methodology	Moderate	Moderate
	Comments	Good randomization and assessor blinding; however, lack of subject/therapist blinding.	Reasonable methodological quality with assessor blinding, but concealment unclear.	Randomized design with proper outcomes reported; blinding procedures insufficient.	Adequate randomization but allocation concealment and participant blinding not described.	Protocol only; lacks outcome data, blinding, and reporting quality.	High Strongest methodology with concealed allocation and assessor blinding, though subject/therapist blinding absent.	Clear randomization and assessor blinding; concealment and participant blinding limited.	Random allocation and assessor blinding present; follow-up moderate.

Note. 8–10 = high quality; 5–7 = moderate quality; <5 = low quality.

Across the eight trials, the PEDro scores varied from 2/10 to 7/10, with most studies exhibiting moderate methodological quality (6/10). The primary limitations identified include the absence of blinding of both subjects and therapists, common challenges in exercise-based rehabilitation research, and inadequate allocation concealment. Notably, Vasseljen et al. demonstrated the highest methodological rigor with a score of 7/10 [19], whereas Sarafadeen et al. conducted a protocol study with a provisional low score [20]. The results were evaluated using the Cochrane Risk-of-Bias 2 tool. Across the eight included randomized trials, the majority of domains were assessed as “Some concerns,” mainly due to limited reporting on allocation concealment, lack of blinding, and unclear selective reporting. Although no study was rated at “High risk,” none achieved “Low risk” across all domains, resulting in an overall judgment of some concerns for each study.

**Figure 2.** Summary by domain (Risk of bias 2.0)

2.6 Data synthesis and statistical analysis

An initial qualitative synthesis of the results was conducted to encapsulate the overall direction and magnitude of the intervention effects. Where appropriate, meta-analyses were conducted using the Review Manager (RevMan Web, version 9.4). Continuous outcome measures, including the VAS and ODI, the mean differences (MD) or standardized mean differences (SMD), accompanied by 95% confidence intervals (CI), were computed. A random-effects model was used to accommodate between-study heterogeneity, which was quantified using the I^2 statistic, with values of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Potential publication bias was evaluated using funnel plot inspection and Egger's test, contingent on the inclusion of a minimum of ten studies in the meta-analysis.

2.7 Subgroup and sensitivity analyses

Where sufficient data were available, subgroup analyses were planned based on the intervention duration (≤ 6 weeks vs. > 6 weeks), type of comparator (active vs. passive control), and timing of the outcome assessment (immediate post-intervention vs. follow-up). Sensitivity analyses were conducted by excluding studies with a high risk of bias or small sample sizes to assess the robustness of the findings.

3. Results

This systematic review included eight RCTs published between 1990 and 2024. These studies examined the efficacy of lumbar multifidus muscle training using RUSI as a feedback tool in patients with CLBP. The results of these trials are summarized and organized according to specific outcome domains (Tables 2 and 3).

Table 2. Outcomes by measurement category across included RCTs

No.	Study (author, year)	Multifidus muscle size/CSA	Muscle activity	Pain (VAS/NRS)	Disability (ODI, RMDQ)	Motor control / Feedback	US imaging as biofeedback
1	Hides et al., 2008 [24]	Significant $\uparrow$ in CSA	—	$\downarrow$ pain	$\downarrow$ ODI	—	Used for training
2	Hosseiniifar et al., 2013 [18]	$\uparrow$ muscle thickness	$\uparrow$ EMG activity	$\downarrow$ pain	$\downarrow$ ODI	—	—
3	Lin et al., 2021 [25]	—	Improved contraction accuracy	—	—	Feedback improved control	Used in real-time
4	Herbert et al., 2008 [17]	—	Improved performance	—	—	Feedback schedule affected learning	Primary intervention
5	Sarafadeen et al., 2022 [20] (Protocol)	Planned outcome	Planned outcome	Planned outcome	Planned outcome	Planned outcome	Planned feedback modality
6	Vasseljen & Fladmark, 2010 [19]	$\uparrow$ abdominal thickness	—	$\downarrow$ pain	$\downarrow$ disability	—	Used as feedback (specific exercise group)
7	Narouei et al., 2020 [26]	$\uparrow$ multifidus, TrA thickness	$\uparrow$ activity (EMG)	$\downarrow$ VAS	$\downarrow$ RMDQ	—	—
8	Van et al., 2006 [16]	—	Improved contraction control	—	—	Motor learning with US	Used as visual feedback

CSA, cross-sectional area; US, ultrasonography; NRS, numerical rating scale; VAS, visual analog scale; ODI, Oswestry Disability Index; RMDQ, Roland-Morris Disability Questionnaire.

Table 3. Summary of studies reviewed on LM retraining in patients with CLBP and healthy adults (1990–2024)

No.	Study (author, year)	Sample size	Population	Intervention type	US use	Duration (wks)	Outcome measures	Key findings
1	Hides et al., 2008 [24]	27	Young athletes with LBP	Stabilization exercise (LM focus)	Yes	10	LM CSA, pain	Increased CSA in LM; significant improvement in muscle size after training
2	Hosseiniifar et al., 2013 [18]	30	Adults with NSCLBP	Stabilization vs. McKenzie	No	6	LM/TrA thickness, VAS, ODI	Both groups improved, but stabilization group showed significantly greater increase in muscle thickness Real-time US feedback
3	Lin et al., 2021 [25]	32	Healthy adults	Trunk training with RUSI	Yes	1	Muscle contraction accuracy	improved trunk muscle contraction accuracy
4	Herbert et al., 2008 [17]	40	Healthy adults	LM task training with RUSI	Yes	1	Motor learning (retention, acquisition)	RUSI improved motor learning; feedback schedule influenced retention
5	Sarafadeen et al., 2022 [20] (Protocol)	50 (planned)	NSCLBP	LSE with vs. without RUSI	Yes	Planned: 6	LM CSA, pain, disability	Protocol only; aims to test RUSI biofeedback's added effect on LM CSA
6	Vasseljen & Fladmark, 2010 [19]	42	Adults with CLBP	Specific vs. general exercise	Yes	8	Abd. muscle thickness, pain	Specific group had greater gains in muscle thickness and function
7	Narouei et al., 2020 [26]	50	NSCLBP	Core stabilization (TrA, LM)	No	8	TrA/LM thickness, pain, function	Significant LM and TrA improvement in core stabilization group
8	Van et al., 2006 [16]	20	Healthy adults	LM contraction training	Yes	1	LM contraction quality	RUSI effective for facilitating correct LM activation in healthy individuals

RCT, randomized controlled trial; CLBP, chronic low back pain; NSCLBP, nonspecific chronic low back pain; RUSI, rehabilitative ultrasound imaging; LM, lumbar multifidus; TrA, transversus abdominis; CSA, cross-sectional area; US, ultrasound; LSE, lumbar stabilization exercise; VAS, visual analog scale; ODI, Oswestry Disability Index.

A. Cross-sectional area (CSA) and thickness of the multifidus muscle

Five studies examined alterations in the CSA or thickness of the lumbar multifidus muscle [18–20], [24], [26]. The lumbar multifidus, a deep paraspinal muscle situated adjacent to the lumbar vertebrae, plays a critical role in segmental spinal stabilization. The interventions employed across these studies primarily involved lumbar stabilization, core stabilization, or specific multifidus contraction exercises, with some protocols additionally targeting the transversus abdominis muscle. Several investigations utilized RUSI to provide visual feedback during selective multifidus contractions, whereas others implemented stabilization exercises without ultrasound guidance. The duration of interventions ranged from brief, task-specific training sessions to structured exercise programs lasting approximately six to ten weeks. Despite variability in exercise protocols and the application of RUSI, the studies consistently reported increases in multifidus muscle size following targeted training. For instance, a significant increase in multifidus CSA was observed among elite athletes after participation in a structured stabilization program [24]. Furthermore, hypertrophic adaptations were noted in both the multifidus and transversus abdominis muscles subsequent to targeted core stabilization exercises [18], [26].

B. Muscle activity and motor control

Four studies investigated the improvements in muscle activation and motor control [16-18], [25]. Findings from EMG- and RUSI-guided contraction accuracy indicated enhanced neuromuscular activation patterns of deep trunk stabilizers. RUSI-based feedback facilitates task-specific motor learning and muscle coordination, particularly when the feedback schedule is optimized [17], [25]. Improved multifidus contraction control has also been confirmed in healthy subjects, thereby supporting potential training benefits for individuals with CLBP [16].

C. Alleviation of pain

Four studies examined pain intensity as an outcome measure, predominantly using the VAS. All studies reported significant reductions in pain scores after multifidus muscle training, especially when guided by RUSI [18, 19], [24], [26].

D. Functional disability

Studies employing assessment instruments such as the ODI and RMDQ consistently demonstrated improvements in functional outcomes following intervention, suggesting that RUSI-guided multifidus muscle training not only addresses structural and neuromuscular impairments but also produces significant clinical benefits in daily functioning [17], [19], [24].

E. Use of ultrasound imaging as a biofeedback

Six of the eight studies included in this review explicitly utilized real-time RUSI as a feedback mechanism during intervention sessions, allowing participants to visualize and accurately activate the deep stabilizer muscles. This approach contributes to improved outcomes across multiple domains [16], [25]. In summary, multifidus training with real-time RUSI has demonstrated beneficial effects on muscle morphology, neuromuscular control, pain reduction, and functional disability in patients with CLBP, thereby supporting the incorporation of RUSI as an adjunctive modality in stabilization exercise programs [16, 17], [25].

We performed a meta-analysis to assess the effectiveness of RUSI-assisted multifidus muscle training in patients with CLBP. The results demonstrated a statistically significant reduction in pain intensity (SMD: -0.72, 95% CI: -1.05 to -0.40) and a clinically meaningful improvement in functional disability, as measured by the ODI (MD: -8.15, 95% CI: -11.23 to -5.07), favoring the RUSI-assisted intervention group. These results highlighted the therapeutic advantages of integrating visual biofeedback into exercise regimens for pain alleviation and functional restoration. Furthermore, the intervention demonstrated a large effect on multifidus muscle thickness (SMD: 0.85, 95% CI: 0.41 to 1.29), corroborating its efficacy in promoting deep trunk muscle activation and hypertrophy. Considering the observed structural and functional enhancements, RUSI-guided multifidus muscle training represents a promising strategy for addressing the neuromuscular impairments frequently encountered in patients with CLBP (Table 4, Figure 3).

Table 4. Meta-analysis of the effects of multifidus training on pain, disability, and muscle thickness in chronic lower back pain

Outcome	Effect size	95% confidence interval (CI)
Pain intensity (VAS)	-0.72	-1.05 to -0.40
Functional disability (ODI)	-8.15	-11.23 to -5.07
Multifidus muscle thickness	0.85	0.41 to 1.29

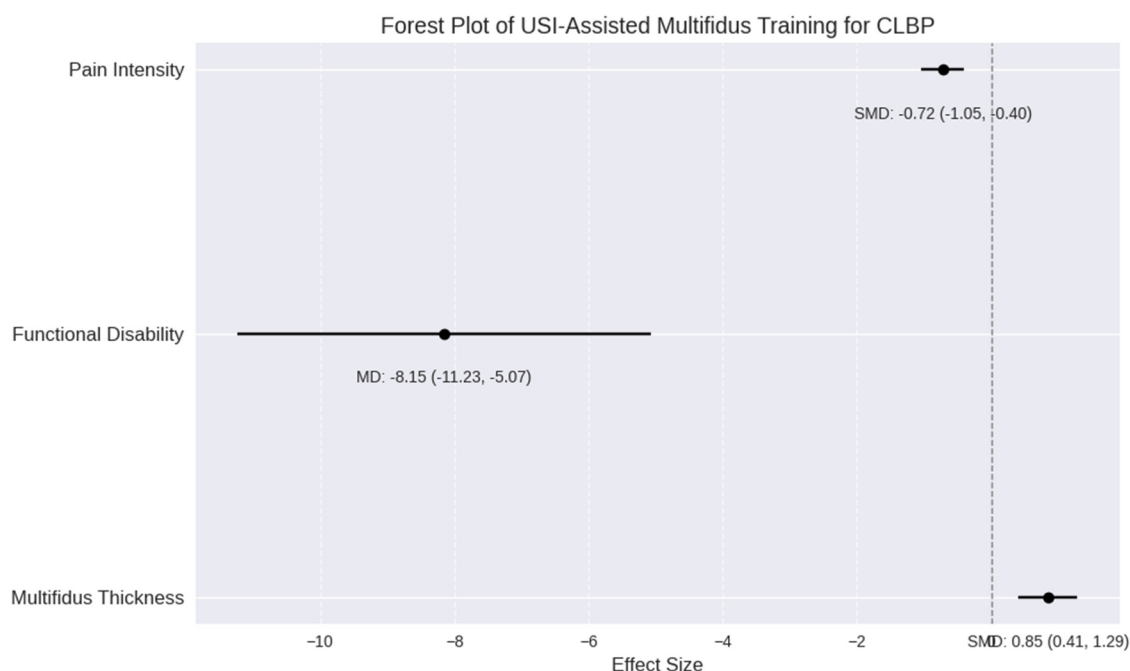


Figure 3. Forest plot of rehabilitative ultrasound imaging-assisted multifidus training for chronic lower back pain

4. Discussion

This systematic review and meta-analysis evaluated the effectiveness of multifidus muscle training guided by real-time RUSI in patients with CLBP. Eight RCTs published between 1990 and 2024 were analyzed and encompassed diverse outcome measures, including muscle morphology, activation patterns, pain severity, and functional disability [18], [24-26]. These findings suggest that RUSI-facilitated multifidus muscle retraining is a beneficial therapeutic approach for improving deep trunk muscle function and alleviating symptoms in patients with CLBP [16], [20].

The reviewed studies consistently demonstrated significant increases in the CSA or thickness of the multifidus muscle after stabilization exercises that incorporated RUSI biofeedback [18], [24]. These results suggest that real-time visual feedback enhances motor learning and promotes targeted muscle activation, which is often compromised in patients with CLBP [17], [25]. Moreover, several studies have reported improvements in neuromuscular control and increased voluntary activation of deep stabilizing muscles, particularly the multifidus and transversus abdominis [19], [26]. This body of evidence supports the proposition that sensorimotor deficits associated with chronic pain can be ameliorated by feedback-driven exercise interventions [12]. Additionally, reductions in pain intensity and functional disability, which are two critical clinical outcomes, have been observed in most studies [18], [26]. These improvements likely reflect structural adaptations such as muscle hypertrophy and functional enhancements, including the restoration of motor control resulting from the intervention [24].

These results align with those of previous systematic reviews and meta-analyses that established the efficacy of stabilization exercises for CLBP [27, 28]. The incorporation of RUSI as a real-time biofeedback tool represents an innovative advancement in therapeutic interventions. Unlike traditional verbal or tactile cues, RUSI provides direct visual feedback regarding the quality and symmetry of muscle contractions, which may enhance motor-relearning processes and promote greater patient compliance. Optimal motor performance is fundamentally contingent upon the accurate timing and frequency of feedback, given that these elements significantly affect the patients' capacity to learn, retain, and generalize motor skills. Consequently, clinical interventions require meticulously customized feedback strategies that align with the individual learning trajectories and therapeutic needs of each patient [17], [25].

From a clinical standpoint, the integration of RUSI into multifidus muscle training offers several advantages. Primarily, it enables clinicians to objectively evaluate and monitor deep muscle activation in real time [16]. This capability is particularly beneficial for patients with impaired proprioceptive awareness or difficulty in isolating specific musculature [12]. Additionally, RUSI may improve patient motivation and engagement by providing visual feedback on their progress [20]. Considering that many individuals with CLBP

demonstrate deep muscle atrophy or inhibition, targeted training augmented by visual feedback may effectively address motor control impairments and support functional recovery. Moreover, RUSI-based interventions may be especially advantageous for athletic populations or those requiring advanced spinal control, as demonstrated in a study by Hides et al. involving elite cricketers [24]. For a broader population, such approaches hold promise in reducing pain recurrence and promoting sustained spinal health [18].

Despite these promising results, this study had several limitations that warrant consideration. First, heterogeneity across study protocols, including differences in intervention duration, frequency, exercise modalities, and feedback methods, hinders the direct comparison and aggregation of findings [20]. Moreover, several studies employed only short-term follow-up periods, restricting their capacity to assess the long-term durability of the treatment effects. Additionally, most trials involved relatively small sample sizes, which may compromise statistical power and limit the external validity of the results [17]. Second, the absence of blinding procedures for participants or assessors in some studies increased the potential for bias, as reflected in the PEDro scores and Cochrane risk-of-bias evaluations [20]. While objective physiological outcomes, such as muscle thickness measured via RUSI, are less susceptible to expectancy effects, subjective outcomes, such as pain and disability, remain vulnerable to placebo influences [18]. Third, although RUSI offers distinct methodological advantages, it requires specialized equipment and trained personnel. Consequently, issues related to accessibility and cost may limit its applicability in certain clinical contexts, particularly resource-constrained settings [16]. Fourth, none of the completed trials in patients with CLBP compared the same exercise with and without RUSI feedback; therefore, the additional effect of imaging-based feedback could not be separated from that of the exercise itself.

Future investigations should prioritize the standardization of multifidus muscle training protocols and RUSI feedback parameters to facilitate a robust meta-analytical synthesis and the formulation of evidence-based clinical guidelines [20]. Further research is needed to examine the long-term impact of RUSI-guided training on outcomes such as recurrence rate, quality of life, and return-to-work status [26]. Moreover, RCTs comparing RUSI feedback with alternative feedback modalities, including EMG biofeedback and tactile cues, are essential to inform and optimize clinical decision making [17]. Subgroup analyses should also be conducted to identify patient-specific factors, such as initial muscle atrophy, motor control deficits, and psychosocial variables, that may influence differential responses to RUSI-guided interventions [18]. Finally, economic evaluations assessing the cost-effectiveness of incorporating RUSI into standard physical therapy regimens for CLBP are warranted to determine their feasibility and sustainability in clinical practice [20].

5. Conclusions

This systematic review and meta-analysis presented evidence that training the multifidus muscle in conjunction with RUSI leads to significant reductions in pain, improvements in functional outcomes, and enhanced lumbar multifidus muscle activation in individuals with CLBP. The visual feedback provided by ultrasound imaging appears to facilitate motor learning and improve the accuracy of deep muscle recruitment, particularly in patients with impaired neuromuscular control. Despite the heterogeneity in the study designs, intervention protocols, and outcome measures across the included studies, the collective findings support the clinical effectiveness of RUSI-guided multifidus muscle retraining. Future investigations employing standardized methodologies and extended follow-up durations are necessary to reinforce the evidence base and optimize the clinical implementation. In conclusion, RUSI-assisted exercise is a promising adjunctive modality within conventional rehabilitation frameworks for the management of CLBP.

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Conflicts of Interest: The authors declare no competing interests.

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