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Review Article

Brace treatment in adolescent idiopathic scoliosis: risk factors for failure—a literature review

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Abstract Brace treatment is the most common nonoperative treatment for the prevention of curve progression in adolescent idiopathic scoliosis. The success reported in level 1 and 2 clinical trials is approximately 75%. The aim of this review was to identify the main risk factors that significantly reduce success rate of brace treatment.

A literature search using the MEDLINE and Embase databases was conducted. Studies were included if they identified specific risk factor(s) for curve progression. Studies that looked at nighttime braces, superiority of one type of brace over another, the effect of physical therapy on brace performance, cadaver or nonhuman studies were excluded. A total of 1,022 articles were identified of which 25 met all of the inclusion criteria. Seven risk factors were identified: Poor brace compliance (eight studies), lack of skeletal maturity (six studies), Cobb angle over a certain threshold (six studies), poor in-brace correction (three studies), vertebral rotation (four studies), osteopenia (two studies), and thoracic curve type (two studies). Three risk factors were highly repeated in the literature which identified specific subgroups of patients who have a much higher risk to fail brace treatment and to progress to fusion. This data demonstrates that 60% to 70% of the patients referred to bracing are Risser 0 and 30% to 70% of this group will not wear the brace enough to ensure treatment efficacy. Furthermore, Risser 0 patients who reach the accelerated growth phase with a curve ≥40° are at 70% to 100% risk of curve progression to the fusion surgical threshold despite proper brace wear. Skeletally immature patients with relatively large magnitude scoliosis who are noncompliant

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are at a higher risk of failing brace treatment.

Keywords: Adolescent idiopathic scoliosis (AIS); Brace treatment; Curve progression; Risk-factors; Orthotic; Spine; TLSO

Introduction

The prevalence of adolescent idiopathic scoliosis (AIS) is estimated to be between 1% and 3% for children between 10 and 16 years of age and is more prevalent in girls than boys [1,2]. The factors responsible for the initiation of the curve are unknown, but the subsequent progression of the curve is clearly associated with the adolescent peak growth velocity [3]. The scoliosis research society guidelines recommend that skeletally immature patients with curves reaching 25° to 40° be treated with a brace for the purpose of preventing curve progression. Skeletally immature patients with curves reaching a magnitude greater than 45° or skeletally mature patients with curves ≥50° most often are offered surgical correction procedure as they are at risk for curve progression in adulthood [4].

As mentioned above, there is a direct relationship between skeletal growth and curve progression in AIS. Application of a spinal brace should reduce the curve, increase the resistance to load and prevent curve progression. Patwardhan et al. [5] identified three important factors that may influence brace treatment: end point control by the brace that reduces the sway of the spinal column and resists curve progression, curve correction in the brace that increases the resistance of the spinal column to buckling (the most important factor), and transverse loading by the pads within the brace. Spinal braces relieve asymmetric loading in the spine and prevent asymmetric growth with perpetuation and progression of the deformity. Thus, the brace has biomechanical and biological effects in preventing curve progression.

Although brace treatment is the most common nonoperative treatment for the prevention of curve progression, the success of brace treatment reported in level 1 and 2 clinical trials in preventing curve progression to above 50° as reported in the literature is at best approximately 75% [6−11]. Acknowledging these factors raises awareness to whether brace treatment is an appropriate option for patients at high risk of curve progression. The aim of this review was to identify risk factors that significantly reduce the expected success rate of brace treatment.

Methods

Two reviewers performed a systematic literature search using the MEDLINE (PUBMED) and Embase databases using the following search strategy:

((idiopathic[Title/Abstract] AND scoliosis[Title/Abstract]) AND (Brace[Title/Abstract] OR bracing[Title/Abstract]) instead of ((idiopathic[Title/Abstract] AND scoliosis [Title/Abstract]) AND (Brace[Title/Abstract] OR bracing[Title/Abstract]) AND (surgery OR fusion)) ((idiopathic[Title/Abstract] AND scoliosis[Title/Abstract]) AND (Brace[Title/Abstract] OR bracing[Title/Abstract]) AND (surgery OR fusion)) between Jan. 2012 − Sep. 2017

and

((idiopathic[Title/Abstract] AND scoliosis[Title/Abstract])) AND ((“natural history”) or (“Disease Progression”)) between Sep. 2007 − Sep. 2017

The search query was filtered to include only articles written in English. Studies were included in the analysis if they identified specific risk factor(s) for AIS curve progression and had a sample size ≥15 patients. Articles that described both AIS and JIS were included; however, if the AIS population was described separately, only AIS patients were reported in this review. All references within these articles were reviewed for additional articles that met inclusion criteria. The list of institutions and authors were reviewed and cross referenced in an effort to diminish the potential for overlapping patients.

Review publications and conference abstracts were excluded. In addition, studies that looked at nighttime braces, the superiority of one type of brace over another, studies that evaluated the effect of physical therapy (PT) on brace performance, cadaver or nonhuman studies were excluded as well. The identified articles' reference lists were not evaluated to retrieve additional studies (ie, snowballing technique was not carried in the present review).

Level of evidence was set using the *Journal of Bone and Joint Surgery* guidelines [12].

Results

A total of 1,022 articles concerning bracing for AIS patients were located in the Medline (247) and Embase (775) databases using the search strategy, 26 duplicate articles were excluded. Of these articles, 803 were not further reviewed because, based on their abstracts, did not meet one or more of the inclusion criteria. The full text of 193 articles was reviewed. Of these, 25 were found to meet all the inclusion criteria.

A flow diagram of the search process is presented in Fig. 1.

Identified risk factors

Relevant articles identified from the search are listed in Table 1 and more detailed description is available in the

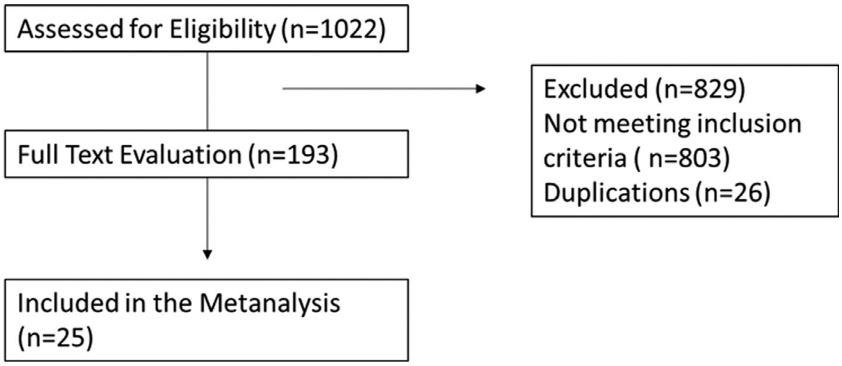

Fig. 1. Article selection process. The details of these studies are summarized in the supplementary data section of this manuscript.

Table 1
Summary of risks identified

Risk	Number of articles	References
Poor brace compliance	8	[10,11,13−18]
Low level of skeletal maturity	6	[9,19−23]
Initial Cobb angle >30°	6 (5 studies)	[6,19,21−24]
Rotation	4	[22,25−27]
Low levels of in-brace correction	3	[9,18,25]
Main thoracic curve	2	[6,21]
Osteopenia	2	[21,28]
Pelvic tilt, spinopelvic inclination	1	[29]
BMI >85th percentile	1	[18]
Low BMI (underweight children)	1	[30]
Angle of the plane of maximal curvature, hypokyphosis, Torsion >5°	1	[27]
Vertebra wedging	1	[31]

supplementary data section of this article. Although some of the risk factors were specific to only one article, seven risk factors were repeatedly mentioned in the literature: Poor brace compliance was mentioned as a major risk factor in eight studies [10,11,13−18], low values of skeletal maturity in six studies [9,19−23], Cobb angle over a certain value at the beginning of brace treatment in six studies [6,19,21−24], in-brace curve correction in three studies [9,18,25], significant vertebral rotation (apical vertebra rotation, Rib Hump, and Rib Vertebral Angle) in four studies [22,25−27], Osteopenia in two studies [21,28] and thoracic curve type in two studies [6,21]. These main risks are discussed in detail below. Notably, many papers pointed out more than one risk factor or a combination of risk factors.

Poor brace compliance

Eight articles described poor brace compliance as a risk factor for curve progression [10,11,13−18]. Three of these articles were prospective studies using sensors embedded in the brace to monitor patient compliance with brace wear and are detailed below [10,11,15]. The BRAIST study was the first prospective, randomized controlled trial designed to objectively demonstrate the efficacy of brace treatment versus observation in preventing curve progression ≥50° or to a recommendation for surgery [10]. The study consisted of 146 AIS patients treated with brace and 96 patients under observation. All patients had a major Cobb angle of 20° to 40° and were Risser 0 to 2. Of the patients treated with a brace, 28% progressed to ≥50° compared to 52% in the observation group. The study findings demonstrated that bracing significantly reduces the risk of curve progression to the surgical threshold. Specifically, the study showed that brace wear for an average of 12.9 h/d is associated with high success rate (90−93%) and that brace wear between 0 and 6 h/d is not beneficial compared to the observation group (41% vs. 48% success rate, respectively).

Sanders et al. [11] prospectively studied a sample of 100 AIS patients treated with brace and also demonstrated a strong correlation between brace compliance and treatment success. Patients who wore the brace for a minimum of 14 h/d demonstrated a success rate of 100% in prevention of progression to surgery. Patients who wore the brace between 2 and 10 h/d showed a success rate of 66.7%. Those patients who were non-compliant and wore the brace for less than 2 h/d, showed a success rate of only 55.6%.

A prospective study by Lou et al. [15] evaluated quantity (% of wear time relative to the prescribed wear) and quality (% of time the wear tightness was within a 20% range of the prescribed tightness level) of brace wear using a force sensor monitor on a sample of 40 patients. Quantity wise, 56±19% of the patients wore their brace for the prescribed time of 23 h/d, and 55±17% of the time the brace was worn at the desired tightness (quality).

Of the total study population, 25% required surgery, which is in agreement with the rate described in the BRAIST study. In summary, 8 papers (Therapeutic Level I:1, Therapeutic Level II:4, Therapeutic Level IV:2, and Level 3:1) included a total of 1,413 patients had identified poor brace compliance as a major risk factor for brace success. There is an agreement, in the recent studies that used sensors to verify compliance, that effective brace treatment requires a high degree of compliance with good compliance defined as a minimum of 10 to 12.9 hours of brace wearing per day.

Low level of skeletal maturity

Skeletal maturity is defined and monitored by different methods in the papers reviewed, with the most common parameter used being the Risser score. However, several articles refer to the Sanders score, chronologic age, menarche status, and triradiate cartilage status. In our review, six articles identified early stage of skeletal maturity at the time of brace initiation as a risk factor for failure of brace treatment [9,19−23]. Karol et al. [19] prospectively studied the effect of Risser score on bracing outcome on a sample of 168 AIS patients, with curve magnitude between 25° and 45° and a Risser stage of 0 to 2. The patients were enrolled at the time that brace wear had been prescribed and were followed until the cessation of bracing or the need for surgery. The majority of the study sample (71%) were Risser 0. Within the Risser 0 patients, 38% had open triradiate cartilage and 62% had a closed triradiate cartilage. Patients with open triradiate cartilage were at a higher risk to progress to surgery compared to patients with a closed cartilage (63% vs 32.4%). Patients with open triradiate cartilage and curve over 30° were at an extremely high risk for surgery (70%) despite wearing the brace for more than 18 h/d. In general, for Risser 0 patients, logistic regression analysis demonstrated no association between the daily hours of wear and progression to the surgery threshold [19].

Zhang et al. [22] retrospectively studied the curve behavior of 89 braced AIS female patients. In his work, logistic regression analysis demonstrated that Risser score of less than 2 is one of the prognostic factors for curve progression by more than 5°. Xu et al. [9] conducted a retrospective study on 488 AIS patients who have completed brace treatment with a minimum of 2-year follow-up. The study compared patients in the failure group to patients in the success group and found that patients in the failure group were significantly younger (12.8±1.6 vs. 13.4±1.6), had a lower Risser score (1.4±1.5 vs. 2.1±1.5), and a lower in brace correction.

A similar difference in Risser score (average Risser of 1.4±1.5 vs. average Risser of 2.2±1.4) between the failure and the success groups was observed by Sun et al. [21]. However, this difference did not reach statistical significance (p=.054). In the logistic regression analysis, this study identified that menstrual status (pre-menarche), bone mineral density (osteopenia), and curve type (thoracic) as risk factors for curve progression as well as a curve magnitude of 31° to 40°. Zhu et al. [20] retrospectively investigated a group of patients with a Cobb of 40°−50° that refused surgery and elected to be treated with brace. The initial Risser score in patients with a curve progression was significantly lower than in patients with a stable or improved curve (0.3±0.8 vs. 1.2±1.4). Charles et al. [23] retrospectively evaluated the risk of curve progression in a sample of 372 patients and identified that the risk of progression when the deformity onset is Risser 0 was closely related to the curve magnitude (discussed in detail in the following section). In summary, 6 papers (Therapeutic Level IV:3, Prognostic Level II:1, Prognostic Level IV:1, and Level 2:1) covering a total of 1,297 patients reveal that early stage of skeletal maturity, defined mainly by Risser 0, is a significant risk factor for curve progression.

Initial Cobb angle

Six articles identified initial curve size at the initiation of brace treatment as a risk factor for curve progression [6,19,21−24]. Karol et al. [19] studied a sample of 222 patients and in addition to the risk of low skeletal maturity described above, the study further assessed the risk for curve progression of patients with Risser 0 in relation to the initial curve size. For curves of 40° or more, the authors found 100% progression with Risser 0 and open triradiate cartilage and 56% progression risk for Risser 0 and closed triradiate cartilage. For curves of 30° to 39° Risser 0 with open triradiate cartilage the risk was 70% (Fig. 2).

Similar findings were also reported by Sitoula et al. [24] who retrospectively studied a sample of 161 patients from initial diagnosis until reaching skeletal maturity, curve progression to ≥50°, or spinal fusion. Fifty-one percent of the patients in the study were braced and half of them progressed at endpoint. Study findings demonstrated that children with initial Cobb angle of ≥40° and Risser score of ≤4 progressed to the surgical threshold in 100% of the cases.

In a study by Zhu et al. [20] described above, of 54 patients refusing surgery with Cobb angle between 40° and 50° and Risser 0, a progression over 5° was seen in 35/54 of the patients (65%). Charles et al. [23] looked at the risks of curve progression at the time of peak height velocity in a sample of 372 patients. In his study, patients received treatment according to their deformity and skeletal maturity. In general, curves less than 20° were observed and curves of 20° or greater were braced. The study found that the risk for Risser 0 patients is closely related to the curve size at onset of puberty and that patients with a curve magnitude greater than 30° have a 100% risk of rapid progression over 45° during peak height velocity. In summary, 6 papers (Prognostic Level II:1, Prognostic Level III:1, Therapeutic Level IV:2, Level 2:1, and Level 3:1) covering total of 912 patients identify an initial Cobb angle of >30° to 40° as risk factors for curve progression.

Low value of in-brace correction

Three articles identified initial in-brace correction as a predictive outcome for curve progression [9,18,25]. A study conducted by Xu et al. [9] evaluated a cohort of 488 AIS patients with a 2-year follow-up after brace treatment. The study calculated brace correction as the difference in Cobb angle

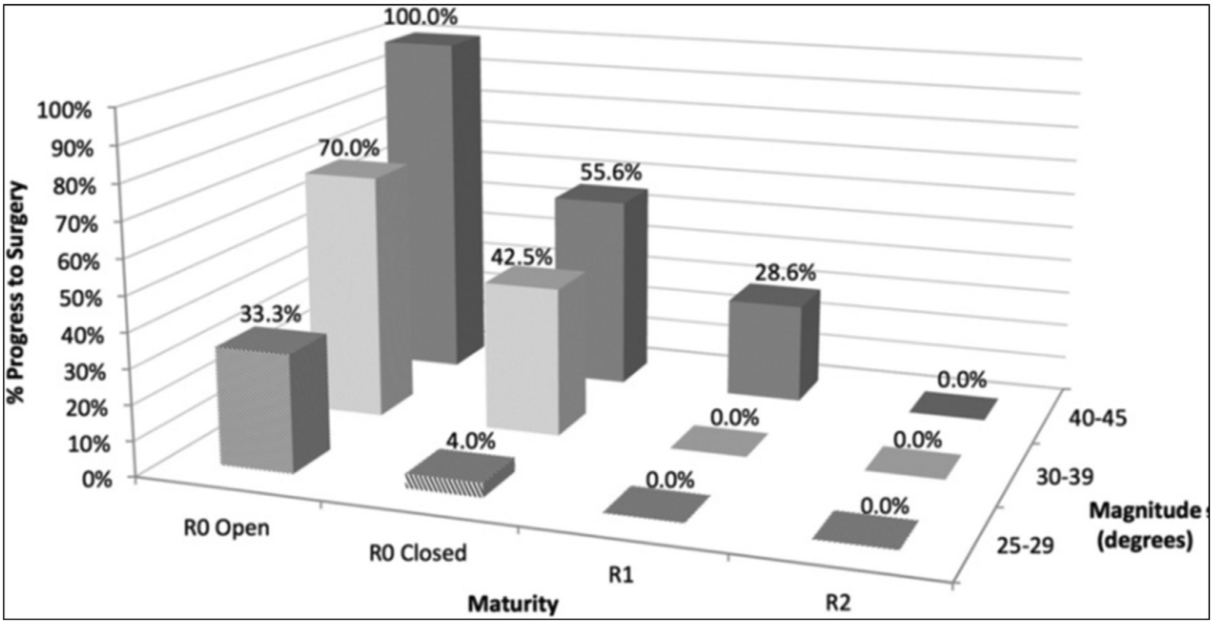

Fig. 2. Rate of progression to surgery versus initial curve magnitude for each Risser sign.
*Adopted with permission from Karol et al. [19].

between prebrace and in-brace radiographs (after 3 months of brace wear) and compared the correction rate between patients with a successful brace treatment (n=368) to patients who had curve progression of more than 5˚ (n=120). A value below 10% in-brace correction cut-off rate was suggested as an indicator for predicting brace failure.

A second study by Maruyama et al. [25] aimed to define the differences between patients that had a successful brace treatment (n=8) to patients who failed brace treatment (progression of Cobb angle of >6˚, n=8). The study followed the patient population up to skeletal maturity and calculated in-brace correction as the difference between Cobb angle at prebrace treatment to first in-brace Cobb angle. The results of the study also pointed out that patients in the failure group had a lower in-brace correction rate (83.4% vs. 37.6% in the failure group).

The third article by Goodbody et al. [18] aimed to study whether body mass index (BMI) affects brace treatment. A cohort of 166 patients was grouped according to patient BMI. The authors identified that high BMI >85th percentile patients are more likely to fail brace treatment (Cobb angle progression to >45˚). This was largely due to their inadequacy of in-brace correction and poor brace compliance. In general, the study findings point out to a cut-off rate of 45% in brace correction below which brace treatments tend to be less successful. In summary, 3 papers (Therapeutic Level IV:2, and Level III:1) with a total of 703 patients, claim that in-brace correction is a significant risk factor for curve progression, but no definitive cut-off rate of in-brace correction could be concluded from the publications. In addition, each publication defined failure and measured brace correction somewhat differently.

Vertebral rotation

Four articles identified rotation (apical rotation, rib hump and rib vertebral angle are all considered as rotation related) as a risk factor for curve progression [22,25−27]. In a sample of 89 patients, Zhang et al. [22] described above noted that apical vertebral rotation beyond grade 3 is one of the risk factors for curve progression of more than 5˚. In another retrospective study [27], a comparison of patients having corrective surgery to patients defined with a nonprogressive curve was made in an attempt to identify three-dimensional parameters by an EOS system in a sample of 133 patients. The study demonstrated a significant increase of 2.4˚ axial rotation was found for the progressive group (increase in Cobb angle ≥6˚) compared to the nonprogressive group. Maruyama et al. [25] described above found that better results were predicted for patients with less clinical rotation. Sun et al. [26] retrospectively evaluated 48 braced AIS girls at Risser 0 and found that the angle between the rib and the vertebra also serves as an indicator for the likelihood of the curve to progress >6˚. The authors describe that curve progression was significantly higher in patients with initial rib vertebral angle difference ≥20˚ versus patients with initial rib vertebral angle difference <20˚, or convex initial rib vertebral angle ≤68˚ versus convex initial rib vertebral angle >68˚. In summary, 4 papers (Therapeutic Level IV:3, and Level III:1) including a total of 303 patients had identified vertebral rotation as a risk factor.

Curve type

Two articles identified thoracic curves to have a higher probability of progression than other curve types [6,21]. Thompson et al. [6] studied retrospectively a sample of 168 braced patients and determined that different curve morphologies responded with variable success rates of bracing. The article further describes that despite similar initial curve magnitudes and daily brace wear, the rate of surgery or curve progression to ≥50˚ was significantly greater for main thoracic curves (34.5% [29 of 84] in Lenke-I curves, 54.5% [6 of 11] in mLenke-II curves, 29.4% [10 of 34] in mLenke-III curves) compared to main lumbar curves (17.6% [3 of 17] in mLenke-V curves, and 13.6% [3 of 22] in mLenke-VI curves). After combining curve types into main thoracic and main lumbar, the rate of surgery or curve progression of ≥50˚ (combined success) was significantly greater in the main thoracic group compared to the main lumbar group (34.1% [44 of 129] vs. 15.4% [6 of 39]). The risk of main thoracic curves to progress was also demonstrated on a sample of 68 braced patients by Sun et al. [21]. This study defined curve progression as an increase in Cobb angle >6˚ or progression to >45˚ and demonstrated by univariate logistic regression analysis and further by multivariate logistic regression analysis that main thoracic pattern versus thoracolumbar/lumbar is a risk factors in predicting the curve progression during brace treatment. In summary, 2 papers (Prognostic Level III:1, Level II:1) including a total of 290 patients had identified thoracic curve as a risk factor.

Osteopenia

Two articles identified osteopenia as a risk factor for curve progression [21,28]. Sun et al. [21] discussed above, compered a group of patients that progressed during brace treatment to those that did not (17:51 respectively). Patients in the progressed group had a significantly greater initial Cobb angle and a significantly lower bone mineral density value (0.80± 0.11 vs. 0.88± 0.12 g/cm^2), as compared to those with non-progressed curves. Osteopenia was assessed by measurements at vertebrae L2−L4, and femoral neck of the nondominant side with the method of dual-energy x-ray absorptiometry (DEXA, Lunar). Yip et al. [28] measured osteopenia on the Bilateral hips by DXA and reached the same conclusion on a larger sample of 513 AIS patients were the proportions of patients with osteopenia having the need for or actually having gone through surgery versus those without osteopenia were 17.2% versus 7.6%, respectively (p=.011).

In summary, 2 papers (Level II:1 and III:1) including a total of 599 patients had identified osteopenia as a risk factor.

Discussion

Our review identified seven main risk factors for curve progression despite brace treatment (Table 1). Three of these risk factors: poor brace compliance, low level of skeletal maturity, and initial Cobb angle >30˚ were highly repeated in the literature (Fig. 3). Four (4) level 2 prospective studies (published in six articles) contribute significantly to the results of our review [6,10,11,15,19,32]. These studies all used sensors to study brace wear compliance and investigated a very similar population: AIS patients in the United States with initial Cobb angle between 20˚ and 40˚ and who less than or equal to Risser 2. As a result, they provide reliable evidence regarding the effect of brace wear on a total of 454 AIS patients.

Although the three major risks for curve progression are well accepted, one of the main questions remaining is the potential cumulative effect when two or more of these major risks are present (Fig. 4). Several researchers in the past have looked into the level of the risk associated with a combination of several risk factors together. In 1984, Carson and Lonstein [33] formulated an equation that calculates the risk of curve progression in AIS patients with a Cobb angle of up to 30˚, taking into account the patients curve size, Risser stage, and chronological age. According to their formula, Risser 0 patients with a Cobb angle of 30˚ have a substantial risk (over 80%) of curve progression >5˚.

Charles et al. [23] demonstrated that untreated Risser 0 patients with a curve magnitude greater than 30˚ at the onset of the accelerating growth phase will progress to more than 45˚ curve magnitude 100% of the time. Karol et al. [19] showed that for braced patients with Risser 0 and curve angle greater than 30˚, there was no correlation between the hours of brace wear and avoiding the surgical threshold of 50˚. In addition, within the Risser 0 group curve size 30˚ to 39˚, the risk of curve progression was 70% for patients with open triradiate cartilage and 42.5% in the closed triradiate cartilage patients. For braced patients with curves between 40˚ and 49˚, the risk of progression to fusion range was 100% in the open triradiate cartilage group and 55.6% in the closed triradiate cartilage group. The author concluded that in general, patients with open triradiate cartilage and curve of ≥30˚ are likely to progress to surgery even when brace is being used properly and state that wearing a brace 12.9 hours per day is

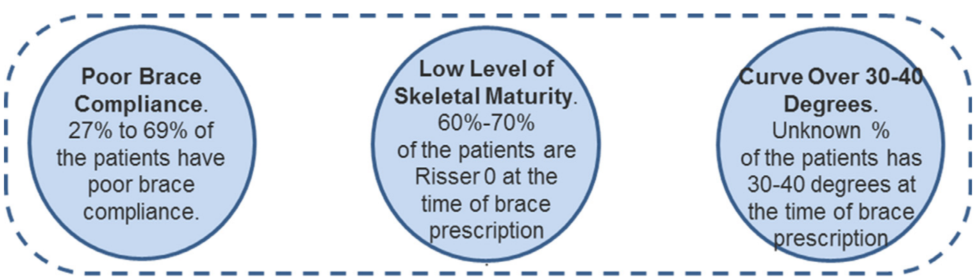

Fig. 3. Schematic presentation of the prevalence of the major three risks for curve progression: curve magnitude, skeletal maturity, and brace compliance.

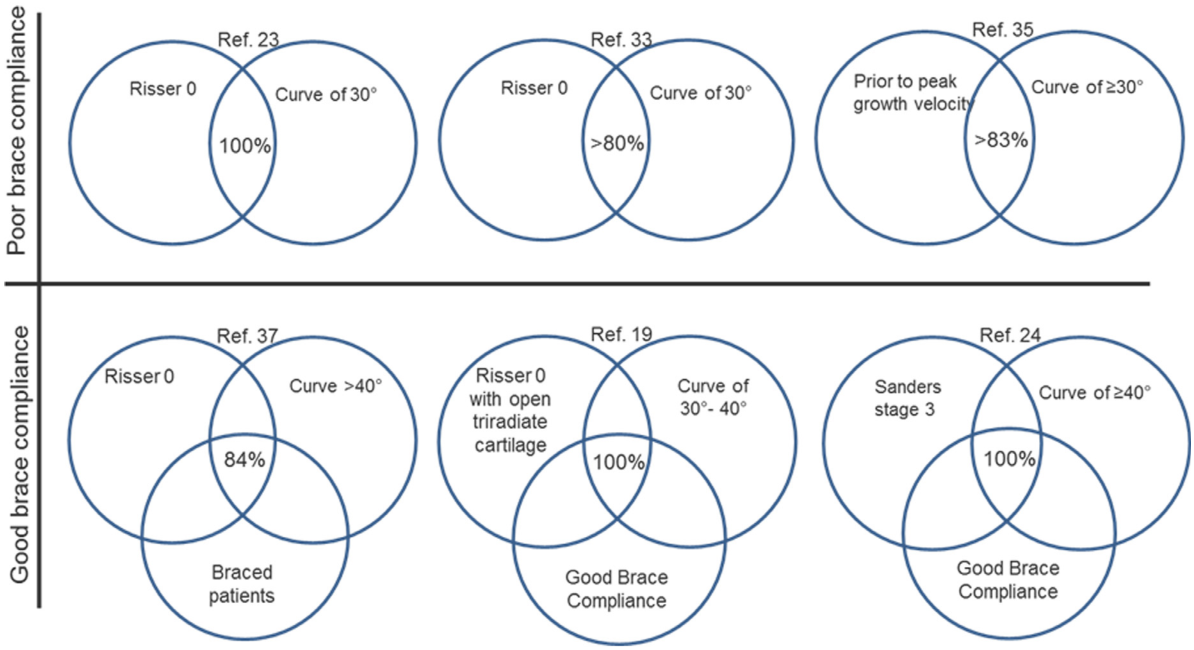

Fig. 4. The combined risk of progression to a surgical level of two or more risk factors.

not effective in patients at Risser stage 0. This conclusion agrees with studies by Little et al. [34,35] in which 83% of braced patients were found to have curve progression to 45° or to a magnitude requiring surgery if their curve was ≥30° and it was before their peak growth velocity. Similar findings were reported by Charles and Dimeglio and others as well [23,36].

Another study by Whitaker et al. [37] looked specifically at the value of bracing patients that are 40° or more and found that of the Risser 0 patients that are >40°, 84% had surgery or were >50° at the end of treatment. Sitoula et al. [24] found that 100% of the patients with curves ≥40° and Risser ≤4 progress to the surgery threshold.

When attempting to quantify the progression risk for patients that are Risser 0 AND above 30° to 40° AND who are noncompliant, it is important to consider that most of these numbers are based on 50° success cut off, whereas there is a significant concern that many of the 45° patients will actually progress to 50° in a short period of time [8,38,39]. If 45° was used as a success cut off, the numbers may have been significantly higher.

Another important question relating to the right time to consider surgical intervention is whether the same surgery threshold of curve >50° should be used for thoracic and for lumbar curves. A study conducted by Souder et al. [40] investigated a total of 126 patients undergoing surgical intervention and 17 patients pursuing nonoperative treatment. The average lumbar curve of the operative group was 43° (range: 35°−49°) and for the nonoperative group was 39° (range: 26°−49°). The authors suggested that thoracolumbar and lumbar curves can behave differently. It is very common that poor self-perception and significant trunk shift drive some patients with smaller lumbar/thoracolumbar curves to seek surgery. The clinical trunk shift deformity causes self-image problems and can cause back pain while young. The authors have mentioned that their findings are in line with Weinstein et al. [41]. In this population, thoracolumbar and lumbar curves were frequently found to progress once reaching the 35- to 40-degree mark. Thoracolumbar curves were also noted to be more commonly associated with marked translational shifts between two vertebrae.

Later, Weinstein [42] noted that thoracolumbar curves >30° had rapid progression initially followed by continual progression through the 40-year follow-up. Other authors have also noted that Lumbar and thoracolumbar curves are more likely to progress and produce a more obvious clinical deformity [41].

Similar findings were reported by Pesenti et al. [43] who demonstrated that lumbar curves reaching skeletal maturity with a Cobb angle of >35° where at a significantly higher risk for 20° aggravation (51% vs. 37.5% for those whose curves were <35° at maturity) and that 77% of the curves that progressed more than 20° were >35° at skeletal maturity. The authors concluded that when Cobb angle exceeded 40° at the end of growth, deformity was progressive, with an increase of 23.3° in Cobb angle over 26 years' follow-up. They concluded that lumbar and thoracolumbar scoliosis may be strongly progressive after skeletal maturity, arguing for more aggressive management during adolescence and that significant deterioration occurred when lumbar curvature exceeded 35°.

There is therefore a question mark on the true benefit for the patients by the decision to include patients with thoracic curves of 45° or lumbar/thoracolumbar curve of 40° at skeletal maturity in the success group, considering the high chance these patients are going to have a more difficult surgery later on. This was demonstrated by Lonner et al. [44] who showed a significantly larger number of vertebrae fused in patients treated at adulthood (12.9 vs. 9.4), a higher risk for pelvic fixation, a longer operative time, and a larger blood loss and longer hospitalizations [44]. The risk for morbidity and a revision risk of nearly 20% is also observed in adults with a corrective surgery [45,46].

These findings are in agreement with Pesenti et al. [43] who showed that corrective surgery in adulthood involves a significant larger number of vertebrae (10.7 vs. 9.7), with a much higher probability (38%) of L5 or pelvis involvement for Lenke 5 patients.

The present review did not asses the question of influence of brace wear on the patient quality of life; however, some articles point to the fact that brace wear has a psychological and social burden and this should be factored into the decision-making when the treated patient is likely to fail brace treatment [47−49]. Currently, when the options of nonfusion surgical systems are becoming available [50−52], early surgical intervention may be carefully considered, based on the available data, for patients having a high progression risk profile.

To summarize, although brace treatment for AIS patients is an effective way to prevent curve progression, there are some specific subgroups of patients that have a much higher risk to fail brace treatment and ultimately progress to fusion surgery. The highest risk is for Risser 0 patients who reach the accelerated growth phase with a curve greater than or equal to 40°. These patients should be counselled that they are at 70% to 100% risk of curve progression to the fusion surgical threshold despite brace wear.

Conclusion

This analysis of the literature on bracing for AIS patients identified seven main risk factors that may affect the likelihood for unsuccessful bracing. Furthermore, several studies concluded that there was a cumulative effect if more than one risk factor was present. This information can be used to better council high-risk patients about the potential for unsuccessful outcomes with brace treatment and to carefully consider early surgical intervention.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi:10.1016/j.spinee.2019.07.008.

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