**Study Design:** Prospective clinical trial.

**Objectives:** To test the hypothesis that quantified trunk rotational strength training will equalize any strength asymmetry, increase strength overall, and stabilize adolescent idiopathic scoliosis.

**Summary of Background Data:** Bracing, the only generally accepted form of adolescent idiopathic scoliosis nonoperative therapy, has many shortcomings. Paraspinal muscle abnormalities, which have been extensively documented in these patients, are generally considered to be secondary. A normal female’s trunk strength in flexion and extension decreases from her juvenile to adolescent years, whereas a male’s increases.

**Methods:** Patients received a 4-month supervised followed by a 4-month home trunk rotational strength training program. Trunk rotational strength was measured in both directions at 5 positions at baseline, 4 months, and 8 months. The patients were followed clinically.

**Results:** Fifteen patients (12 females and 3 males), with an average age of 13.9 years and an average main Cobb of 33 degrees were enrolled. At baseline there was no significant asymmetry. After 4 months of supervised strength training, involving an average of 32 training sessions, each lasting about 25 minutes, their strength had significantly increased by 28% to 50% (P < 0.005 to P < 0.001). After 4 months of unsupervised home strength training their strengths were unchanged. The 3 patients with baseline curves of 50 to 60 degrees all had main or compensatory curve progression and 2 had surgery. For patients with 20 to 40-degree curves, survivorship from main curve progression of ≥6 degrees was 100% at 8 months, but decreased to 64% at 24 months.

**Conclusions:** Quantified trunk rotational strength training significantly increased strength. It was not effective for curves measuring 50 to 60 degrees. It appeared to help stabilize curves in the 20 to 40-degree ranges for 8 months, but not for 24 months. Periodic additional supervised strength training may help the technique to remain effective, although additional experimentation will be necessary to determine this.

**Key Words:** adolescent idiopathic scoliosis, strength training, trunk rotational strength, strength asymmetry

(J Spinal Disord Tech 2008;21:349–358)
asymmetry, increasing strength, and preventing curve progression at the end of a 4-month program. However, the testing and training protocol and data presentations lacked details, and the training effect reported was limited to 4 months. In our previous studies, we have developed a reliable protocol for trunk rotational strength measurement, compared untreated adolescent AIS females with healthy adolescent females, and found that adolescent AIS females have a small, but significant strength side difference.

Our studies are based on the hypothesis that trunk rotational instability is an important component of the pathogenesis of AIS. The purposes of the current study were to develop protocols for supervised trunk rotational strength training and home maintenance programs, to determine the effectiveness of these programs at 4 and 8-month follow-ups on patients’ trunk strength and scoliosis deformity, and to follow the patients clinically.

**METHODS**

The criteria for inclusion were a diagnosis of AIS, a Cobb angle of 20 to 60 degrees, a Risser sign ≤III, and age from 10 to 17 years. The exclusion criteria were any diagnosable cause of scoliosis. Any patient with a left apex thoracic curve or hyperkyphosis received a cervical spine to sacrum screening magnetic resonance imaging to rule out Chiari malformation, syringomyelia, or other structural neural abnormality. The study protocol was approved by the institutional review board of the Kansas University Medical Center. All participants and parents/guardians were appropriately assented and consented before joining the study.

Demographic and anthropometric data gathered included menarche status for females, standing height, weight, and lean body weight (LBW) (defined as body weight minus the estimated weight of body fat). A patient’s interval height velocity was determined at subsequent follow-up visits. From the standing frontal plane scoliosis radiograph the scoliosis curve(s), Risser sign, and triradiate cartilage closure status were determined by the treating doctor (D.B.). The curves were classified as thoracic, double thoracic, double, or thoracolumbar/lumbar following Scoliosis Research Society criteria. A progression risk factor was calculated for patients with curves from 20 to 29 degrees using the method described by Lonstein and Carlson. Progression was defined as main curve progression of 6 degrees or more at any follow-up visit.

**Overview of Study Protocol**

Upon enrollment each patient completed a baseline isometric trunk rotational strength testing session. During the following 4 months all received individually supervised trunk rotational strength training twice a week. Their strength testing was repeated at the end of the treatment. At a separate session they were seen clinically. From that point on the patients were instructed to perform the home strength maintenance program, and no further supervised strength training was done. After an additional 4 months (8 mo after beginning the program), patients were strength tested and at a separate time evaluated clinically. The patients were followed at 4 to 6-month intervals until reaching skeletal maturity. If progression was documented at any of the follow-up periods, the patient was offered repeat formal strength training, bracing, or surgery, as appropriate.

**Isometric Strength Testing**

The details of the testing protocol and its reliability have been reported elsewhere. Briefly, a Biodex Multi-joint System 3 Pro (Biodex Medical Systems; Shirley, NY) (Fig. 1) was used to test trunk rotational isometric strength at 5 prerotated trunk positions: 36, 18, 0, –18, and –36 degrees (negative values indicating a convex trunk position) in both the contraction toward and away from the midline. Recorded torque data were processed using a “stable one” moving window to determine the maximum strength and minimum SD (Newton meters) within a specified 1-second window and then normalized to LBW to obtain the trunk rotational strength (Nm/kg). The patients’ strength data were oriented as toward the concavity or toward the convexity of their main thoracic or thoracolumbar/lumbar curves.

Several studies have shown that isometric trunk rotational strength values from a prerotated position are higher when rotating toward the midline than away from it. Therefore, we have termed all contractions from...
any prerotated trunk position toward the midline a **high force arc** and all contractions from any prerotated trunk position away from the midline a **low force arc**. When describing a contraction, the side of the trunk prerotation was listed first, followed by the degree of trunk prerotation, and finally either **high force or low force contraction**, for example, left 36 degrees high force contraction. Values for the neutral position, which technically was a low force contraction because both contraction directions were away from the midline, were described as neutral position and the contraction direction, for example, neutral rotating toward the concavity.

**Supervised Strength Training Protocol**

The supervised training program lasted for 4 months with 2 training sessions per week, for a total of 32 training sessions. The 4-month period was extended if needed to ensure that each subject received at least 30 training sessions before the posttraining radiographic examination. The training was conducted on a MedX Rotary Torso Machine (MedX 96, Inc, Ocala, FL), the same training machine used by Mooney et al (Fig. 2A). During strength training, the patient’s pelvis was stabilized in a sitting position, and the torso was free to rotate to the left or right within a range of 40 degrees or greater on each side. Trunk rotation was resisted by a weight stack providing a constant resistance through the full range of trunk rotation. Trunk rotation was divided into 4 arcs (Fig. 2B). The concentric contractions toward the midline from either the left or right side were labeled high force arc [Fig. 2B (a, b)] and away from midline was labeled low force arc [Fig. 2B (c, d)]. The weights used in strength training were different for the high and low force arcs to improve a subject’s strength in all arcs.

The strength training was broken into preparation and strengthening phases with a different number of training sessions (days) within each phase. Each training session began with a warm-up, followed by strengthening, and ended with a burn-out period. The warm-up consisted of a 7-minute walk on the treadmill at a speed of 3.0 mph and 1% grade followed by one set of 20 repetitions on the trunk rotational machine at 9 kg (20 lb, the lightest weight), rotating to the right and left in one full 40 to –40-degree range. The strengthening was divided into the 2 force arcs (high and low) on both the right and left sides. The burn-out session began after the strengthening and consisted of 20 to 40 repetitions of either 9 or 13.5 kg of weight (20 or 30 lb). The appropriate weight was determined by the therapist. The patient would rotate from the prerotated position through the entire range of motion.

The preparation phase introduced the patient to the training environment and trunk rotational movement during the first 2 or 3 visits. During the first visit after the warm-up, exercise began using 30% of the patient’s LBW for the high force arc and 20% LBW for the low force arc. The patient was instructed to perform 3 sets of 10 repetitions. In subsequent visits the therapist would anecdotally discern, based upon the performance during the first visit, if the patient should continue with another preparation visit or should proceed to the strengthening phase. This was a purely subjective assessment, and no harmful effects were reported as a result.

The goal of the strengthening phase was to reach equal strength on the right and left sides and subsequently to increase the strength on both sides at the same pace. Training began with a weight of 35% to 55% of a subject’s LBW for a high force arc and 25% to 45% for a low force arc. The patient was instructed to complete 3 sets of 7 repetitions for each side for both high and low force arcs. If the patient completed the task successfully only on one side in a training session, the same weight stack would be used in the next session. The weight stack would be increased for the next training session by 5% of a subject’s LBW for both sides if the patient could perform the task successfully on both sides. If the patient showed difficulty in lifting the increased weight, the therapist would assist the patient’s early attempts during the concentric contraction and allow the

**FIGURE 2.** A, MedX Rotary Torso Machine used for strength training. B, Diagram showing the concept of the high force arc (a and b) and the low force arc (c and d) as employed during the supervised training portion of the protocol. The squares represent the starting position and the arrow represents the direction of contraction. The contraction is a concentric rotation away from and an eccentric rotation back to the starting position.
patient to lower the weight eccentrically. The increase of weight stack during training was decided separately on either the high or low force arc. Therefore, increases of weight proceeded at different paces for 2 force arcs depending upon the patient’s performance on the specific force arc. The strengthening phase continued to the end of the training program, that is, a total of 32 training sessions. During the supervised strength training, researchers documented the weight and number of repetitions in each training session.

**Home Strength Exercise Protocol**

The goal of the home strength exercise protocol was to maintain any strength gains obtained after supervised training. The home protocol consisted of trunk rotations using gold-colored Thera-Band (The Hygenic Corp, Akron, OH) for resistance. According to the manufacturer’s specifications, it is reported to need 88.96 N (20 lb) of force to double its starting length. With the Thera-Band attached at one end directly behind the patient at the same level as her/his shoulders and held at its other end by the subject across the upper arm, an approximately 15.24 cm (6 inch) moment arm was produced in applying the resistive torque to the spine (Fig. 3). The resultant beginning torque was about 13.34 Nm (10 lb ft) if the Thera-Band was stretched to double its original length. The spine had to overcome this resistance at the beginning of its opposite rotation. The resistance increased as the spine further rotated to the opposite side. This was an approximation of the resistive torque because a precise estimation could be quite complex.\(^49,50\) Practically, the subject could adjust the sitting position to change the starting length of the Thera-Band to find an appropriate resistive torque. The home strength exercise was simply a full range of trunk rotational motion while holding the Thera-Band. Patients were instructed to perform 3 sets of 15 repetitions to the left and to the right 3 to 5 times a week.

**Statistical Analysis**

Descriptive statistics were used to characterize the study group. A mixed linear model omnibus F test on the differences between the concave and convex contraction directions was used to compare group strength asymmetry. In this initial omnibus F test, the mean difference between concave and convex contraction direction strength values was compared with 0 by removing the intercept of the fixed factor (position) from the analysis. The patients were included as the random factor with correlated effects. If the F test was significant, paired t tests were used to test for trunk strength. This type of statistic was used to reduce the risk of type I error when multiple t tests were required to compare 2 sides for multiple prerotated trunk positions and 2 contraction directions. For the training effect a repeated measures analysis of variance was used. Alpha was set at < 0.01 for significant differences and < 0.05 for marginal differences.

Life table survival analysis was determined for survival from progression.\(^51\) Curve progression was defined as an increase of the main curve by 6 degrees or more at any follow-up visit.

**RESULTS**

From August 2002 to August 2005, 17 patients were enrolled. One withdrew because of the rigor of the training schedule, and one with a main high thoracic curve was not included in the analysis. This left 15 (12 females and 3 males) patients, whose baseline clinical data are presented in Table 1. Their average age was 13.9 ± 1.7 years (range, 10.8 to 16 y). Menarche had occurred in 5 of the 12 girls, the Risser sign was 0 in 7 of 14 (not available for 1), and the acetabular triradiate cartilage was open in 3 of the 15 patients. Eight had thoracic curves, 2 double thoracic curves, and 5 thoracolumbar/lumbar curve patterns. Their average main curve Cobb was 33 ± 12 degrees (range, 20 to 59 degrees).

Measured trunk rotational strengths were normalized to LBW for all 15 patients at baseline and at the 4-month follow-up and for 12 of the 15 at the 8-month follow-up intervals. The results are presented in Table 2 and Figure 4. There were no significant or marginally significant differences in normalized strengths between 2 mirror contraction directions at any prerotated trunk position for all measurements made at the baseline, 4 and 8-month follow-up intervals.

At the end of the 4-month supervised strength training, strength values in both contraction directions at all trunk positions significantly increased from baseline values (P < 0.005 to P < 0.001) (Table 2). At the 5 trunk positions, strength increased an average of 43% from the baseline value in concave and by 37% in convex contractions. The highest percentage increase was 50% at
the concave 18 degrees low force contraction (0.62 ± 0.22 Nm/kg to 0.93 ± 0.23 Nm/kg). The lowest percentage increase was 28% at the neutral convex contraction (0.93 ± 0.23 Nm/kg to 1.19 ± 0.29 Nm/kg). The strength increase in the neutral concave contraction was marginally significantly ($P < 0.05$) more than that in the convex contraction, 41% versus 28%, respectively.

Twelve of the 15 patients were followed through the next 4 months during the home training phase (8-month follow-up, Table 2). There were no significant differences between the 4 and 8-month follow-up strength values. The follow-up clinical data are shown in Table 3. Two patients (nos. 2 and 4) of the 3 with baseline main thoracic curves of 50 to 59 degrees had main curve progression of 12 and 15 degrees, respectively, and eventually received surgery. The third patient (no. 3) was lost to follow-up at 7 months, at which point she had 2-degree progression of her main thoracic curve and 7-degree progression of her compensatory thoracolumbar/lumbar curve. Three patients (nos. 8, 10, and 13) of the remaining 12 (25%) had progression in their main curves. Two additional patients (nos. 14 and 15) dropped out of the study (one moved with her family to another city and the other changed to bracing) after 5 months. Finally, 7 of 10 (70%) patients with follow-up of 9 months or more showed no main curve progression.

### TABLE 1. Baseline Clinical Data

<table>
<thead>
<tr>
<th>Patient (No.)</th>
<th>Sex</th>
<th>Age (y)</th>
<th>Menarche</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>LBW (kg)</th>
<th>Risser</th>
<th>TRC</th>
<th>Curves*</th>
<th>Main T or TL/L Apex Direction</th>
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<tr>
<td>1</td>
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<td>43.1</td>
<td>I</td>
<td>Cl</td>
<td>25</td>
<td>Thoracic Left</td>
</tr>
<tr>
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<td>F</td>
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<td>3</td>
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<td>59.0</td>
<td>46.1</td>
<td>0</td>
<td>Cl</td>
<td>53</td>
<td>Thoracic Right</td>
</tr>
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<td>F</td>
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<td>5</td>
<td>161.3</td>
<td>58.8</td>
<td>47.4</td>
<td>I</td>
<td>Cl</td>
<td>31</td>
<td>Thoracic Right</td>
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<td>M</td>
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<td>Nap</td>
<td>179.5</td>
<td>55.8</td>
<td>54.0</td>
<td>II</td>
<td>Cl</td>
<td>50</td>
<td>Thoracic Right</td>
</tr>
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<td>F</td>
<td>13.4</td>
<td>2</td>
<td>170.2</td>
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<td>40.4</td>
<td>II</td>
<td>Cl</td>
<td>50</td>
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<td>0</td>
<td>Op</td>
<td>21</td>
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<td>Op</td>
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<tr>
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<td>152</td>
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<td>35.5</td>
<td>0</td>
<td>Op</td>
<td>30</td>
<td>Double Thor. Right</td>
</tr>
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<td>Cl</td>
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<td>F</td>
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<td>Cl</td>
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<td>Double Thor. Right</td>
</tr>
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<td>M</td>
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<td>Nap</td>
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<td>49.9</td>
<td>47.4</td>
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<td>Cl</td>
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<td>TL/L Left</td>
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<td>F</td>
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<td>54.0</td>
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<td>Cl</td>
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<td>159.4</td>
<td>58.7</td>
<td>47.2</td>
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<td>Cl</td>
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<td>F</td>
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<td>49.9</td>
<td>40.6</td>
<td>Nav</td>
<td>Cl</td>
<td>22</td>
<td>TL/L Right</td>
</tr>
</tbody>
</table>

*Main thoracic or thoracolumbar curve in bold.

Cl indicates closed; HT*, high thoracic Cobb; Nap, not applicable; Nav, not available; Op, open; Risser, Risser sign; T*, thoracic Cobb; TL/L*, thoracolumbar/lumbar; TRC, triradiate cartilage.

### TABLE 2. Trunk Rotational Torque for all 5 Prerotated Trunk Positions, Normalized to LBW (Nm/kg)

<table>
<thead>
<tr>
<th>Pre-Rotation*</th>
<th>Concave 36°</th>
<th>Concave 18°</th>
<th>Convex 36°</th>
<th>Convex 18°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force Arc</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>All Patients</td>
<td>0.53 ± 0.25</td>
<td>1.08 ± 0.25</td>
<td>0.62 ± 0.22</td>
<td>1.00 ± 0.27</td>
</tr>
<tr>
<td>Baseline (n = 15)</td>
<td>0.78 ± 0.21</td>
<td>1.46 ± 0.33</td>
<td>0.93 ± 0.23</td>
<td>1.35 ± 0.30</td>
</tr>
<tr>
<td>4 mo fu (n = 15)</td>
<td>0.81 ± 0.25</td>
<td>1.14 ± 0.29</td>
<td>0.93 ± 0.23</td>
<td>1.19 ± 0.29</td>
</tr>
<tr>
<td>%</td>
<td>47</td>
<td>35</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>$P &lt;$</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Strength values in 2 contraction directions (concave or convex) are shown below each position figure, prerotation degree, prerotation side, and contraction direction. $P$ values are given for comparisons from the same contraction and position and the previous time interval, for example, concave 36-degree low force are baseline (0.53 Nm/kg ± 0.25) versus the same value but at 4 months’ follow-up (fu) (0.78 Nm/kg ± 0.21) ($P < 0.001$).
Of the 10 patients with 9 or more months of follow-up, 4 (nos. 5, 6, 10, and 12) had the requisite baseline curves of 20 to 29 degrees for predicting risk of progression using the Lonstein and Carlson model.41 For 1 patient (no. 5) the risk was quite small: 20%. The average risk of progression for the other 3 (nos. 6, 10, and 12) was 77% (range, 72% to 85%). One of these 3 patients (no. 12) had no growth and no curve progression during her 9-month follow-up period. The 2 remaining patients (nos. 6 and 10) had peak interval height velocities of 7.5 cm/y and 5.4 cm/y, respectively. One patient (no. 10) of the 2 (50%) most at risk progressed.

The effect of interval height velocity on curve progression was also estimated. Six (nos. 2, 5, 6, 7, 8, and 13) of the 13 patients with 7 or more months’ follow-up had an interval peak height velocity of 7 cm/y or greater. The average was 9.5 cm/y (range, 7.5 to 13.3 cm/y). Three (nos. 2, 8, and 13) of the 6 (50%) had progression of their main curve.

Finally, survivorship from curve progression of the 12 patients (10 females, 2 males with curves from 20 to 40 degrees) was determined (Fig. 5). After a 4-month supervised training and at the 8-month follow-up, their survivorship from main curve progression was 100%. At 24 months survivorship from progression of the main

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**TABLE 3. Follow-up Clinical Data**

<table>
<thead>
<tr>
<th>Patient (No.)</th>
<th>Follow-up (mo)</th>
<th>Age (y)</th>
<th>Menarche No/mo</th>
<th>Menarche Post</th>
<th>PHHV (cm/y)</th>
<th>Risser*</th>
<th>Curves</th>
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<tr>
<td>1</td>
<td>43</td>
<td>19.8</td>
<td>40</td>
<td>V</td>
<td>2.2</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>11†††</td>
<td>13.8</td>
<td>16</td>
<td>III</td>
<td>7.7</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>7§§</td>
<td>12.8</td>
<td>12</td>
<td>II</td>
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<td>A</td>
</tr>
<tr>
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<td>8‡‡‡</td>
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<td>IV</td>
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<td>A</td>
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<td>Nap</td>
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<td>Nav</td>
<td>4.3</td>
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</tr>
</tbody>
</table>

*Acetabular triradiate cartilage closed in all patients.
†Increase of ≥6 degrees in main curve in bold and underlined.
‡Increased at this point and eventually operated.
§Lost to further follow-up at this point.
¶Left study to pursue nighttime bracing.
PHHV indicates Peak Interval Height Velocity.
curve of 6 degrees or more was 64%, no better than control in the Nachemson SRS study.6

DISCUSSION
We have introduced the rationale and fully described and tested a protocol of quantified trunk rotational strength training as a nonoperative management option for AIS. We found no rotational strength asymmetry at baseline, significant strengthening in all tested trunk positions of 28% to 50% after 4 months of supervised strength training, maintenance of strength gains after an additional 4 months of a home-based strengthening program, failure to control curves of 50 to 59 degrees, and good control of 20 to 40-degree curves from baseline to the 8-month follow-up, after which there was a loss of control.

Rotational strength asymmetry in AIS is plausible given the extensive documentation of histologic, biochemical, and electromyographic asymmetries. In the only 3 prior studies trunk rotational strength in patients with AIS was less when rotating toward the curve concavity than its convexity.32,33,35 Prior studies by Mooney et al,33 which included males and females, curves up to 60 degrees, and different curve patterns, reported strength deficiency in contractions toward the concavity in all tested positions.32,33 However, the results were not statistically detailed. In our previous report, trunk strength was less in contractions toward the concavity only at neutral and the 2 prerotated trunk positions toward the concave side.35 The patient study group was quite homogenous having all females with main thoracic or thoracolumbar/lumbar curves from 14 to 41 degrees. Ten of those patients were included in the current study, and when analyzed separately, their trunk strength demonstrated the strength asymmetry noted earlier. However, in the current study we did not find rotational strength asymmetry at baseline in our analysis of trunk strength in all 15 patients. This may indicate that rotational strength asymmetry in AIS patients, if present, is generally small and dependent upon at least sex and curve magnitude and perhaps curve pattern.

Large increases in trunk rotational strength of 28% to 50% were achieved after the supervised training program of about 32 sessions over 4 months. These seem to be comparable to those reported by Mooney in 2000,33 although direct comparison is not possible because our data were normalized for LBW. In addition, we have shown that these increases were maintained over an additional 4 months. Although the patients were instructed in the home-based strength exercise program previously described, we did not effectively monitor their compliance. Our impression through retrospective inquiries was that only about one-third of them were reasonably compliant. Thus, it seemed that the supervised strength training effect lasted at least 4 months.

It appeared in the current study that curves from 20 to 40 degrees were controlled within the 4-month supervised strength training and also during the following 4 months. After these first 8 months the curve control in the home-based strength exercise program appeared to be no better than observation in the Nachemson SRS study of girls with curves from 25 to 35 degrees (Fig. 5).6 Although the study groups are somewhat different, these differences would tend to compensate for each other. For instance 2 of our patients had curves >35 degrees and 5 had curves of <25 degrees at baseline. We did include 2 boys, but 70% (7/10) of the girls in our study were premenarchal, compared with 45% (56/129) in the Nachemson study. We defined curve increase as Z6 degrees on 1 radiograph, compared with an increase of ≥6 degrees on 2 consecutive radiographs in the Nachemson study.

This finding is preliminary for 3 reasons. First, compliance with the 4-month home-based strength exercise was low. Second, no emphasis was placed on
continuing the home training after the 8-month follow-up. And third, our protocol did not provide for additional supervised training intervals, which could be anticipated to result in further strengthening and thus added spine stabilization. If further investment is to be made in attempting to develop rotational trunk strengthening as a nonoperative treatment option for AIS, better monitoring of compliance with the home-based program and further experimentation to determine the optimum dose of strength training will be needed.

A spine without muscles cannot maintain an erect posture if an axial load of 10 kg or greater is applied. An important factor responsible for AIS progression may be disuse atrophy of trunk stabilizing muscles. The deep spinal muscles on the concave side of an AIS curve have been consistently found to have increased number of type II and decreased number of type I muscle fibers, reduced muscle cross-sectional area, and reduced low-level tonic activity. These changes suggest muscle disuse atrophy. Type I fibers are the slow twitch endurance group. Type II fibers are the slow twitch fatigue group. Type II fibers are more resistant to disuse and might even increase in size. In contrast, on the convex side of the curve larger number of type I fibers are found. This is usually seen after endurance training or prolonged exposure to stretching and may help explain the paradox of shorter multifidus on the convex than the concave side.

Muscle disuse atrophy may be secondary to the initial spinal curvature, but have an important influence on spinal stability and make the curve more susceptible to progression on the basis of “vicious cycle” theory. The deep stabilizing atrophic muscles in AIS patients may not necessarily be apparent as preexisting weakness or asymmetry in measured trunk strength. For instance, AIS patients have similar flexion and extension as well as left and right bending strengths in comparison to a control group. The results of current study showed that there was not necessarily a preexisting trunk rotational strength asymmetry in AIS patients when both sexes and various curve types were mixed. The most important muscle groups for trunk rotation are the oblique abdominal muscles, which may not necessarily be affected by AIS. However, trunk paraspinal musculature, which has an important role in stabilizing the spine and may be atrophic in AIS patients, contributes only 5% of the total torque involved in trunk rotation. The effect of disuse atrophy in paraspinal muscles on measured trunk rotational strength in AIS patients may be detectable in a homogenous group of patients, as indicated in strength asymmetry in our results of female patients with similar curve size.

Enhancing spine stability is the principle underlying our approach to the management of AIS with quantified rotational trunk strengthening. Muscle activation patterns can and usually do widely vary between individuals. The nervous system must learn which muscles and strategies to use to achieve stability on the basis of the mechanical properties, fiber type, strength of each muscle, and many other factors. An effective way to counteract disuse atrophy is through progressive resistive exercises that not only sufficiently stress the agonistic and antagonistic muscles for trunk rotation, but also stress and modulate those stabilizing muscles to control and stabilize trunk posture throughout a full range of rotational motion. The paraspinal muscles act in a stabilizing role during trunk rotation, as suggested in several studies. Trunk rotational strengthening may be effective in improving their stabilizing roles as it has been shown that resisted and unresisted trunk rotations activate the superficial and deep paraspinal muscles in both the lumbar and thoracic regions. Additionally, it has been suggested that while the more superficial multifidus controls spinal orientation, the deeper components of the multifidus control intersegmental motion. Strengthening these stabilizing muscles through the entire range of motion would result in changes typically seen in strength training, for example, increased strength, increased motor unit recruitment, and changes in muscle fiber types. Those changes would result in a more stabilized spine.

The training protocol we used was focused on trunk rotational strengthening, similar in principle to the training conducted by Mooney et al but with several differences. The training protocol used in this study was well defined and described in a step-by-step fashion. Our training protocol divided the range of trunk rotation into high and low force arcs on the basis of the data from earlier reports. Patients were trained with different resistances for different force arcs. This was effective in increasing trunk strength for all force arcs. Each training session included 3 well-designed subsessions: warm-up, strengthening, and burn-out. Our training protocol was divided into 2 well-defined phases. The preparation phase gave the subject an easy entrance to the training program. The strengthening phase allowed the subject to reach a symmetric strength status and further improve trunk strength while maintaining strength side symmetry. Finally, we used a highly reliable testing technique to monitor the trunk rotational strength and strength side difference.

One weakness of the study was the heterogeneity of the study group. It would have been preferable to have tested the hypothesis on patients meeting the criteria of the SRS brace study. However, we simply could not find and enroll enough females between 10 and 15 years of age with single thoracic or thoracolumbar curves of 25 to 35 degrees. Another weakness of the current study was a lack of effective monitoring of patient compliance with the home strength exercise program and regularly scheduled strength testing followed by retraining as needed. Although the initial dose of supervised strength training seemed adequate, the maintenance dose might not have been sufficient.

CONCLUSIONS
The reliable, quantified trunk rotational strength measuring and training protocol described did not reveal
trunk strength asymmetry in this study group. Significant trunk strengthening of 28% to 50% was achieved during the 32 session, 4-month training program. This strengthening was maintained 4 months later despite incomplete compliance with the home maintenance program. Control of 50 to 59-degree curves was not achieved. Control of 20 to 40-degree curves was achieved for 8 months, but after that they seemed to progress at a rate similar to historical controls. Despite its theoretical appeal, our findings do not support rotational trunk strength training as an effective long-term treatment for AIS. However, further study within the framework of an experimental protocol seems warranted.

REFERENCES