

RESEARCH ARTICLE

A correlation study of paraspinal muscle functions in adolescent idiopathic scoliosis

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Abstract

Objective: To explore the correlation among paraspinal muscle functions electromyography (EMG), muscle stiffness, and pain threshold in patients with adolescent idiopathic scoliosis (AIS). **Methods:** Eighteen patients with AIS were recruited. A Noraxon system equipped with four wireless EMG sensors was used to collect EMG data on the paraspinal muscles in relaxed standing and weight-bearing standing states. Muscle stiffness and pain threshold were measured using a muscle tonometer. The differences in mean EMG amplitude, muscle stiffness, and pain threshold between the concave and convex sides of the scoliosis were analyzed. **Results:** Among patients with different scoliosis locations, Cobb angles, ages, and brace treatment durations, the mean EMG amplitude of the paraspinal muscles on the convex side of scoliosis was significantly higher than that on the concave side ($P < 0.05$). The muscle stiffness and pain threshold of the paraspinal muscles on the convex side were also significantly higher than those on the concave side (both $P < 0.05$). There was a low correlation between the mean EMG amplitude of the paraspinal muscles, muscle stiffness, and pain threshold ($R < 0.5$, $P > 0.05$). **Conclusion:** In AIS patients, the electromyographic activity, muscle stiffness, and pain threshold of the paraspinal muscles on the convex side of scoliosis were all higher than those on the concave side, and the correlation among the three indicators was low.

Keywords: Scoliosis, Paraspinal muscles, Electromyographic activity, Muscle stiffness, Pain threshold**Highlights**

- Electromyographic activity, muscle stiffness, and pain threshold on the convex side of the scoliotic curve exhibited significantly higher than those on the concave side.
- In adolescent idiopathic scoliosis patients, there was a weak correlation between electromyographic activity, muscle stiffness, and pain threshold of the paraspinal muscles.

1 INTRODUCTION

Scoliosis is a three-dimensional spinal deformity with an incidence rate of 0.23%–2.40% [1]. The vast majority of scoliosis patients are diagnosed with adolescent idiopathic scoliosis (AIS). The etiology of AIS remains unclear, but it may be relat-

ed to factors such as genetics, growth and development, abnormal neurological function, and melatonin secretion [2]. Among the many influencing factors, paraspinal muscle dysfunction is considered to be the main cause of the occurrence and progression of scoliosis [3, 4]. The paraspinal muscles are mainly composed of the superficial erector spinae muscles and the deep



multifidus muscles on both sides of the spine [5]. The two work together to maintain the upright posture of the human body and support trunk movement [6]. Patients with scoliosis have paraspinal muscle imbalance, which is manifested by differences in muscle volume and different degrees of muscle activation during movement [7]. This muscle imbalance is both a cause and a result of scoliosis. Symmetrical paraspinal muscles have regulatory and balancing mechanisms that can correct mild scoliosis and further control the progression of the disease [8].

Surface electromyography (EMG), muscle stiffness, and muscle pain threshold are important indicators for assessing the paraspinal muscle status in individuals with AIS. They can reflect muscle imbalance, adaptive changes in muscle activity, muscle activation patterns, and functional limitations in scoliosis patients. These three parameters were selected because they characterize paraspinal muscle function from complementary dimensions, covering neuromuscular activation status, biomechanical properties, and sensory pain characteristics, respectively. Their combined application allows for a multidimensional assessment of paraspinal muscle dysfunction in AIS. Surface EMG can reveal muscle activation patterns, detect muscle activity imbalances, and assess the functional performance of paraspinal muscles under different activity states. In the field of scoliosis research, surface EMG is particularly suitable for identifying asymmetric muscle activation patterns and compensatory muscle recruitment patterns caused by changes in spinal alignment. Previous studies have found that surface EMG signal levels in scoliosis patients are higher than in healthy individuals, and the signal level on the convex side of the scoliosis is higher than on the concave side [9-11].

Muscle stiffness refers to the resistance generated when the paraspinal muscles are passively stretched by external force [12]. Changes in muscle stiffness can reflect changes in muscle tissue characteristics, including muscle tension, stiffness, and other biomechanical and structural features. It can also reflect potential changes in muscle tissue composition caused by long-term asymmetrical loading. Liu et al. found that the stiffness of the paraspinal muscles on the concave side was higher than that on the convex side in AIS patients [5]. This difference can affect the alignment of the spinal force line and thus aggravate spinal deformity.

Paraspinal muscle pain threshold assessment is the measurement of the pressure threshold that the human body can withstand when it begins to feel pain [13]. Monitoring the muscle pain threshold can help understand the pain sensitivity and pain perception of the paraspinal muscles in scoliosis patients. According to statistics, 23% of scoliosis patients have symptoms of lower back pain [14]. A comprehensive exploration of the physiological characteristics of the paraspinal muscles in scoliosis patients, including EMG signals, muscle stiffness, and pain threshold, can provide an important reference for elucidating the pathogenesis of scoliosis. At the same time, the above

indicators can be applied in clinical practice to provide a basis for individualized diagnosis, treatment plan formulation, and clinical efficacy evaluation of scoliosis.

Therefore, this study aims to explore the symmetry and correlation among surface EMG of the paraspinal muscles, muscle stiffness, and muscle pain threshold in individuals with AIS. The findings are expected to deepen our understanding of musculoskeletal dysfunction in scoliosis at the research context and provide a reference for developing individualized intervention programs for specific muscle problems in scoliosis patients at the clinical level.

2 MATERIALS AND METHODS

2.1 Study design

All participants were recruited from the Department of Rehabilitation, First Affiliated Hospital of Kunming Medical University. This study was approved by the Medical Ethics Committee of Kunming Medical University (Approval No: KMMU2023MEC088), and the recruitment period was from May 2023 to February 2024.

Inclusion criteria: (1) AIS patients with a Cobb angle $<60^\circ$; (2) Age 10-18 years old; (3) Risser sign ≤ 4 .

Exclusion criteria: (1) Non-AIS; (2) History of spinal surgery; (3) Comorbid neuromuscular diseases and spinal lesions affecting muscle function or pain sensitivity.

Surface EMG signals of the paraspinal muscles were collected using a surface EMG system (TeleMyo 2400 G2, Noraxon, USA). Participants were placed in a prone position with their arms relaxed. After cleaning the skin of the paraspinal muscles with a damp cotton ball, the electrode pads were placed on the erector spinae muscles at the apical level, 2 cm from the midline of the spine. For patients with unilateral curvature, two pairs of electrodes were placed at the apical level; for patients with bilateral curvature, four pairs of electrodes were placed at two apical levels (**Figure 1**). The sensor was connected to the electrodes and fixed 1 cm from them. Surface EMG signals were collected for 10 seconds each in a naturally standing, resting state and under a 2 kg load, with a 30-second rest interval between collections. All measurements were repeated three times. The ratio of the average EMG amplitude on the convex side to the concave side was calculated as the paraspinal muscle symmetry index; the closer the value was to 1, the higher the symmetry of the muscles on both sides; the farther the value deviated from 1, the lower the symmetry.

The paraspinal muscle stiffness and pain threshold were measured using a muscle state detection system (Itochu, Japan, model OE-220). Subjects were placed in a prone position with arms relaxed. The erector spinae muscles at the apical level

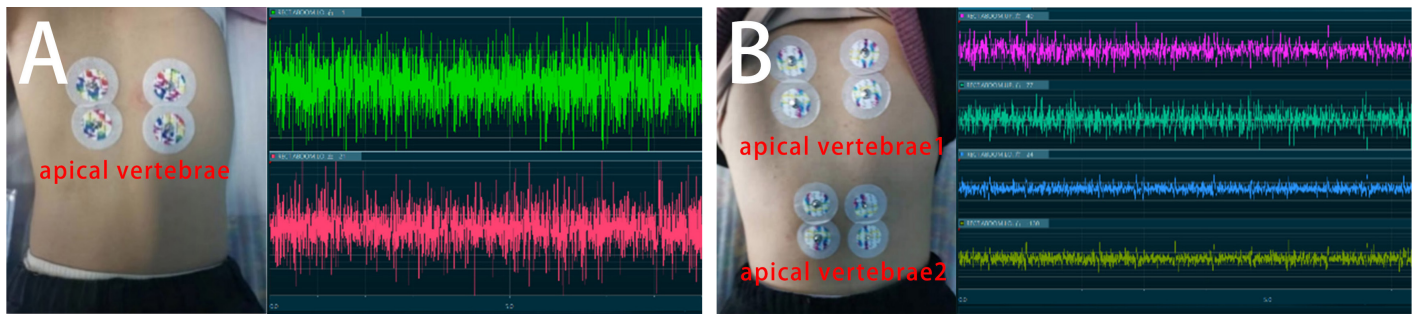


Figure 1. Electrodes placement and real-time sEMG. (A) Single curve; (B) Double curve. EMG, electromyography.

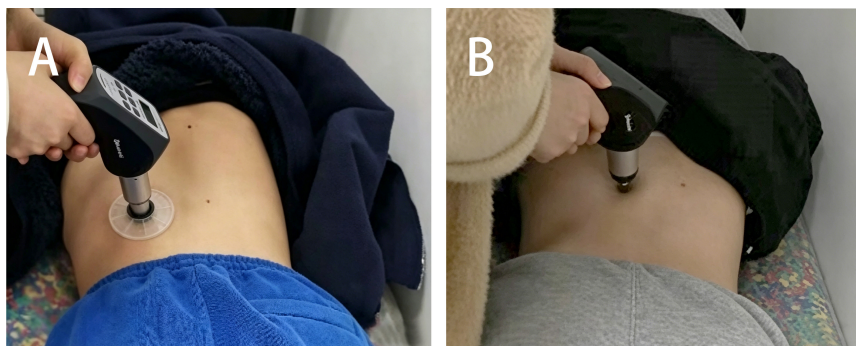


Figure 2. Assessment of paraspinal muscle. (A) Measurement of muscle hardness; (B) Measurement of pain threshold.

Table 1. Demographic data

Number	Age	BMI	Cobb angle	Risser sign	Apex
n=18	13.56±3.00	17.26±2.46	32.54±10.83	0~4	T8-L2

Note: BMI, body mass index; Apex, apical vertebra.

were marked as detection sites; two detection sites were marked for patients with unilateral curvature, and four detection sites were marked for patients with bilateral curvature.

For paraspinal muscle stiffness assessment, the rapid muscle condition detection device was aligned to the detection site, and pressure was slowly applied vertically (**Figure 2**). Once the device screen displayed the test results, the single test ended and the data was saved. Each subject underwent the test three times. The ratio of muscle stiffness on the convex side to the concave side was defined as the paraspinal muscle symmetry index; the closer the value was to 1, the higher the symmetry between the two sides; the further the value deviated from 1, the lower the symmetry.

For paraspinal muscle pain threshold test, the muscle condition detection device was applied vertically to the designated detection site, and pressure was gradually increased through the detection probe. The subject held the braking device throughout the test. As the pressure slowly increases, the subject actively pressed the remote control to terminate the test when the pain threshold was reached, and the data displayed on

the device was recorded. Each test was repeated three times, with a 30-second rest interval between tests. The ratio of the pain threshold on the convex side to the concave side was used as the paraspinal muscle symmetry index; the closer the value was to 1, the higher the symmetry between the two sides; the further the value deviated from 1, the lower the symmetry.

2.2 Statistical analysis

Data analysis was performed using IBM SPSS Statistics 26.0 statistical software. Paired t-tests were used to compare the differences in mean surface EMG amplitude, muscle stiffness, and muscle pain threshold of the paraspinal muscles on the concave and convex sides of scoliosis. Analysis of variance with Bonferroni post-hoc tests was used to analyze the effects of different scoliosis types, Cobb angles, age, and treatment duration of scoliosis braces on mean surface EMG amplitude. Pearson correlation coefficients were used to analyze the correlation among mean surface EMG amplitude, muscle stiffness, and muscle pain threshold of paraspinal muscles in scoliosis patients.

3 RESULTS

3.1 Demographic data

This study included 18 participants, of whom 13 had received or were undergoing scoliosis exercise therapy, and 9 were undergoing orthotic therapy. Demographic data of the participants are shown in **Table 1**.

3.2 Surface EMG signals

The mean EMG amplitudes of the paraspinal muscles on the convex and concave sides of the spine are shown in **Table 2**. The results showed that the mean EMG amplitude on the convex side of the paraspinal muscles was significantly higher than

Table 2. Mean surface electromyographic amplitude of paraspinal muscles in patients with scoliosis

Position	Mean EMG convex (mV)	Mean EMG concave (mV)	Concave-convex ratio	P value
Relax standing (n=18)	16.57±7.52	10.83±3.99	1.56±0.49	P<0.001
Weight-bearing standing (n=18)	83.64±55.41	52.84±46.99	1.94±0.96	P<0.001
P value	P<0.001	P<0.001	P<0.001	

Note: EMG, electromyography.

Table 3. Symmetry of mean surface electromyographic amplitude of paraspinal muscles in different subgroups

	Relax standing	P value	Weight-bearing standing	P value
Double curves (n=10)	1.40±0.41	0.128	1.97±1.04	0.586
Single curve (n=8)	1.73±0.16		2.22±1.06	
Cobb angle <30° (n=7)	1.64±0.60	0.467	2.02±1.01	0.725
Cobb angle ≥30° (n=11)	1.50±0.40		1.88±0.94	
Age <15 years (n=11)	1.48±0.40	0.807	1.80±0.83	0.267
Age ≥15 years (n=7)	1.54±0.53		2.27±1.22	
Orthosis <6 m (n=9)	1.31±0.30	0.260	2.31±1.19	0.706
Orthosis ≥6 m (n=9)	1.73±0.65		2.64±1.12	

Table 4. Symmetry of paraspinal muscle stiffness and pain threshold

Measurement index	Convex side	Concave side	Ratio	P value
Muscle hardness m/N (n=18)	47.63±12.72	44.41±13.17	1.10±0.20	0.047
Muscle pain threshold N (n=18)	32.00±12.45	29.28±11.50	1.12±0.24	0.030

Table 5. Correlation analysis of paraspinal muscle surface electromyographic signal, muscle stiffness, and pain threshold symmetry

Measurement index	Pearson correlation coefficient	P value
Surface EMG & muscle hardness	0.418	0.734
Surface EMG & pain threshold	0.356	0.390
Muscle hardness & pain threshold	0.394	0.618

that on the concave side (P<0.05). The mean EMG amplitude under weight-bearing standing conditions was higher than that under relaxed standing conditions (P<0.05). Furthermore, the dispersion of the mean EMG amplitude data under weight-bearing standing conditions was significantly greater.

Patients were grouped according to the location of the scoliosis (single curve, double curve), Cobb angle (<30°, ≥30°), age (<15 years, ≥15 years), and duration of orthotic treatment (<6 months, ≥6 months). The influence of each variable on the symmetry of the paraspinal muscles was analyzed (Table 3). Pairwise comparisons between groups showed no statistically significant difference in the symmetry of the mean surface EMG amplitude of the paraspinal muscles between any two groups, regardless of whether the patient was standing relaxed or with loading (P>0.05).

3.3 Muscle stiffness and pain threshold

The results of paraspinal muscle stiffness and pain threshold tests are shown in Table 4. Muscle stiffness results showed that

the stiffness of the paraspinal muscles on the convex side was significantly greater than that on the concave side in AIS patients (P=0.047). Pain threshold results revealed showed that the pain threshold on the convex side of the paraspinal muscles was significantly higher than that on the concave side (P=0.030).

3.4 Correlation analysis

Pearson correlation analysis was used to explore the correlation among the symmetry of mean surface EMG amplitude, muscle stiffness, and pain threshold symmetry of the paraspinal muscles on the convex and concave sides in AIS patients (Table 5). The results indicated symmetry of mean surface EMG amplitude was weakly correlated with muscle stiffness symmetry (R=0.418, P=0.734); symmetry of mean surface EMG amplitude was weakly correlated with pain threshold symmetry (R=0.356, P=0.390); and symmetry of muscle stiffness was also weakly correlated with pain threshold symmetry (R=0.394, P=0.618).

4 DISCUSSION

Paraspinal muscles play a crucial role in the pathogenesis and progression of scoliosis. This study confirmed that, regardless of curve location, Cobb angle, patient age, or orthotic treatment duration, the surface EMG signal on the convex side was significantly higher than that on the concave side, consistent with previous findings [15, 16]. This asymmetry may stem from atrophy of the concave paraspinal muscle fibers accompanied by excessive stretching of the convex fibers [17, 18]. Mechanistically, metabolic processes in the paraspinal muscles may disrupt the balance between melatonin and calmodulin. Increased calmodulin levels on the convex side can enhance contractile force, thereby amplifying EMG activity [19].

Significant differences in mean EMG signals were observed under weight-bearing standing conditions, likely due to increased contraction amplitude during weight-bearing and individual variability in neuromuscular control strategies. Weight-bearing conditions require greater postural control, leading patients to develop individualized compensatory activation patterns to maintain trunk stability. These differentiated force

exertion patterns, prevalent in scoliosis populations, increase the dispersion of surface EMG results.

The study also found that different curve locations, Cobb angles, ages, and orthotic treatment durations did not significantly affect the symmetry of paraspinal surface EMG signals.

This study found that muscle stiffness and pain threshold on the convex side were higher than those on the concave side, a finding that differs from previous studies reporting higher stiffness on the concave side. This discrepancy may stem from differences in detection methods, study population characteristics, and clinical conditions. Severity of scoliosis, age, and treatment history may also affect long-term adaptive changes.

Patients who rely predominantly on the convex side for postural compensation may develop increased muscle tension and stiffness on that side due to chronic overactivation. Clinical observation indicates that most scoliosis patients habitually use the convex side as the primary force-generating muscle group [20]. Long-term continuous contraction of convex-side muscles leads to changes in muscle stiffness. Increased muscle stiffness is also associated with chronic musculoskeletal dysfunction, suggesting possible pathological changes such as tissue edema, hypoxia, and acidosis [21].

Asymmetry in pain threshold is primarily related to individual differences in pain sensitivity and subjective perception. Scoliosis orthoses apply corrective force to the apical vertebra on the convex side, placing muscles under prolonged stress, which may increase their tolerance to external forces and raise the pain threshold. Studies have confirmed that scoliosis rehabilitation exercises can effectively retrain dominant muscle group force exertion habits through diverse specific movements, thereby relieving pain and improving paraspinal muscle asymmetry [22].

Assessing muscle stiffness and pain threshold helps comprehensively evaluate neuromuscular function and provides a basis for developing personalized rehabilitation programs and pain management strategies. Rehabilitation training should focus on improving bilateral muscle symmetry and correcting compensatory force exertion habits on the convex side. For patients with high muscle stiffness, targeted local relaxation and stretching exercises are recommended; for those with low pain threshold, gentler intervention methods should be considered.

Changes in muscle stiffness and pain threshold before and after treatment can serve as important indicators for evaluating efficacy and adjusting treatment plans. Future research should compare these indicators before and after rehabilitation exercise interventions to achieve more accurate and objective evaluation of treatment efficacy.

This study found a low correlation between the surface EMG, muscle stiffness, and pain threshold in scoliosis patients.

Muscle stiffness is defined as the degree of deformation of muscle morphology under specific pressure, while mean EMG signal reflects changes in EMG amplitude during paraspinal muscle contraction [23].

Leonard et al. showed that muscle stiffness and surface EMG were positively correlated in non-scoliosis patients, whereas the present study found a low correlation in scoliosis patients [24]. This difference may be explained by pathological abnormalities in scoliosis disrupting the original correlation between these indicators. This disruption is more pronounced in patients wearing orthotics, whose muscle activity is restricted and who are subjected to long-term pressure.

Only a few subjects reported significant back muscle pain symptoms in daily life. Such symptoms are more common in adult scoliosis patients but have a relatively low incidence in those with AIS [25]. Other studies have shown that rehabilitation exercises have no significant effect on muscle stiffness and pain sensitivity in healthy individuals [26]. Further research is needed to determine whether specific rehabilitation exercises can improve muscle stiffness and reduce pain sensitivity in scoliosis patients.

This study has several limitations. First, the sample size was relatively small (n=18), primarily focusing on adolescents with mild to moderate scoliosis, limiting generalizability to patients with severe scoliosis or other age groups. Second, as a cross-sectional study, causality cannot be inferred; it remains unclear whether abnormal muscle characteristics induce scoliosis progression or whether spinal deformity leads to secondary adaptive muscle changes. Third, previous rehabilitation exercises and orthotic treatments may have confounded the results, although subgroup analysis based on treatment duration did not reveal significant differences.

Future studies should conduct large-scale, stratified longitudinal follow-up studies based on treatment history to clarify the causal relationship and dynamic changes in paraspinal muscle function in AIS.

5 CONCLUSION

In AIS patients, EMG activity, muscle stiffness, and pain threshold are all higher on the convex side than on the concave side, and the correlation among these three indicators is low. In-depth research on paraspinal muscle function can provide important references for developing individualized diagnosis and treatment plans for AIS.

DECLARATIONS

Author contributions

Rong Pang participated in data curation, software development, investigation, writing the original draft, resource provi-

sion and visualization; Chen He was responsible for conceptualization, methodology, software development, investigation, formal analysis and writing the original draft; Huidong Wu contributed to data curation, resource provision and investigation.

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Data availability

Not applicable.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board (IRB) at the Kunming Medical University (Approval No: KMMU2023MEC088). Written informed consent was obtained from all participants for publication of relevant data.

Consent for publication

All authors have given their consent for publication of this manuscript.

Competing interests

The authors declare that they have no competing interests.

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