Effects of High-Energy Laser Combined with Specific Exercise Therapy on Ultrasonographic Morphology of the Multifidus Muscle in Patients with Idiopathic Scoliosis and Low Back Pain: Postprint

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Abstract

Background Adolescent idiopathic scoliosis (AIS) is a progressive three-dimensional skeletal deformity that affects spinal mobility and trunk symmetry. Scholars once believed that adolescent idiopathic scoliosis was not associated with pain, but recent studies have shown that approximately 31.5% of patients suffer from low back pain. The cause of low back pain may be due to factors such as paraspinal muscle imbalance and fatigue. Objective To observe the morphological changes of the multifidus muscle at the apex of the primary curve in AIS patients with low back pain after treatment with high-intensity laser therapy (HILT) combined with physiotherapeutic scoliosis-specific exercises (PSSE) using musculoskeletal ultrasound, and to evaluate the clinical effect of the combined therapy on correcting paraspinal muscle imbalance. Methods Thirty adolescent idiopathic scoliosis patients with Rigo type E1 admitted to the Scoliosis Correction Center of Harbin Fifth Hospital from December 2020 to December 2021 were selected for a randomized single-blind controlled trial. Patients were randomly divided into an experimental group and a control group; the experimental group received HILT combined with PSSE, while the control group received HILT alone. Both groups underwent musculoskeletal ultrasound examination, Visual Analogue Scale (VAS) scoring, lumbar spinal range of motion examination, and Roland-Morris Disability Questionnaire (RDQ) survey before treatment and after 4 weeks of treatment. Pearson correlation analysis was used to explore whether there was a correlation between changes in the multifidus muscle and treatment outcomes after treatment. Results After treatment, the concave side cross-sectional area of the multifidus muscle, flexion range, left lateral flexion range, left rotation range, and right rotation range in the experimental group were higher than those in the control group (P<0.05). In the experimental group after treatment, the concave side cross-sectional area, concave side thickness, convex-to-concave side cross-sectional area ratio, convex-to-concave side thickness ratio, and extension range were higher than before treatment (P<0.05). In both groups after treatment, VAS scores and RDQ scores were lower than before treatment, while flexion range, left lateral flexion range, right lateral flexion range, left rotation range, and right rotation range were higher than before treatment (P<0.05). In the control group after treatment, extension range was lower than before treatment (P<0.05). Pearson correlation analysis showed that the convex-to-concave side cross-sectional area ratio of the multifidus muscle after treatment was negatively correlated with right rotation range of the lumbar spine after treatment (r=-0.660, P<0.01), and the convex-to-concave side thickness ratio of the multifidus muscle after treatment was negatively correlated with right lateral flexion range of the lumbar spine after treatment (r=-0.614, P<0.05). Conclusion High-intensity laser therapy combined with physiotherapeutic scoliosis-specific exercises can alter the morphology of the concave side multifidus muscle at the apex of the scoliotic curve, reduce low back pain, increase lumbar spine mobility, decrease lumbar dysfunction, and improve daily living abilities. Although HILT alone does not significantly affect multifidus muscle morphology, it can effectively relieve low back pain caused by scoliosis. The morphological balance of multifidus muscles on both sides of the spine plays a positive role in improving lumbar lateral flexion and rotation functions.

Full Text

Effect of High-Intensity Laser Combined with Physiotherapy Scoliosis-Specific Exercise Therapy on Ultrasound Morphology of Multifidus Muscles in Idiopathic Scoliosis Patients with Low Back Pain

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Abstract

Background: Adolescent idiopathic scoliosis (AIS) is a progressive three-dimensional skeletal deformity affecting spinal mobility and trunk symmetry. While previously considered painless, recent studies indicate that approximately 31.5% of AIS patients experience low back pain, potentially resulting from paravertebral muscle imbalance and fatigue.

Objective: To observe morphological changes in paravertebral multifidus muscles at the apex of the primary curve following high-intensity laser therapy (HILT) combined with physiotherapy scoliosis-specific exercises (PSSE) in AIS patients with low back pain, using musculoskeletal ultrasound, and to evaluate the clinical efficacy of this combined treatment in correcting paravertebral muscle imbalance.

Methods: Thirty AIS patients with Rigo E1 curvature admitted to the Scoliosis Correction Center of the Fifth Hospital of Harbin between December 2020 and December 2021 were enrolled in a randomized, single-blind controlled trial. Patients were randomly assigned to either an experimental group receiving HILT combined with PSSE or a control group receiving HILT alone. Both groups underwent musculoskeletal ultrasound examination, visual analogue scale (VAS) scoring, lumbar range of motion (ROM) assessment, and the Roland-Morris Disability Questionnaire (RDQ) before treatment and after 4 weeks of intervention. Pearson correlation analysis was used to investigate potential correlations between post-treatment multifidus muscle changes and treatment outcomes.

Results: Post-treatment, the experimental group showed significantly greater cross-sectional area of the multifidus muscle on the concave side, anterior flexion, left lateral flexion, left rotation, and right rotation compared to the control group ($P<0.05$). Within the experimental group, post-treatment values for concave-side cross-sectional area and thickness, concave/convex cross-sectional area ratio, concave/convex thickness ratio, and extension were significantly higher than pre-treatment values ($P<0.05$). Both groups exhibited decreased VAS and RDQ scores and increased anterior flexion, left/right lateral flexion, and left/right rotation after treatment ($P<0.05$); however, the control group showed decreased extension post-treatment ($P<0.05$). Pearson correlation analysis revealed that the post-treatment concave/convex cross-sectional area ratio was negatively correlated with right lumbar rotation ($r=-0.660$, $P<0.01$), while

the thickness ratio was negatively correlated with right lateral flexion (r=-0.614, P<0.05).

Conclusion: HILT combined with PSSE can alter multifidus muscle morphology on the concave side of the scoliotic apex, reduce low back pain, increase lumbar mobility, decrease lumbar dysfunction, and improve daily living activities. Although HILT alone does not significantly affect multifidus morphology, it effectively relieves scoliosis-related low back pain. Balancing bilateral multifidus muscle morphology positively impacts lumbar lateral flexion and rotation function.

Keywords: Scoliosis; Adolescent; Spinal diseases; Laser therapy; Exercise therapy; Low back pain; Ultrasonography; Paraspinal muscles

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Study Design and Subjects

This study enrolled AIS patients admitted to the Scoliosis Correction Center of the Fifth Hospital of Harbin between December 2020 and December 2021. To eliminate the influence of brace wear during adolescence on skeletal and paravertebral muscle measurements, we included patients with mature bone age who had either discontinued brace use or never worn braces.

Inclusion criteria were: (1) confirmed AIS diagnosis; (2) Rigo E1 curvature type; (3) Risser sign grade V females; (4) self-reported low back pain in daily life with visual analogue scale (VAS) score $ $3 persisting for over 2 weeks. Exclusion criteria comprised: (1) postoperative AIS patients; (2) patients with other types of low back pain; (3) patients currently wearing braces.

This study received ethical approval from the Fifth Hospital of Harbin (HSWYL2021005), and all participants provided informed consent. All researchers held relevant medical practitioner or rehabilitation therapist qualifications.

Based on these criteria, 30 Rigo E1 patients were included and randomly divided into experimental and control groups (15 patients each) using a single-blind randomized controlled design with a random number table method. The experimental group had a mean age of 15.2$\pm 1.7 years and weight of 49.9 \pm 6.6 kg, while the control group had a mean age of 16.6$ kg. No statistically significant differences were found between groups in age or weight (t=-1.952, P=0.061; t=-2.001, P=0.055).

Interventions

High-Intensity Laser Therapy (HILT): Both groups received HILT using an MLS®Mphi high-intensity laser (ASAlaser, Italy). Following the MLS®Mphi manual recommendations, treatment parameters were: 25 W handheld probe, 700 Hz frequency, 10-minute total duration, 100% intensity, 345.12 J total energy output, and 18.32 J/cm^2 energy density. The treatment protocol involved: (1) broad-area scanning over the convex-side muscles for 4 minutes; (2) "rice grain" pattern treatment on scoliosis apex paravertebral muscles and painful areas using Italian FM® fascial manipulation (30 seconds per area); (3) final broad-area scanning for 3 minutes. Treatments were administered 3 times weekly for 4 weeks.

Physiotherapy Scoliosis-Specific Exercises (PSSE): The experimental group additionally performed PSSE based on Chen Yanqiu's protocol, including right-side bridging, Schroth strengthening exercises, and muscle cylinder movements. For low back pain management, functional rehabilitation exercises were incorporated: supine gluteal bridge, supine leg raises, trunk plank exercises, and side-lying hip abduction. PSSE training was conducted in the exercise therapy clinic 3 times weekly for 4 weeks.

Outcome Measures

Primary Indicators: Musculoskeletal ultrasound examination of multifidus muscles bilaterally at the apex vertebra was performed before and after 4 weeks of treatment. Using a Philips EPIQ-5 color Doppler ultrasound system (probe frequency 1.0-5.0 MHz), we measured multifidus muscle thickness and cross-sectional area on both sides of the apical vertebra. Following the 2010 European Society of Musculoskeletal Radiology (ESSR) ultrasound guidelines, patients were positioned prone with a thin pillow under the abdomen to prevent excessive lumbar flexion. After identifying the apical vertebra from full-spine X-ray coronal images and marking the spinous process, the probe was placed at the marked point. Upon visualizing the spinous process, the probe was shifted 3 cm left and right to measure bilateral multifidus thickness and cross-sectional area. Three consecutive measurements were averaged to minimize error, with the same sonographer performing all pre- and post-treatment assessments for each patient.

illustrates multifidus muscle morphology at the apical vertebra under ultrasound.

Secondary Indicators: Collected before and after 4 weeks of treatment: (1) VAS pain assessment (0=no pain, 10=unbearable pain); (2) Roland-Morris Disability Questionnaire (RDQ, 24 items, score 1 for "yes" and 0 for "no", higher scores indicate greater dysfunction); (3) lumbar ROM measurement (anterior flexion, extension, left/right lateral flexion, left/right rotation), with each plane measured 4 times and averaged.

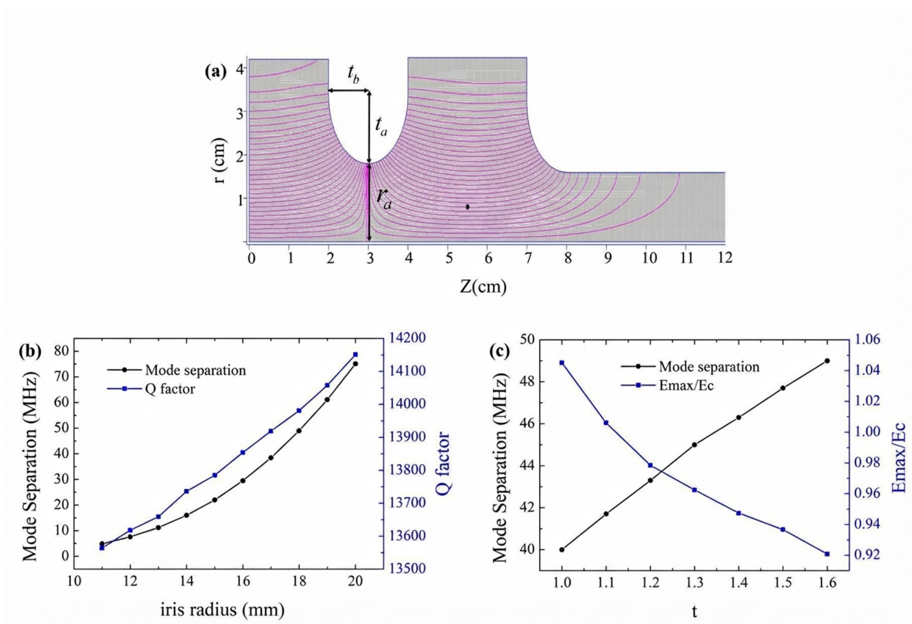

Figure 1: Figure 1

Statistical Analysis

Data were analyzed using SPSS 26.0 software. Normality and homogeneity of variance tests were performed. Normally distributed data with homogenous variance were expressed as mean±standard deviation ($\bar{x}\pm s$), with paired t-tests for within-group comparisons and independent t-tests for between-group comparisons. Non-normally distributed data were expressed as median (interquartile range) [M(P25, P75)], analyzed using non-parametric rank-sum tests. Pearson correlation analysis was performed between concave/convex cross-sectional area ratios and thickness ratios with VAS scores, RDQ scores, and all ROM parameters. Statistical significance was set at $P<0.05$.

Results

Comparison of General Data: No significant differences were found between groups in age or weight (see above).

Multifidus Muscle Changes: Post-treatment, the experimental group showed significantly greater concave-side cross-sectional area compared to the control group ($P<0.05$). Within the experimental group, post-treatment concave-side cross-sectional area and thickness, concave/convex cross-sectional area ratio, and concave/convex thickness ratio were significantly higher than pre-treatment values (P<0.05). No significant differences were found between groups or within groups for convex-side parameters (P>0.05). The control group showed no significant changes in any multifidus parameters (P>0.05). Detailed data are presented in .

VAS and RDQ Scores: Both groups demonstrated significantly reduced VAS and RDQ scores post-treatment (P<0.05), with the experimental group showing significantly lower RDQ scores compared to the control group after treatment (P<0.05). No significant between-group differences were observed in VAS scores (P>0.05). See .

Lumbar ROM: Both groups exhibited increased anterior flexion, left/right lateral flexion, and left/right rotation post-treatment (P<0.05). The experimental group showed increased extension (P<0.05), while the control group demonstrated decreased extension (P<0.05). Post-treatment, the experimental group had significantly greater anterior flexion, left lateral flexion, and left/right rotation compared to the control group (P<0.05). No significant differences were found in extension or right lateral flexion between groups (P>0.05). See .

Correlation Analysis: Post-treatment concave/convex cross-sectional area ratio was negatively correlated with right lumbar rotation (r=-0.660, P<0.01), and thickness ratio was negatively correlated with right lateral flexion (r=-0.614, P<0.05). See .

Discussion

This study investigated the effects of HILT combined with PSSE on multifidus muscle morphology, pain, lumbar mobility, and quality of life in AIS patients with low back pain. The 4-week intervention improved pain and functional outcomes, with more balanced concave/convex ratios for multifidus cross-sectional area and thickness in the experimental group, surpassing HILT alone.

The paravertebral muscles, with the multifidus being the deepest layer, primarily extend the spine and participate in rotation, maintaining upright posture. Multifidus cross-sectional area reflects muscle fiber quantity and atrophy degree, serving as an indicator of lumbar muscle strength. Reduced cross-sectional area can diminish axial rotation capacity and increase spinal load. Previous research identified paravertebral muscle imbalance as a key factor in AIS progression. Our prior work demonstrated that bilateral multifidus thickness differences correlate with muscle imbalance, suggesting paravertebral muscle pathology may represent secondary compensatory changes in scoliosis. Studies have also shown correlations between bilateral root-mean-square ratios of apical paravertebral muscles and axial trunk rotation (ATR), with larger ATR indicating more severe imbalance. Since Cobb angle increases correlate positively with ATR, scoliosis progression appears linked to paravertebral muscle imbalance.

While once considered benign and painless, AIS affects 31.5% of patients with low back pain, likely due to muscle imbalance, fatigue, or foraminal stenosis. Chronic pain reduces lumbar ROM and increases daily life burdens, including medication use, reduced school/work attendance, and activity limitations. Recent evidence supports physical therapy combined with PSSE for correcting bilateral muscle imbalance and controlling curve progression.

We selected Rigo E1 patients (single left-convex/right-concave lumbar curve, apex at L1-L2, prone to trunk imbalance progression) to control for confounding factors. All female participants eliminated gender-related muscle differences, and Risser sign V status excluded growth and brace interference. Both groups had moderate scoliosis (similar Cobb angles), excluding severity bias.

HILT's photobiological effects enhance mitochondrial oxidation, increasing ATP, RNA, and DNA production while improving blood flow, vascular permeability, and cellular metabolism. Compared to low-level laser, high-intensity laser delivers substantial energy output in shorter durations with deeper penetration, activating deep paravertebral muscles. However, our ultrasound findings revealed that while HILT alone effectively reduced pain through mechanical and biological stimulation (releasing endogenous enkephalins, inhibiting Aδ and C fiber transmission, and controlling pain gating), it did not alter multifidus morphology or correct muscle imbalance. The combined approach yielded superior pain relief and functional improvements.

Post-treatment improvements in lumbar ROM and RDQ scores in both groups indicate that pain reduction enhances quality of life. The experimental group' s superior performance in anterior flexion, left lateral flexion, and rotation likely stems from PSSE-induced morphological changes in concave-side paravertebral muscles, reduced fat infiltration, and altered muscle fiber composition, enabling better spinal mobility and daily function.

Correlation analysis revealed relationships between bilateral multifidus imbalance and right lateral flexion/rotation, suggesting that increased muscle fiber thickness and quantity improve rotational capacity. The thickness ratio' s correlation with right lateral flexion may relate to Rigo E1 characteristics (pelvic shift to concave side, trunk imbalance with center of gravity on convex side). Increased concave-side muscle thickness enhanced lateral flexion function post-treatment. Although multifidus parameters didn' t correlate directly with quality of life or pain scores, achieving paravertebral muscle balance and improved lumbar mobility likely contributed to pain relief and enhanced quality of life.

Limitations

This study had a small sample size and short follow-up period. We did not assess changes in ATR or other scoliotic parameters, which should be addressed in future research with expanded sample sizes and longitudinal follow-up using musculoskeletal ultrasound.

Author Contributions

SUN Xiaolei and ZHANG Xiaohui conceived the study and designed the protocol. SUN Xiaolei conducted the experiments, collected samples, performed treatments, follow-up, and drafted the manuscript. LEI Xiaolong collected data and performed musculoskeletal ultrasound sampling. LIN Jiasheng recruited participants, evaluated treatment efficacy, and supervised the experimental process. SUN Xiaolei and LI Keliang performed statistical analysis and created figures. GUO Ao conducted final proofreading and detailed revisions. ZHANG Xiaohui was responsible for quality control, overall article review, and supervision.

Conflict of Interest: The authors declare no conflict of interest.

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