Back muscles biometry in adolescent idiopathic scoliosis

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Abstract

BACKGROUND CONTEXT: Many studies have been devoted to the role of back muscle activity in the development of scoliosis. While an imbalance in the electromyographic (EMG) activity has often been detected at the skin surface, very little information is available on the mechanisms by which such an imbalance could take place. To gain insight into those mechanisms, an important step could be the collection of anatomical data on the volume of the erector spinae muscle on both sides of the spine as well as on the skin and subcutaneous fat (skinfold) thickness separating those muscles from the body surface. For this purpose, the use of magnetic resonance (MR) imaging is appropriate.

PURPOSE: To collect anatomical information on the erector spinae muscles and skinfold thickness along the spinal deviations of scoliotic patients.

STUDY DESIGN: In an observational retrospective study, MR images of scoliotic patients treated in a pediatric hospital in the last 5 years were analyzed.

PATIENT SAMPLE: Images were obtained from adolescent idiopathic scoliosis patients.

METHODS: For 15 patients (Group I), three clinical acquisition protocols were used. Five investigators were asked to grade the contrast of the images obtained with each protocol. All the assessments were carried on the same monitor without any change in its settings. For the MR sequence providing the best contrast, 25 fully imaged scoliotic deviations were obtained from 17 patients (Group II). A manual segmentation with an image processing software package was done on the erector spinae muscle on both sides of the spine on each of the available images in order to determine their volume. Skinfold was also measured; first at regular intervals from C7 to L3 over the erector spinae muscle and then at sites centered over the apex of each curve.

RESULTS: For Group I, the spin echo (SE-T1) was found to provide the best contrast to identify the contour of individual muscle. With this sequence, the analysis of the fully imaged scoliotic curves (Group II) revealed that back muscle volume was found larger 14 times on the concave side and 11 times on the convex one. When the length of each curve was normalized and then divided into three equal regions, muscle volume was larger 11 times at the apex (6 times on concave side), 7 times above and 7 times below (4 times on the concave side for both positions). From C7 to L3, the mean skinfold thickness of each patient ranged from 7.3 mm to 16.3 mm. On average, this thickness was \(<10 \text{ mm between T3 and T12 but became larger at L3 level. At the apex of each scoliotic deviation, skinfold thickness was always larger on the concave side, and the difference decreased progressively as the distance from the apex increased.}

CONCLUSION: A larger back muscle volume in adolescent idiopathic scoliosis patients was slightly more frequent on the concave than on the convex side. The differences were more frequent at the apex of the curve. Skinfold thickness was always greater on the concave side at the apex region. © 2007 Elsevier Inc. All rights reserved.

Keywords: Adolescent idiopathic scoliosis; Magnetic resonance imaging; Back muscle biometry; Skinfold thickness
Introduction

Scoliosis affects mainly adolescent girls, and its initial cause is known only in 15–20% of the cases. For the other patients, classified as idiopathic, various factors are suspected such as genetic defects, uneven growth of the vertebrae, hormonal effects, abnormal muscular activity [1], postural problems [2], or a mix of some of these elements [3]. Because muscles are essential to maintain or modify the position of the spine, many studies have been devoted to this factor and in adolescent idiopathic scoliosis, a larger electromyographic (EMG) signal has often been observed on the convex side of the curves [4,5]. It is still not known whether the presence of a muscle imbalance could be at the origin of scoliosis or should be considered a consequence of the mechanical deformation of the spine. Unknown also are the mechanisms that could explain how an EMG asymmetry can take place around a scoliotic deviation. While it could be associated with an imbalanced neural input [6], the presence of a larger muscle volume on one side of the deviation or an unequal skin and subcutaneous fat (skinfold) thickness separating muscles from the skin surface can also be considered.

In order to shed light on the distribution of muscle mass along scoliotic curves and to facilitate the interpretation of EMG signal that can be collected over the back muscles of adolescent idiopathic scoliosis patients, we initiated an observational retrospective study based on magnetic resonance (MR) images acquired from adolescent idiopathic scoliosis patients. Among the MR sequences used with these patients, our initial goal was to identify which one seemed to offer the best contrast between the anatomical structures. From the images acquired with this sequence, our second goal was to collect anatomical dimensions of the erector spinae muscles and skinfold thickness along the spinal deviations.

Materials and methods

A MR databank of adolescent idiopathic scoliosis patients from the scoliosis clinic of Sainte-Justine University Hospital Center (Montreal, Canada) over a 5-year period was retrospectively analyzed (Table 1A). Among the 88 patients, it was found that for 15 of them (Group I), the same three acquisition sequences have been successively used. Five observers evaluated the contrast obtained for each of those 45 series of images. These observers were individually introduced to MR image contrast analysis during a 1-hour session, and verification was made that they could rate similarly the contrast of a few selected images. They were then asked to assess the contrast between subcutaneous fat and muscle tissue, between healthy muscle fibers and infiltrated fat, between adjacent muscles, and between the spine and back muscles. Using the same monitor where the zooming factor and gamma correction were kept constant, each observer rated the contrast on each image of the three sequences from 1 (blurred) to 5 (excellent), and one sequence was identified as providing the best contrast for muscle segmentation.

The databank was searched a second time to identify patients for whom that sequence had been used and where the entire span of the scoliotic deviation had been imaged. Seventeen patients (Group II, 4 boys and 13 girls, 11.6±3.2 years) with 25 scoliotic curves in total were found. To facilitate comparison between those patients, the lower and upper inflexion points (end vertebrae spinal marrow centroids) of each scoliotic curve were respectively considered as 0% and 100% of the curve and the apex position (α) was referenced to this scale. As can be seen in Figure 1, the value of the curvature cord ρ is given by:

$$\rho = \left\| I_{1} A_{p} \right\| \cdot \sin(\theta)$$

(1)

where θ is the angle between the directions I_{1}I_{2} and I_{1}A_{p}. In the frontal plane, the offset of the cord (ρ) is the distance between A_{p} and the segment composed of the inflexion points I_{1} and I_{2}. The offset of the deviation (ρ) at the apex was expressed in percentage of the distance between the two inflexion points.

The normalized curves were divided in three equal lengths (Fig. 1) to study muscle volume distribution. Image processing was done with a specialized software package (Tomovision, Montreal, Canada). On each slice, a manual segmentation minimizing operator errors [7] was used to obtain the contour of the anatomical structures of interest. With small slice thickness (<4 mm), muscle boundaries were assumed to be constant within each slice and the volume of a muscle was obtained by multiplication of its cross section area (CSA) with the slice thickness. Left and right muscle volume was assessed over three equal sections located above the apex, at the apex, and below the apex of the normalized curve (Fig. 1). The difference in muscular volume between the convex and concave sides was measured with a muscle difference index (MDI) defined as:

$$MDI(\%) = \frac{1}{N} \sum_{i=1}^{N} \left[ 1 - \frac{Volume_{\text{concave},i}}{Volume_{\text{convex},i}} \right] \times 100$$

(2)

<table>
<thead>
<tr>
<th>Pulse sequence</th>
<th>Sequence parameters</th>
<th>Pixel dimension (mm)</th>
<th>Slice thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>TR (ms)</td>
<td>TE (ms)</td>
<td></td>
</tr>
<tr>
<td>Spin echo (SE-T1)</td>
<td>450–750</td>
<td>20</td>
<td>0.72–1.00</td>
</tr>
<tr>
<td>Fast spin echo (FSE-T2)</td>
<td>3500–4000</td>
<td>90–126</td>
<td>0.75–1.00</td>
</tr>
<tr>
<td>Gradient recalled echo (GRE-T1)</td>
<td>25</td>
<td>5</td>
<td>1.87–1.88</td>
</tr>
</tbody>
</table>

Table 1A

Magnetic resonance sequence parameters identified in the databank (field strength 2T). The most frequently used appears on the top and the least used at the bottom.
where $N$ is the number of slices present in each third of the normalized curvature and $i$ each individual slice. An index value was obtained for the upper, middle, and lower third of each normalized curve. Because the MDI was always $<5\%$ for two young normal subjects and four nonscoliotic dystrophic patients, only MDI $\geq 5\%$ are considered here.

On both sides of each deviation, skinfold thickness was measured above the spinalis, the longissimus, and the iliocostalis at regular intervals along the spine. Measurements were also made at 6 cm from the spine at the apex level and at three equal intervals between the apex and the upper end vertebra as well as between the lower one and the apex.

To verify that the gray levels associated with different anatomical structures could be used reliably, 160 images were used. Coming from three patients of Group II, they were obtained under identical conditions (spin echo [SE-T1]: 564/14 ms, slice thickness of 10 mm, pixel of 0.39 mm). From the set of 160, 30 images were randomly selected and a pixel considered as representing muscle tissue, subcutaneous fat, or infiltrated fat was randomly chosen on each of them. A mean value was calculated out of the 30 images which were put back in the set, and another ensemble of 30 images was randomly selected to make new measurements. The whole process was repeated 30 times.

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To test statistical significance between curvature severity, $\alpha$, $\rho$, and MDI, a bivariate Pearson’s correlation coefficient with a two-tailed test of significance ($p<.05$) was used. Differences between the convex and concave sides of the spine were tested with an analysis of variance ($p<.05$).

**Results**

The SE-T1 sequence provided the best contrast between muscles as well as for subcutaneous and infiltrated fat identification (Table 1B). The fast spin echo (FSE-T2) sequence provided best contrast for the skeleton. Contrast with the gradient recalled echo (GRE-T1) sequence was always low as can be expected from a sequence mainly used as a localizer. Mean duration of the assessments was $3.1\pm 1.2$ hours with a rest period of approximately 1 hour in the middle. The mean time spent on the images of each case was $11\pm 4$ minutes (range: 6–19 minutes) in total for the three sequences.

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Subcutaneous fat</th>
<th>Infiltrated fat</th>
<th>Muscle-muscle</th>
<th>Skeleton</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSE-T2</td>
<td>3.8±1.0</td>
<td>2.5±1.1</td>
<td>2.5±1.0</td>
<td>3.6±0.9</td>
</tr>
<tr>
<td>GRE-T1</td>
<td>2.3±1.3</td>
<td>1.2±0.5</td>
<td>1.7±0.9</td>
<td>1.9±1.0</td>
</tr>
<tr>
<td>SE-T1</td>
<td>4.0±1.0</td>
<td>3.1±1.1</td>
<td>3.3±1.1</td>
<td>3.4±0.9</td>
</tr>
</tbody>
</table>

TR=repetition time; TE=echo time.
Seventeen patients (Group II) were found to have had their scoliotic deviations entirely imaged with the SE-T1 sequence, and with this group of patients a total of 25 curves were obtained. Among these deviations, 2 were proximal thoracic, 14 were main thoracic, and 9 were thoracolumbar/lumbar. The length of those curves ranged from 65 to 190 mm, the single ones being the longest (7 ± 1 vertebrae) followed by the double (5 ± 2 vertebrae) and the
triple (4 ± 1 vertebrae). For 24 of the 25 curves, the apex level was located at mid-distance between the inflexion points (± 50%). A sample of those deviations is presented in Figure 2 where important shape differences can be observed between the single, double, and triple curves.

The analysis of the gray levels associated to subcutaneous and infiltrated fat as well as to muscle tissue indicated that only minimal superimposition can be observed with the SE-T1 sequence (Fig. 3).

For the nine single scoliotic curves, muscular volume of the erector spinae muscle had a mean value of 116 ± 64 cm³ on the concave side and of 109 ± 64 cm³ on the opposite side. For the seven double curves, a mean value of 105 ± 50 cm³ and 103 ± 46 cm³ was respectively found on the convex and concave sides. For the triple curve, the volume was larger on the convex side (73 ± 14 cm³ vs. 67 ± 9 cm³). Once the 25 deviations were grouped, mean erector spinae volume was slightly larger on the concave side (103.3 ± 51.3 cm³, range of 42.7 to 236.2 cm³) than on the convex one (102.8 ± 52.8 cm³, range of 44.0 to 242.8 cm³). None of those differences is significant.

The muscle volume was found larger on the convex side of 13 curves (mean value of 105.7 vs. 98.3 cm³) and on the concave side for the others (mean value of 108.7 vs. 99.6 cm³). When muscle volume difference (ie, MDI) at the upper, middle (apex), and lower third of each curve was obtained, differences were similar over each third of the curves on the concave side but larger than on the convex side where the differences were more important at the apex region than above or below (Table 2A). When only the largest MDI for each deviation was considered (Table 2B), it was found located more often on the concave side than on the convex one (14 vs. 11) and at the apical region. Six of the nine patients with a single curve had their largest differences on the concave side, but only two at the apical level. As for the seven double curves, the largest difference of both deviations was always on the same side of the spine (4 times on the left and 3 on the right). For 9 of the 14 thoracic curves, largest MDI was also on the concave side and 5 times in the apex region.

Table 2A
Average muscular difference index (MDI) obtained from the 25 scoliotic curves

<table>
<thead>
<tr>
<th></th>
<th>Concave</th>
<th>Convex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above</td>
<td>15.3%</td>
<td>9.9%</td>
</tr>
<tr>
<td>Apex</td>
<td>15.8%</td>
<td>12.1%</td>
</tr>
<tr>
<td>Below</td>
<td>14.3%</td>
<td>9.0%</td>
</tr>
</tbody>
</table>

The frontal curve-offset $p_f$ was correlated with Cobb angle (Fig. 4, top panel) but not the sagittal offset (not illustrated). The three-dimensional value of $p$ was weakly correlated linearly with $p_f$ ($R^2=0.36$) but when the two most severe scoliotic curves (66° and 76°) were removed, $R^2$ increased to 0.59 (Fig. 4, lower panel).

Between T12 and L3, mean fat thickness for each of our 17 patients ranged from 7.3 mm to 16.3 mm. As a group average, this thickness was below 10 mm between T3 and T12 but increased above 15 mm at the L3 level (Fig. 5, upper left panel). On each scoliotic deviation, skinfold thickness was always larger on the concave side at the apex region. The difference was 20% at the apex and diminished progressively to 10% when measured at the end vertebrae above and below (Fig. 5, upper right panel). The observers having noticed that the contrast of the images appeared to be better for patients with a large skinfold thickness, the relationship between the assessed contrasts and the average skinfold thickness measured between C7 and L3 was investigated for the Group II patients and a significant correlation was obtained (Fig. 5, lower panel).

### Table 2B
Position of the most significant MDI for each of those curves

<table>
<thead>
<tr>
<th></th>
<th>Concave</th>
<th>Convex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Apex</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Below</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>11</td>
</tr>
</tbody>
</table>

### Discussion

Three MR sequences generally used with young scoliotic patients have been evaluated for the contrast obtained
between skinfold, infiltrated fat, bone, and muscle. The SE-T1 sequence was found the best of the three, and the gray levels associated with each of these structures presented practically no overlap. In a study specifically dedicated to back muscle volume analysis, the only improvement we made to the SE-T1 sequence was to reduce the echo time to make it more sensitive to some tissue components [8] such as the membrane enveloping each muscle. Manual segmentation is time-consuming and the use of MR substances to increase the visibility of those membranes [9,10] could lead to automatic segmentation. The apex position was near the middle of the curvature for 24 of 25 curves, and the two-dimensional and three-dimensional offsets were similar for most patients.

In adolescent idiopathic scoliosis, a larger back muscle volume has been reported at the apex on the convex side of the spine [11,12]. Our results also indicate the presence of a larger muscle volume on the convex side at the apex level but on some curves only. For the other deviations, a larger volume was found above or below the apex and not always on the convex side. Such differences can be associated with the experimental protocols. In one study [12], only a single 10-mm-thick slice located at the apex of the curve from 14 patients was used; in the other project [11], one image per vertebra from T6 to L2 was obtained from only one patient. This is quite different from our study where 9 to 24 images, depending on slice thickness (5 to 10 mm) and the length of the curve (65 to 190 mm) were used for each curve. Characteristics of the curves of the patients were also different: nearly all the curves in [11,12] were mainly thoracolumbar/lumbar, whereas this happened only in 9 of our 25 curves. In adolescent idiopathic scoliosis, thoracic kyphosis depends mostly on the spinal deformity, whereas lumbar lordosis is influenced mainly by the pelvic configuration [13]. Consequently, scoliosis developed in thoracic region could impact differently on the erector spinae muscle volume distribution along its length compared with a deformity in the lumbar region. As for our manual segmentation, its precision was evaluated with a phantom [14] and with a mean surface of the erector spinae equivalent to a circle with a diameter of 34.2 mm, it was estimated at ±1.0% which is well below the values presented in Table 2A.

Most of the time, when EMG data are collected, no MR or computed tomography images are taken and vice-versa. To explain the presence of a larger EMG activity on the convex side at the apex level [4,5], hypotheses have thus to be formulated. To help formulate these hypotheses, anatomical information, when available, can be very valuable.

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**Fig. 5.** (Top left panel) Average (−SD or +SD) skinfold thickness obtained at three sites (above the ilio-costalis, longissimus, and spinalis) on the left (solid line) and on the right (dotted line) along the spine of the 17 patients (Group II). (Top right panel) Average (−SD) ratio of (concave-convex)/convex skinfold thickness around each scoliotic deviation (n=25). The numbers 1 to 2 represent the position of regularly spaced sites above (+) and below (−) the apex level. (Lower panel) Relationship between contrast of the magnetic resonance images as evaluated by the observers and mean values of the skinfold thickness measured between C7 and L3 (Group II).
From our anatomical results, for instance, the presence of a larger EMG signal on the convex side at the apex region could have been associated with a larger muscle volume in only one of five curves. In the other situations, one has to consider a greater neural input on the convex than on the other side, or a larger feedback from muscle spindles on the convex side where muscles are more stretched. Skinfold thickness has also to be considered: compression on the concave side and stretch on the convex side results in a larger thickness on the concave side especially at the apex. Detection of a larger EMG signal on the convex side can thus be expected because a smaller distance separates the active muscles from the surface electrodes. Those hypotheses have to be further tested with EMG recordings and the collection of MR images from the same patients, because the presence of a larger muscle mass is no indication on the number of muscle fibers activated by the central nervous system at a given moment.

Conclusion

SE-T1 sequence was found to provide the best contrast to identify boundaries of muscles and of fat around or inside it. A larger muscle volume could be present on the convex or concave side of a scoliotic deviation and not always at the apex region. Thus, an image at the apex and at each end of a scoliotic curve may not always be representative of the distribution of muscular masses along its length. As for skinfold thickness over back muscles, it was always larger on the concave side at the apex. This anatomical information can help explain the differences in the level of the EMG signals collected on each side of the spine. It follows also that EMG recording at the apex level and at each end vertebra could be complemented by additional recording sites along the scoliotic deviation.

References