

# Update in Nonoperative Management of Adolescent Idiopathic Scoliosis to Prevent Progression

Brett A. Shannon, MD; W.G. Stuart Mackenzie, MD; Arun R. Hariharan, MD; Suken A. Shah, MD

Department of Orthopaedic Surgery, Nemours Alfred I. duPont Hospital for Children, Wilmington, DE

## Abstract:

The primary goal of nonoperative treatment of adolescent idiopathic scoliosis (AIS) is to prevent curve progression. The risk of progression and estimation of growth remaining should be performed through a combination of serial X-rays, menarche history, serial height measurement, triradiate cartilage status, Risser grade, and Sanders Skeletal Maturation Stage with a left-hand bone age X-ray. For AIS patients with growth remaining and a curve magnitude between 25 and 45 degrees, conservative treatment with a rigid thoracolumbosacral orthosis (TLSO) is indicated. Rigid TLSOs (e.g., Wilmington, Boston, Rigo-Cheneau) are superior to other brace types, but there is insufficient evidence to recommend a specific type of rigid TLSO. Brace wear for at least 13 hours per day is indicated until skeletal maturity to limit curve progression. Physiotherapeutic scoliosis-specific exercises (PSSE) should be considered in addition to bracing for patients with moderate curves because there is growing evidence that PSSE improve overall patient-perceived back status when used as an adjunct to brace treatment. However, PSSE have not been shown to decrease the likelihood of curve progression for patients with mild curves; therefore, insufficient evidence exists to recommend PSSE for asymptomatic patients with mild curves. The nonoperative treatment of AIS remains an active area of investigation, and further research is needed to better compare brace types, optimize brace weaning, and understand the effectiveness of PSSE.

## Key Concepts:

- For adolescent idiopathic scoliosis patients with growth remaining and a curve magnitude between 25 and 45 degrees, conservative treatment with a rigid thoracolumbosacral orthosis (TLSO) is indicated until skeletal maturity to limit curve progression.
- The success of brace treatment is time dependent, and rigid TLSOs should be worn for at least 13 hours per day. Electric brace-wear sensors are helpful in routine clinical practice to assist with counseling patients and families.
- Rigid TLSOs (e.g., Wilmington, Boston, Rigo-Cheneau) are superior to other brace types, but there is insufficient evidence to recommend a specific type of rigid TLSO.
- Physiotherapeutic scoliosis-specific exercises (PSSE) should be considered in addition to bracing for patients with moderate curves.
- Insufficient evidence exists to recommend for or against PSSE for patients with mild curves.

## Introduction

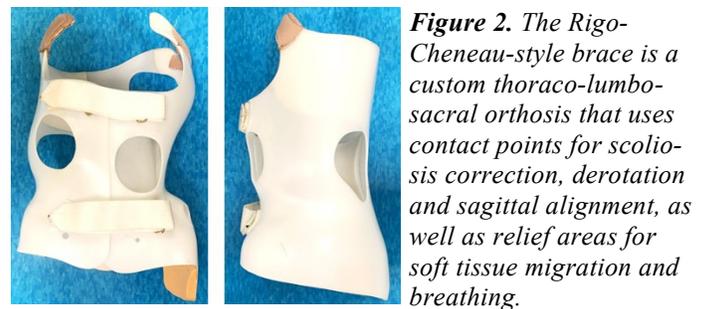
Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity defined by coronal plane angulation of at least 10 degrees (measured by the Cobb method) first detected in a patient between 10 and 17 years of age with no identifiable congenital, neuromuscular, or syndromic etiology. Most AIS curves remain mild, but patients with coronal curve magnitude greater than 50 degrees at skeletal maturity are likely to have progressive spinal deformity as adults. The risk of curve progression is generally highest during the prepubescent period of peak height velocity. Therefore, active observation with serial examination and/or X-rays is indicated for patients with curve magnitude less than 25 degrees without progression, which account for the majority of cases. Operative treatment with spinal fusion is generally reserved for patients with curve magnitude greater than 45–50 degrees. For patients with growth remaining and a curve magnitude between 25 and 45 degrees, conservative treatment with bracing and/or physiotherapeutic scoliosis-specific exercises (PSSE) is indicated. The primary goal of conservative treatment is to prevent curve progression. Other goals expressed by the Society for Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) include prevention of respiratory dysfunction, prevention of spinal pain, and improvement of aesthetics.<sup>1</sup>

## Brace Treatment

A wide variety of scoliosis brace designs are available, and they can be classified according to biomechanical intent, material rigidity, spine region affected, and opening number and location. Early Milwaukee-style cervicothoracolumbosacral orthoses were traction based, and they were poorly tolerated by patients. These have largely been replaced by single-opening, rigid underarm thoracolumbosacral orthoses (TLSO), such as the prefabricated modular system developed at Boston Children's Hospital<sup>2</sup> and the custom molded system from the Alfred I. duPont Institute, which provide two-dimensional control (coronal and sagittal) (Figure 1).<sup>3,4</sup> More recently designed Rigo-Cheneau-style braces are



**Figure 1.** The Wilmington brace is a custom underarm thoraco-lumbosacral total-contact orthosis that provides a corrective scoliosis mold from a Risser-type cast with a fit high in the axilla and low over the greater trochanters and pubic symphysis.



**Figure 2.** The Rigo-Cheneau-style brace is a custom thoraco-lumbosacral orthosis that uses contact points for scoliosis correction, derotation and sagittal alignment, as well as relief areas for soft tissue migration and breathing.



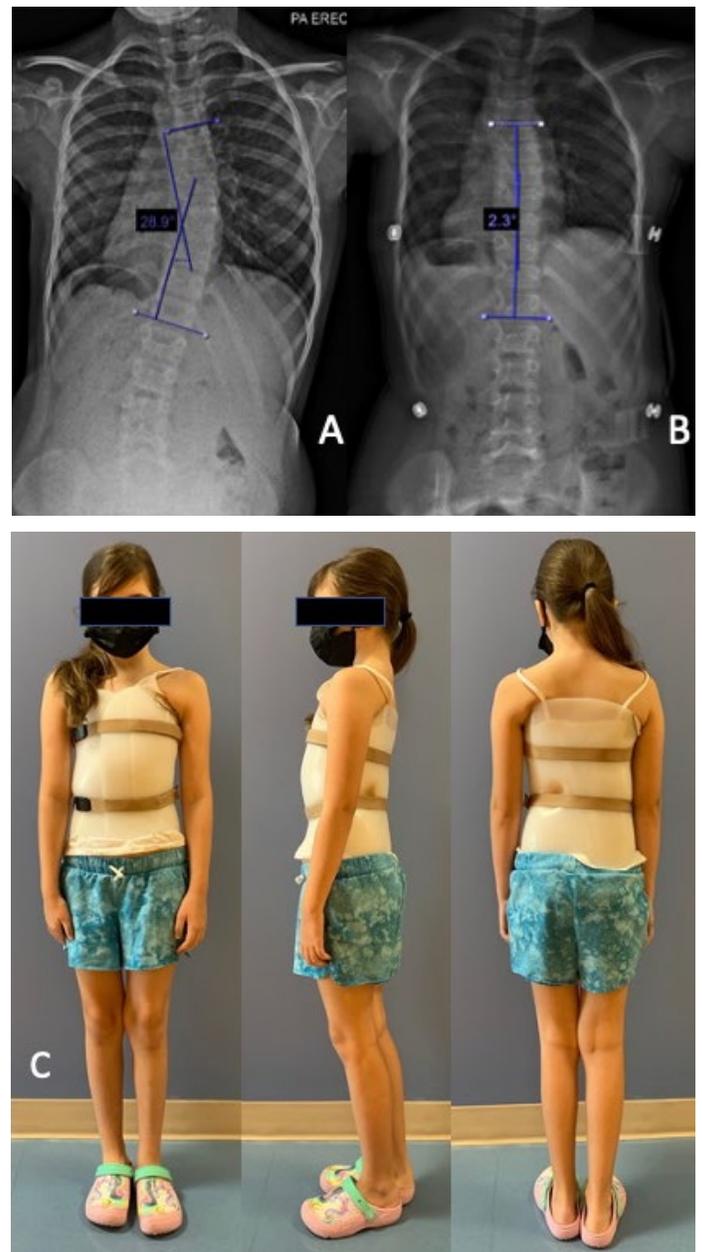
intended to provide three-dimensional (coronal, sagittal, and axial) control (Figure 2). These braces are designed according to the Rigo scoliosis classification: imbalanced thoracic, double curve, balanced thoracic and false double, and single lumbar or thoracolumbar. Other available brace types include night-time bending braces (e.g., Charleston, Providence), which apply large bending forces, as well as softer, motion-based systems intended to promote postural change (e.g., SpineCor).

Brace treatment is proposed to be effective via three mechanisms: (1) end-point control that resists curve

progression by reducing spine swaying, (2) in-brace correction that reduces spine buckling, and (3) transverse loading to mold and derotate the rib cage and spine.

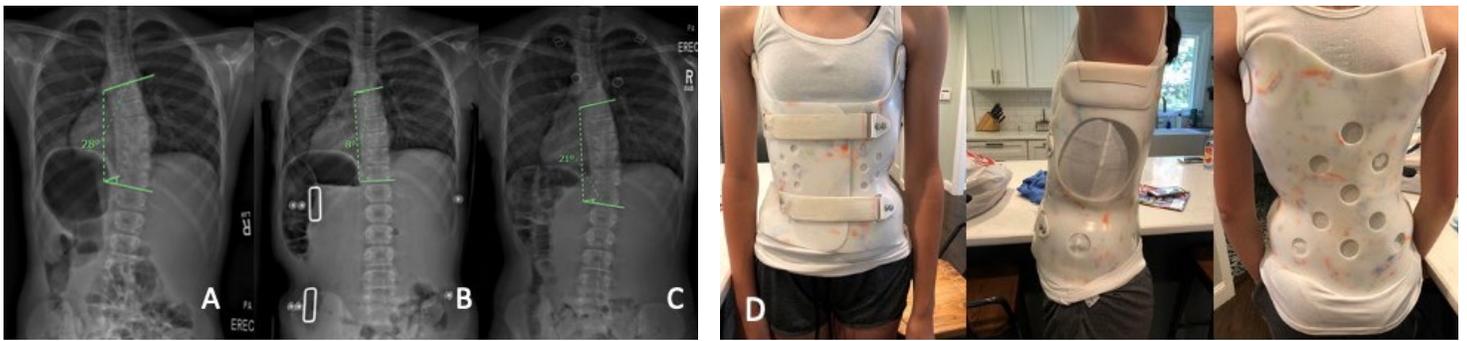
These mechanisms are thought to modulate remaining spinal growth and are therefore only useful in patients with substantial growth remaining.<sup>5</sup> Most experts recommend confirming in-brace coronal plane correction of at least 50% in a non-bending rigid TLSO or at least 75% correction in a bending brace and modifying (or re-fabricating) the brace if initial correction is not obtained (Figures 3 and 4). Recent interest extends beyond in-brace coronal deformity correction to both the sagittal and axial planes. While there are not yet parameters for ideal correction, patients with mismatched pelvic incidence and lumbar lordosis in brace, and those who become hypo-kyphotic during bracing, have been shown to be at increased risk of scoliosis progression.<sup>6</sup> There is also prospective data showing increased pre-brace apical vertebral rotation and decreased apical vertebral rotation correction velocity in brace, present increased risk for scoliosis progression.<sup>7</sup> Despite the partial radiographic correction achieved during brace wear, realistic goals and expectations of brace treatment should be set. Following discontinuation of bracing, the curve magnitude will be similar to that before treatment initiation,<sup>8</sup> and permanent curve correction should not be expected in most AIS patients.

Early studies on the effectiveness of brace treatment in the prevention of curve progression had conflicting results. In both retrospective and prospective studies, patients with moderate curves were two to three times less likely to have curve progression requiring surgery.<sup>9,10</sup> However, some retrospective analyses found no difference in curve progression and rates of surgery.<sup>11,12</sup> The inclusion of patients with mild curves in these studies likely caused studies to underestimate the effectiveness of bracing for moderate curves. The conflicting conclusions contributed to wide variation in opinion among scoliosis care providers regarding the effectiveness of bracing<sup>13</sup> and an effort to standardize the criteria for studies of bracing was completed.<sup>14</sup>



**Figure 3.** Radiographs of an 11-year-old girl with Adolescent Idiopathic Scoliosis with progression of TS-12 curve to 29 degrees (A). Radiographs in a custom-molded Wilmington brace demonstrate >50% curve correction (B). The Wilmington brace sits close to the skin and is tolerated well by this patient >20 hours per day (C).

The prospective Bracing for Adolescent Idiopathic Scoliosis Trial (BrAIST) provided the foundation for modern bracing recommendations. It included patients ages 10–15 years, Risser stage 0–2, with a curve between 20 and 40 degrees<sup>15</sup> studied at 25 centers. Both patients who



**Figure 4.** Radiographs of an 11-year-old girl with Juvenile Idiopathic Scoliosis with progression of T6-11 curve to 28 degrees. The patient was treated with a Rigo-Cheneau-style brace with >50% curve correction (B). This patient wears her brace >21 hours per day and has no curve progression 2.5 years later (C). The Rigo-Cheneau-style brace applies 3D scoliosis correction principles using contact points and relief areas.

agreed to undergo randomization between brace treatment and active observation as well as those who refused randomization but agreed to participate if allowed to choose (between bracing and observation) were included. Braces used in the study were Boston-style (posterior-opening rigid plastic TLSO with three-point molding) or Wilmington (anterior-opening custom molded Orthoplast), and brace-wear compliance was recorded using a temperature sensor embedded in the brace. The primary outcome was prevention of curve progression to greater than 50 degrees at skeletal maturity. During interim analysis, it was found that patients were more likely to have a successful outcome when treated with bracing (72%) compared to observation (48%), and therefore the study was terminated earlier than planned. The BrAIST study remains a landmark in establishing level 1 evidence for the effectiveness of bracing for moderate AIS; furthermore, a Cochrane systematic review concluded that brace treatment for moderate AIS is effective.<sup>16</sup>

Multiple studies have demonstrated a time-dependent response to success of brace treatment. Although a study on the Wilmington brace found no difference in curve progression or surgery with full (23 hours per day) or part-time (12-16 hours per day) wear prescription,<sup>17</sup> subsequent studies have identified 12-13 hours per day as a threshold for effective brace wear. The BrAIST data showed 90% success among patients who wore their brace for at least an average of 12.9-17.7 hours per day and a slightly higher success rate for those who wore it

at least 18 hours per day.<sup>15</sup> Similarly, Katz et al. found that the rate of surgery was lower among patients who wore their brace for at least 12 hours per day (6%) compared to those who wore it for 7 to 12 hours per day (25%) or less than 7 hours per day (32%).<sup>18</sup> Additionally, studies have documented that patients overreport their average daily hours of brace wear to their physician and wear the brace fewer hours than prescribed.<sup>19</sup> Brace wear monitor data can provide feedback to the patient, family, orthotist, and physician. Therefore, most experts recommend that brace wear should be monitored using electronic sensors in routine clinical practice.<sup>20</sup> Counseling patients and families about their wear time and opportunities to improve compliance will make brace treatment more effective.

The decision to begin brace treatment should be made after a thorough discussion between the physician, patient, and family regarding the progression risk of AIS and the available treatment options. The BrAIST data suggest that if all patients Risser 0-2 patients with curves of 20 to 40 degrees are braced, the number needed to treat to prevent one patient from progressing to a curve of surgical magnitude is approximately 3. Thus, it is appropriate for some patients with mild curves (<25 degrees) to be observed and assessed for progression over a 4- to 6-month interval. On the other hand, initiation of bracing can still be considered for patients who present at Risser grade 3 with curves of 30-45 degrees. The risk of progression and estimation

of growth remaining should be performed through a combination of serial X-rays, menarche history, serial height measurement, triradiate cartilage status, Risser grade, and Sanders Skeletal Maturation Stage (SMSS) with a left-hand bone age X-ray.<sup>21</sup> The predictive value of the SMSS for main thoracic and double major curve patterns was validated in a large cohort of AIS patients.<sup>22</sup> There are skeletal maturity scales validated in AIS utilizing radiographs of the thumb<sup>23</sup> and proximal humerus,<sup>24</sup> though the SMSS and Risser grade remain the most widely used and studied at this time. Online calculators utilizing predictive models incorporating the curve pattern, curve magnitude, and either the SMSS or the patient age, sex and Risser grade are available from the University of Iowa (<https://uichildrens.org/ais-prognosis-calculator-simplified>) and can help facilitate the shared decision-making process with families.

Patient and orthotist selection are likely far more important than selection of a brace type, and excellent results can be obtained with many types of rigid TLSOs. Rigid non-bending TLSOs have been shown to be more effective at preventing surgery than both bending braces<sup>25</sup> and soft braces;<sup>26</sup> therefore, they are recommended by most experts.<sup>20</sup> A comprehensive review by SOSORT found that there is insufficient evidence to recommend a specific type of rigid non-bending TLSO.<sup>1</sup> More recently, results of computer-assisted design/manufacturing (CAD/CAM) suggest improvement in curve correction and brace weight compared to manual techniques<sup>27</sup> with encouraging early clinical outcomes after 2 years of bracing.<sup>28</sup> Research on low-cost, quick-production 3D-printed braces is also underway.<sup>29</sup> In addition to radiographic and clinical measurements, the orthotist can utilize a three-dimensional optical scan of the patient to prepare the brace design. Minsk et al. reported that patients with comparable deformity and brace-wear times were less likely to have curve progression or surgery when treated with a Cheneau-style orthosis than with a Boston-style orthosis.<sup>30</sup> However, this study was limited by inclusion of only 13 patients treated with a Cheneau-style orthosis, and further research is needed to compare

results of the different rigid TLSO types. Nevertheless, Cheneau-style and three-dimensional CAD/CAM designs have become popular at many North American centers and in the online community.

Once brace treatment is initiated, in-brace posteroanterior (PA) and lateral X-rays are made 2–6 weeks later to verify adequate correction and exclude worsening of sagittal plane parameters, and brace adjustments are made as needed. Clinical examination and subsequent out-of-brace (for at least 6 hours prior) PA X-ray are performed every 4–6 or 6–12 months for rapidly growing (SMSS 3 or 4) or slowly growing patients, respectively. When patients reach skeletal maturity, as determined either by stable height for 6 months, 2 years since menarche, Risser 5, or SMSS 7, the brace should be weaned over a period of 6 months,<sup>20</sup> although further research is needed to better understand the benefits of weaning compared to abrupt discontinuation. Recent attention has been paid to stopping bracing at SMSS 7, with curve progression reported in up to 11.4% of patients.<sup>31</sup> In contrast, cessation of bracing at SMSS subtype 7b (>50% fusion of the medial distal ulnar physis) is reported to be more reliable, with no cases of curve progression and no need to wait until SMSS 8 for discontinuation of bracing.<sup>31</sup>

Despite appropriate assessment of risk of progression, wear monitoring, and compliance counseling, some patients will not benefit from brace treatment. Patients with greater curve magnitude at the time of brace initiation, excessive thoracic hypokyphosis, or very high or low body mass indices are less likely to benefit from brace treatment.<sup>32,33,34</sup> Additionally, curves with an apex proximal to T7 are not well-controlled by underarm TLSO braces. There is no role for bracing curves greater than 50 degrees or any curves in skeletally mature patients (Risser grade 5, SMSS 7/8) with AIS.

## Physiotherapeutic Scoliosis Specific Exercises

The primary aim of PSSE is to prevent progression of spinal deformity by altering the soft tissues and

neuromuscular control of the spine. PSSE may be prescribed either in combination with a brace for patients with moderate (25–45 degree) curves or in the absence of a brace for patients with mild curves (<25 degrees) who are highly motivated to avoid needing a brace. There are seven major schools of PSSE, and they share several common features: three-dimensional self-correction, training activities of daily living, and stabilization of corrected posture.<sup>35</sup> The Schroth technique is one of the most widely publicized and studied methods of PSSE. Intended to promote three-dimensional correction through elongation, rotational breathing, and stabilization, the Schroth method emphasizes curve-specific postural corrections during daily activities.<sup>36</sup>

PSSE typically consist of at least 15 minutes of daily exercise combined with at least one weekly 60-minute session with a physical therapist for a duration of 9–12 weeks. The equipment for home exercises costs approximately \$60–\$90 and wall bar installation can be >\$500 (Figure 5). Specific goals include muscle strengthening (e.g., periscapular and abdominal muscles), increased flexibility (e.g., latissimus and paraspinals), postural correction through visual and tactile feedback, and breathing exercises intended to strengthen the diaphragm, decrease the use of accessory respiratory muscles, and expand the rib cage. Manual therapy is performed to improve spinal segment and rib mobility. Education is provided in anticipation of transition to a home exercise program after 12 weeks.

There is limited evidence regarding the effectiveness of PSSE as isolated therapy. A 2012 Cochrane review found limited, low-quality evidence in support of PSSE.<sup>37</sup> Since then, the feasibility of a randomized controlled trial has been demonstrated in the United Kingdom,<sup>38</sup> and two small randomized controlled trials with short-term (24–52 week) follow-up have found that PSSE as a standalone intervention are effective to slow progression in patients with mild curves compared to typical exercise programs or observation.<sup>39,40</sup> Additionally, Liu et al. performed a prospective cohort study of



**Figure 5.** Equipment to perform the Schroth method includes wall bars for hanging, sitting and standing exercises, mirrors to assess alignment and body position, a floor mat for supine exercises, straps to provide traction for elongation exercises, and bean bags as cues for body position (A). Less expensive portable options can be created for home such as a door jamb anchor, graduated stretching strap and dowel to recreate the wall bar (B).

children with scoliosis measuring 10–25 degrees, treated with PSSE alone, with minimum of 1 year of follow-up.<sup>41</sup> While their study lacked any control group, they were able to demonstrate that only 7% of patients' scoliosis progressed, which is lower than previously published rates of observation alone. PSSE are safe and may be a reasonable choice for patients with mild curves who are highly motivated to avoid a brace and want to “take action.” However, the associated cost is not insignificant for many families, and the number of these patients needed to treat to prevent progression remains unknown.

There is growing evidence in support of the effectiveness of PSSE as an adjunct to brace treatment. In a prospective, historical cohort-matched study, 24 patients treated with bracing who were also prescribed a Schroth-type PSSE program were more likely to have stable or improved curve magnitude, angle of trunk rotation, and quality of life scores compared to historical controls.<sup>36</sup> In a well-designed randomized controlled trial of 50 patients with 10- to 45-degree curves also being treated with standard care (i.e., braces were worn if indicated), a

6-month Schroth exercise program improved pain, self-image and back muscle endurance.<sup>42</sup> Additionally, patients in the PSSE group demonstrated a small, statistically significant difference in curve magnitude compared to the control group—the largest curve decreased on average by 1.2 degrees in the PSSE group and increased by 2.3 degrees in the control group over the 6-month period.<sup>43</sup> In a secondary analysis of these data, Schreiber et al. calculated that to prevent one progression of the largest curve beyond 5 degrees over the 6-month interval, the number needed to treat is approximately 4.<sup>44</sup> Finally, in further analysis of the same data, they reported that despite the absence of a clinically meaningful curve magnitude improvement, patients still perceived significant improvement of overall back status.<sup>45</sup> A second prospective randomized trial recently performed by Gao et al. similarly found that patients treated with 6 months of PSSE, in addition to bracing, had small but significant improvements in Cobb angle (4.87 vs. 2.05 degrees), in addition to improvement in back muscle endurance and pulmonary function.<sup>46</sup> Unfortunately, completion of a structured PSSE program (>10 visits) still only results in 50% rate of compliance with home exercises at one week and 23.5% at one year.<sup>47</sup> Despite questionable compliance, Fan et al. have demonstrated that in a prospective trial, 40 patients treated with 6 months of PSSE +/- bracing had statistically significant, durable improvement in curve magnitude at 2 years with no cases of deterioration.<sup>48</sup> While PSSE have been shown to contribute to halting curve progression, the clinical significance of such improvements remain unproven, and further research is needed to better define the impact of this treatment discipline.

## Summary

Bracing and exercises for AIS remain active areas of research. High-quality evidence supports rigid TLSO treatment for at least 13 hours per day to limit the risk of curve progression for AIS patients with growth remaining and curve magnitude between 25 and 45 degrees. Available progression-risk calculators provide objective data that can facilitate the patient's decision to begin

brace treatment. Preliminary findings suggest that CAD/CAM techniques may improve three-dimensional correction, but further research is needed to determine whether recent advances in brace design affect curve progression. Although insufficient evidence exists to recommend PSSE for asymptomatic patients with mild curves, there is growing evidence that PSSE improve overall patient-perceived back status when used as an adjunct to brace treatment.

## Additional Links

- A guide to different braces and their intended uses by the Scoliosis Research Society: <https://www.srs.org/professionals/online-education-and-resources/srs-bracing-manual>
- A nonprofit organization to help educate and connect families and promote research of pediatric spinal deformity: <https://www.settingscoliosisstraight.org>
- A scoliosis calculator that predicts the risk of progression of Cobb angle >45 degrees without treatment, utilizing Simplified Skeletal Maturity Scoring System, curve location, and curve magnitude: <https://uichildrens.org/ais-prognosis-calculator-simplified>
- International peer-led support group to connect and support young women with scoliosis: <https://www.curvygirlsscoliosis.com>

## References

1. Negrini S, Donzelli S, Aulisa AG, et al. 2016 SOSORT Guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. *Scoliosis Spinal Disord.* 2018 Jan 10;13:3.
2. Gomez JA, Hresko MT, Glotzbecker MP. Nonsurgical Management of Adolescent Idiopathic Scoliosis. *J Am Acad Orthop Surg.* 2016 Aug;24(8):555-64.
3. Bunnell WP, MacEwen GD, Jayakumar S. The use of plastic jackets in the non-operative treatment of idiopathic scoliosis. Preliminary report. *J Bone Joint Surg Am.* 1980 Jan;62(1):31-8.
4. Bassett GS, Bunnell WP, MacEwen GD. Treatment of idiopathic scoliosis with the Wilmington brace. Results in patients with a twenty to thirty-nine-degree curve. *J Bone Joint Surg Am.* 1986 Apr;68(4):602-5.

5. Castro FP Jr. Adolescent idiopathic scoliosis, bracing, and the Hueter-Volkman principle. *Spine J*. 2003 May-Jun;3(3):180-5.
6. Matsumoto H, Warren S, Simhon ME, et al. It is not just about the frontal plane: sagittal parameters impact curve progression in AIS patients undergoing brace treatment. *Spine Deform*. 2020;8(5):921-929.
7. Kwan KYH, Cheung AKP, Koh HY, Cheung KMC. Brace Effectiveness Is Related to 3-Dimensional Plane Parameters in Patients with Adolescent Idiopathic Scoliosis. *J Bone Joint Surg Am*. 2021;103(1):37-43.
8. Lenke L, Silva F, Lehman R. Idiopathic Scoliosis. In: Rothman RH, Simeone FA, Herkowitz HN, eds. *Rothman-Simeone and Herkowitz's, The Spine, Seventh edition*. Philadelphia, PA: Elsevier; 2018: 451–468.
9. Fernandez-Feliberti R, Flynn J, et al. Effectiveness of TLSO bracing in the conservative treatment of idiopathic scoliosis. *J Pediatr Orthop*. 1995 Mar-Apr;15(2):176-81.
10. Nachemson AL, Peterson LE. Effectiveness of treatment with a brace in girls who have adolescent idiopathic scoliosis. A prospective, controlled study based on data from the Brace Study of the Scoliosis Research Society. *J Bone Joint Surg Am*. 1995 Jun;77(6):815-22.
11. Miller JA, Nachemson AL, Schultz AB. Effectiveness of braces in mild idiopathic scoliosis. *Spine (Phila Pa 1976)*. 1984 Sep;9(6):632-5.
12. Goldberg CJ, Moore DP, Fogarty EE, Dowling FE. Adolescent idiopathic scoliosis: the effect of brace treatment on the incidence of surgery. *Spine (Phila Pa 1976)*. 2001 Jan 1;26(1):42-7. doi: 10.1097/00007632-200101010-00009. PMID: 11148644.
13. Dolan LA, Donnelly MJ, Spratt KF, et al. Professional opinion concerning the effectiveness of bracing relative to observation in adolescent idiopathic scoliosis. *J Pediatr Orthop*. 2007 Apr-May;27(3):270-6.
14. Richards BS, Bernstein RM, D'Amato CR, et al. Standardization of criteria for adolescent idiopathic scoliosis brace studies: SRS Committee on Bracing and Nonoperative Management. *Spine (Phila Pa 1976)*. 2005 Sep 15;30(18):2068-75; discussion 2076-7.
15. Weinstein SL, Dolan LA, Wright JG, et al. Effects of bracing in adolescents with idiopathic scoliosis. *N Engl J Med*. 2013 Oct 17;369(16):1512-21.
16. Negrini S, Minozzi S, Bettany-Saltikov J, et al. Braces for idiopathic scoliosis in adolescents. *Cochrane Database Syst Rev*. 2015 Jun 18;(6):CD006850.
17. Allington NJ, Bowen JR. Adolescent idiopathic scoliosis: treatment with the Wilmington brace. A comparison of full-time and part-time use. *J Bone Joint Surg Am*. 1996 Jul;78(7):1056-62.
18. Katz DE, Herring JA, Browne RH, et al. Brace wear control of curve progression in adolescent idiopathic scoliosis. *J Bone Joint Surg Am*. 2010 Jun;92(6):1343-52.
19. Takemitsu M, Bowen JR, Rahman T, et al. Compliance monitoring of brace treatment for patients with idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2004 Sep 15;29(18):2070-4; discussion 2074.
20. Roye BD, Simhon ME, Matsumoto H, et al. Establishing consensus on the best practice guidelines for the use of bracing in adolescent idiopathic scoliosis. *Spine Deform*. 2020 Aug;8(4):597-604.
21. Sanders JO, Khoury JG, Kishan S, et al. Predicting scoliosis progression from skeletal maturity: a simplified classification during adolescence. *J Bone Joint Surg Am*. 2008 Mar;90(3):540-53.
22. Sitoula P, Verma K, Holmes L Jr, et al. Prediction of Curve Progression in Idiopathic Scoliosis: Validation of the Sanders Skeletal Maturity Staging System. *Spine (Phila Pa 1976)*. 2015 Jul 1;40(13):1006-13.
23. Hung ALH, Chau WW, Shi B, et al. Thumb Ossification Composite Index (TOCI) for Predicting Peripubertal Skeletal Maturity and Peak Height Velocity in Idiopathic Scoliosis. *J Bone Joint Surg Am*. 2017 Sep 6;99(17):1438-1446.
24. Li DT, Linderman GC, Cui JJ, et al. The Proximal Humerus Ossification System Improves Assessment of Maturity in Patients with Scoliosis. *J Bone Joint Surg Am*. 2019 Oct 16;101(20):1868-1874.
25. Katz DE, Richards BS, Browne RH, et al. A comparison between the Boston brace and the Charleston bending brace in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 1997 Jun 15;22(12):1302-12.
26. Guo J, Lam TP, Wong MS, et al. A prospective randomized controlled study on the treatment outcome of SpineCor brace versus rigid brace for adolescent idiopathic scoliosis with follow-up according to the SRS standardized criteria. *Eur Spine J*. 2014 Dec;23(12):2650-7.
27. Cobetto N, Aubin CÉ, Parent S, et al. 3D correction of AIS in braces designed using CAD/CAM and FEM: a randomized controlled trial. *Scoliosis Spinal Disord*. 2017 Jul 23;12:24.
28. Guy A, Labelle H, Barchi S, et al. Braces designed using CAD/CAM combined or not with Finite Element Modeling lead

- to effective treatment and quality of life after 2 years: A randomized controlled trial. *Spine (Phila Pa 1976)*. 2021 Jan 1;46(1):9-16.
29. Zhang Y, Liang J, Xu N, et al. 3D-printed brace in the treatment of adolescent idiopathic scoliosis: A study protocol of a prospective randomised controlled trial. *BMJ Open*. 2020;10(11):1-6.
30. Minsk MK, Venuti KD, Daumit GL, et al. Effectiveness of the Rigo Chêneau versus Boston-style orthoses for adolescent idiopathic scoliosis: a retrospective study. *Scoliosis Spinal Disord*. 2017 Mar 20;12:7.
31. Cheung PWH, Cheung JPY. Sanders stage 7b: Using the appearance of the ulnar physis improves decision-making for brace weaning in patients with adolescent idiopathic scoliosis. *Bone Joint J*. 2021 Jan;103-B(1):141-147.
32. El-Hawary R, Chukwunyerena C. Update on evaluation and treatment of scoliosis. *Pediatr Clin North Am*. 2014 Dec;61(6):1223-41.
33. Goodbody CM, Asztalos IB, Sankar WN, et al. It's not just the big kids: both high and low BMI impact bracing success for adolescent idiopathic scoliosis. *J Child Orthop*. 2016 Oct;10(5):395-404.
34. Karol LA. Effectiveness of bracing in male patients with idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2001 Sep 15;26(18):2001-5.
35. Berdishevsky H, Lebel VA, Bettany-Saltikov J, et al. Physiotherapy scoliosis-specific exercises - a comprehensive review of seven major schools. *Scoliosis Spinal Disord*. 2016 Aug 4;11:20.
36. Kwan KYH, Cheng ACS, Koh HY, et al. Effectiveness of Schroth exercises during bracing in adolescent idiopathic scoliosis: results from a preliminary study-SOSORT Award 2017 Winner. *Scoliosis Spinal Disord*. 2017 Oct 16;12:32.
37. Romano M, Minozzi S, Bettany-Saltikov J, et al. Exercises for adolescent idiopathic scoliosis. *Cochrane Database Syst Rev*. 2012 Aug 15;2012(8):CD007837.
38. Williams MA, Heine PJ, Williamson EM, et al. Active Treatment for Idiopathic Adolescent Scoliosis (ACTivATeS): a feasibility study. *Health Technol Assess*. 2015 Jul;19(55):1-242.
39. Monticone M, Ambrosini E, Cazzaniga D, et al. Active self-correction and task-oriented exercises reduce spinal deformity and improve quality of life in subjects with mild adolescent idiopathic scoliosis. Results of a randomised controlled trial. *Eur Spine J*. 2014 Jun;23(6):1204-14.
40. Kuru T, Yeldan İ, Dereli EE, et al. The efficacy of three-dimensional Schroth exercises in adolescent idiopathic scoliosis: a randomised controlled clinical trial. *Clin Rehabil*. 2016 Feb;30(2):181-90.
41. Liu D, Yang Y, Yu X, et al. Effects of Specific Exercise Therapy on Adolescent Patients With Idiopathic Scoliosis: A Prospective Controlled Cohort Study. *Spine (Phila Pa 1976)*. 2020 Aug 1;45(15):1039-1046.
42. Schreiber S, Parent EC, Moez EK, et al. The effect of Schroth exercises added to the standard of care on the quality of life and muscle endurance in adolescents with idiopathic scoliosis-an assessor and statistician blinded randomized controlled trial: "SOSORT 2015 Award Winner," *Scoliosis*. 2015 Sep 18;10:24.
43. Schreiber S, Parent EC, Khodayari Moez E, et al. Schroth Physiotherapeutic Scoliosis-Specific Exercises Added to the Standard of Care Lead to Better Cobb Angle Outcomes in Adolescents with Idiopathic Scoliosis - an Assessor and Statistician Blinded Randomized Controlled Trial. *PLoS One*. 2016 Dec 29;11(12):e0168746.
44. Schreiber S, Parent EC, Hill DL, et al. Schroth physiotherapeutic scoliosis-specific exercises for adolescent idiopathic scoliosis: how many patients require treatment to prevent one deterioration? - results from a randomized controlled trial - "SOSORT 2017 Award Winner". *Scoliosis Spinal Disord*. 2017 Nov 14;12:26.
45. Schreiber S, Parent EC, Hill DL, et al. Patients with adolescent idiopathic scoliosis perceive positive improvements regardless of change in the Cobb angle - Results from a randomized controlled trial comparing a 6-month Schroth intervention added to standard care and standard care alone. *SOSORT 2018 Award winner*. *BMC Musculoskelet Disord*. 2019 Jul 8;20(1):319.
46. Gao C, Zheng Y, Fan C, et al. Could the clinical effectiveness be improved under the integration of orthotic intervention and scoliosis-specific exercise in managing adolescent idiopathic scoliosis? *Am J Phys Med Rehabil*. 2019;98:642-648.
47. Simhon ME, Fields MW, Grimes KE, et al. Completion of a formal physiotherapeutic scoliosis-specific exercise training program for adolescent idiopathic scoliosis increases patient compliance to home exercise programs. *Spine Deform*. 2021;9(3):691-696.
48. Fan Y, Ren Q, To MKT, Cheung JPY. Effectiveness of scoliosis-specific exercises for alleviating adolescent idiopathic scoliosis: A systematic review. *BMC Musculoskelet Disord*. 2020;21(1).