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Original

Fatigue-related differences in erector spinae between adult spinal deformity patients and healthy individuals using surface electromyographic power spectral analysis

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Abstract

The erector spinae muscles are responsible for initiating and controlling all vertebral column movements; however, they may atrophy after lumbar fusion surgery, and their post-surgical muscle fiber composition in adult spinal deformity (ASD) patients is unclear. It is important to assess this composition to strengthen the muscle effectively during treatment.

We aimed to evaluate differences in erector spinae muscles between healthy adults and ASD patients after lumbar fusion surgery using surface electromyographic (EMG) power spectral analysis. Thirteen women with post-operative ASD and 7 age-matched healthy women underwent the unsupported trunk holding test combined with surface EMG power spectral analysis until exhaustion. The results of the EMG power spectral analysis were compared between the two groups.

The maximum voluntary contractions were significantly lower in the ASD group than in the control group. No significant differences in the initial median frequency (MF) and MF slopes were found between the two groups.

The results suggested that the relative area of each erector spinae muscle fiber in the postoperative ASD patients did not change despite decreasing muscle strength. Future studies need to focus on methods to strengthen muscle fibers to improve outcomes.

Key words : *adult spinal deformity, surface electromyographic power spectral analysis, erector spinae muscle fiber*

I. Introduction

Adult spinal deformity (ASD) affects the thoracic or thoracolumbar spine throughout the aging process. The spectrum of ASDs includes *de novo* scoliosis, progressive adolescent idiopathic scoliosis in adulthood, hyperkyphosis, iatrogenic sagittal deformity, focal deformity due to multiple degenerative disc disease with global deformity, and

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post-traumatic spinal deformity. ASD has a substantial debilitating effect on the patient's general health and activities of daily living (ADL). Spinal surgery is indicated by the presence of disability, pain, neurological symptoms, documentation of curve progression, decreased quality of life, worsening ADL, and ineffective non-operative management. Surgical treatment for ASD, regardless of corrective procedures, is associated with high complication rates [1]. The reported complications include pseudarthrosis, infection, neurological deficits, cerebrospinal fluid leaks, failure of implants, and adjacent segment disease [2, 3]. Furthermore, the erector spinae are responsible for initiating and controlling all the movements of the vertebral column. However, atrophy of erector spinae muscles is known to arise after lumbar fusion surgery [4]. To our knowledge, the muscle fiber composition of erector spinae in ASD patients following lumbar fusion surgery is still unclear. It is important to assess the muscle fiber type and composition to strengthen the muscle effectively during the course of treatment.

Biering-Sørensen [5] demonstrated that the unsupported trunk holding time in the horizontal prone position was a predictor of the first episode of lower back pain. Also, power spectral analysis of surface electromyographic (EMG) recording has previously indicated that muscle fatigue is associated when the median frequency shifts (MF) towards a lower value [6-10]. Furthermore, the relative area of type I erector spinae muscle fibers correlates with the MF slope [11]. Thus, the trunk holding test combined with EMG power spectral analysis is widely used by clinicians to assess the fatigability of the erector spinae muscles [7, 10, 12, 13]. The purpose of this study was to evaluate the differences in erector spinae muscles between healthy adults and ASD patients following lumbar fusion surgery using only surface EMG power spectral analysis.

II. Methods

1. Participants

Thirteen elderly women who underwent surgery for ASD (postoperative ASD group) and 7 age-matched healthy women (control group) were included in this study. The Cobb angle of the postoperative ASD group was 8.1 ± 5.1° (range = 0.2 - 15.9°). Table 1 lists the convex side of the lumbar curve, Cobb angle, and surgical technique for each postoperative ASD patient.

All participants were recruited from our institution and they had no history of severe renal, hepatic, or any other significant underlying disease. The present study was approved by the Human Ethics Committee of Iwate Medical University (IRB: MH2018-580), and written informed consent was obtained from all subjects before their participation.

2. Isometric maximum voluntary contractions

The muscle strength of the trunk extensor was measured with a hand-held dynamometer (μTas F-1, ANIMA, Tokyo, Japan) as described previously [14, 15]. After a 15-minute rest, the subject was positioned prone over two treatment tables that could be lowered; the upper body rested over one table, while the anterior superior iliac spines were positioned at the edge of the other table, supporting the lower body. Three straps were used to stabilize the hips, knees, and ankles.

Table 1. Convex side, Cobb angle and surgical technique of each postoperative ASD patient

Patient	Convex side	Cobb angle (°)	Surgical technique
No. 1	Left	9.7	OLIF + TLIF + PSF
No. 2	Left	5.4	OLIF + TLIF + PSF
No. 3	Left	13.8	OLIF + PSF
No. 4	Left	10.7	OLIF + PSF
No. 5	Left	0.2	OLIF + TLIF + PSF
No. 6	Left	11.3	OLIF + PSF
No. 7	Left	4.3	OLIF + PLIF + PSF
No. 8	Left	15.9	OLIF + PSF
No. 9	Right	7.8	OLIF + TLIF + PSF
No. 10	Left	2.6	VCR + PSF
No. 11	Left	10.5	OLIF + PSF
No. 12	Left	0.3	OLIF + PLIF + PSF
No. 13	Left	13.0	OLIF + PSF

OLIF, oblique lumbar interbody fusion; TLIF, transforaminal lumbar interbody fusion; PSF, pedicle screw fixation; VCR, vertebral column resection.

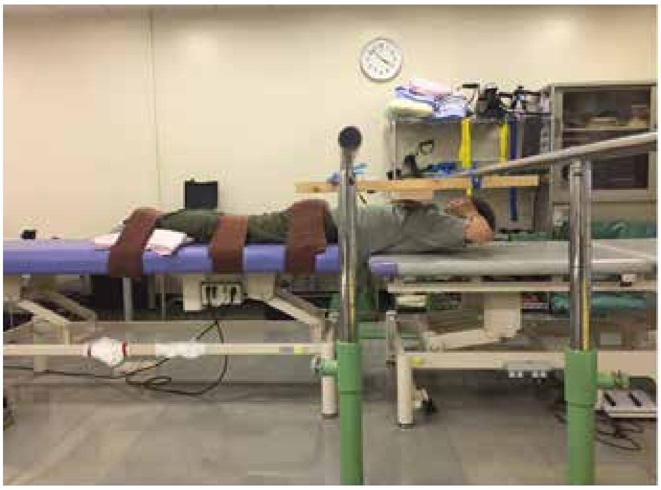

Fig. 1. Body position during the evaluation of trunk extensor muscle strength.

Maximum voluntary contraction (MVC) was measured with the subject in the prone position, with the hands placed behind the head, elbows bent outwards to the sides, and the head present in the mid-line. The end piece of the dynamometer was applied to the inferior angle of the scapulae on the center of the back between the shoulder blades (Fig. 1). The subject was asked to take 1-2 seconds to achieve maximum effort. The test was performed 3 times with a 30-second rest interval, and the maximum force was recorded. Torque values were expressed in newton meters (Nm) and in newton meters relative to body weight (Nm/kg).

3. Trunk muscle holding test

After a 30-minute rest, the subject was positioned prone over 2 treatment tables,

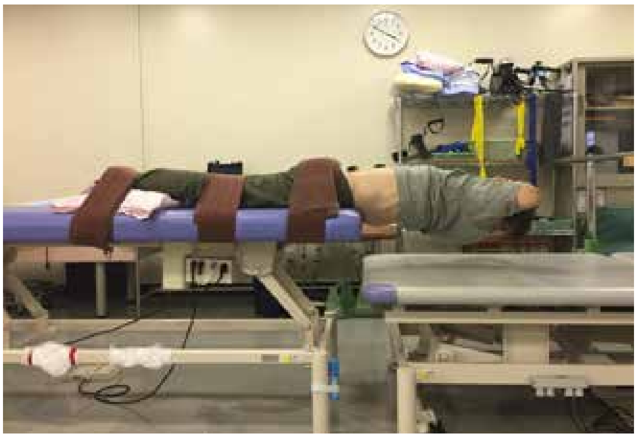

Fig. 2. Body position during the trunk holding test.

similar to the previous position. Three straps were used to stabilize the hips, knees, and ankles. The upper table was lowered, and the subject was instructed to keep the upper body in a horizontal position in relation to the lower body for 60 seconds (Fig. 2). The horizontal position during the test was controlled by feedback. The test was terminated when the subject could no longer maintain the upper body in a horizontal plane (defined as a >2 cm reduction in height for 2 seconds) despite strong verbal encouragement and feedback.

4. EMG signal recording and analysis

EMG activity was monitored during the trunk holding test using the Trigno EMG system (Delsys Inc., Boston, MA, USA) according to the international recommendation for electrode placement on the surface EMG [16]. Before attaching the electrodes, the skin was cleaned with an alcohol swab. After confirming the position of the erector spinae using ultrasonography, the active electrode was placed over the muscles at the L1 level, 3 cm lateral to the midline. The EMG signals were recorded using a DELSYS wireless dynamic EMG tester (TrignoT1qM Wireless Systems, Delsys Inc., Boston, MA, USA) with a sampling frequency of 2000 Hz and a bandwidth of 20-450 Hz. The wireless EMG signals were transmitted to the EMG acquisition software through the electrodes placed on the muscle surface. The signals were then processed and analyzed using the EMG software (EMGworks Analysis). Linear regression analysis was applied to the MF time series (MF as a function of time) to calculate the initial MF and MF slope. In this study, the Cobb angle of the postoperative ASD group was 8.1 ± 5.1° (range = 0.2 - 15.9 °). A previous study revealed that there were no differences in MF slope derived from erector spinae between convex and concave sides with a Cobb angle of less than 30° [17]. In addition, some studies [9, 14, 18] compared the MF slope on the left side, when there was no difference in MF slope between the left and right sides. Based on these reports, MF indices derived from the left erector spinae were evaluated in this study.

5. Statistical Analysis

Data were shown as mean ± standard deviation. The difference between the 2 groups was evaluated by the Mann-Whitney U test. Also, correlations between the number-

Table 2. Anthropometric characteristics of the participants

	Postoperative ASD Group (n = 13)	Control Group (n = 7)	p value
Age (y)	73.2 ± 3.4	76.6 ± 8.5	0.65
Height (m)	1.46 ± 0.06	1.50 ± 0.07	0.25
Body weight (kg)	49.7 ± 8.3	52.2 ± 8.3	0.43
Body mass index (kg/m^2)	23.2 ± 4.9	23.2 ± 3.2	0.38

Date are presented as mean ± standard deviation.

fused segments and MVC or MF slope in the postoperative ASD group were analyzed by using the Spearman's rank correlation coefficient. A p-value of less than 0.05 was considered statistically significant. Statistical analysis was performed using the SPSS software (version 24.0; SPSS Inc., Chicago, IL).

III. Results

Table 2 lists the age, height, body weight, and body mass index (BMI) of each patient group. There were no significant differences between each index in the two groups.

1. Differences in MVC between the two groups

The MVC in the postoperative ASD group (3.2 ± 1.9 Nm/kg) was significantly lower than in the control group (5.2 ± 1.2 Nm/kg) (p = 0.01) (Fig. 3).

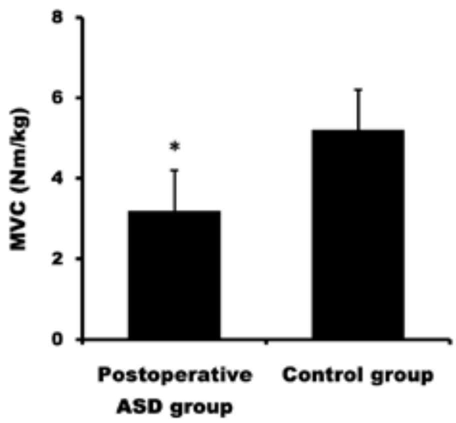

Fig. 3. The maximum voluntary contractions (MVC) in the postoperative adult spinal deformity (ASD) and control groups. Values are presented in mean ± standard deviation; *p < 0.01.

2. Initial MF and MF slopes during the test

All participants in the control group were able to perform the trunk holding test for 60 seconds. However, 2 out of 13 patients in the postoperative ASD group could not complete the test.

The MF derived from the left side decreased linearly with time in all participants in the control group ($p < 0.001$). On the other hand, left-side MF showed a non-significant decrease in 4 out of 13 participants in the postoperative ASD group. However, in the same group, MF derived from the right side showed a significant decrease; therefore, the right side was adopted for evaluation instead. Figure 4 shows the changes in MF in a representative postoperative ASD patient and a healthy individual.

There was no significant difference in the initial MF between the postoperative ASD group (61.8 ± 12.0 Hz) and the control group (67.6 ± 6.2 Hz) (p = 0.08). There was also no significant difference in the MF slope between the postoperative ASD group (− 0.26 ± 0.17 Hz/sec) and the control group (− 0.30 ± 0.09 Hz/sec) (p= 0.12).

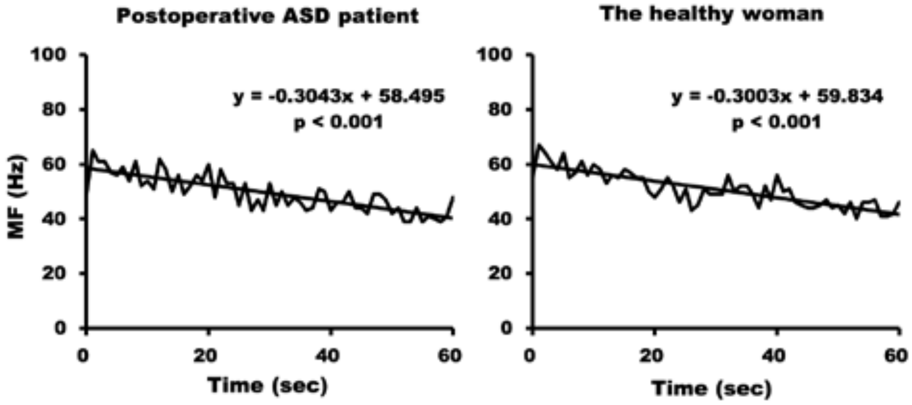

Fig. 4. Changes in the median frequency (MF) in a representative postoperative adult spinal deformity (ASD) patient and a healthy individual.

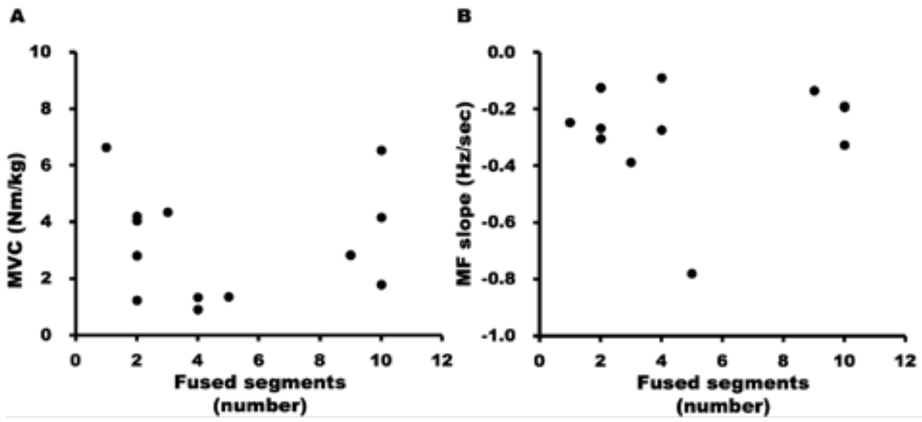

Fig. 5. Correlations between the number-fused segments and maximum voluntary contractions (MVC) or slope of median frequency (MF) in the postoperative adult spinal deformity group.

3. The correlations between the number-fused segments and the MVC or MF slope

Figure 5A shows the correlation between the number-fused segments and the MVC in the postoperative ASD group. There was no significant correlation between the two variables in this group ($p = 0.77$).

Figure 5B shows the correlation between the number-fused segments and the MF slope in the postoperative ASD group. There was no significant correlation between the two variables in this group ($p = 0.77$).

IV. Discussion

This is the first study to evaluate the difference in the fatigability of the erector spinae muscle between postoperative ASD patients and healthy adults using surface EMG power spectral analysis.

We found that the MVC was significantly lower in the postoperative ASD group than in the control group. Previous studies have shown that atrophy of the paraspinal muscles occurs after open dorsal lumbar fusion surgery [19, 20]. However, this study did not assess muscle mass, and the factor of lower MVC in the postoperative ASD group was unclear. No significant difference was found in the initial MF and MF slopes in this study. Previous studies showed that the MF slope correlated significantly with the relative area of Type 1 muscle fibers in the erector spinae [21-23]. In addition, type 2 muscle fibers showed selective atrophy with aging and disuse, and some studies revealed that MF slopes in healthy elderly men [9] and young athletes with terminal stage lumbar spondylolysis [15] were lower than those in healthy control individuals. Therefore, the MF slope derived from erector spinae during the trunk holding test is an index that was used to evaluate muscle fatigability and measure the relative area of muscle fibers on the erector spinae. Thus, the findings of this study suggest that the relative area of each muscle fiber on the erector spinae in postoperative ASD patients did not change despite decreasing muscle strength.

Also, no significant correlation was found between the number-fused segments and the MVC or MF slope. Therefore, we assume that muscle weakness of the erector spinae may occur in postoperative ASD patients if the patients have at least one fused vertebral body.

It has been shown that the lower the strength of the back extensor muscle, the worse the degree of spinal kyphosis [24, 25]. Additionally, the center of gravity shifts too far forward, with the mechanical axis of the spine located in front of the femoral head. When the center of gravity is located more frontally, there is more stress load on the proximal instrumentation [26]. Thus, future studies are needed to establish safe and valid treatment methods to strengthen type 1 and 2 muscle fibers.

This study has certain limitations. First, the number of subjects in the postoperative group was relatively small. Second, the subjects were elderly women only. A previous study reported that there was no significant difference in MF slope derived from the erector spinae between elderly healthy women and men [9]. However, ASD-related sex differences in elderly patients are unclear, and the results of this study may not reflect the entire ASD population. Third, these observations did not address the time of occurrence of muscle weakness in postoperative ASD patients. Despite the above-mentioned limitations, this study identified differences in the erector spinae muscles between healthy elderly women and age- and sex-matched postoperative ASD patients.

To our knowledge, this is the first study to evaluate the properties of erector spinae muscles in postoperative ASD patients using surface EMG power spectral analysis. The major finding in this study suggested that the relative area of each muscle fiber on the erector spinae in postoperative ASD patients did not change despite decreasing muscle strength. Thus, future studies are needed to establish safe and valid treatment methods to strengthen type 1 and 2 muscle fibers in such patients, and to ensure restoration of function and abolishment of pain.

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Conflict of interest: The authors have no conflict of interest to declare.

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筋電図周波数パワースペクトル解析を用いた術後成人脊柱変形患者の脊柱起立筋疲労特性の検討

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要旨

成人脊柱変形（ASD）患者に対する脊椎固定術は脊椎アライメントが矯正される一方で，脊椎固定術後は脊柱起立筋が萎縮することが報告されている．しかし，その筋線維組成の変化は不明である．本研究の目的は脊椎固定術後の ASD 患者と同年齢の健常者の脊柱起立筋の違いを評価することである．ASD 術後女性 13 名（ASD 群）と同年代の健常女性 7 名（コントロール群）に等尺性体幹伸展最大随意収縮力測定と Trunk holding test を実施した．Trunk holding test 中の筋活動を表面筋電図で計測し，記録した干渉波形に対して周波数パワースペクトル解析を行い，周波数中央値の傾きを算出した．ASD 群の MVC はコントロール群より有意に低かった．周波数中央値の傾きは両者間に有意差がなかった．本研究の結果は ASD 術後患者の脊柱起立筋は筋力が低下しても各筋線維タイプの相対的な面積は変化しないことを示唆する．