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REVIEW ARTICLE

Predictive factors for brace treatment outcome in adolescent idiopathic scoliosis: a best-evidence synthesis

Manon van den Bogaart[1] · Barend J. van Royen[1] · Tsjitske M. Haanstra[1] · Marinus de Kleuver[2] · Sayf S. A. Faraj[1]

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Abstract

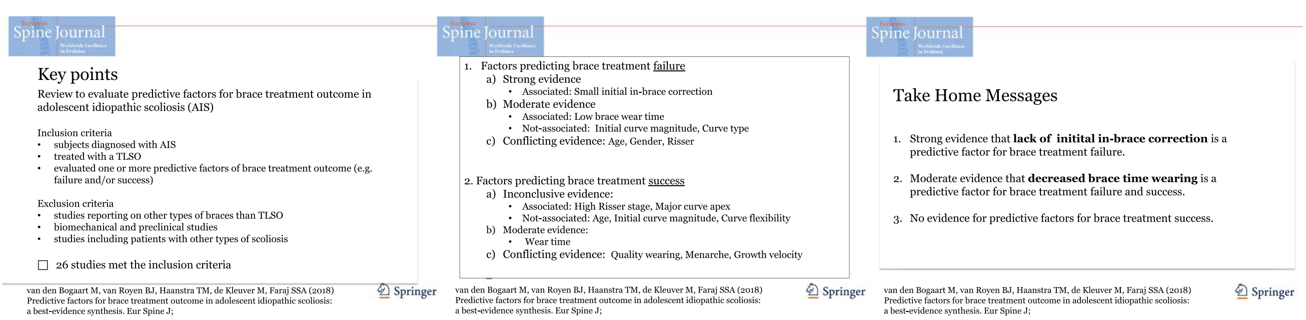
Purpose To evaluate predictive factors for brace treatment outcome in adolescent idiopathic scoliosis (AIS) by a systematic review of the literature.

Methods Eligible studies evaluating one or more predictive factors for brace treatment outcome were included following a systematic search in PubMed and EMBASE on October 23, 2017. Inclusion criteria were: (1) subjects diagnosed with AIS, (2) age ≤ 18 years, (3) treated with a thoraco-lumbo-sacral orthosis (TLSO), and (4) evaluated one or more predictive factors of treatment outcome (failure and/or success). The methodological quality of included studies was independently assessed by two authors. Pooling was not possible due to heterogeneity in statistical analysis. Predictive factors were presented according to a best-evidence synthesis.

Results The literature search identified 26 studies that met the inclusion criteria, and multiple types of TLSO braces were identified (Boston, Wilmington, Chêneau, Osaka Medical College, Dresdner Scoliosis Orthosis and SPoRT). A total of 19 radiographic and 8 clinical predictive factors were reported. Strong evidence was found that lack of initial in-brace correction is associated with treatment failure. Moderate evidence suggests that brace wear time is associated with failure and success, whereas initial curve magnitude and curve type are not.

Conclusion The results of this review suggest that lack of initial in-brace correction is strongly associated with brace treatment failure. Future studies on the threshold for minimal immediate in-brace correction, as a potential indication for brace treatment, are recommended.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



Keywords Adolescent idiopathic scoliosis · Brace · Treatment · Outcome · Predictive

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the spine and is radiographically defined by a Cobb angle of 10° or more in the coronal plane

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[1]. This type of spinal deformity is most commonly seen in healthy girls and tends to worsen during skeletal growth. AIS is often asymptomatic, but it can result in severe back pain, limited range of motion, and waistline asymmetry. Over time, the deformity may progress and subsequently result in a high level of functional disability, cosmetic and emotional distress for the patient [2]. Management depends on curve severity and remaining growth potential and includes intensive brace treatment for smaller curvatures, whereas surgical correction is needed for more severe curves [3].

In mild to moderate AIS, ranging from 20 to 45° Cobb angle, bracing is currently the primary therapy to prevent curve progression in skeletal immature patients. As was demonstrated in a landmark study by Weinstein in 2013, external corrective forces applied to the trunk by a rigid plastic orthotic is effective for the treatment of AIS [4]. Currently, there are many different braces available for AIS; however, thoraco-lumbo-sacral orthosis (TLSO) braces are most widely used [5]. There are two types of frequently used TLSO braces: The Boston and Wilmington. The Boston brace was developed in 1972 and mainly used in North America. It is a prefabricated symmetric brace with apical pads and trimlines (cutouts) at the concave side of the spine to allow room for shifting of the trunk. The Wilmington brace was designed in 1969 and is a total contact TLSO. The Wilmington brace is, unlike the Boston brace, a custom-fitted brace based on a cast [5]. Most braces are recommended to be worn for at least 18 h per day during several years (until skeletal maturity has been reached). Even though this may cause a high level of physical discomfort, according to the actual evidence, this seems not be associated with emotional and psychological stress [6].

Predictive factors are clinical or radiological characteristics that provide information on the likely benefit from a certain treatment [7]. In brace treatment of AIS patients, it is important to be able to predict outcome, and provide valuable information for clinical decision making. In patients with AIS, various possible predictive factors for brace treatment outcome have been reported (e.g., curve magnitude, brace wear time, and bone mineral status) [8–11]. These predictive factors, however, are mostly derived from relatively small patient cohorts, and contradicting findings have been reported [12, 13]. It is unclear whether these contradictions can be explained by differences in study populations, method of measurement or patient sample. This inconsistency makes it challenging for healthcare providers to adequately inform patients about their prognosis and streamline the crucial process of shared decision making. For this reason, it is important to identify, appraise, synthesize and combine all currently available evidence to improve current supportive guidelines for brace treatment in AIS [14].

The primary aim of this study was to identify and evaluate clinical and radiological predictive factors for brace treatment outcome, failure and success, in patients with AIS through a systematic review of the literature.

Methods

Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were used to develop the current systematic review protocol [15]. Relevant published studies on predictive factors for brace treatment outcome in AIS were identified by a systematic literature search in PubMed and Embase performed by an experienced medical information specialist, and backwards citation searching of obtained articles. The systematic literature search was performed on October 23, 2017, to identify relevant studies published in English, German and Dutch language. Search terms expressing "idiopathic scoliosis" were used in combination with "brace treatment" (eTable 1; Supplementary Material). Relevant study designs included randomized controlled trials, prospective studies, retrospective studies or follow-up studies. Two reviewers (*blinded for review*) independently screened the titles, abstracts and full-text articles identified by the literature search for inclusion using Covidence, an online platform for Cochrane Reviews (www.covidence.org). Full-text articles were retrieved if the abstract passed the first eligibility screening.

Selection criteria

Inclusion criteria for eligible studies were as follows: (1) subjects diagnosed with AIS, (2) age ≤ 18 years, (3) treated with a TLSO (e.g., Boston, Wilmington), (4) evaluated one or more predictive factors of brace treatment outcome (e.g., failure and/or success). Exclusion criteria were: (1) studies reporting on other types of braces than TLSO (e.g., Providence, Charleston and cervico-thoraco-lumbo-sacral orthosis (e.g., Milwaukee)), (2) biomechanical and preclinical studies, or (3) studies including patients with other types of scoliosis (e.g., congenital, neuromuscular or degenerative scoliosis). Full-text articles were independently screened for inclusion by two reviewers (*blinded for review*).

Data extraction

The following data of included studies were extracted: authors, year of publication, study design, number of patients, gender, age, Risser stage, Cobb angle prior to treatment, type of brace, prescribed wear time, duration of follow-up, definition of treatment failure and success (if reported), and reported predictive factors of treatment outcome, including their method of measurement.

Methodological quality

All included studies were subjected to a 13-item quality assessment based on criteria described by Hayden et al. [16] These criteria were developed to assess the methodological quality of prediction studies and includes the following domains: (1) study participation, (2) study attrition, (3) measurement of predictive factors, (4) adjustment for confounding, (5) measurement of outcomes, and (6) appropriateness of statistical analyses (eTable 2; Supplementary Material). Items were scored with 1 point if sufficiently fulfilled, and 0 points in case of missing data or insufficient information regarding a distinct quality domain, with a maximum score of 13 points. Studies scoring ≥ 9 were considered as high-quality studies, whereas studies scoring < 9 low quality. The same approach of quality assessment has also been applied in studies on prognostic factors of curve progression in degenerative scoliosis, and in knee and hip arthritis [17–19]. Included articles were scored independently by two reviewers (*blinded for review*). In case of disagreement, these points were discussed in a consensus meeting, or by consulting a third reviewer *(blinded for review)*. Finally, the kappa statistic was used to calculate inter-observer agreement [20].

Analysis

In case of sufficient clinical and statistical homogeneity on study design, study population, measured determinants, assessment and definition of outcome (failure or success), correlation coefficients will be statistically pooled. In the absence of statistical analysis (correlation, beta coefficients, hazard ratios (HR) and accompanying 95% confidence intervals (CI)) or heterogeneity in measured determinants, assessment and definition of outcome, the level of evidence for the predictive factors was assessed according to a best-evidence synthesis [18].

- *Strong evidence* Consistent (> 75%) findings in multiple (≥ 2) high-quality studies
- *Moderate evidence* Findings in one high-quality study and consistent (> 75%) findings in multiple (≥ 2) low-quality studies
- *Limited evidence* Findings in one high-quality study or consistent (> 75%) findings in ≥ 3 low-quality studies
- *Inconclusive evidence* findings found in < 3 low-quality studies
- *Conflicting evidence* < 75% of the studies reported consistent findings.

Predictive factors for treatment success and failure were reported separately.

Results

Studies included

The literature search generated a total of 2199 references in PubMed and Embase. After removing duplicates, 1374 references remained. One additional study was identified by backward citation. In total, 26 studies met the inclusion criteria and were included (Fig. 1). A list of all excluded full-text studies assessed for eligibility, and reason for exclusion is provided (eTable 3; Supplementary Material).

Methodological quality (eTable 4; Supplementary Material)

Two reviewers scored a total of 338 items in order to assess the methodological quality of the included studies. The inter-observer agreement was 0.92 ($\kappa = 0.84$). Of the 26 studies included, 10 studies had a score of 9 points or more and were classified as high quality [4, 12, 21–28]. The majority of studies had a retrospective design; therefore, most methodological shortcomings concerned "follow-up (item F and G)" and "blinding (item H and J)" (eTable 4; Supplementary Material).

Study characteristics (Table 1)

An overview of study characteristics is presented in Table 1. We identified 24 studies published in the English language [4, 8, 12, 13, 21–40] and 2 in the German language [41, 42]. A large variation in sample size was seen in the included studies (range: 12–488). The majority of patients were girls. The mean age varied between 11.6 and 15.5 years old. Nine studies used the Boston brace [8, 13, 23, 29, 31, 33, 35–37], whereas seven studies used a TLSO brace without further specification [12, 21, 22, 24, 25, 39, 40]. Tree studies used the Chêneau brace [34, 38, 42], two studies the Wilmington [30, 32], one study the DSO (Dresdner Scoliosis Orthosis) [41], one study the OMC (Osaka Medical College) [28], one study the SPoRT brace [27], and two studies used both the Boston and Wilmington [4, 26]. In 14 studies, full-time (20–23 h/day) brace wear time was prescribed. In the remaining studies, a wear time of > 12 h was prescribed ($n = 10$), or prescribed wear time was not provided ($n = 2$). Treatment failure was defined as "curve progression > 5°," "progression beyond 45°" or "surgery," whereas treatment success was defined as "curve progression < 5°," "progression < 10°," or "progression not further than 50°" (Table 1).

Study results (Tables 2, 3)

A total of 19 different radiographic and 8 clinical predictive factors were assessed as possible predictors of brace

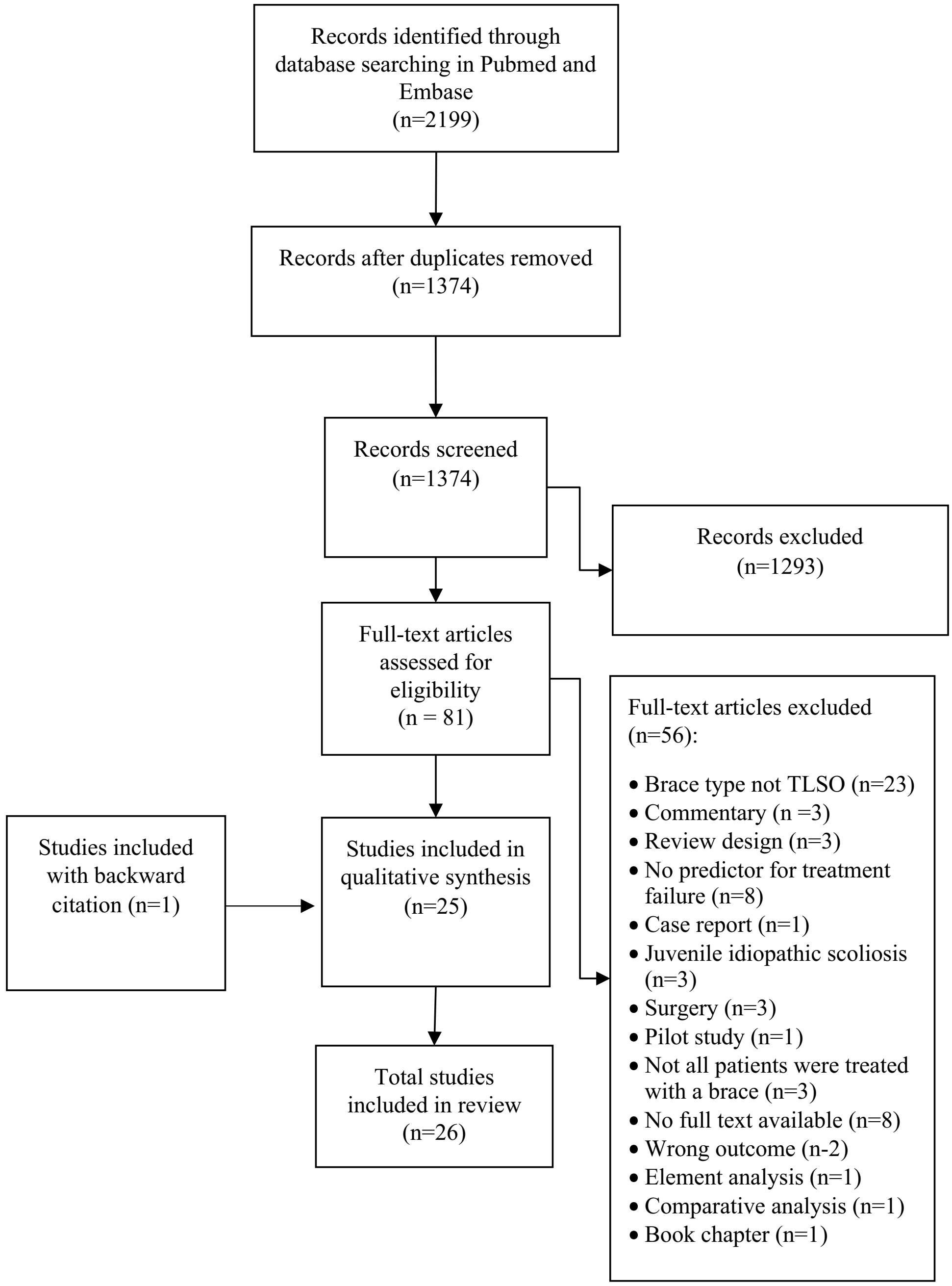

Fig. 1 PRISMA flow diagram of identification, screening, and inclusion of papers

treatment outcome (Tables 2 and 3). Most studies did not include or report a measure of association of a predictive factor with brace treatment success or failure. In addition to a lack of statistical data in most studies, a large heterogeneity between sample sizes, and variations in outcome definition were found. Considering the variations in outcome definitions and lack in statistical data, pooling was not possible and it was necessary to combine the current evidence according to a best-evidence synthesis. This will subsequently provide the opportunity to determine the strength of association of identified predictive factors with brace treatment outcome.

Best-evidence synthesis (Figs. 2, 3)

Strong evidence suggests that lack of initial in-brace correction is associated with brace treatment failure. In-brace correction was calculated by dividing the in-brace curve correction by the initial Cobb angle. Katz et al. [13] found that an in-brace correction < 25% is a predictive factor of brace treatment failure in patients with double curves ($p = 0.02$). Castro [21] found a different mean in-brace correction in the success and failure group of 65% versus 33% ($p = 0.001$), respectively. Xu et al. [23] found a mean in-brace correction of 16.3% in the success group and 4.0% in the failure group

Table 1 Characteristics of included studies

References	No. of patients (n men)	Age of total group, years, mean (range)	Initial Risser stage, mean (range)	Type of brace	Prescribed wear time hours/day, mean (range)	Initial cobb angle, mean (range)	Months of follow-up, mean (range)	Definition treatment failure	Definition treatment success
Emans et al. [29]	295	13.2 (4–18)	1 (0–4)	Boston	13–24	(29.1) 20–59	17 (12–67)	Progr. > 5° or surgery	Decrease > 5°
Hanks et al. [30]	100 (0)	11.6 (7.5–15.0)	0 > 2[b]	Wilmington	23[a]	25.3	39.6 (6–72)	Progr. ≥ 10°	Progr. < 10°
Ylikoski et al. [31]	107 (5)	15.5 (10–17)	n/a	Boston	23	36	36	Progr. > 5°	Decrease > 5°
Castelein and Veraart [33]	138 (0)	n/a	n/a	Boston	n/a	n/a	n/a	Progr. beyond 40° or surgery	Cobb < 40°
Katz and Durrani [13]	51 (9)	n/a	0.1 (0–2)	Boston	n/a	n/a	32 (3–138)	Progr. > 5° or surgery	Progr. < 5°
Castro [21]	41 (7)	12.1 ± 0.25	n/a	TLSO	23	27 ± 0.9	41 (24–119)	Progr. > 5°	Progr. < 5°
Landauer et al. [34]	62 (0)	10–14	n/a	Chêneau	23	20–40	12	n/a	Decrease > 5°
Lou et al. [35]	12 (25)	14.1 (12.2–16.8)	n/a	Boston	23	34 (20–50)	n/a	Progr. > 5°	Decrease > 5°
Bullmann et al. [42]	52 (7)	13 (6–17)	n/a	Chêneau	23	31 (25–40)	42 (36–78)	Progr. > 5°	Progr. ≤ 5°
O'Neill et al. [36]	276 (12)	12.8 (11–17)	n/a*	Boston	18	31 ± 4.4	25 ± 13	Progr. > 5° and beyond 45°	Progr. ≤ 5°
Rahman et al. [32]	34 (12)	12 (10–16)	n/a	Wilmington	23	n/a	n/a	Progr. > 5°	Progr. ≤ 5°
Lou et al. [37]	20 (15)	13.4 (9.0–15.9)	n/a	Boston	20.8 (12–23)	32 (18–50)	n/a	Progr. > 5°	n/a
Ryan et al. [26]	62 (7)	12.9 (10.8–17.1)	0.56 (0–2)	Boston/Wilmington	23	32.31 (25–43)	2.92 (1–6.25)	Progr. > 5° or surgery	Progr. ≤ 5°
Seifert et al. [41]	90 (10)	13.3 (3.4–17.1)	n/a	DSO	20–23	n/a*	52 (24–84)	Progr. > 5°	Progr. ≤ 5
Ovadia et al. [38]	93 (14)	12.8 (9–16)	1.07 (0–2)	Chêneau	20–22	31.97 (22–54)	24	Progr > 5°, beyond 45° or surgery	Progr. < 5°
Weinstein et al. [4]	146 (11)	12.7 ± 1.0	(0–5)	Boston/Wilmington	18	30.5 ± 5.8	n/a	Progr. beyond 50°	Cobb < 50°
Xu et al. [23]	488 (11)	13.2 (10–15)	1.5 (0–2)	Boston	22	29.5 (25–35)	35 (18–53)	Progr. > 5°	Progr. ≤ 5°
Lou et al. [25]	20 (15)	13.4 ± 1.8	n/a	TLSO	23	33 ± 6	24	Progr. > 5°	Progr. ≤ 5°
Shi et al. [39]	200 (0)	12.1 (10–14)	0.4 (0–2)	TLSO	23	27.7 (20–40)	51.4 (24–190)	Progr > 5°, beyond 45° or surgery	n/a
Kuroki et al. [28]	31 (2)	12.0 (10.8–14.7)	0.55 (0–2)	Chêneau	20	27.3 (21–36)	16 (0–36)	Progr. > 5°	Decrease > 5°
Goodbody et al. [22]	182 (14)	12.5 (10–16)	n/a	TLSO	> 12	n/a*	24 (3–56)	Progr ≥ 5°, beyond 45° or surgery	Progr. < 5°, Cobb < 45°
Karol et al. [24]	171 (6)	12.3 (10.2–16.0)	0.4 (0–2)	TLSO	> 12	n/a*	n/a	Progr. > 5° or surgery	n/a

Table 1 (continued)

References	No. of patients (n men)	Age of total group, years, mean (range)	Initial Risser stage, mean (range)	Type of brace	Prescribed wear time hours/day, mean (range)	Initial cobb angle, mean (range)	Months of follow-up, mean (range)	Definition treatment failure	Definition treatment success
Karol et al. [12]	168	12.3 (10.2–16.0)	0.4 (0–2)	TLSO	> 12	33.8	n/a*	Progr. > 5° or surgery	n/a
Sun et al. [8]	350 (0)	12.2 (11.2–12.8)	1.4 (0–3)	Boston	n/a	26.7 (21–30)	26 ± 14	Progr. > 5° or surgery	Progr. ≤ 5°
Thompson et al. [40]	168 (10)	12.3 (10.2–16)	(0–2)	TLSO	n/a	n/a	22	Progr. to ≥ 50° or surgery	Cobb < 50° and no need for surgery
Zaina et al. [27]	351 (45)	12.9 ± 1.4	2 (0–3)	SPoRT	18–23	37.6 ± 11.4	n/a	Progr. > 5°	n/a

DSO Dresdner scoliosis orthesis, *n/a* not available

*Not reported for the whole study population

[a]75% 23 h/day; 25% 16 h/day

[b]72% 0; 8% 1; 5% 2; 12% > 2

($p < 0.001$). Goodbody et al. [22] reported that an in-brace correction < 45% is associated with brace treatment failure ($p < 0.01$). Bullman et al. [42] found a mean initial in-brace correction of 14.9° in the success group, and 11.0° in the failure group ($p < 0.05$).

Moderate evidence suggests that low brace wear time is associated with brace treatment failure, whereas initial curve magnitude and curve type are not. Limited evidence suggests that open triradiate cartilage and low body mass index are associated with brace treatment failure. For age, gender, high body mass index and skeletal maturity, conflicting evidence was found (Fig. 2). No predictive factors were found to be strongly associated with brace treatment success. Moderate evidence suggested that a high brace wear time is associated with success, whereas curve type is not. Conflicting evidence for success was found for quality of brace wearing, menarche, growth velocity, and skeletal maturity (Fig. 3).

Discussion

It is important to be able to predict outcome of brace treatment in AIS patients to adequately inform patients and their families about their prognosis, and provide valuable information for the crucial process of shared decision making. The aim of this systematic review was to identify predictive factors for brace treatment outcome in patients with AIS. Despite the absence of adequate statistical analysis, heterogeneity in measured determinants and differences in the definition of outcome, using a qualitative best-evidence synthesis, we identified 19 radiological and 8 clinical predictive factors for outcome (failure and success). Nachemson et al.'s was the first study to prospectively demonstrate the effectiveness of brace treatment in girls with AIS. This landmark study was not included in the present systematic review, since no predictive factors were studied. Nevertheless, it was the first study that demonstrated that brace treatment prevented curve progression in girls with AIS until they were 16 years old [43].

In-brace correction

Initial in-brace correction is the response of the scoliotic spine to the initial brace application and mainly depends on the flexibility of the spinal curve. Strong evidence was found that lack of initial in-brace correction is a predictive factor for failure (Fig. 2). A small in-brace correction was found to associated with treatment failure in 6 studies [13, 21–23, 29, 42]. All studies used AP or PA standing in-brace radiographs to measure the Cobb angle. Despite the given variability between studies in the amount of initial in-brace correction needed, the results indicate that AIS patients with a higher degree of initial in-brace correction are less prone to treatment failure. It is, however, still not established what the exact minimal threshold of immediate in-brace correction should be to minimize the risk of failure as all five studies reported different in-brace correction percentages. Katz et al. [13] found that an in-brace correction < 25% is a predictive factor of brace treatment failure in patients with double curves ($p = 0.02$). Castro [21] found a different mean in-brace correction in the success and failure group of 65% versus 33% ($p = 0.001$), respectively. Goodbody et al. [22] reported that an in-brace correction < 45% is associated with brace treatment failure ($p < 0.01$). Xu et al. [23] found a mean in-brace correction of 16.3% in the success group and 4.0% in the failure group ($p < 0.001$). Emans et al. [29]

Table 2 Clinical characteristics studied as predictors for brace treatment outcome

Clinical determinant	References	Study quality	Measurement method	Statistical analysis	Association with treatment failure	Association with treatment success
Age	Hanks et al. [30]	Low	Continuous (years)	$p>0.05$	x	o
	Shi et al. [39]	Low	Continuous (years)	$p=0.496$	o	x
	Katz and Durrani [13]	Low	Continuous (years)	$p=0.68$	o	x
	Sun et al. [8]	Low	Continuous (years)	$p=0.31$	o	x
	Xu et al. [23]	High	Continuous (years)	OR = 2.16 (1.29–3.63), $p=0.001$	–	x
	Emans et al. [29]	Low	Continuous (years)	Not provided	–	x
	O'neill et al. [36]	Low	Continuous (years)	$r=-0.118$	–	x
	Kuroki et al. [28]	High	Continuous (years)	$p>0.05$	x	o
	Bullman et al. [42]	Low	Continuous (years)	$p=0.0007$	–	x
Male gender	Xu et al. [23]	High	–	$p=0.43$	o	x
	O'neill et al. [36]	Low	–	$r=0.151$, $\beta=0.144$	+	x
	Bullmann et al. [42]	Low	–	Not provided	+	x
Menarche	Hanks et al. [30]	Low	Pre- versus postmenarchal	$p=0.013$	x	+
	Shi et al. [39]	Low	Menarche age (years)	$p=0.517$	o	x
	Katz and Durrani [13]	Low	Pre- versus postmenarchal	$p=0.242$	o	x
	Ylikoski et al. [31]	Low	Pre- versus postmenarchal	Not provided	x	–
Wear time	Lou et al. [25]	High	Brace monitoring device	Not provided	x	+
	Hanks et al. [30]	Low	Part-time versus full-time	$p>0.05$	x	o
	Karol et al. [24]	High	Thermochron iButton	$p<0.05$[a]	–	x
	Katz and Durrani [13]	Low	Report of a physician's prediction (hours/day)	$p=0.022$	–	x
	Emans et al. [29]	Low	Review of patients' charts on wear time (complete/partial/none)	Not provided	–	x
	Lou et al. [35]	Low	Load monitoring device	Not provided	x	o
	O'neill et al. [36]	Low	Reported by patient (hours/day)	$r=-0.265$, $\beta=-0.256$	–	x
	Lou et al. [37]	Low	Brace monitoring device	Not provided	o	x
	Rahman et al. [32]	Low	temperature sensor, worn/prescribed time (%)	$p=0.004$	–	x
	Ryan et al. [26]	High	Worn/prescribed time (%)	$p=0.0314$	x	+
	Weinstein et al. [4]	High	Temperature sensor (0–6 h, 6–12 h, 12–18 h or 18–24 h)	$p<0.001$	x	+
	Kuroki et al. [28]	High	Instruction adherence rate < 50% versus instruction adherence rate > 50%	$p<0.01$	x	+

Table 2 (continued)

Clinical determinant	References	Study quality	Measurement method	Statistical analysis	Association with treatment failure	Association with treatment success
	Landauer et al. [34]	Low	Good compliance (score > 2) versus bad compliance (score < 3)	$p<0.004$	x	+
	Seifert et al. [41]	Low	Compliant (> 20 h/day) versus non-compliant(< 20 h/day)	Not provided	x	+
Quality wearing	Lou et al. [25]	High	Load monitoring device	Not provided	x	+
	Lou et al. [35]	Low	Load monitoring device	Not provided	x	o
	Lou et al. [37]	Low	Load monitoring device	Not provided	o	x
High body mass index	Goodbody et al. [22]	High	≥ 85th percentile (weight[kg]/height[m]^2)	OR = 2.4, $p=0.04$	+	x
	O'neill et al. [36]	Low	≥ 85th percentile (weight[kg]/height[m]^2)	$r=0.203$, $\beta=0.153$	+	x
	Zaina et al. [27]	High	≥ 85th percentile (weight[kg]/height[m]^2)	$r=0.16$, $p=0.02$	o	x
Low body mass index	Goodbody et al. [22]	High	< 20th percentile (weight[kg]/height[m]^2)	OR = 3.7, $p<0.01$	+	x
	Sun et al. [8]	Low	< 5th percentile (weight[kg]/height[m]^2)	$r^2=0.57$, OR = 9.3 (4.51–13.5), $p<0.001$	+	x
Growth velocity	Katz and Durrani [13]	Low	Bracing pre- versus postpeak height velocity, ≥ 9 cm/year	$p=0.294$	o	x
	Ylikoski et al. [31]	Low	Difference standing height/time	Not provided	x	+
	Ryan et al. [26]	High	Cm/month	$p=0.14$	x	o

o, No correlation/no relationship found between predictive factor and treatment outcome

+, Positive association found between predictive factor and treatment outcome

−, Negative association found between predictive factor and treatment outcome

x, Association between predictive factor and treatment success/failure was not assessed

[a]Surgery ($p=0.029$), ≥ 6° progression ($p<0.0001$)

did not report initial in-brace correction percentages. Further research on the minimal threshold of immediate in-brace correction, as a potential indication for AIS brace treatment, would provide valuable information for future clinical decision making. He et al. [44] investigated which assessment method of spinal flexibility is most correlated with the initial in-brace correction. Spinal flexibility was assessed in four positions: supine, prone, sitting with lateral bending and prone with lateral bending. Prone position was found to be the best position for measuring spinal flexibility to predict the initial in-brace correction.

Brace wear time

Moderate evidence suggests that brace wear time is associated with treatment failure (Fig. 2). In 3 studies, brace wear time was measured by a monitoring device [24, 32, 37], whereas 6 other studies the physician's prediction or patients report was used [13, 28, 29, 34, 36, 41]. Kuroki et al. [28] found that success rate depends on compliance, and reported a higher success rate in the patient group whose instruction adherence rate was greater than 50% compared to 50% or less (88.2% and 42.8%, respectively). Karol et al.

Table 3 Radiographic characteristics studied as predictors for brace treatment outcome

Radiographic determinant	References	Study quality	Measurement method	Statistical analysis	Association with treatment failure	Association with treatment success
Initial curve magnitude	Hanks et al. [30]	Low	Cobb angle on standing radiographs	$p > 0.05$	o	x
	Shi et al. [39]	Low	Cobb angle on standing radiographs	$p = 0.952$	o	x
	Katz and Durrani [13]	Low	Cobb angle on standing PA radiographs[f]	$p = 0.35$	o	x
	Sun et al. [8]	Low	Cobb angle	$p = 0.25$	o	x
	Xu et al. [23]	High	Cobb angle on standing AP radiographs[f]	$p = 0.23$	o	x
	Emans et al. [29]	Low	Cobb angle on standing AP radiographs	Not provided	+	x
	Ylikoski et al. [31]	Low	Cobb angle on standing PA radiograph	Not provided	x	o
	Ovadia et al. [38]	Low	Cobb angle on standing radiographs	OR = 0.92 (0.85–0.99), $p = 0.02$	x	–
	Kuroki et al. [28]	High	Cobb angle on standing radiographs	$p > 0.05$	x	o
Initial in-brace correction	Katz and Durrani [13]	Low	Standing PA radiographs	$p = 0.02$[d]	–	x
	Emans et al. [29]	Low	Standing AP radiographs	Not provided	–	x
	Castro [21]	High	In-brace correction radiograph AP	$p = 0.024$	–	x
	Goodbody et al. [22]	High	Cobb in-brace/initial cobb	OR, 3.2, $p < 0.01$	–	x
	Shi et al. [39]	Low	Not provided	$p = 0.851$	o	x
	Xu et al. [23]	High	(initial cobb − cobb 3mnt)/initial cobb × 100 (%)	OR = 9.61 (3.37–25.3), $p \leq 0.001$	–	x
	Bullmann et al. [42]	Low	Not provided	$P < 0.05$	–	x
Correction at 6-month follow-up	Landauer et al. [34]	Low	> 40% versus < 40% relative to Cobb angle prior to bracing	$p > 0{,}05$[i], $p < 0.02$[j]	x	+
Curve flexibility	Hanks et al. [30]	Low	(primary Cobb − in-brace)/primarily Cobb	$p > 0.05$	x	o
	Kuroki et al. [28]	High	Cobb angle in brace > Cobb angle in hanging position versus Cobb angle in brace < Cobb angle in hanging position	$p > 0.05$	x	o
	Bullmann et al. [42]	Low	Cobb angle correction in bending	$P = 0.095$	o	x

Table 3 (continued)

Radiographic determinant	References	Study quality	Measurement method	Statistical analysis	Association with treatment failure	Association with treatment success
Skeletal maturity	Hanks et al. [30]	Low	Risser sign 0 versus 1–5	$p=0.015$	x	+
	Karol et al. [12]	High	Risser sign 0 versus 1 versus 2	$p<0.0001$	–	x
	Katz and Durrani [13]	Low	Risser sign 0 versus 1 versus 2	$p=0.303$	o	x
	Sun et al. [8]	Low	Risser sign	$p=0.10$	o	x
	Xu et al. [23]	High	Risser sign	OR = 2.29, (1.36–3.83), $p\leq.001$	–	x
	O'neill et al. [36]	Low	Risser sign	$r=-0.262$, $\beta=-0.241$	–	x
	Ovadia et al. [38]	Low	Risser sign	OR = 2.97, (1.18–7.44), $p=0.02$	x	+
	Kuroki et al. [28]	High	Risser sign 0 versus 1 versus 2	$p>0.05$	x	o
Curve type	Thompson et al. [40]	Low	Lenke classification (modified)	$p=0.087$	x	o
	Thompson et al. [40]	Low	Th, L[g]	$p=0.027$	x	+
	Hanks et al. [30]	Low	Th, L, ThL, double	$p>0.05$	x	o
	Shi et al. [39]	Low	Th, ThL/L, double	$p>0.05$	o	x
	Katz et al. [13]	Low	Th, L, ThL, double	$p=0.519$	o	x
	Sun et al. [8]	Low	Not provided	$p=0.65$	o	x
	Xu et al. [23]	High	Th, ThL/L, double	$p=0.49$	o	x
	Emans et al. [29]	Low	Single, double, triple	Not provided	+	x
	Kuroki et al. [28]	High	Th, L, ThL	$p>0.05$	x	o
	Bullmann et al. [42]	Low	Th, L, ThL	$p>0.05$	o	x
Major curve apex	Emans et al. [29]	Low	T, TL L	Not provided	–	x
	Ylikoski et al. [31]	Low	T, TL, L	Not provided	x	+
Digital skeletal age	Sun et al. [8]	Low	Hand radiographs (Stage I–III)	$p=0.29$	o	x
Cobb ratio	Katz et al. [13]	Low	Thoracic Cobb/lumbar Cobb	$p=0.77$	o	x
Vertebral tilt angle	Katz and Durrani [13]	Low	Measured at the intersection of a line perpendicular to the CSL[h]	$p=0.33$; $p=0.08$; $p=0.82$; $p=0.85$*	o	x
Apical vertebral rotation	Katz and Durrani [13]	Low	Nash and Moe method	$p=0.23$; $p=0.56^{a}$	o	x
	Emans et al. [30]	Low	Nash and Moe method	Not provided	o	x
Angle of thoracic rotation (ATR)	Ovadia et al. [38]	Low	Not provided	OR = 0.86 (0.75–0.99), $p=0.04$	x	–
Rib-vertebral angle	Katz and Durrani [13]	Low	As described by Mehta [39]	$p=0.11$; $p=0.75$; $p=0.21^{b}$	o	x
Coronal decompensation	Katz and Durrani [13]	Low	Distance between C7 plumbline and the CSL	$p=0.45$	o	x
Apical vertebral translation	Katz and Durrani [13]	Low	Lateral distance from the thoracic apical vertebra center to the plumbline	$p=0.56$; $p=0.39$, $p=0.31^{c}$	o	x
Relative apical distance	Katz and Durrani [13]	Low	Lateral distance between the vertebral body centers of the thoracic and lumbar apexes	$p=0.85$	o	x

Table 3 (continued)

Radiographic determinant	References	Study quality	Measurement method	Statistical analysis	Association with treatment failure	Association with treatment success
Lateral trunk shift (LTS)	Katz and Durrani [13]	Low	A horizontal line to the edges of the ribs of the apical vertebra was drawn. The distance between the CSL and the perpendicular line that bisects the horizontal line represents the LTS	$p = 0.42$	o	x
Retroverted orientation of the vertebrae	Castelein and Veraart [33]	Low	Angle of the superior endplate on lateral X-ray	$p < 0.05$[e]	+	x
Triradiate cartilage (TRC)	Ryan et al. [26]	High	Open/close	$p = 0.0069$	+	x

*Thoracic-superior; thoracic-inferior; lumbar-superior; lumbar-inferior

o, No correlation/no relationship found between predictive factor and treatment outcome

+, Positive association found between predictive factor and treatment outcome

−, Negative association found between predictive factor and treatment outcome

x, Association between predictive factor and treatment success/failure was not assessed

[a] Thoracic apex; lumbar apex

[b] Convex side; concave side; difference

[c] Thoracic; lumbar; ratio

[d] Only for double curves

[e] T6-8 ($p < 0.05$), T4–T5 ($p < 0.005$)

[f] AP = anteroposterior, PA = posteroanterior

[g] T = thoracic, L = lumbar

[h] CSL = central sacral line

[i] Non-compliant group

[j] Compliant group

Strong evidence[A]	
Associated with failure	**Not- associated with failure**
• Initial in-brace correction	
Moderate evidence[B]	
Associated with failure	**Not- associated with failure**
• Wear time	• Curve magnitude (initial) • Curve type
Limited evidence[C]	
Associated with failure	**Not- associated with failure**
• Low body mass index • Open triradiate cartilage	
Inconclusive evidence[D]	
Associated with failure	**Not- associated with failure**
• Major curve apex • Retroverted orientation of the vertebrae	• Menarche • Quality wearing • Growth velocity • Digital skeletal age • Cobb ratio • Vertebral tilt angle • Apical vertebral rotation • Rib-vertebral angle • Coronal decompensation • Apical vertebral translation • Relative apical distance • Lateral trunk shift • Curve flexibility

Conflicting evidence[E]
• Age • Gender • Skeletal maturity (Risser) • High body mass index

[A] Consistent (>75%) findings in multiple (≥2) high quality studies
[B] Findings in one high quality study and consistent (>75%) findings in ≥2 low quality studies
[C] Findings in one high quality study *or* consistent (>75%) findings in ≥3 low quality studies
[D] Findings found in <3 low-quality studies
[E] <75% of the studies reported consistent findings

Fig. 2 Level of evidence for all factors predicting brace treatment failure

found an averaged brace wear time of 14.4 h for patients who showed < 6° of curve progression. While for patients who did have progression of ≥ 6°, the average daily brace wear time was 11.0 h ($p < 0.0001$) [24]. Of note, conflicting evidence for treatment success was found for quality brace wearing (Fig. 3). Lou et al. [35] reported in 2004 that quality of brace wearing (tightness) is not associated with brace treatment success. In 2015, Lou et al. [25] found an association between brace treatment success and quality of brace wearing. Although the same measurement method (an in-house brace monitor with a force sensor to record the quality of wearing) was used in both studies, the monitor used in 2015 was technically more advanced, which may explain the degree of inconsistency found. Another possible explanation for these conflicting results may be the difference in patient sample size. In 2004, 12 subjects were included, whereas in 2015 20 subjects were included. Nevertheless, based on these results, insufficient brace wearing seems to be an important driver for treatment failure and AIS patients should be counseled accordingly. It is, however, still not clear what the exact minimal brace wear time should be to avoid failure and further studies, using the same or a similar method of measurement, are highly recommended.

Curve magnitude

Moderate evidence suggests that initial curve magnitude is not associated with treatment failure (Fig. 2) [8, 13, 23, 30,

Moderate evidence[B]	
Associated with success	**Not- associated with success**
• Wear time	• Curve type

Limited evidence[C]	
Associated with success	**Not- associated with success**
	• Age • Curve flexibility • Curve magnitude (initial)

Inconclusive evidence[D]	
Associated with success	**Not- associated with success**
• Major curve apex • Correction at 6 months FU • Angle of thoracic rotation	

Conflicting evidence[E]
• Quality wearing • Menarche • Growth velocity • Skeletal maturity (Risser)

[B] Findings in one high quality study and consistent (>75%) findings in ≥2 low quality studies
[C] Findings in one high quality study *or* consistent (>75%) findings in ≥3 low quality studies
[D] Findings found in <3 low-quality studies
[E] <75% of the studies reported consistent findings

Fig. 3 Level of evidence for all determinants predicting brace treatment success

39]. Additionally, Ovadia et al. [38] found that initial curve magnitude is not associated with treatment success (Table 3; Fig. 3). Note that these results are based on studies including patients with relative mild to moderate AIS of 20–45° (Table 1). This seems to suggest that, in case of AIS patients fulfilling the appropriate criteria to undergo brace treatment (Cobb angle < 45°), initial curve magnitude is most likely not associated with treatment failure or success (Figs. 2, 3).

Clinical factors

Clinical factors (i.e., body mass index, menarche, age and gender) were identified, but were not found to be strongly or moderately associated with treatment failure or success (Figs. 2, 3).

Limitations

This study has several limitations and results therefore may not be directly applicable to the individual patient. Firstly, most results are based on data of observational studies that are subject to various biases that may account for discrepancies found between predictive factors and brace treatment outcome. Studies published in languages other than English, German or Dutch were excluded. In addition, there was a large heterogeneity in measurement methods of determinants and difference in the definition of outcome, which made pooling of data not possible. Based on the description and information of brace types provided in the assessed studies, it was in some cases challenging to categorize (modified) brace types. As result, some relevant studies using a type of TLSO may have been missed. A clear description of brace type used in future studies is recommended. Notable, the currently used definition for treatment failure (> 5° progression) may represent false negative results. Patients that progressed > 5°, but have an end-stage curvature of < 40–45°, avoided surgery and bracing should therefore not be considered as a failure of treatment. There were only four studies that specifically used "progression to > 40–45°" and/or "surgery" (and not > 5° progression) as definition for treatment failure and a secondary analysis was therefore not feasible [4, 33, 40]. Moreover, it was not possible to evaluate the interplay between multiple predictive factors and outcome. Finally, we included only studies with AIS patients treated with a TLSO brace and these results may not be applicable to other brace types (e.g., CTLSO, Charleston or Providence). Further studies on predictive factors for outcome in other brace types would provide valuable information, and provide opportunities to help predict individual treatment efficacy at the time of bracing.

Conclusion

The results of this review showed strong evidence that lack of initial in-brace correction is a predictive factor for brace treatment failure. Moderate evidence suggests that decreased brace time wearing is predictive of brace treatment failure, and increased brace time wearing of treatment success. Further research is needed to determine the exact threshold for minimal immediate in-brace correction for brace treatment failure. This will subsequently provide valuable guidelines for future practices and help to predict individual brace efficacy at the time of brace initiation. Future investigations into predictive factors with conflicting or limited evidence are warranted.

Compliance with ethical standards

Conflict of interest None.

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Affiliations

Manon van den Bogaart[1] · Barend J. van Royen[1] · Tsjitske M. Haanstra[1] · Marinus de Kleuver[2] · Sayf S. A. Faraj[1]

✉ Barend J. van Royen
bj.vanroyen@amc.uva.nl

[1] Department of Orthopaedic Surgery, Amsterdam University Medical Center, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands

[2] Department of Orthopedics, Radboud University Medical Center, Nijmegen, The Netherlands