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Original Article

Biofeedback-Based Deep Muscle Strengthening in Elderly Patients with Low Back Pain: A Randomized Controlled Trial

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SUMMARY

Background: This study examined the effects of deep muscle strengthening exercises based on biofeedback regarding pain, functional disability, balance ability, quality of life, and muscle thickness in elderly individuals aged over 65 years with low back pain (LBP).
Objects: Forty-four elderly individuals aged over 65 years with LBP participated in the study. The participants were assigned to either the experimental group (n = 23) or the control group (n = 23) using a randomization program. Both groups performed deep muscle strengthening exercises with the abdominal drawing-in maneuver (ADIM). The experimental group also incorporated biofeedback. All interventions were conducted for approximately 30 minutes per session, three times a week, for four weeks. The Numeric Rating Scale (NRS), the Korean version of the Oswestry Disability Index (K-ODI), the Berg Balance Scale (BBS), quality of life (Short Form-12 Health Survey Questionnaire, SF-12), muscle thickness, and thickness ratio were measured before and after the intervention and compared.
Results: Both groups showed significant changes in the NRS, K-ODI, BBS, PCS, MCS, muscle thickness during contraction, and contraction ratio after the intervention ($p < 0.05$). In addition, the experimental group showed significant differences in NRS, K-ODI, BBS, PCS, MCS, muscle thickness during contraction, and contraction ratio compared to the control group ($p < 0.05$).
Conclusion: Deep muscle strengthening exercises based on biofeedback can be an effective intervention for improving the pain levels, motor function, quality of life, muscle thickness, and contraction ratio of the diaphragm in elderly patients aged 65 years or older with LBP.

1. Introduction

The improvements in living standards and medical technology have led to increases in the average life expectancy of the elderly in Korea, and the proportion of the elderly population is increasing rapidly.[1] Low back pain is one of the most common musculoskeletal disorders, affecting up to 85% of adults at least once in their lifetime and imposing significant physical, psychological, and social burdens, particularly in the elderly. In this population, degenerative changes in the spine because of aging, weakening of the surrounding muscles, and muscle imbalance worsen functional limitations and quality of life.[2]

The degenerative changes in the spine, along with spinal deformities, result in instability of the lumbar region, causing misalignment and imbalance.[3] In addition, they impair the motor control, strength, and endurance of muscles surrounding the lumbar spine, leading to persistent stress and discomfort in the lumbar area.[4] This discomfort and stress cause physical and mental anxiety, decrease basic motor control, deteriorate activities of daily living, and diminish balance.[5]

Chronic low back pain leads to physical impairments, such as a restricted range of motion in the lumbar joints and decreased trunk strength, endurance, and flexibility, resulting in a decline in balance, a critical factor for the elderly.[6] Maintaining balance is a fundamental requirement for the daily activities and purposeful tasks of elderly individuals, and it plays a key role in sustaining stability.[7] Age-related decline in balance ability increases the risk of falls, lowers the quality of life, reduces physical activity, and causes challenges in maintaining independent daily living, negatively impacting the quality of life in the elderly.[8]

Low back pain in the elderly causes reduced lumbar strength and endurance, impairs postural control, and restricts social participation and daily activities.[9] Moreover, low back pain has psychological effects on elderly patients, causing anxiety, depression, decreased exercise self-efficacy, and reduced quality of life.[9] These psychological problems can adversely affect the health and quality of life of the elderly.[10] The quality of life scale for the elderly is important for evaluating the impact of psychological and socio-cultural factors, as well as social participation in older adults.[11]

The abdominal drawing-in maneuver (ADIM) is one of the primary interventions for reducing pain, restoring functional ability, improving balance, and enhancing spinal alignment in patients with low back pain.[12] This technique is commonly used in clinical settings to enhance the stability of the lumbar spine and strengthen the deep muscles, particularly in elderly patients with low back pain.[12] The

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ADIM involves applying an abdominal hollowing technique and diaphragmatic breathing to induce contractions of the diaphragm and transverse abdominis, increasing the intra-abdominal pressure and stabilizing the lumbar region through muscle contraction.[13] Building on this approach, biofeedback can be incorporated to provide real-time visual or auditory cues, allowing patients to more accurately engage the targeted deep muscles and optimize the effects of ADIM.

Deep muscle strengthening exercises, which focus on controlling the small and large muscle groups, are practical in enhancing lumbar segmental control, improving lumbar dysfunction and coordination, and strengthening core muscles.[14] This leads to an increase in intra-abdominal pressure, improving the lumbar stability. These exercises help align the spinal segments correctly, enhance the strength and function of the abdominal muscles, and reduce pressure on the lumbar spine.[15] In particular, deep muscle strengthening exercises engage the abdominal muscles and activate pelvic muscles, positively affecting the balance ability.[16]

Extensive research has been conducted on interventions for pain reduction, functional improvement, and balance enhancement in patients with low back pain.[17,18] However, no study has specifically examined deep muscle-strengthening exercises using biofeedback to improve pain, function, balance, quality of life, and diaphragm muscle thickness in elderly individuals with low back pain. Therefore, this study investigated the effects of deep muscle strengthening exercises with bio-pressure feedback on lumbar pain, motor function, quality of life, and diaphragm muscle thickness in elderly patients aged 65 years and older with low back pain. This study aims to provide evidence for the clinical utility and validity of deep muscle-strengthening exercises using biofeedback.

2. Methods

2.1. Participants

This study was conducted on 53 patients aged 65 or older receiving outpatient treatment for low back pain at S Hospital in M City. The participants were selected after receiving a detailed explanation of the study purpose and procedures, and they voluntarily agreed to participate. The intervention period lasted from April to August 2024. The inclusion criteria were as follows: 1) individuals aged 65 or older, 2) a minimum score of 3 on the Numeric Rating Scale (NRS) for pain,[19] 3) no history of lumbar surgery, and 4) no fractures or spinal deformities. The exclusion criteria were as follows: 1) individuals unable to participate due to systemic diseases such as cancer, 2) those with difficulty performing movements, 3) individuals unable to participate because of respiratory diseases, and 4) those exposed to fractures or infectious diseases.

2.2. Study design

This study used a pre-test post-test control group design, with the sample size determined using the G*power program (G-power, University of Kiel, Kiel, Germany). Twenty-one participants were required for the groups based on the primary effect size (d) of 0.80 from Oh et al.,[13] a significance level (α) of 0.05, and a power ($1-\beta$) of 0.80. The minimum number of participants per group was set to 23, considering a 10% dropout rate.[20] Of the 53 participants initially recruited, seven dropped out during the selection process because they refused to participate. After conducting pre-tests on the remaining 46 participants, they were assigned randomly to the experimental group and control group using the random assignment program (http://www.randomizer.org), which generated random numbers to assign participants to the experimental group (n = 23) or control group (n = 23).

The intervention was conducted over 4 weeks, which was determined based on previous randomized controlled trials reporting significant improvements in pain, muscle activation, and functional ability after 3–6 weeks of core stabilization or biofeedback-assisted exercise programs in elderly individuals with low back pain.[13] All outcome assessments were performed by a physical therapist who was blinded to group allocation to minimize measurement bias.

All participants performed deep muscle strengthening exercises accompanied by the ADIM, and the experimental group additionally received biofeedback. Outcome measures were assessed before and after the intervention and included the Numeric Rating Scale (NRS), Korean version of the Oswestry Disability Index (K-ODI), quality of life (Short Form-12 Health Survey Questionnaire, SF-12), Berg Balance Scale (BBS), and diaphragm muscle thickness and contraction ratio (thickness ratio) (Figure 1). This study was approved by the Ethics Committee of Kwangju Women's University and registered in the WHO International Clinical Trials Registry Platform (KCT0010431).

2.3. Intervention

2.3.1. Abdominal drawing-in maneuver (ADIM)

The ADIM, which was applied to both groups, is a breathing technique designed to selectively contract the diaphragm and transverse abdominis, increasing intra-abdominal pressure and stabilizing the lumbar spine.[21] All participants performed the exercise in the supine position, inhaling through their nose while expanding their abdomen as much as possible without moving the chest. During exhalation, they were trained to gently open their mouth and breathe out, ensuring maximal abdominal contraction.[21] The participants were instructed to prolong exhalation while maintaining lower abdominal contraction, minimizing the residual volume of air in their lungs.

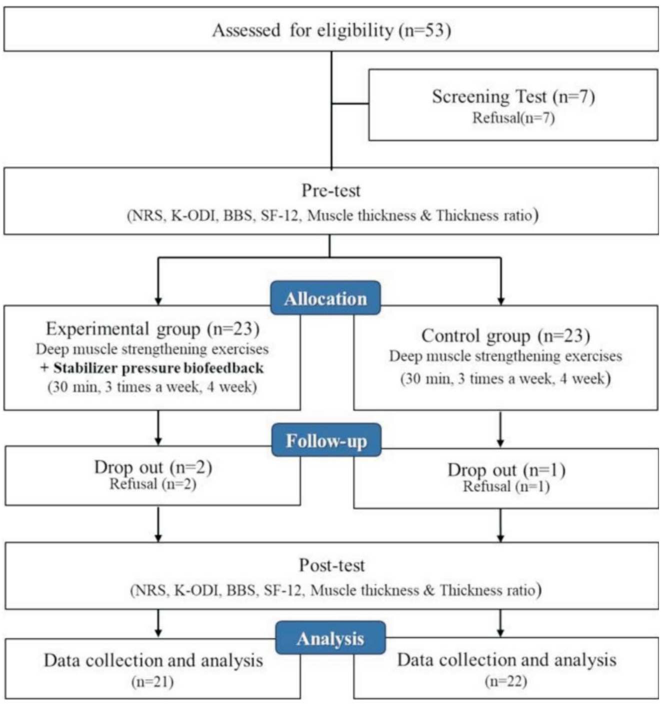

Figure 1. CONSORT flow chart. BBS, Berg Balance Scale; K-ODI, Korean version of the Oswestry Disability Index; NRS, Numeric Rating Scale; SF-12, Short Form-12 Health Survey Questionnaire.

2.3.2. Deep muscle strengthening exercises

The deep muscle strengthening exercises applied to both groups were modified and supplemented from the intervention exercise program method developed by Oh et al.[13] This exercise promotes the stability of the abdominal muscles through selective contraction, maintaining a neutral posture. The program consisted of five movements: lying leg raises (Figure 2A), lying leg tilt to the left (Figure 2B), lying leg tilt to the right (Figure 2C), cross-arm curl-ups (Figure 2D), and lift arms forward curl-ups (Figure 2E). Five-minute warm-up and cool-down stretching routines were implemented before and after the intervention. The exercise program was performed for three sets of three repetitions, increasing the duration by 20 seconds each week, with a 30-second rest between sets. The intervention was conducted for 30 minutes per session, three times a week, over four weeks.

2.3.3. Deep muscle strengthening exercises with biofeedback

In the experimental group, deep muscle strengthening exercises were conducted with the ADIM, and biofeedback was incorporated to quantify exercise intensity. Stabilizer pressure biofeedback (Chattanooga, USA) was used to achieve this. The biofeedback device was positioned on the participant's lumbar lordosis, with the pressure set to 40 mmHg, maintaining a pressure range of 0 to 6 mmHg until the end of exhalation. Most participants showed a 0–10 mmHg pressure increase from 40 mmHg while performing ADIM. Pressure increases above 6 mmHg exacerbated low back pain and muscle fatigue. Thus, the exhalation intensity was adjusted to maintain the pressure within the 0–6 mmHg range.[13]

2.4. Assessment methods

2.4.1. Pain level

The NRS, which quantifies pain intensity on a scale from 0 to 10, was used to assess the level of lumbar pain among participants. Higher scores indicate greater pain intensity. The NRS has shown high reliability, with an intraclass correlation coefficient (ICC) of .61.[22]

2.5. Motor function

2.5.1. Functional ability

The Korean version of the Oswestry Disability Index (K-ODI) proposed by Kim et al.[23] was used to evaluate the degree of functional impairment caused by low back pain in the study participants. The K-ODI consists of nine items, including social activities, traveling and mobility, standing, walking, sitting, pain level, personal hygiene, lifting objects, and sleeping, each rated on a scale from 0 to 5, with a total score of 45 points. A higher score indicates a greater functional limitation caused by low back pain. The test-retest reliability of the K-ODI was high, with a correlation coefficient of r = .92.[23]

2.5.2. Balance ability

The participants' balance ability was assessed using the BBS for the evaluations before and after the intervention. The BBS is a tool for assessing static and dynamic balance, divided into three areas: sitting, standing, and transitions, consisting of 14 detailed items.[24] The tool uses a five-point scale ranging from 0 to 4, with a maximum total score of 56. The intra-rater reliability of the BBS is r = 0.99, while the inter-rater reliability is r = 0.98, indicating a high level of reliability.[25]

2.5.3. Quality of life

The SF-12 was used as a health-related quality of life measurement tool to measure the participants' quality of life. The SF-12, developed by Ware and Sherbourne,[26] is a shortened version of the SF-36 and comprises 12 items categorized into two main components: physical and mental health. These components were further divided into eight subdomains. The physical health component comprises four subdomains: physical functioning, role limitations due to physical problems, bodily pain, and general health. Similarly, the mental health component includes four subdomains: role limitations caused by emotional problems, mental health, vitality, and social functioning. Each item is rated on a one to five-point scale, with higher scores indicating better health status. The total score ranges from a minimum of 6 to a maximum of 30 in the Physical Component Summary (PCS) and Mental Component Summary (MCS) domains.[27] The overall score is derived by summing the scores of all 12 items. The reliability of the SF-12 has been reported as high, with a Cronbach's alpha value of .81.[27]

2.5.4. Muscle thickness and thickness ratio

An ultrasound device (MySonoU6, Samsung, Korea) was used to

Figure 2. Deep muscle strengthening exercises with biofeedback.

measure the diaphragm thickness of the participants. The participants were positioned supine, and the mid-axillary line between the eighth and ninth ribs was identified. A 3.5 MHz linear transducer was placed perpendicularly against the chest wall to capture a two-dimensional image of the area between the eighth and ninth ribs during contraction. The measurements were taken during expiration after setting the pressure to 5 mmHg during relaxation. The inter-rater reliability for measuring diaphragm movement and thickness using ultrasound was reported to be very high, with a correlation coefficient of r = .99.[28]

Calculation of Contraction Ratio: Contraction Thickness / Relaxation Thickness.

2.6. Statistical analysis

The data were analyzed using SPSS software (version 21.0, IBM, USA). The general characteristics of the participants are presented using descriptive statistics, including means and standard deviations. The Shapiro-Wilk test was used to assess normality. A chi-square test was performed to analyze the participants' gender, while a t-test was conducted to analyze the homogeneity of the other general characteristics and pre-test values. An independent samples t-test was used to compare the changes before and after the intervention between groups, and paired samples t-tests were used to compare the changes in the dependent variables before and after the intervention within groups. The statistical significance level (α) was set to 0.05.

3. Results

Among the 46 participants initially enrolled in this study, three participants withdrew (two from the experimental group and one from the control group), resulting in final data from 21 participants in the experimental group and 22 in the control group. Table 1 lists the general characteristics of the study participants.

For the NRS, K-ODI, PCS, MCS, and BBS, there were no significant differences between the two groups before the intervention. Both groups showed significant improvement after the intervention ($p < 0.05$). The experimental group demonstrated greater improvements in the NRS, K-ODI, PCS, MCS, and BBS scores compared to the control group ($p < 0.05$) (Table 2).

The expiration, inspiration, and thickness ratios of the diaphragm were similar in the two groups before the intervention. Both groups showed significant improvement in diaphragm thickness during inspiration and thickness ratios after the intervention ($p < 0.05$). Furthermore, the experimental group showed better results in diaphragm thickness during inspiration and thickness ratios than the control group ($p < 0.05$) (Table 3).

4. Discussion

This study examined the qualitative effects of deep strengthening exercises using biofeedback on elderly patients aged 65 years and older with low back pain. The results indicated significant differences in the NRS, K-ODI, PCS, MCS, BBS, diaphragmatic muscle thickness during contraction, and contraction ratio among all participants. Furthermore, in the experimental group, which performed deep strengthening exercises with biofeedback, significant changes in the NRS, K-ODI, PCS, MCS, BBS, muscle thickness during contraction, and contraction ratio were observed compared to the control group.

Elderly individuals aged 65 and older often experience physical imbalances due to aging, including decreases in muscle mass, strength, and endurance. Degenerative changes in the lumbar spine, decreased muscular endurance, and reduced flexibility further increase the burden on the lumbar region. GE et al.[29] reported a de-

Table 1
General characteristics.

	Experimental group (n = 21)	Control group (n = 22)	t/χ^2	p
Sex (male/female)	6/15	6/16	-0.930	0.927
Age (year)	69.94 ± 3.24	70.32 ± 2.94	-0.364	0.718
Height (cm)	159.81 ± 3.10	160.29 ± 4.35	-0.395	0.695
Weight (kg)	58.28 ± 4.66	57.47 ± 4.35	0.505	0.617
BMI (score)	22.30 ± 1.63	21.78 ± 1.60	0.975	0.336

[a] Mean ± standard deviation. BMI, body mass index.

Table 2
Comparison of before and after the intervention between groups.

	Experimental group (n = 21)	Control group (n = 22)	t(p)
NRS (point)			
Pre	7.67 ± 0.69	7.95 ± 0.78	-1.164 (0.252)
Post	2.55 ± 1.10	3.74 ± 0.56	
Post-pre	-5.11 ± 1.13	-4.21 ± 0.92	2.758 (0.013)*
t(p)	-19.159 (0.000)*	-20.000 (0.000)*	
K-ODI (score)			
Pre	19.11 ± 6.17	18.05 ± 4.29	0.609 (0.547)
Post	9.17 ± 3.11	13.53 ± 3.12	
Post-pre	-9.94 ± 4.81	-4.53 ± 2.74	4.336 (0.000)*
t(p)	-8.776 (0.000)*	-7.211 (0.000)*	
BBS (score)			
Pre	33.06 ± 5.12	33.11 ± 5.94	-0.027 (0.978)
Post	43.56 ± 4.08	39.11 ± 5.35	
Post-pre	10.50 ± 6.14	6.00 ± 2.71	-3.012 (0.008)*
t(p)	7.258 (0.000)*	9.658 (0.000)*	
PCS (score)			
Pre	32.18 ± 2.89	32.26 ± 3.96	-0.068 (0.946)
Post	51.68 ± 1.73	47.70 ± 2.90	
Post-pre	19.50 ± 3.05	15.44 ± 4.24	-2.864 (0.011)*
t(p)	27.099 (0.000)*	15.881(0.000)*	
MCS (score)			
Pre	29.94 ± 3.42	29.65 ± 4.27	1.104 (0.278)
Post	51.85 ± 4.46	46.37 ± 2.98	
Post-pre	21.91 ± 6.49	16.72 ± 5.88	-2.418 (0.027)*
t(p)	14.316 (0.000)*	12.404 (0.000)*	

[a] Mean ± standard deviation. BBS, Berg Balance Scale; K-ODI, Korean version of the Oswestry Disability Index; MCS, mental component summary; NRS, Numeric Rating Scale; PCS, physical component summary.

Table 3
Comparison of before and after the intervention between groups.

	Experimental group (n = 21)	Control group (n = 22)	t(p)
Expiration (mm)			
Pre	0.22 ± 0.02	0.23 ± 0.02	-0.602 (0.552)
Post	0.22 ± 0.02	0.23 ± 0.02	
Post-pre	0.00 ± 0.01	0.00 ± 0.01	0.437 (0.668)
t(p)	0.187 (0.854)	0.438 (0.667)	
Inspiration (mm)			
Pre	0.27 ± 0.02	0.28 ± 0.02	-0.888 (0.381)
Post	0.48 ± 0.03	0.34 ± 0.03	
Post-pre	0.21 ± 0.03	0.06 ± 0.02	-18.548 (0.000)*
t(p)	33.388 (0.000)*	11.914 (0.000)*	
Thickness ratio (%)			
Pre	1.22 ± 0.06	1.22 ± 0.07	-0.023 (0.982)
Post	2.16 ± 0.18	1.49 ± 0.12	
Post-pre	0.94 ± 0.15	0.27 ± 0.13	-14.347 (0.000)*
t(p)	26.638 (0.000)*	9.325 (0.000)*	

[a] Mean ± standard deviation.

crease in pain ($p < 0.05$, effect size, $d = 1.71$) after four weeks of deep strengthening exercises using small equipment in women aged 60 years and older. Lee et al.[30] reported a significant reduction in pain ($p < 0.05$, effect size, $d = 1.39$) after 16 weeks of lumbar stabilization exercises for elderly patients aged 65 years and older with chronic low back pain. In this study, all participants showed a significant decrease in pain after the intervention (effect size, $d = 2.81$), with additional significant differences observed between the experimental group using biofeedback and the control group ($p < 0.05$, effect size, $d = 0.87$). These results suggest that deep strengthening exercises with biofeedback enhanced the quantification and accuracy of exercise intensity in the experimental group, helping improve muscle strength and pain indicators.

In elderly patients with low back pain, the recruitment patterns and activation levels of deep trunk muscles and hip extensor muscles differ from those without low back pain. These differences lead to dysfunction, imbalance in trunk muscles, and reduced balance in patients with low back pain. Shin[31] reported a decrease in functional disability ($p < 0.05$, effect size, $d = 0.54$) after eight weeks of lumbar stabilization exercises in elderly patients with chronic low back pain aged 65 and older. Patti et al.[32] observed improvements in balance ability ($p < 0.05$, effect size, $d = -0.76$) following 13 weeks of lumbar stabilization exercises in elderly patients with low back pain. Consistent with these findings, this study observed significant improvements in functional disability (effect size, $d = 2.03$) and balance ability (effect size, $d = 2.26$) among the participants after the intervention ($p < 0.05$). Significant differences were observed between the experimental group using biofeedback and the control group ($p < 0.05$, effect size, $d = 1.38$). Hence, deep strengthening exercises with biofeedback helped stabilize the trunk muscles and enhance core stability, ultimately improving the indicators of functional disability and balance ability.

The decline in physical function due to aging negatively impacts healthy physical activity in older adults and has been reported to reduce their quality of life, which is often assessed through their ability to perform daily activities. Ozsoy et al.[33] observed significant improvements in quality-of-life indicators ($p < 0.05$, effect size, $d = 0.47$) after a six-week deep strengthening training program for patients aged 65 and older. Ülger et al.[34] reported significant enhancements in the quality-of-life domains ($p < 0.05$, effect size, $d = 0.30$) after applying a six-week lumbar stabilization exercise program to patients aged 70 years and older. In the present study, significant improvements in the quality of life were observed among the participants in the physical (effect size, $d = 8.18$) and mental domains (effect size, $d = 5.51$) after the intervention ($p < 0.05$). In addition, the experimental group that performed biofeedback-based exercises showed significant differences compared to the control group ($p < 0.05$, effect size, $d = 1.09$). These findings suggest that the biofeedback intervention, which focused on quantifying exercise intensity, helped enhance physical fitness in the experimental group, improve the physical and mental quality of life, and foster a greater sense of stability. Furthermore, biofeedback-assisted training may positively influence psychological aspects of rehabilitation, including exercise motivation, confidence, and fear of movement, thereby supporting more active and engaged participation in the exercise program.

The diaphragm is a critical muscle within the thoracoabdominal complex for elderly patients with low back pain. This muscle helps coordinate the lumbar muscles by increasing the pressure on the abdomen and the stability of the lumbar region, which are very important factors in back pain. Kim and Kim[35] reported that an eight-week lumbar stabilization exercise program incorporating Maitland thoracic exercises led to a significant increase in diaphragmatic thickness in patients with low back pain ($p < 0.05$, effect size, $d = 0.44$). In this study, all participants showed significant improvements in diaphragmatic thickness during contraction (effect size, $d = 8.23$) and contraction ratio (effect size, $d = 7.00$) after the intervention ($p < 0.05$). In addition, significant differences were observed between the control group and the experimental group, who performed biofeedback-based exercises ($p < 0.05$, effect size, $d = 5.88$). These findings suggest that the deep strengthening training using the ADIM applied to both groups promoted respiratory facilitation, contributing to improvements in diaphragmatic thickness and contraction ratio. The biofeedback-based quantification of deep muscle exercises in the experimental group likely provided more precise and effective exercise doses, enhancing the overall quality of the exercise intervention and suggesting potential strategies for improving long-term exercise adherence in elderly populations.

This study examined the qualitative effects of deep strengthening exercises incorporating biofeedback and the ADIM for patients aged 65 years and older with low back pain. On the other hand, several limitations should be noted. First, the average participant age of approximately 70 years makes it challenging to generalize the findings to other age groups. Second, follow-up assessments were not conducted after the intervention, limiting the evaluation of its long-term effects. Third, the sample was skewed towards female participants, making it difficult to generalize the findings across genders. Future studies should explore the potential clinical applications of biofeedback-based deep strengthening exercises in community-dwelling elderly populations and consider strategies to promote sustained long-term participation. In the future, research will be needed to provide better exercise and intervention methods for patients aged over 65 years with low back pain, taking these limitations into account.

5. Conclusion

This study examined the qualitative effects of deep strengthening exercises incorporating biofeedback and the ADIM for patients with low back pain. The findings showed significant improvements in pain, motor function, quality of life, diaphragmatic thickness during contraction, and contraction ratio in the experimental group that used biofeedback. These results highlight the innovative application of biofeedback-based deep strengthening exercises, demonstrating their potential for precise exercise dosing and enhanced engagement. Based on these results, deep strengthening training with biofeedback represents a clinically translatable intervention strategy for reducing pain, enhancing motor function and quality of life, and improving diaphragmatic thickness and contraction ratio in elderly patients aged 65 years and older with low back pain. Furthermore, this intervention shows promise for application in community-based settings and long-term rehabilitation programs, supporting sustainable improvements in physical function and quality of life among elderly populations.

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Conflict of interest

None declared.

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