Predictive Factors on Initial in-brace Correction in Idiopathic Scoliosis A Systematic Review

Peeters, C M M; van Hasselt, Arthur Justus; Wapstra, Frits Hein; Jutte, Paulus Christiaan; Ruth Kempen, Diederik Hendrik; Faber, Christopher

Published in:
SPINE

DOI:
10.1097/BRS.0000000000004305

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2022

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 14-09-2023
Predictive Factors on Initial in-brace Correction in Idiopathic Scoliosis

A Systematic Review

Charles Marcelis Maria Peeters, MD,a Arthur Justus van Hasselt, MD,a Frits Hein Wapstra, MD, PhD,a Paulus Christiaan Jutte, MD, PhD,a Diederk Hendrik Ruth Kempen, MD, PhD,b and Christopher Faber, MD, PhDa

Study Design. Systematic literature review.

Objective. The aim of this study was to systematically review the literature and provide an overview of reported predictive factors on initial in-brace correction in patients with idiopathic scoliosis (IS).

Summary of Background Data. Brace therapy is the best proven non-surgical treatment for IS. There is strong evidence that lack of initial in-brace correction is associated with brace treatment failure. To improve initial in-brace corrections and subsequently long-term brace treatment success, knowledge about factors influencing initial in-brace correction is a prerequisite.

Methods. A systematic literature search was performed in Pubmed, Embase, Web-of-Science, Scopus, Cinahl, and Cochrane in November 2020. Studies which reported factors influencing initial in-brace correction in IS patients treated with brace therapy were considered eligible for inclusion.

Results. Of the 4562 potentially eligible articles identified, 28 studies fulfilled the inclusion criteria and were included in this systematic review. Nine studies (32%) were classified as high quality studies and the remaining 19 studies (68%) as low quality. Thirty-four different reported factors were collected from the included studies. Strong evidence was found for increased curve flexibility as favorable predictive factor for initial in-brace correction. Moderate evidence was found for thoracolumbar or lumbar curve pattern as favourable predictive factor, and double major curve pattern as unfavourable predictive factor for initial in-brace correction. Also moderate evidence was found that there is no significant difference on initial in-brace correction between computer-aided design and manufacturing systems (CAD/CAM) braces with or without finite element models (FEM) simulation, and braces fabricated using the conventional plaster cast.

Conclusion. The results of this systematic review indicate that increased curve flexibility is strongly associated with increased initial in-brace correction.

Key words: brace therapy, curve flexibility, in-brace correction, predictive factors, scoliosis, systematic review.

Level of Evidence: 1

Spine 2022;47:E353-E361

Idiopathic scoliosis (IS) is a complex three-dimensional deformity of the spine characterized by a lateral curvature of at least 10 degrees with vertebral rotation and often hypokyphosis.1 Severe lateral curves exceeding 50 degrees in Cobb angle have a high risk of progression during adulthood and are therefore usually treated surgically.2 To prevent surgical treatment, patients with smaller curves are treated with a brace during their adolescent growth spurt aiming to maintain the curve below 45 to 50 degrees.3 Brace treatment can significantly decreased the progression risk and subsequent risk for surgical treatment in patients with adolescent idiopathic scoliosis (AIS).3 Unfortunately, bracing is not successful in every patient and the number needed to treat was three to prevent one case of curve progression requiring surgery.

Predictive factors for brace treatment outcome are recently evaluated in a systematic review.4 Besides moderate evidence that increased brace time wearing is predictive for long-term treatment success, strong evidence was reported that lack of initial in-brace correction is associated with brace treatment failure.4 To improve initial in-brace corrections and subsequently long-term brace treatment success, knowledge about factors influencing initial in-brace
correction are a prerequisite. This systematic review provides an overview of reported predictive factors on initial in-brace correction in patients with IS.

**METHODS**

**Search Strategy**
A systematic literature search was performed in November 2020. Pubmed, Embase, Web-of-Science, Scopus, Cinahl (Ebsco), and Cochrane were used as databases to identify relevant studies since January 1995 up to November 2020. An overview of the search strategy is presented in Table 1.

**Inclusion and Exclusion Criteria**
The studies retrieved from the literature search were included in this systematic review according to the following inclusion criteria: Patients were diagnosed with idiopathic scoliosis and treated with brace therapy, study described factors influencing initial in-brace correction, full-text of the article was available, and the study was published in English, Dutch or German. Measure methods other than radiography, ultrasound, computed tomography (CT) or magnetic resonance imaging (MRI) for initial in-brace correction, reviews, case reports, editorials, comments, letters, guidelines and protocols were excluded.

**Study Selection**
Two reviewers (C.P. and A.H.) independently examined article titles and abstracts for eligibility. Subsequently, full text of potential studies was screened for final inclusion in this review. Any uncertainty concerning the inclusion of specific studies was solved in a single consensus meeting with a third reviewer (D.K.). In addition, reference lists of included articles were screened for eligible studies which were not identified by the electronic search.

**Quality Assessment**
Two reviewers (C.P. and A.H.) independently assessed the methodological quality of each included study, using questions from the refined Quality in Prognosis Studies tool and Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies. The nine quality criteria are listed in Table 2. Each item was assigned “yes,” “no,” or “cannot determine,” and scored one point for yes, and no point for no or cannot determine. If an item was described insufficiently, no point was assigned. Disagreements were solved by consensus. Consultation of a third reviewer (D.K.) in case of persistent disagreement appeared unnecessary.

Studies were defined as “high quality” when at least 70% of the 10 items was assigned with one point (≥7 points), and as “low quality” when <70% (<7 points) was assigned with one point. The level of evidence was classified into the following levels:7-9

---

**TABLE 1. Search Strategy in Pubmed**

```
```

**TABLE 2. Methodological Quality Criteria**

<table>
<thead>
<tr>
<th>Item</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A) Was a prospective evaluation of factors of influence on immediate in-brace correction stated? (CB)</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>2. Were potential factors of influence on immediate in-brace correction predefined?</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>3. Was the study population clearly specified and defined?</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>4. Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>5. Was a sample size justification, power description, or variance and effect estimates provided?</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>6. Method of prognostic factor measurement is adequately described, valid and reliable.</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>7. Was the immediate in-brace correction measured using Cobb method on radiographs, CT or MRI in all patients?</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>8. Was the pre-treatment scoliosis curve and immediate in-brace correction verified independently?</td>
<td>Yes/No/CD/NA</td>
</tr>
<tr>
<td>9. Was loss to follow-up after baseline 20% or less?</td>
<td>Yes/No/CD/NA</td>
</tr>
</tbody>
</table>

This timeframe was arbitrarily chosen, because the longer the time frame, the less reliable would be the outcome due to potential progression of scoliosis curve.

CD indicates cannot determine; CT, computed tomography; MRI, magnetic resonance imaging.
(1) Strong evidence: Generally consistent findings (≥75% of the studies showed results in the same direction) in at least two high-quality studies;

(2) Moderate evidence: Generally consistent findings (≥75%) in one high-quality study and at least one low-quality study, or consistent findings in multiple (two or more) low-quality studies;

(3) Insufficient evidence: only one study available or inconsistent findings in multiple (two or more) studies.

Data extraction and Presentation
Two reviewers (C.P. and A.H.) extracted the data of included studies. Information was collected on study design, study population, outcome measures, measure instrument for in-brace correction, time frame, and study results. All included studies are listed in a table and potential factors influencing initial in-brace correction are documented in the results.

RESULTS

Study Inclusion and Characteristics
The literature search in the databases yielded 4562 studies after removal of duplicates (Figure 1). Finally, 28 studies fulfilled the inclusion criteria and were included in this systematic review. An overview of the included studies is presented in Table 3. A more comprehensive overview of

Figure 1. Study selection.
<table>
<thead>
<tr>
<th>First Author, Year of Publication</th>
<th>Design</th>
<th>QA</th>
<th>No.</th>
<th>Age, y, Mean ± SD (range)</th>
<th>% Male</th>
<th>Brace Type</th>
<th>Instrument for Measuring In-brace Correction, and Time Frame</th>
<th>Reported Factor(s)</th>
<th>F</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheung et al., 201818</td>
<td>RS</td>
<td>H</td>
<td>105</td>
<td>12.2 ± 1.2</td>
<td>8%</td>
<td>Boston</td>
<td>x-Ray; 2 wk</td>
<td>Increased curve flexibility</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>He et al., 201722</td>
<td>PS</td>
<td>H</td>
<td>35</td>
<td>12 ± 2</td>
<td>9%</td>
<td>RSO</td>
<td>x-Ray; 2–3 wk</td>
<td>Increased curve flexibility</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labelle et al., 200727</td>
<td>RCT</td>
<td>H</td>
<td>48</td>
<td>12.9 ± 1.4</td>
<td>4%</td>
<td>Boston</td>
<td>3D Reconstruction from two x-rays; 3–4 wk</td>
<td>Brace designed with computer-assisted tool compared to conventional plaster-cast method, higher Risser stage, increased pre-brace Cobb angle</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hedayati et al., 201824</td>
<td>PS</td>
<td>H</td>
<td>30</td>
<td>11.2 (8–17)</td>
<td>0%</td>
<td>Milwaukee</td>
<td>x-Ray; 11 wk</td>
<td>Brace adjustment twice per week and group exercise for 11 weeks</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karam et al., 201925</td>
<td>PS</td>
<td>H</td>
<td>52</td>
<td>12.4 ± 1.4</td>
<td>21%</td>
<td>—</td>
<td>Fulcrum bending x-ray; &lt;1 day</td>
<td>A lateral force applied at the apical vertebra of the thoracic curve compared to a force placed at the apical rib</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohrt-Nissen et al., 201630</td>
<td>RS</td>
<td>H</td>
<td>127</td>
<td>13.6 ± 1.5</td>
<td>11%</td>
<td>Providence</td>
<td>x-Ray; NA</td>
<td>Increased curve flexibility</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gay et al., 202134</td>
<td>RCT</td>
<td>H</td>
<td>120</td>
<td>13 (10–16)</td>
<td>NA</td>
<td>TLSO</td>
<td>EOS x-ray; 5.7 mo</td>
<td>Braces designed with CAD/CAM-FEM method compared to CAD/CAM alone</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li et al., 202039</td>
<td>RS</td>
<td>H</td>
<td>44</td>
<td>14.2 ± 2.4 (6–18)</td>
<td>18%</td>
<td>Chêneau</td>
<td>x-Ray; 2 mo</td>
<td>Increased apical rotate factor, increased pelvic rotate factor in patients with lumbar ISLumber lordosis factor, coronal balance factor, vertical balance factor, pelvic symmetry factor</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lang et al., 201935</td>
<td>RS</td>
<td>H</td>
<td>119</td>
<td>12.6 ± 1.16 (10–15)</td>
<td>15%</td>
<td>Gensingen</td>
<td>x-Ray; &lt;6 wk</td>
<td>Curve type (thoracic vs. (thoraco) lumbar curves), age, sex, weight, height, BMI, Risser stage, menarche status, increased C-DAR, increased prebrace major CA</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lang et al., 201936</td>
<td>RS</td>
<td>L</td>
<td>112</td>
<td>12.6 ± 1.2 (10–15)</td>
<td>16%</td>
<td>Gensingen</td>
<td>x-Ray; CD</td>
<td>Curve type (thoracic vs. (thoraco) lumbar curves), age, sex, weight, height, BMI, Risser stage, menarche status, increased LPR, spinal coronal or sagittal imbalance, increased prebrace total (&gt;55 degrees), major (&gt;30 degrees) or minor curve CA</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bussert et al., 200837</td>
<td>RS</td>
<td>L</td>
<td>39</td>
<td>NA</td>
<td>NA</td>
<td>Boston</td>
<td>3D reconstruction from biplanar x-ray; &lt;1 day</td>
<td>More severe scoliotic curve in the lower thoracic segment</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Chu et al., 200638</td>
<td>PS</td>
<td>L</td>
<td>34</td>
<td>14 ± 1.0 (12–15)</td>
<td>0%</td>
<td>TLSO</td>
<td>MRI; &lt;1 day</td>
<td>Prone position during assessment of initial in-brace correction, compared to other recumbent positions</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 3. Overview of Reported Predictive Factors on Initial In-brace Correction**
<table>
<thead>
<tr>
<th>First Author, Year of Publication</th>
<th>Design</th>
<th>QA</th>
<th>No.</th>
<th>Age, y, Mean ± SD (range)</th>
<th>% Male</th>
<th>Brace Type</th>
<th>Instrument for Measuring In-brace Correction, and Time Frame*</th>
<th>Reported Factor(s)</th>
<th>F</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulthuis et al, 2008&lt;sup&gt;16&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>63</td>
<td>11.3 ± 3.1</td>
<td>10%</td>
<td>TriaC</td>
<td>x-Ray; 4 mo</td>
<td>An increase in the continuous corrective force applied in a TriaC-brace</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobetto et al, 2016&lt;sup&gt;17&lt;/sup&gt;</td>
<td>RCT</td>
<td>L</td>
<td>40</td>
<td>11.1 (10–16)</td>
<td>13%</td>
<td>TLSO</td>
<td>EOS x-ray; NA</td>
<td>Braces designed with CAD/CAM-FEM method compared to CAD/CAM alone</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>D’ Amato et al, 2001&lt;sup&gt;18&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>102</td>
<td>NA (10–16.5)</td>
<td>0%</td>
<td>Providence</td>
<td>x-Ray; NA</td>
<td>Increased curve flexibility, higher Risser stage (Risser 2 compared to Risser 0–1), curve apex below T8, primary thoracolumbar or lumbar curve pattern</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Jarvis et al, 2008&lt;sup&gt;19&lt;/sup&gt;</td>
<td>RS</td>
<td>L</td>
<td>23</td>
<td>8.3 y (5.5–9.9)</td>
<td>30%</td>
<td>Charleston</td>
<td>x-Ray; 3 wk</td>
<td>Single major curve type compared to double major and triple curve type in JIS, major curve of double major curve type compared to secondary curve in JIS</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>van den Hout et al, 2002&lt;sup&gt;20&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>16</td>
<td>13.7 (8–17)</td>
<td>13%</td>
<td>Boston</td>
<td>x-Ray; 6.5 mo</td>
<td>An increase in mean compressive force over the thoracic or lumbar brace pad in a Boston brace</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wong et al, 2005&lt;sup&gt;21&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>40</td>
<td>12.6 (10–14)</td>
<td>0%</td>
<td>NA</td>
<td>x-Ray; NA</td>
<td>Braces designed with CAD/CAM compared to conventional manual method</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sankar et al, 2007&lt;sup&gt;22&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>10</td>
<td>8.9</td>
<td>NA</td>
<td>TLSO</td>
<td>x-Ray; 3 wk</td>
<td>Braces designed with CAD/CAM compared to conventional plaster-cast method</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desbiens-Blais et al, 2012&lt;sup&gt;23&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>6</td>
<td>NA (11–13)</td>
<td>0%</td>
<td>TLSO</td>
<td>EOS x-Ray; &lt;1 day</td>
<td>Braces designed with CAD/CAM-FEM compared to conventional plaster-cast method</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobetto et al, 2014&lt;sup&gt;24&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>15</td>
<td>NA (11–14)</td>
<td>0%</td>
<td>TLSO</td>
<td>EOS x-Ray; NA</td>
<td>Braces designed with CAD/CAM-FEM compared to conventional plaster-cast method</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al-aubaidi et al, 2013&lt;sup&gt;25&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>24</td>
<td>12.8</td>
<td>0%</td>
<td>Providence</td>
<td>x-Ray; 2 wk</td>
<td>In- vs. outpatient protocols at the initiation phase of brace treatment</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goodbody et al, 2016&lt;sup&gt;26&lt;/sup&gt;</td>
<td>RS</td>
<td>L</td>
<td>182</td>
<td>12.5 ± 1.4 (10–16)</td>
<td>14%</td>
<td>TLSO</td>
<td>x-Ray; NA</td>
<td>BMI &gt;85th percentile, BMI &lt;50th percentile</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baharoo et al, 2020&lt;sup&gt;27&lt;/sup&gt;</td>
<td>RS</td>
<td>L</td>
<td>75</td>
<td>6.94 ± 1.86</td>
<td>24%</td>
<td>Milwaukee</td>
<td>x-Ray; 4–6 mo</td>
<td>Juvenile IS patients with Lenke type III curves, compared to Lenke type I, II, and V</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li et al, 2014&lt;sup&gt;28&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>9</td>
<td>12.9</td>
<td>0%</td>
<td>NA</td>
<td>Clinical ultrasound; 1 day</td>
<td>Time in brace ≤2 h before assessment of initial in-brace correction</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weiss et al, 2007&lt;sup&gt;29&lt;/sup&gt;</td>
<td>PS</td>
<td>L</td>
<td>81</td>
<td>12.9 ± 1.9</td>
<td>NA</td>
<td>Cheneau light</td>
<td>x-Ray; 6 wk</td>
<td>Greater Age, higher Risser stage, increased pre-brace Cobb angle, thoracolumbar and lumbar compared to thoracic or double major curve types</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 3 (Continued)

<table>
<thead>
<tr>
<th>First Author, Year of Publication</th>
<th>Design</th>
<th>QA</th>
<th>No.</th>
<th>Age, y, Mean ± SD (range)</th>
<th>% Male</th>
<th>Brace Type</th>
<th>Instrument for Measuring In-brace Correction, and Time Frame</th>
<th>Reported Factor(s)</th>
<th>F</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aubin et al., 1997</td>
<td>PS</td>
<td>L</td>
<td>36</td>
<td>12.5 ± 1.7</td>
<td>11%</td>
<td>Boston</td>
<td>3D reconstruction from two x-rays; 1 - 6 mo</td>
<td>X</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chan et al., 2014</td>
<td>PS</td>
<td>L</td>
<td>42</td>
<td>12.6 ± 1.0 (11 - 15)</td>
<td>0%</td>
<td>TLSO (HK brace)</td>
<td>x-ray; 4 - 6 mo</td>
<td>Primary thoracolumbar curve pattern compared to thoracic pattern; brace compliance</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

*Time frame between out-of-brace images or start brace wear and in-brace images for the determination of in-brace correction.

**Factors Associated With Initial In-brace Correction**

An overview of 44 different reported factors is presented in Table 3 and supplementary data 1, [https://www.spinejournal.com](https://www.spinejournal.com) (E358). A best-evidence synthesis was performed to determine the strength of evidence of identified factors associated with initial in-brace correction and to identify potential factors for future research.

### Methodological Quality

Nine studies (27%) were classified as high quality and the remaining 19 studies (68%) as low quality during quality assessment. Two studies from the same scoliosis center included 119 and 112 patients in the same time period and with comparable baseline characteristics. Since this study provided a very close estimation of the actual in-brace correction, only one study was presented from the center (B845). The overall sample size of the included studies ranged from six to 182 patients. The mean age of the included studies ranged from 11 to 18 years, and the sex of involved patients was mainly female. In-brace correction was determined by radiography in 93% of the studies. The mean quality score was 5.2 (SD 2.2) with a range of 1 (low quality) to 9 (high quality).

One study used MRI and another used clinical ultrasound as the method of identification of patients treated with underarm bracing (Pearson correlation coefficient r = 0.74, P < 0.001). The mean age of the included studies ranged from 11 to 18 years, and the sex of involved patients was mainly female. In-brace correction was determined by radiography in 93% of the studies. The mean quality score was 5.2 (SD 2.2) with a range of 1 (low quality) to 9 (high quality).
### Curve Pattern

Eight studies investigated the influence of scoliosis curve type on initial in-brace correction.\(^1\),\(^2\),\(^2\),\(^4\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\),\(^10\),\(^11\) Moderate evidence was found for double major curve type as unfavorable predictive factor for initial in-brace correction in patients with AIS or juvenile idiopathic scoliosis (JIS).\(^1\),\(^2\),\(^4\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\),\(^10\) One study reported less in-brace correction for the secondary curves (42%) compared to the major curves (85%) in 12 JIS patients with double major curve patterns.\(^11\) Also moderate evidence was found for thoracolumbar or lumbar curve types as favourable predictive factor for initial in-brace correction compared to thoracic curve types.\(^1\),\(^2\),\(^4\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\) Four studies, including one of high quality, found significant less initial in-brace correction in AIS patients with thoracic curve type compared to thoracolumbar and lumbar curve types.\(^1\),\(^2\),\(^4\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\) The \(P\) values for this factor were reported in two studies (\(P < 0.01\) and \(P = 0.002\)).\(^1\),\(^8\) However, two studies from the same group reported no significant difference in initial in-brace correction between thoracic and (thoraco)lumbar curve patterns (\(P = 0.79\) and \(P = 0.76\)).\(^8\),\(^9\)

### Brace-related Factors

Moderate evidence was found that there is no significant difference on initial in-brace correction between braces designed with computer-aided design and manufacturing systems (CAD/CAM) combined with or without finite element models (FEM) simulation, and braces fabricated using the conventional plaster-cast method.\(^2\),\(^4\),\(^5\),\(^6\),\(^8\),\(^9\) Only one high-quality study reported a significant improvement of initial coronal curve correction in braces designed and adjusted with a 3D visualization software tool compared to conventional plaster-cast method (\(P < 0.01\) and \(P = 0.02\) for thoracic and lumbar curves, respectively).\(^8\) Insufficient evidence was found for the added value of CAD/CAM-FEM compared to CAD/CAM alone for initial in-brace correction.\(^9\),\(^4\)

A high-quality study discovered that a lateral force applied at the apical vertebra of the thoracic curve was significantly more efficient at correcting coronal deformity than a force placed at the apical rib (\(P = 0.001\)).\(^8\) Furthermore, translations generated by the Boston brace system on the thorax generally are statistically and linearly related to corresponding corrections of the spine.\(^1\) Derotation forces at the apex of the rib hump were found to be limited and did not allow the reduction of axial rotation (\(r = 0.12\)), but were correlated with the reduction of spine offset in the frontal plane (\(r = 0.43\)). Also a tendency was found that anterior displacements of the rib cage at apical level is accompanied by an increase of the spinal thoracic curve (\(r = -0.41, P = 0.01\)).\(^4\) Insufficient evidence for a correlation between magnitude of the corrective force over the thoracic or lumbar brace pad and degree of in-brace correction of the major curve was found.\(^1\),\(^6\),\(^9\)

### Radiologic Factors

Insufficient evidence was found for increased pre-brace major Cobb angle, rib vertebral angle difference, rib vertebral angle-convex side, rib vertebral angle-concave side, lumbar lordosis factor, coronal balance factor, vertical balance factor, and pelvic symmetry factor as influencing factors for initial in-brace correction.\(^1\),\(^2\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\),\(^10\) There is also insufficient evidence for higher Risser stage, curve apex \(<T8\), increased lumbo-pelvic ratio, coronal deformity angular ratio, apical rotate factor, pelvic rotate factors, and spinal coronal or sagittal imbalance as predictive factors for initial in-brace correction.\(^2\),\(^5\),\(^6\),\(^7\),\(^8\),\(^9\),\(^10\)

### Other Reported Factors

Insufficient evidence was found for age, sex, height, weight, menarche status, and BMI as predictive factors for initial inbrace correction.\(^1\),\(^4\),\(^6\),\(^7\),\(^8\) A high-quality study discovered that brace adjustment of a Milwaukee brace twice per week combined with group exercise under supervision of a skilled physiotherapist for 11 weeks resulted in significantly better initial in-brace Cobb angle curve correction, compared to a routine protocol in the control group (\(P = 0.04\)).\(^3\) There is also a time lag between brace application and its effect on scoliotic curve.\(^3\) The spinal response to brace application or removal seemed to plateau after approximately 120 minutes, and therefore radiographs should not be obtained within 2 hours after brace application or removal for the most reliable image. When assessing in-brace correction with a MRI, the largest in-brace correction in a thoracic lumbar sacral orthosis was observed when the patient is in prone position, compared to supine, right and left decubitus positions.\(^10\) No significant difference on

### Table 4: Overview of Strong and Moderate Evidence Predictive Factors on Initial In-brace Correction

<table>
<thead>
<tr>
<th>Level of Evidence</th>
<th>Factor</th>
<th>F</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong evidence(^1)</td>
<td>Increased curve flexibility</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate evidence(^1)</td>
<td>Thoracolumbar or lumbar curve pattern</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Braces designed with CAD/CAM or CAD/CAM FEM compared to conventional plaster-cast method</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Double major curve pattern</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

\(^1\) Generally consistent findings (\(\geq 75\%\) of the studies showed results in the same direction) in at least two high-quality studies.
\(^2\) Generally consistent findings (\(\geq 75\%\)) in one high-quality study and at least one low-quality study, or consistent findings in multiple (\(\geq 2\)) low-quality studies.

CAD/CAM indicates computer-aided design and manufacturing systems; FEM, finite element model; F, favorable predictive factor; N, non-influencing factor; U, unfavorable predictive factor.
primary in-brace correction was reported between in-hospitalization and outpatient clinic protocols, at the initiation phase of brace treatment with a Providence night time only brace.\textsuperscript{15} Lastly, insufficient evidence was found for compliance as influencing factor for initial in-brace correction.\textsuperscript{17} One study reported no significant difference on in-brace correction (<40% and ≥40% correction) after 4–6 months between three groups of different hours of brace wear (0–8 hours, 9–16 hours, and 17–23 hours).\textsuperscript{17} In this study, brace wearing hours were recorded on a log sheet and by an orthosis monitoring system.

**DISCUSSION**

This systematic review provides an overview of predictive factors on initial in-brace correction in patients with IS. Strong evidence was found for increased curve flexibility as favorable predictive factor for initial in-brace correction. Moderate evidence was found for thoracolumbar or lumbar curve pattern as favorable predictive factor, and double major curve pattern as unfavorable predictive factor for initial in-brace correction.

Although curve type and curve flexibility are patient factors which cannot be influenced by the orthotist, this information is useful to clarify differences in between patients. Less initial in-brace correction in a Providence for thoracic curve type and double major curves was seen compared to thoracolumbar and lumbar curve types.\textsuperscript{30} However, when subsequently adjusted for curve flexibility, no difference in curve correction between curve types was found ($P = 0.77$). This indicates that the differences in initial in-brace correction between curve types might be the result of differences in curve flexibility rather than the curve pattern itself.\textsuperscript{30} Measuring curve flexibility can provide a very close estimation of the actual in-brace correction in clinical practice.\textsuperscript{18,23,30} A high quality study reported a regression model (in-brace Cobb angle = 0.809 x supine Cobb angle) which could be used as a guide to determine initial in-brace correction.\textsuperscript{18} Although a lack of initial in-brace correction is associated with brace treatment failure, a minimum threshold for in-brace correction has not been established.\textsuperscript{4} Various cutoff values between < 10% and 45% for initial in-brace correction have been reported to be predictive for brace treatment failure.\textsuperscript{4,38}

Unlike curve type and flexibility, brace manufacturing technologies are factors that can be further optimized by the orthotists. So far, no significant differences in initial in-brace correction were seen between braces designed with CAD/CAM combined with or without FEM simulation, and braces fabricated using the conventional plaster-cast (moderate evidence). Although a CAD/CAM (FEM) technology did not significantly improve initial in-brace correction compared to a conventional plaster-cast method, an added value of CAD/CAM (FEM) braces on brace comfort was reported.\textsuperscript{22,28} Better brace comfort could improve compliance and subsequently brace treatment success. Furthermore, CAD technology can be useful to three-dimensionally quantify the trunk and brace characteristics to further investigate the effect of brace modifications on initial in-brace correction.

This review has several strengths and limitations worth mentioning. A best-evidence synthesis was performed, since a meta-analysis could not be performed due to the heterogeneity of the included studies. This heterogeneity resulted also in insufficient evidence for most reported factors, mainly because factors were only studied once. The time frame between out-of-brace images or start brace wear and in-brace images to determine the correction varied between the same day and 6.5 months. Long time frame may generate a potential bias since curves could have progressed. Although in-brace correction plateaued after 120 minutes and shorter time frames decrease the risk of curve progression, patients should be adapted sufficiently to the brace to obtain an image with neutral posture.\textsuperscript{11} Therefore, standardization of the time frame to determine in-brace correction would be beneficial. Another limitation of this study is that 25% of the included studies used absolute Cobb angle corrections instead of percentage curve corrections for analysis of initial in-brace correction. Ideally, future studies identifying potential predictive factors on initial in-brace correction should provide both absolute and percentage curve corrections.

In conclusion, the results of this systematic review indicate strong evidence for increased curve flexibility, and moderate evidence for thoracolumbar or lumbar curve pattern as favorable predictive factors for initial in-brace correction. Moderate evidence indicates that a double major curve pattern is an unfavorable predictive factor for initial in-brace correction. Braces designed with CAD/CAM or CAD/CAM-FEM did not result in improved initial in-brace correction compared to braces fabricated using the conventional plaster-cast method.

### Key Points

- Increased curve flexibility is strongly associated with increased initial in-brace correction.
- Moderate evidence indicates that thoracolumbar or lumbar curve patterns are favorable predictive factors, and that a double major curve pattern is an unfavorable predictive factor for initial in-brace correction.
- Moderate evidence indicates that there is no significant difference on initial in-brace correction between braces designed with computer-aided design and manufacturing systems (CAD/CAM) combined with or without FEM simulation, and braces fabricated using the conventional plaster-cast.

### Acknowledgments

The authors thank D.G. van Itersum from research institute SHARE/research office UMCG for her librarians’ contributions to the systematic literature search.
Supplemental digital content is available for this article. Direct URL citations appearing in the printed text are provided in the HTML and PDF version of this article on the journal’s Web site (www.spinejournal.com).

References