The Effect of the Risser Stage on Bracing Outcome in Adolescent Idiopathic Scoliosis

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**Background:** To determine the influence of the Risser sign on the need for surgery in children wearing orthoses for the treatment of adolescent idiopathic scoliosis (AIS), data on compliance with brace wear were collected and analyzed.

**Methods:** One hundred and sixty-eight patients were prospectively enrolled at the time that brace wear had been prescribed and were followed until the cessation of bracing or the need for surgery. Inclusion criteria were a curve magnitude between 25° and 45°; a Risser stage of 0, 1, or 2; and, if female, <1 year post menarche at the time of brace prescription. Compliance was measured using thermal monitors.

**Results:** The prevalence of surgery, or progression to a curve magnitude of ≥50°, was 44.2% for patients at Risser stage 0 (n = 120), 6.9% for patients at Risser stage 1 (n = 29), and 0% for patients at Risser stage 2 (n = 19). Brace wear averaged 11.3, 13.4, and 14.2 hours per day for the Risser stage-0, 1, and 2 groups, respectively. While the groups had no difference in initial curve magnitude (p = 0.11), more patients at Risser stage 0 had progression to surgery than did patients at Risser stage 1 or stage 2 despite bracing (p < 0.0001). Twenty-six (41.9%) of 62 Risser stage-0 patients who wore braces ≥12.9 hours per day had progression to surgery. Ten patients at Risser stage 0 with closed triradiate cartilage wore braces ≥18 hours per day, and none underwent surgery. In comparison, 7 of 10 patients at Risser stage 0 with open triradiate cartilage and similar daily brace wear underwent surgery. Of 9 patients at Risser stage 0 with open triradiate cartilage who wore braces ≥12.9 hours daily for curves measuring <30°, 7 had a nonsurgical outcome.

**Conclusions:** Patients at Risser stage 0 are at risk for surgery despite brace wear. In these patients, 12.9 hours of daily wear—the number of hours linked with a successful outcome in the BRAIST (Bracing in Adolescent Idiopathic Scoliosis Trial)—did not prevent surgery. Patients with open triradiate cartilage were at highest risk, especially those with curves of ≥30°. Risser stage-0 patients should be prescribed a minimum of 18 hours of brace wear. Bracing should be initiated for curves of <30° in patients at Risser stage 0, especially those with open triradiate cartilage.

**Level of Evidence:** Prognostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Recent literature from the Texas Scottish Rite Hospital for Children and the BRAIST (Bracing in Adolescent Idiopathic Scoliosis Trial) supported the use of bracing to control curve progression and decrease the likelihood of surgery in patients with adolescent idiopathic scoliosis (AIS). The BRAIST, which was a multicenter comparative study measuring the rate of progression to surgery in adolescents with AIS treated with either observation or bracing, was halted by the National Institutes of Health when interim analysis showed a strong benefit in favor of patients treated with bracing. Progression to a magnitude of deformity requiring surgery was noted for 52% of the patients who were observed compared with 28% of the patients who wore a brace. A large number of the BRAIST patients also had compliance monitoring data gathered from the first 6 months of brace wear. The authors reported a threshold of 12.9 hours of daily wear that was associated on a

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dose-response curve with rates of success in preventing surgery of 90% to 93%.

Katz et al. reported overall poor compliance with prescrib- ed brace wear in patients with AIS. Using temperature sensors, they measured actual hours that the brace was worn by 100 patients with AIS. Few patients complied with wearing the brace the recommended number of hours, with only 16 using the brace at least half the time prescribed. Yet, they concluded that 12 hours of average daily wear (especially if occurring during daytime hours) was significantly related to decreasing curve progression, especially progression to a magnitude requiring surgery.

Our center undertook a study to compare average brace wear in patients with AIS who either were or were not counseled regarding their actual hours of brace use throughout their treatment course. While the study concluded that counseling patients increases the use of the brace, we noted that we had amassed a large cohort of patients managed with bracing with accurate data regarding their orthotic use throughout their entire course of treatment. The present study was undertaken to further analyze the data with respect to the relationship between stages of skeletal maturity, as reflected by the Risser sign and the status of the triradiate cartilage, and the success of bracing in light of actual knowledge of the amount of brace use.

**Materials and Methods**

Two hundred and twenty-two patients were prospectively enrolled in this institutional review board-approved study between 2008 and 2013. Inclusion criteria were a curve magnitude between 25° and 45°; a Risser stage of 0, 1, or 2; and, if the patient was a girl, <1 year post menarche at the time of brace prescription. Compliance was measured using thermal monitors. Parents provided informed consent for sensors to be used to monitor the temperature in their child’s brace. All patients were treated with a TLSO (thoracolumbosacral)-type orthosis, which was either the Boston brace or a CAD/CAM (computer-assisted design/computer-assisted manufacturing)-designed TLSO. Two Thermochron iButtons (Maxim Integrated) were embedded into the brace and held in place by an adhesive. Each sensor was programmed to collect temperature data every 15 minutes, with the first sensor starting at the time of the clinic visit and the second starting 3 months later, for a total of 6 months of collected wear data for each visit.

Patients were seen in the clinic at intervals of 4 to 6 months. At each visit, the temperature sensors were removed from the brace, data were downloaded, and the devices were rebooted and then reinserted into the orthosis. Compliance information was shared with 121 patients, whereas 101 were blinded as previously reported.

Data gathered at the time of brace prescription included age, sex, menarcheal status, curve magnitude, Risser sign, and whether the triradiate cartilage was open or fused. Radiographs were measured by a single experienced observer who was blinded to compliance data. Curve progression was defined as an increase in curve magnitude of ≥5°. Progression to a magnitude warranting surgery was defined as either a curve magnitude of ≥50° or the necessity to perform spinal arthrodesis. Compliance data were obtained from each visit. Data from the time of brace discontinuation or surgery included the Cobb angle of the largest curve and the Risser sign.

Statistical analysis was performed. Means and ranges were used to describe continuous variables, and percentages were used for categorical variables. Transformation of variables was used to ensure that normality assumptions were satisfied. When necessary, a nonparametric test (Mann-Whitney) was used. A chi-square test was used to compare categorical variables between Risser groups. When the sample size was small, a Fisher exact test was performed. Significance was set at p < 0.05.

**Results**

Two hundred and twenty-two patients were enrolled in the study. Eight patients became ineligible during the study (4 had abnormal findings on magnetic resonance imaging [MRI] indicating cord pathology, 1 did not receive functional sensors, 1 elected stapling at another center, 1 was diagnosed with a connective tissue disease, and 1 was diagnosed with endocrine disease). Five patients resigned from the study. Thirty patients were excluded because they had lost their braces (n = 3), moved and could not return for follow-up (n = 2), or were lost to follow-up (n = 25) before brace discontinuation. Two patients remained in brace treatment at the time of writing. Two patients underwent spinal arthrodesis without progression and were therefore excluded. Final compliance data were available for 175 patients who either had completed bracing and were advised to stop wearing their orthoses or had gone on to have spinal arthrodesis. Seven patients had the use of braces discontinued by their treating physicians before the patients had reached Risser stage 4. Of the 7

**TABLE I Characteristics of Patients Excluded from Final Review**

<table>
<thead>
<tr>
<th>No. of Patients</th>
<th>Mean Curve (deg)</th>
<th>Follow-up Duration*</th>
<th>Outcome*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resigned</td>
<td>5</td>
<td>31.8</td>
<td>11 to 33</td>
</tr>
<tr>
<td>Lost to follow-up</td>
<td>25</td>
<td>32.8</td>
<td>0 to 26</td>
</tr>
<tr>
<td>Lost brace</td>
<td>3</td>
<td>37.3</td>
<td>NA</td>
</tr>
<tr>
<td>Moved</td>
<td>2</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>Surgery but no curve progression</td>
<td>2</td>
<td>38</td>
<td>NA</td>
</tr>
<tr>
<td>Brace discontinued early</td>
<td>7</td>
<td>32.9</td>
<td>NA</td>
</tr>
<tr>
<td>In brace</td>
<td>2</td>
<td>31.0</td>
<td>28 to 34</td>
</tr>
</tbody>
</table>

*NA = not available.
patients, 3 subsequently progressed to surgery, 1 had progression of 13° but did not require surgery at maturity, 1 was followed to maturity without progression, and 2 were lost to follow-up at Risser stage 3 and had incomplete data. This left a total of 168 patients with complete data from the date of brace delivery to the date of either brace discontinuation or surgery (Fig. 1). The average age at the time of brace prescription was 12.33 years (range, 10.2 to 16.0 years). The average curve magnitude at the time of brace prescription for the 168 patients was 33.8°. The average curve magnitude for the 35 patients who resigned, relocated, lost their braces, or were lost to follow-up was 32° (Table I).

There were 120 patients at Risser stage 0, 29 at Risser stage 1, and 19 at Risser stage 2 at the time of brace prescription. Of the 120 patients at Risser stage 0, 46 had open triradiate cartilages and 74 had closed.

Patients at Risser stage 0 were most at risk for progression of scoliosis to magnitudes requiring surgery. Fifty-three (44.2%) of 120 patients at Risser stage 0 who had completed bracing underwent surgery or reached a magnitude requiring surgery compared with 2 (6.9%) of the 29 patients at Risser stage 1 and none of the 19 patients at Risser stage 2. While the groups had no difference in initial curve magnitude (p = 0.11), the difference in the rate of progression to surgery for patients at Risser stage 0 compared with patients at Risser stage 1 or 2 was significant despite bracing (p < 0.0001). The difference in the rate of progression to surgery between patients at Risser stage 1 and patients at Risser stage 2 was not significant (p = 0.51). The rate of surgery for patients at Risser stage 0 was 32.4% for the 74 patients with closed triradiate cartilage and 63% for the 46 patients with open triradiate cartilage (p = 0.0005) (Table II).

Overall, the 168 patients wore their braces 12.6 hours daily throughout the course of treatment. Average daily brace wear was 11.3 hours for patients at Risser stage 0, 13.4 hours for patients at Risser stage 1, and 14.2 hours for patients at Risser stage 2. The difference in hours of brace wear compared with the initial Risser sign was not significant (p = 0.1299). The

<p>| TABLE II Rate of Curve Progression of ≥6° and to Surgery According to Risser Sign at Initiation of Bracing |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|</p>
<table>
<thead>
<tr>
<th>No. of Patients</th>
<th>Progression of &lt;6° (no. [%])</th>
<th>Progression of ≥6° with No Surgery (no. [%])</th>
<th>Surgery (no. [%])</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>168</td>
<td>87 (51.8)</td>
<td>26 (15.5)</td>
</tr>
<tr>
<td>Risser stage 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>120</td>
<td>44 (36.7)</td>
<td>23 (19.2)</td>
</tr>
<tr>
<td>Open</td>
<td>46</td>
<td>11 (23.9)</td>
<td>6 (13.0)</td>
</tr>
<tr>
<td>Closed</td>
<td>74</td>
<td>33 (44.6)</td>
<td>17 (23.0)</td>
</tr>
<tr>
<td>Risser stage 1</td>
<td>29</td>
<td>26 (89.7)</td>
<td>1 (3.4)</td>
</tr>
<tr>
<td>Risser stage 2</td>
<td>19</td>
<td>17 (89.5)</td>
<td>2 (10.5)</td>
</tr>
</tbody>
</table>

Fig. 1
Flow diagram of 222 patients initially enrolled in study. Dc = discontinued, R4 = Risser stage 4, and f/u = follow-up.
55 patients who underwent surgery had worn the brace for an average of 11.9 hours per day.

In analyzing only the 120 patients at Risser stage 0 (who had the highest rate of progression to surgery), 62 wore their braces at least 12.9 hours per day, and of those, 26 required surgery. Therefore, the risk of requiring spinal arthrodesis if a child at Risser stage 0 wears a brace at least 12.9 hours per day was 41.9%. Conversely, the risk of needing spinal arthrodesis if a child at Risser stage 0 does not wear a brace an average of 12.9 hours per day was 46.6% (27 of 58 patients). Therefore, wearing a brace 12.9 hours per day is not effective in patients at Risser stage 0. Of the 120 patients at Risser stage 0, only 20 wore their brace ≥18 hours per day, and 7 (35%) of them went on to surgery. The remaining 100 patients at Risser stage 0 wore their orthoses <18 hours per day, and 46% of them went on to surgery. Using logistic regression, there was no association between hours of brace wear and progression to surgery for patients at Risser stage 0.

Patients at Risser stage 1 fared better, with no patient who wore their brace >6 hours per day requiring surgery. None of the 19 patients at Risser stage 2 required surgery, regardless of their brace wear, but only 3 wore their brace <12 hours per day. Unfortunately, this study is underpowered to conclude with certainty that bracing is not needed for patients at Risser stage 2.
The patient at Risser stage 2 either responds well to bracing or may not need bracing. The lack of an untreated group prevents the ability to reach a conclusion.

A subanalysis of the 120 patients at Risser stage 0 was performed, with the group divided according to curve magnitude and whether the triradiate cartilage was open when brace wear was initiated (Tables III and IV). We compared our success rate in preventing progression to surgery with that in the study by Lonstein and Winter, who reported the success rate for Risser stage-0 and stage-1 patients grouped together, with curves ranging from 20° to 50°. First, for 118 patients with curves in the 20° to 29° range, Lonstein and Winter reported that 9% (11) had progressed to a magnitude requiring surgery. In our study, when patients at Risser stage 0 and stage 1 with curves between 25° and 29° (n = 47) were combined, we found a 12.8% rate of surgery. After eliminating the patients at Risser stage 1, 37 patients at Risser stage 0 with curves measuring between 25° and 29° (n = 47) were analyzed, we found an 18.4% rate of surgery. Finally, the hours of wear versus the likelihood of surgery were analyzed separately for the group at Risser stage 0 with closed triradiate cartilage (n = 74) (Table III) and the group with open triradiate cartilage (n = 46) (Table IV). Despite ≥15 hours of daily wear, 54.5% of patients with open triradiate cartilage needed surgery. At ≥18 hours of measured wear, 7 of 10 children had curve progression to a magnitude requiring surgery. In a chart review, these 7 compliant surgical patients experienced rapid progression during peak growth velocity, all had curves of ≥33° (average, 36.4°) when the brace was prescribed, and they wore their braces an average of 19.3 hours (range, 18.4 to 20.2 hours) per day. In comparison, 10 patients at Risser stage 0 with closed triradiate cartilage at the time of brace prescription wore their brace for ≥18 hours per day. None of these 10 patients had progression to surgery, and only 2 had worsening of their curve by ≥6° (Fig. 3).

An analysis was performed of the 12 patients who had open triradiate cartilage at the time of brace prescription and curves between 25° and 29°. Eight of them did not progress to surgery.

Discussion

This study is the first, to our knowledge, to have large numbers of patients at various Risser stages with objective data on compliance collected throughout the entire course of bracing. Previous studies either did not group patients by skeletal maturity, in particular by whether the triradiate cartilage was open or closed, or did not have objective information as to whether the patients were wearing their orthoses. Katz et al. and Morton et al. both reported that physician estimates of brace wear and self-reporting by patients are inaccurate compared with measured actual wear. For this reason, studies that do not include objective measures of brace compliance should not be included when deciding if bracing is effective in AIS.

The BRAIST was published in 2013 and is currently quoted widely in support of the effectiveness of bracing. One
thousand and eighty-six adolescents were enrolled, with 242 patients comprising the preliminary study group on which the conclusions were based. Of the 242 patients, 146 were managed with bracing. Although the methods stated that compliance information would be collected on all braced patients, only 116 patients had compliance information reported for the first 6 months of bracing. In our study, compliance data were collected throughout the entire course of bracing. A decrease in brace compliance was seen in many of our patients as they approached skeletal maturity, so the hours of wear reported in our investigation may be lower than those reported in the BRAIST study.

Although 97% of the BRAIST patients were at Risser stage 0, 1, or 2 at brace prescription, 4 patients with advanced maturity (Risser stage 3, 4, or 5) at the start of their bracing were included. The 12.9-hour threshold for successful brace wear was identified on the basis of the compliance data gathered for all of the monitored patients irrespective of their initial Risser sign, and they were not stratified on the basis of either Risser sign (or on the status of the triradiate cartilage closure in the 82 patients at Risser stage 0) or by the initial curve magnitude. Our study is novel in that we report the influence of the Risser sign as well as compliance on the rate of progression to surgery in patients with AIS who were managed with bracing. While many of the subgroups become quite small, it opens the door for future studies of larger groups of patients.

Our study as well as that by Katz et al. found that no patient managed with bracing for AIS at an initial maturity of Risser stage 2 had progression to surgery. The current study describes only 19 patients at Risser stage 2, and Katz et al. included 10 additional patients who were at Risser stage 2 at the initiation of bracing. As there were no untreated controls in either study, it remains unknown whether patients who are at Risser stage 2 require bracing but respond favorably to it or do not require bracing at all and are at low risk for progression to surgery. Interestingly, there was a trend, although not significant, for patients who were at Risser stage 2 at the start of bracing to wear their braces more than their less mature counterparts. It may be that the shorter duration that a brace is used for a patient at Risser stage 2 encourages those teenaged patients to wear the brace as prescribed until they reach maturity. Nonetheless, it is plausible that many of the patients at Risser stage 2 may represent a group of “overtreated” patients who do not require treatment, in agreement with the study by Sanders et al.

While it is widely accepted that patients who are at Risser stage 0 are at greatest risk for progression, this study documents that even in children who compliantly wear their orthoses, curve progression and surgery are likely if the curve is moderate in size (>30°) and the patient has an open triradiate cartilage. This agrees with studies by Little et al., in which 83% of patients were found to have curve progression to 45° or to a magnitude requiring surgery if their curves were ≥30° prior to peak growth velocity11,12. Those studies, however, did not measure brace compliance, and one is left wondering whether the patients wore their braces or not. We did not make either elbow or hand radiographs; therefore, we cannot comment on the Sauvegrain method or the Sanders criteria for the assessment of skeletal maturity and brace outcome13,14. Of patients with smaller curves (25° to 29°) and open triradiate cartilage, 66.7% did not progress to surgery, perhaps lending support to the use of bracing for smaller curves in very immature patients.

There are shortcomings in this study. First, some groups that were based on a combination of Risser sign and initial curve magnitude were quite small, which was mentioned where appropriate. Second, this study reviewed only patients who wore a TLSO or Boston-type brace. Some braces were made with computer-assisted design and manufacturing technology, while others were not. We did not see a difference among the groups with respect to the correction obtained in the brace. The quality of brace wear, as evidenced by brace strap tension, was not measured15. Finally, all radiographs were measured by a blinded single reviewer. Intrarater and interrater reliability for curve magnitude, Risser sign, and the status of the triradiate cartilage were not studied.

In conclusion, there is a relationship between advancing Risser sign and orthotic success. All patients at Risser stage 1 and stage 2 were noted to meet with success, with the exception of 2 patients at Risser stage 1 (both of whom had not achieved 6 hours of daily brace wear). Whether this proves the effectiveness of bracing in this group or illustrates the lack of evidence that these children need a brace cannot be determined from these data. Patients at Risser stage 0 are most likely to have curve progression, and even those who are compliant with brace wear are likely to require surgery if their triradiate cartilages are nonossified at the start of the brace wear period and their curves measure ≥30°.

Following analysis of these data, we prescribe the use of braces for a minimum of 18 hours per day for patients at Risser stage 0 with closed triradiate cartilage and the use of braces for 12 to 16 hours per day for patients at Risser stage 1. The role of bracing in patients at Risser stage 2 remains unknown. In our practice, patients at Risser stage 0 with open triradiate cartilage are currently prescribed full-time brace wear, and bracing is currently initiated for curves measuring ≥20°, although whether bracing can prevent surgery in a patient with open triradiate cartilage is an area for future research.

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