Muscle Strength and Electromyography of Paraspinal Muscles during Isokinetic Exercise in Adolescent Idiopathic Scoliosis

KYOKO MINEHISA, MS, RPT1), ISAO NARA, PhD, RPT2), TORU ENDOH, MD3)
1)Department of Rehabilitation, Mitoyo General Hospital: 708 Himehama Toyohama-cho, Mitoyo-gun, Kagawa, 769-1601, Japan. TEL +81-875-52-3366 FAX +81-875-52-4936
2)Institute of Health Sciences Hiroshima University School of Faculty
3)Department of Orthopedic Surgery, Mitoyo General Hospital

Abstract. The muscle strength of the trunk and electromyography (EMG) of paraspinal muscles were recorded during maximal isokinetic exercise in 17 girls with adolescent idiopathic scoliosis (AIS) and in 12 matched control subjects. Median power frequency (MdPF) and Integrated EMG (IEMG) were calculated. The muscle strength in the AIS group was significantly lower than in the control group. Positive correlation of Cobb angle with strength of trunk extensors, but not with flexors was observed, and negative correlation with the flexion-extension ratio (F/E value). There was a close relationship between the Cobb angle and the decrease of rotation muscle strength on the convex side to that on the concave side. MdPF’s in AIS were lower than those in the control, and the difference between right and left sides tended to be large. Exercises to strengthen the muscles of the trunk at a high speed with an effort close to the maximum, with consideration given to flexion and rotation on the concave side of the trunk, are recommended for AIS patients.

Key words: Adolescent idiopathic scoliosis, Electromyography, Muscle strength

INTRODUCTION

The function of the human trunk is to provide both stability and mobility. The spinal column has a biomechanically fragile and unstable structure, and the neuromuscular control system plays an important role1-4). The activities of trunk muscles for preserving posture or producing movement in patients with adolescent idiopathic scoliosis (AIS), a complex three-dimensional deformity of the spine, have not yet been completely clarified.

Previous histological and histochemical studies have shown that the paravertebral muscles in AIS patients have muscle imbalance, atrophy, pathologic changes, and a predominance of type 1 fibers on the convex side5-8). In addition, previous studies using ultrasound imaging or CT scan suggest an inequality in muscle size5,10), and those using electromyography (EMG) show the difference in myoelectric activity between the concave and convex sides11,12). Some report that there is no difference in muscle strength of the trunk between AIS patients and healthy subjects13,14), and others report that muscle strength in AIS patients is weaker than in healthy subjects15,16). Results of the measurement of muscle strength of the trunk vary considerably, depending on the measurement apparatus, position of the axis and the effect of gravity, which is dependent on the subject’s position; thus intra- and inter-individual comparison is difficult17). Moreover, many previous tests of dynamic function...
of the trunk in AIS patients have used isometric contraction exercises, and there are few recent reports in which dynamic functional tests were used.

The remaining mobility of spinal alignment in AIS patients is influenced by gravity. Understanding of the neuromuscular control system may lead to an improvement in stability and mobility of the spinal column in AIS patients. For this purpose, it is useful to understand the physiological conditions of the trunk muscles by combining the measurement of muscle strength with EMG under certain exercise conditions. In order to investigate the characteristics of back muscles in patients with AIS, muscle strength and EMG of back muscles were measured during isokinetic exercise at the maximum effort with uniaxial movement in the sagittal and horizontal planes in subjects whose trunk was fastened firmly to a dynamometer using the trunk frame.

**METHODS**

The subjects were adolescent females who were recruited at Mitoyo General Hospital. The AIS group consisted of 17 patients who had AIS or who tended to have scoliosis, and the Control Group were 12 volunteers whose trunks were structurally normal. The AIS group showed spinal curvature of not less than 5 degrees on X-ray images taken while the subjects were in a lying position. Mean height, weight, and age of the AIS group were 157.2 ± 4.5 cm, 45.7 ± 6.0 kg and 13.5 ± 2.6 years, respectively. Mean height, weight, and age of the Control group were 154.3 ± 5.9 cm, 47.2 ± 7.0 kg and 12.9 ± 0.7 years, respectively. All subjects were right handed.

Table 1 shows the spinal curvature in the AIS group. No patients in the AIS group had undergone surgery. Four patients with large curvature had received physical therapy, and two of them wore the active corrective brace. The lower thoracic spinal curvature in 4 patients who had secondary thoracic curvature was classified as “lumbar spine curve” for the sake of convenience. Experiments were conducted following our institutional guidelines for experimental investigations on human subjects and written informed consent was obtained from all the subjects and their parents.

Isokinetic exercise was performed using a dynamometer MYORET RZ-450 and a trunk unit (Kawasaki Heavy Industries, Japan). The subjects sat on the trunk unit, and their trunk and lower limbs were firmly fastened by belts attached to the frames. They were asked to grasp the front grips of the frame fastening the chest by the upper limbs.

The test protocol was as follows. Firstly, three cycles of concentric isokinetic exercise with flexing and extending the trunk at a velocity of 20 degrees per second (°·s⁻¹) (range of motion: 60 degrees) were performed, and the mean peak extension torque in the cycle showing the maximum peak extension torque was measured. Isometric trunk extension with the trunk angle at –15 extension degrees at 30% of the strength of the mean peak torque obtained was performed for 20 seconds, a stable surface EMG was recorded for 5 seconds during the exercise to normalize the integrated EMG. Secondly, three cycles of concentric isokinetic exercise with flexing, extending and rotating the trunk at a velocity of 20°·s⁻¹ (range of motion: 60°) were performed, and muscle strength and surface EMG were measured. Each test was preceded by a submaximal warm-up of the test procedure. Verbal encouragement was used for all tests. The parameter for the muscle strength was the torque-weight ratio that was obtained as follows: The torque-weight ratio = PT/W × 1000, where “PT” was the maximum peak torque (kg·m) on the trunk flexion, extension, right-rotation and left-rotation at a velocity of 20°·s⁻¹ obtained during the aforementioned exercise, and “W” was body weight (kg) of each subject.

The surface EMG was measured on bilateral paraspinal muscles at the apical vertebra level in the AIS group, and at T7 and L3 levels in the Control Group. The skin surface of the test portions was rubbed with skin pretreatment agents to minimize skin resistance. Compact bipolar surface electrodes (Blue Sensor, Medicotest, Denmark) were used. Based on the monopolar lead method, the neutral electrodes were attached 2 cm bilateral to the spinal
process at the apical vertebra level, and the differential electrodes were attached to the spinal process that was proximal to the neutral electrode by one vertebral body. The ground electrodes were attached at the crest of the ilium.

EMG analog signals from surface electrodes were led simultaneously with angle data from the MYORET using a telemetry system (SYNA ACT MT11; NEC Corporation, Japan) to a 16 bit A/D conversion board (AD16-16E, Comtec, Japan) and into a personal computer (PC9801, NEC Corporation, Japan). One minute signals were captured with a sampling time of 2 ms, and the signals over a frequency band of 0–500 Hz were analyzed.

Analysis of the EMG signals was performed using a multi-purpose biological information analysis program, BIMUTAS-E (Kissei Comtec Company, Japan). The wave form of the raw EMG data from the middle two seconds of the cycle, when the largest muscle strength among the three cycles was observed, was selected based on the angle data of the MYORET, and band-pass filtered between 10 Hz and 200 Hz. Subsequently, the median power frequency (MdPF) was calculated using a fast Fourier transform. In addition, EMG data from each exercise was converted into the integrated EMG per second (IEMG). These IEMGs were normalized by the previously recorded, stable 1-second IEMG during isometric contraction exercise with trunk extension to obtain a normalized IEMG (NIEMG).

Statistical analysis was performed using Stat View J5.0 software (SAS Institute Inc. Japan). The data in the AIS and Control groups were compared using an unpaired t-test. In the case of skew distributions, significance was tested using the Mann-Whitney U test. The data from the left and right sides of the Control group, and those of the concave and convex sides in the AIS Group were compared using a paired t-test. For skewed distributions, Wilcoxon’s test was used. Laterality in the AIS group was regarded to be present when it was larger than the mean laterality in the Control group. The relation between the Cobb angle and laterality in the AIS group was calculated using Pearson’s product moment correlation coefficient (r) analysis. A P value of less than 0.05 was considered to indicate statistical significance.

RESULTS

For all exercises, muscle strength was significantly lower in the AIS group than in the Control group, but no difference in the ratio of the flexing muscle strength to the extending muscle strength (F/E value) was observed between these two groups. There was no difference in the ratio of strength on the left side to that on the right side (L/R value) in the rotator muscle. However, rotator muscle strength was stronger on the left side than on the right side in both groups, which was observed more remarkably in the Control group than in the AIS group (Table 2). Positive correlation of Cobb angle with strength of trunk extensors, but not with the flexors was observed, and negative correlation with F/E value (Figs. 1, 2). L/R value in the rotator muscle had a correlation with the corrected Cobb angle, which was obtained by changing the direction of the Cobb angle to minus on the left convex side (Fig. 3).

No laterality of MdPF was observed in the Control group. MdPF of muscles of the back on the right side of the lumbar spine in the AIS group was significantly decreased compared with that in the Control group. MdPF of the other regions in the

Table 2. Muscle strength (torque weight ratio) during flexing, extending and rotating the trunk

<table>
<thead>
<tr>
<th></th>
<th>AIS (n=17)</th>
<th>Control (n=12)</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (± SD)</td>
<td>mean (± SD)</td>
<td></td>
</tr>
<tr>
<td>flexion</td>
<td>106.16 ± 28.29</td>
<td>151.15 ± 38.05</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>extension</td>
<td>205.87 ± 48.87</td>
<td>273.05 ± 52.55</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>flexion-extension ratio (F/E value)</td>
<td>0.52 ± 0.14</td>
<td>0.56 ± 0.14</td>
<td>NS</td>
</tr>
<tr>
<td>right rotation</td>
<td>57.35 ± 10.84</td>
<td>70.35 ± 16.15</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>left rotation</td>
<td>65.18 ± 17.28</td>
<td>89.53 ± 28.72</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>left rotation /right rotation ratio (L/R value)</td>
<td>1.12 ± 0.22</td>
<td>1.26 ± 0.22</td>
<td>NS</td>
</tr>
</tbody>
</table>

Torque weight ratio = PT (kg · m)/W (kg) × 1000. SD = standard deviation. *: t-test.
AIS group did not significantly differ from that in the Control group, but tended to be lower (Table 3). Absolute value of MdPF laterality showed no significant difference between the two groups, but tended to be larger in the AIS group than in the Control group. No correlation between the Cobb angle and the absolute value of MdPF laterality was observed.

No laterality of NIEMG was observed in the Control group. There was no difference in NIEMG between the AIS and Control groups (Table 4). The absolute value of NIEMG laterality showed no significant difference between the two groups, but was larger in the AIS group than in the Control group. No significant correlation between the Cobb angle and laterality of NIEMG was observed. The difference in NIEMG between concave and convex sides was investigated for each curve. Among 6 patients with a single curve, 3 showed higher NIEMG on the convex side, 2 showed no difference and one showed higher NIEMG on the concave side, on trunk extension. A relation between the Cobb angle and NIEMG laterality on the convex or concave side was not observed. The patients with a compensatory curve also showed dispersion in the results, and NIEMG tended to be higher on the convex side of an active curve, regardless of the degree of the Cobb angle.

**DISCUSSION**

In the present study, the muscle strength of the
trunk in the AIS Group was lower than that in the Control Group in all exercises. Since the trunk frame was used in a sitting position, the data obtained was influenced by gravity, but rarely by deviation of movement axis (e.g., displacement and wobbling) or by the hip joint surrounding muscles. Therefore, dynamic activities of the trunk muscles could be measured, and intra- and inter-individual comparison of the data were possible.

Regarding relation between the muscle strength and scoliotic deformity, the extending muscle strength of the trunk positively correlated with Cobb angle. Four patients whose Cobb angle was over 25° had received physical therapy and had experience in undergoing dynamometer tests. Therefore, the data obtained from them might have been influenced by their experience of therapy and measurement techniques. However, it is worth noting that the Cobb angle did not correlate with the strength of trunk flexion, but was negatively correlated with F/E value. This might be due to resistance to the training of trunk flexors, but further intervention study is required to clarify the reasons for this. It is known that correct alignment of scoliosis is achieved by reducing lumbar lordosis using braces in AIS patients with three-dimensional deformity. The flexors play a role in reduction of lumbar lordosis, and strengthening of the muscles presents a significant task for these patients.

There was a close relation between the degree of Cobb angle and the degree of relative decrease of rotation muscle strength on the convex side to that on the concave side. Mooney reports that the weakness of the muscle strength on the concave side is observed during isometric contraction exercise in AIS patients and resistive exercise performed twice a week has a muscle-strengthening effect. Fidler suggests that the erector spinae muscle on the convex side is stretched but the multifidus muscle is contracted as the slow twitch fibers increase, which is related to rotation deformity.

There has been no consensus view about the relationship of muscle strength to the imbalance of

### Table 3. Median Power Frequency (MdPF) of paraspinal muscles during trunk extension and rotation

<table>
<thead>
<tr>
<th>Exercise electrode level</th>
<th>AIS mean ± SD (Hz)</th>
<th>AIS n</th>
<th>Control mean ± SD (Hz)</th>
<th>Control n</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension thoracic right</td>
<td>45.35 ± 18.37</td>
<td>16</td>
<td>50.29 ± 12.61</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>left</td>
<td>43.67 ± 17.10</td>
<td>16</td>
<td>52.39 ± 13.55</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>lumbar right left</td>
<td>30.13 ± 9.68</td>
<td>9</td>
<td>47.14 ± 10.51</td>
<td>12</td>
<td>&lt;0.01**</td>
</tr>
<tr>
<td>left</td>
<td>37.94 ± 12.22</td>
<td>9</td>
<td>46.73 ± 7.17</td>
<td>12</td>
<td>NS**</td>
</tr>
<tr>
<td>Rotation thoracic right</td>
<td>50.32 ± 15.47</td>
<td>16</td>
<td>52.5 ± 8.31</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>left</td>
<td>48.75 ± 16.49</td>
<td>16</td>
<td>54.7 ± 11.49</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>lumbar right left</td>
<td>31.30 ± 11.39</td>
<td>9</td>
<td>46.2 ± 13.14</td>
<td>12</td>
<td>&lt;0.02**</td>
</tr>
<tr>
<td>left</td>
<td>41.16 ± 14.23</td>
<td>9</td>
<td>43.6 ± 12.59</td>
<td>12</td>
<td>NS**</td>
</tr>
</tbody>
</table>

SD = standard deviation. *: t-test, **: Mann-Whitney U-test.

### Table 4. Normalized integrated EMG (NIEMG) of paraspinal muscles during trunk extension and rotation

<table>
<thead>
<tr>
<th>Exercise electrode level</th>
<th>AIS mean ± SD</th>
<th>AIS n</th>
<th>Control mean ± SD</th>
<th>Control n</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension thoracic right</td>
<td>329.87 ± 184.72</td>
<td>16</td>
<td>234.51 ± 98.52</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>left</td>
<td>270.78 ± 150.04</td>
<td>16</td>
<td>230.47 ± 92.35</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>lumbar right left</td>
<td>374.05 ± 280.62</td>
<td>9</td>
<td>476.93 ± 226.49</td>
<td>12</td>
<td>NS**</td>
</tr>
<tr>
<td>left</td>
<td>312.61 ± 138.66</td>
<td>9</td>
<td>505.46 ± 252.60</td>
<td>12</td>
<td>NS**</td>
</tr>
<tr>
<td>Rotation thoracic right</td>
<td>425.39 ± 317.66</td>
<td>16</td>
<td>318.03 ± 145.75</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>left</td>
<td>400.04 ± 325.36</td>
<td>16</td>
<td>294.12 ± 143.72</td>
<td>12</td>
<td>NS*</td>
</tr>
<tr>
<td>lumbar right left</td>
<td>327.58 ± 236.69</td>
<td>9</td>
<td>341.22 ± 161.29</td>
<td>12</td>
<td>NS**</td>
</tr>
<tr>
<td>left</td>
<td>276.87 ± 154.54</td>
<td>9</td>
<td>353.62 ± 203.11</td>
<td>12</td>
<td>NS**</td>
</tr>
</tbody>
</table>

SD = standard deviation. *: t-test, **: Mann-Whitney U-test.
content and electric discharge of the muscles. However, the results of the present study suggested that stretching the rotators on the convex side and strengthening the rotators on the concave side would be beneficial for AIS patients.

A dynamometer can measure the joint torque influenced by the synergist, antagonist, tendon and ligament, and inertia, but cannot measure activities of individual muscles. A combination of its use with EMG is useful for comprehensively investigating the mechanism of the neuromuscular systems in exerting muscle strength. The adequacy of comparing the amount of electric discharge from the muscle among various muscles for comparison of muscle strength has been generally questioned. However, in the present study, since the monopolar lead method was used, the amount of electrical discharge is considered to reflect the muscle strength on both left and right sides, at least to some extent.

The absolute value of NIEMG laterality, which is a quantitative parameter of muscle activity, tended to be larger in the AIS Group than in the Control Group. The reasons why electrical discharge from the muscle on the convex side dominates that on the concave side are still controversial: some authors report that it is due to accentuation of secondary stretch reflex, and others that it is due to a compensatory mechanism or fatigue reaction. Many reports relate the large signals on the convex side with the presence of curve progression. In the present study, laterality of NIEMG was related to the variability of the curve, rather than to the severity of scoliosis.

MdPF, which is a qualitative parameter of muscle activity, tended to be lower in the AIS Group than in the Control Group. This corresponds to the result of a histochemical study that found type I fibers bilaterally increased in the paraspinal muscles in AIS patients. The reason why a significant decrease of MdPF was observed on the right side of lumbar spine might be that the mean Cobb angle was largest in the curve on the right convex side of the lumbar part. In addition, there is the possibility that EMG detected electrical discharges from the erector spinae muscle that is histologically little changed in the region of thoracic spine, and from the multifidus muscle that is histologically quite different in the region of the lumbar spine.

When an electrophysiologically very strong contractive force is exerted, synchronization occurs physiologically. Katoh reported that adjustments including recruitment and synchronization, rather than rate coding, are performed in the slow twitch fibers containing a lot of type I fibers, and synchronization has specificity of decreasing frequencies. Based on these results, the decrease of MdPF in the AIS group might be due to synchronization that occurred within the physiological range, which resulted from strong muscle contraction in the back muscles containing a lot of type I fibers and having decreased strength. However, the presence of synchronization could not be confirmed either physiologically or pathologically in the present study. Further study is required to investigate the nerves and muscles in more detail.

There was no correlation of the Cobb angle with MdPF or absolute value of MdPF laterality. This might be because the two patients whose Cobb angle was large had received bracing treatments. Meta-analysis of AIS treatments suggests that long-term bracing treatments are effective, and reports that transformation of the fibers in multifidus muscle is observed in AIS patients who wear a corset. The muscle characteristics of the motor unit type are influenced by training, and transform to those of the muscle fiber type. Training that induces muscle contraction with a maximal effort at the maximal speed is reported to be favorable for strengthening type II fibers. The results of the present study indicate that qualitative strengthening of the muscles (e.g., strengthening all the muscles of the trunk, with particular emphasis on the flexors and rotators on the concave side at a fast speed with an effort close to the maximum) will lead to the functional improvement of the trunk in AIS patients. The effects of training intervention should be investigated in a further study.

REFERENCES