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Does in-brace correction affect coronal spinal and thoracic cage parameters in individuals with idiopathic scoliosis? A retrospective cohort study

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The aim of the study is to identify the effects of in-brace correction on coronal spinal and thoracic cage parameters in individuals with idiopathic scoliosis (IS). The coronal spinal parameters [Cobb angle, apical vertebral rotation (AVR), lateral trunk shift, coronal alignment, biacromial slope and pelvic asymmetry] and the thoracic cage parameters [T1-12 height, T1-S1 height, thoracic transverse diameter, and apical vertebral body-rib ratio (AVB-R)] of 89 child and adolescent patients were measured on posterior-anterior full-spine radiographs at pre-brace and in-brace conditions using Surgimap software. The initial in-brace correction (IBC) was calculated as a percentage decrease in the Cobb angle on the in-brace radiographs. The mean IBC rate for the primary curve was 37% (range = 10-100%). In the in-brace condition, the Cobb angle ($p<0.001$), AVR ($p<0.001$) and lateral trunk shift ($p<0.001$) decreased significantly; no statistically significant difference was found in the biacromial slope ($p=0.713$) and the coronal alignment ($p=0.074$). The T1-12 height and the T1-S1 height increased significantly ($p<0.001$) whereas the thoracic transverse diameter and the AVB-R decreased significantly ($p<0.001$). Unlike IBC rate was below 30% as IBC rate was above 30%, the T1-12 height ($p<0.001$) increased and the AVB-R decreased ($p<0.001$). The bracing improved the lateral trunk shift, the AVB-R, the thoracic and spine heights, but decreased the thoracic transverse diameter. The thoracic cage parameters may be better when the IBC rate is above 30%.

Key words: braces, biomechanics, scoliosis, rib cage.

INTRODUCTION

Bracing is the most common conservative treatment for moderate or severe idiopathic scoliosis (IS). It is used to prevent curve progression in patients with growth potential and a Cobb angle above 25°[1]. Currently, thoraco-lumbo-sacral orthoses (TLSOs) are used with different designs and characteristics[2]. The more commonly used of these braces are the Chêneau-type brace, the Sibilla and Sforzesco braces, and the Boston brace system. These braces have different corrective force mechanisms. The Chêneau-type brace, which performs three-dimensional (3D) correction of deformity, creates a detorsional mechanism formed by forces and counterforces acting on the trunk and wide expansion chambers in the three planes[3]. The Sibilla and Sforzesco braces are full-contact braces that are based on the Symmetrical, Patient-oriented, Rigid, Three-dimensional, active (SPoRT) concept of bracing[4]. The Boston brace system has a prefabricated design and antilordotic and antirotative effects[5], but similar principles of correction include external corrective 3D forces that act as lateral deviation and rotation components of the scoliotic curve[6]. The modified Boston brace is the custom-made brace, including similar corrective forces as the Boston brace. This brace provides a symmetrical posture by achieving a 3D correction action, including protective force on the physiological curvatures in the sagittal plane, and is based on the SPoRT concept[7,8].

These spinal braces with different designs and characteristics correct spinal deformity using 3D forces: in the frontal plane, concave distraction, convex compression, and lateral bending; in the transverse plane, derotation; and in the sagittal plane, restoration of physiological curves plus longitudinal traction[6]. Therefore, the effects of these forces of braces on the thoracic cage mechanics and the coronal spinal parameters are unavoidable. The effects of these forces on the coronal spinal parameters such as the Cobb angle, trunk shift, and coronal alignment are well documented, but the effects of in-brace correction on the thoracic cage parameters such as the thoracic diameter, trunk height, and apical vertebral body-rib ratio (AVB-R) remain unclear.

Previous studies have found that in-brace correction is an independent predictive factor of curve progression in braced patients with IS[9]. The in-brace correction defines the percentage of improvement in the curve magnitude at the initial brace prescription. Given the significance of in-brace correction, some studies have been performed to find related imaging parameters in order to predict the in-brace correction[10]. IS self-parameters, including the primary Cobb angle and the coronal deformity angular ratio, have been found to be related to in-brace correction[11]. Although the effects of bracing in the coronal and sagittal planes have been documented in several studies[11-13], little information is available on the effect of in-brace correction on the thoracic cage parameters. It is well known that the thoracic dimensions, especially the T1-12 height, are significant predictors of pulmonary function in early-onset scoliosis (EOS)[14] and that to avoid severe respiratory insufficiency, a thoracic spine height of 18-22 cm or more is needed for thoracic spine fusions[15]. Considering that the effects of bracing on the thoracic dimensions are inevitable, measurement of in-brace thoracic cage parameters may provide additional knowledge for in-brace design and rehabilitation programs. Hence, the aim of this study was to identify the effects of in-brace correction on the coronal spinal and especially thoracic cage parameters in IS patients fitted with a modified Boston brace system.

MATERIALS AND METHODS

This single-center retrospective study was approved by the Institutional Review Board of the authors' affiliated institutions (ID: GO 21/172). Data on patients treated with a modification of the Boston brace between 2014 and 2020 in our institution were reviewed. The data with and without the brace were collected from the hospital database retrospectively.

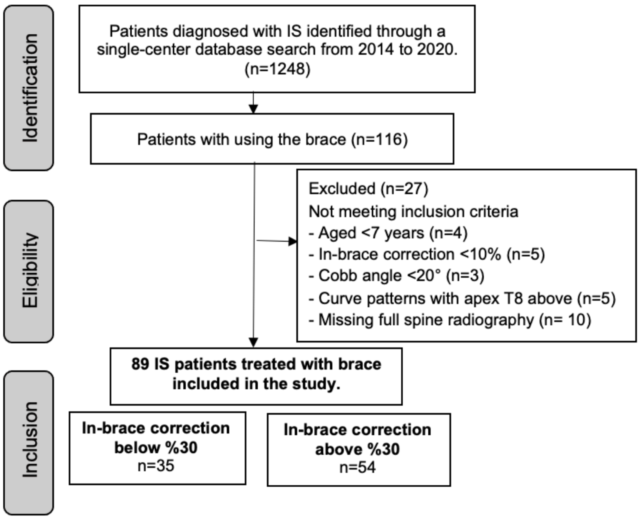

Figure 1 — Flow chart of the study.

The inclusion criteria were patients with (1) IS with a Risser grade of 0-3, (2) a Cobb angle of 20-45°, (3) an age of ≥ 7 years, (4) posteroanterior full-spine radiographs with and without the brace, (5) an in-brace correction of at least 10%, and (6) all curve patterns with an apex of T8 and below (as indications of the under-arm braces). The exclusion criteria were patients who (1) had undergone spine surgery, (2) had chest wall anomalies such as pectus excavatum and pectus carinatum, (3) had a neuromuscular or rheumatological disease, and (4) had a congenital malformation of the spine, spina bifida aperta, or spondylolisthesis. All the posterior-anterior full-spine radiographs of the patients' pre-brace (without the brace) and in-brace (with the brace, while the brace was wearing) were collected, except those with blurry images that hindered accurate data measurement. All spine X-rays (pre-brace and in-brace) were taken in the standing position. In-brace X-ray was taken the day of the orthosis fitting.

The patients were divided into two groups: those who experienced less than 30% in-brace correction of their primary curve and those who experienced higher than 30% correction of their primary curve. Literature suggests that to prevent significant progression of the curve, the in-brace correction must be at least 30-50%, with the optimal cut-off point at least 10%[13,16-18]. Figure 1 presents the flowchart of the study.

The demographic characteristics of each patient, i.e., the age, gender, and scoliosis-specific clinical characteristics such as the curve pattern classification, were recorded. The Lenke classification system was used to evaluate the curve pattern classification. The sagittal Lenke modifier was not studied[19].

On the full-length posterior-anterior spine radiography images of all the patients, all the coronal spinal

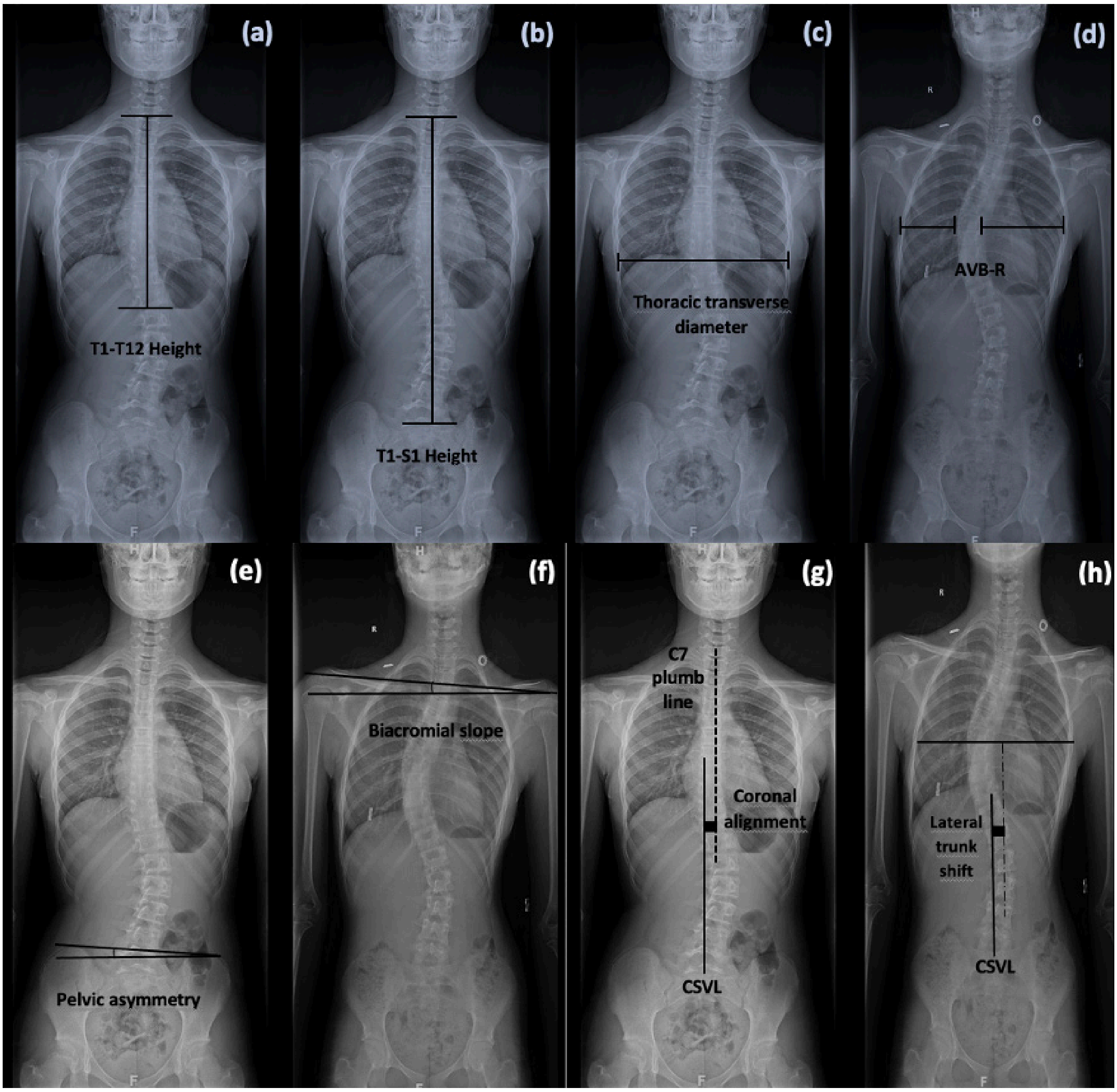

Figure 2 — (a) Thoracic height: T1-12 distance; (b) Spine height: T1-S1 distance; (c)Thoracic transverse diameter; (d) Apical vertebral body-rib ratio (AVB-R); (e) Pelvic asymmetry; (f) Biacromial slope (g) Coronal alignment; (h) Lateral trunk shift.

and thoracic cage parameters in both the pre-brace and in-brace conditions were measured using the Surgimap software (version 2.3.2.1, Nemaris, Inc., New York, USA). The software was developed for safe spine measurement on radiographs and for surgical planning in both the research and clinical fields[20]. In this study, an orthopedic spine surgeon calibrated the software using the ruler at the bottom of the radiograph and independently measured the coronal spinal parameters (Cobb angle, AVR, lateral trunk shift, coronal alignment, biacromial slope, and pelvic asymmetry) and the thoracic cage parameters (T1-12 height, T1-S1 height, thoracic transverse diameter, and AVB-R) on each of the radiographs. The radiographic measurements with the software are shown in Figure 2.

The initial in-brace correction was calculated as the percentage decrease in the Cobb angle on the in-brace radiographs, as follows: percent in-brace correction = [(pre-brace Cobb angle – in-brace Cobb angle) / (pre-brace Cobb angle) × 100%]. The in-brace correction was calculated for the primary curves, which were determined by the largest Cobb measurement and the Lenke classification[19]. In the double- nature curves, the primary curve was selected by the greatest Cobb angle. In addition, the mean in-brace correction rate was calculated for the thoracic and lumbar regions.

Figure 3 — The brace.

The curve magnitude was measured with the Cobb angle[21]. Interobserver and intraobserver reliability in the measurement of the Cobb angle have shown a measurement error of approximately 3°[22]. A change in Cobb's angle of more than 5° in consecutive measurements is seen as an indication of the curve's progression[23]. The AVR was measured using the Raimondi method[24,25]. The average intrarater error of 0.4° and the average interrater error of 3.63° for Raimondi measurement have been shown[24].

The lateral trunk shift was measured as follows. A horizontal line was drawn through the apical vertebra, and then two marks were drawn – one, at the end of the left thorax, and the other, at the end of the right thorax. Then a perpendicular line was drawn at the midpoint of the line that was deemed the vertical trunk reference line. The distance between the vertical trunk reference line and the center sacral vertical line (CSVL) was measured[26]. The coronal alignment was evaluated through the horizontal distance between the C7 plumb line and the CSVL[27]. The biacromial slope for shoulder balance was measured as the angle between the lines that touch the acromion and the horizontal plane[28]. The pelvic asymmetry was evaluated as the angle between the horizontal plane and the line iliac crest[29].

The T1-12 height was measured as the vertical distance (mm) between the middle of the superior end plate of T1 and the middle of the inferior end plate of T12[30]. Interrater reliability of 0.894 and intrarater reliability of 0.906 for spine height have been determined to be excellent[31]. The T1-S1 height was measured as the vertical distance (mm) between the middle of the superior end plate of T1 and the superior end plate of S1[30]. Interrater reliability of 0.890 and intrarater reliability of 0.898 for thoracic height have been shown to be excellent[31]. The transverse thoracic diameter was measured from the costal attachments of the diaphragm to the ribs at the point where the chest diameter was greatest[32]. The AVB-R was evaluated as the ratio of the linear measurements from the lateral borders of the apical thoracic vertebrae to the chest wall[33].

All the patients were treated with a modified Boston brace in our department from 2014 to 2020. A custom-made, thoraco-lumbo-sacral underarm brace was fabricated and fitted to each patient by an experienced orthotic technician. The manufacturing process included casting, negative and positive model forming, and fabrication of the polyethylene mold of the brace. The biomechanical principles of orthotic correction were applied with respect to the corrective forces against the spinal column lateral deviation and axial rotation while protecting the spinal curves in the sagittal plane and allowing thoracic expansion and extremity movements. The brace also provided a symmetrical posture by achieving a 3D correction action[34] (Figure 3).

The statistical analysis was performed using the Statistical Product and Service Solutions (SPSS) Statistics software package (version 23.0, SPSS Inc., Chicago, IL, USA). The normality of the distribution of the data was assessed using visual methods (a histogram and probability graphics) and an analytical method (the Kolmogorov-Smirnov test). The data were not normally distributed. They were divided into two groups: according to the in-brace correction rate of their primary curve (below 30% versus above 30%). Differences between the mean values of the pre-brace and in-brace conditions were tested for significance using the Wilcoxon signed-rank test. Also, a comparison of the mean difference of pre-brace and in-brace radiographic measures in EOS and adolescent idiopathic scoliosis (AIS) was performed with the Mann-Whitney U test. The data were expressed as means ± standard deviations or as frequencies (%). The alpha level for determining statistical significance was set at 0.05.

RESULTS

Eighty-nine patients (78 female and 11 male, mean age = 13.4±2.2 years, range = 7-18) with IS were included in this retrospective study. Their curve patterns were single-nature (thoracic, n = 40, 44.9% and lumbar, n = 27, 30.3%) or double-nature (n = 22; 24.7%). Their Lenke classification ranged from Lenke type-1 to Lenke type-6 curves. The mean in-brace correction rate for the primary curve was 37% (range = 10-100%), and for the thoracic and lumbar regions, 32% (range = 10-100%) and 38% (range = 10-95%), respectively. The demographic and clinical characteristics of the patients are shown in Table 1. The mean Cobb angle of the primary curve was 29.6±6.09° (range = 20-45°), and of the thoracic and lumbar regions, 29.5±6.4° (range = 20-45°) and 28.4±5.6° (range = 20-42°), respectively. The mean AVR of the primary curve was 11.3±7.1°, and of the thoracic and lumbar regions, 11.4±7.1° and 9.7±6.4°, respectively.

In the in-brace condition, the Cobb angle and the AVR decreased significantly (p < 0.001), as did the coronal spinal parameters, including the lateral trunk shift and the pelvic asymmetry (p < 0.001 and p = 0.042, respectively). No statistically significant difference was found in the biacromial slope and the coronal alignment

Table I. — Demographic and clinical characteristics of the patients

	Mean±SD n=89
Age (years)	13.4±2.2
Gender n (%)	
Female	78 (87.6)
Male	11 (12.4)
Scoliosis Type n (%)	
Early-onset scoliosis	3 (3.4)
Adolescent idiopathic scoliosis	86 (96.6)
Curve Type n (%)	
Thoracic	40 (44.9)
Lumbar	27 (30.3)
Double	22 (24.7)
Lenke classification n (%)	
Type 1	32 (36)
Type 2	1 (1.1)
Type 3	17 (19.1)
Type 4	1 (1.1)
Type 5	35 (39.3)
Type 6	3 (3.4)
In-brace correction rate (%)	
Primary Curve	37.1 (21.8)
Thoracic	32.0 (18.4)
Lumbar	38.1 (23.8)

SD: standard deviation. Values are frequency (%) or mean±standard deviation.

Table II. — Pre-brace and in-brace data and the change in radiographic measures

n=89	**Pre-brace mean±SD**	**In-brace mean±SD**	**Mean difference mean±SD (%95 CI)**	
Cobb angle (°)				
Primary curve	29.6±6.0	19.0±8.2	10.5±5.7 (9.3, 11.7)	**<0.001**
Thoracic	29.5±6.4	20.3±7.7	9.1±5.0 (7.8, 10.4)	**<0.001**
Lumbar	28.4±5.6	18.1±7.6	10.2±7.0 (8.2, 12.2)	**<0.001**
Apical vertebral rotation (°)				
Primary curve	11.3±7.1	7.6±6.4	3.7±4.0 (2.8, 4.5)	**<0.001**
Thoracic	11.4±7.1	7.4±6.7	3.8±4.0 (2.8, 4.8)	**<0.001**
Lumbar	9.7±6.4	6.3±5.3	3.3±3.7 (2.2, 4.4)	**<0.001**
Coronal spinal parameters				
Pelvic asymmetry (°)	1.55±1.36	1.21±1.12	0.34±1.3 (0.0, 0.6)	**0.042**
Biacromial slope (°)	2.29±1.92	2.23±1.99	0.06±1.9 (-0.3, 0.4)	0.713
Lateral trunk shift (mm)				
Thoracic	20.9±10.3	13.9±9.2	6.78±7.8 (4.7, 8.7)	**<0.001**
Lumbar	24.0±8.8	15.6±7.7	8.52±7.7 (6.3, 10.7)	**<0.001**
Coronal alignment (mm)	12.3±7.8	10.9±9.0	1.40±9.4 (-0.5, 3.3)	0.074
Thoracic Cage Parameters				
T1-T12 height (mm)	245.9±38.2	249.7±27.0	-3.8±30.2 (-10.1, 2.5)	**<0.001**
T1-S1 height (mm)	408.4±51.5	414.2±42.7	-5.8±36.3 (-13.4, 1.8)	**<0.001**
Thoracic transverse diameter (mm)	222.9±29.8	213.6±22.7	9.23±21.3 (4.7, 13.7)	**<0.001**
Apical vertebral body-rib ratio	1.43±0.19	1.35±0.24	0.07±0.1 (0.0, 0.1)	**<0.001**

SD: standard deviation, CI: confidence interval. Wilcoxon signed-rank test.

Table III. — Comparison of coronal spinal and thoracic cage parameters of patients' pre-brace and in-brace related to in-brace correction rate

	In-brace correction rate below 30% (n=35)				**In-brace correction rate above 30% (n=54)**			
	Pre-brace	**In-brace**	**MD (%95 CI)**	**P**	**Pre-brace**	**In-brace**	**MD (%95 CI)**	**P**
Cobb angle (°)								
Primary curve	30.6±7.2	24.7±6.6	5.8 (5.1-6.5)	**<0.001**	28.9±5.1	15.3±6.9	13.6 (12.1-15.0)	**<0.001**
Thoracic	31.1±7.1	25.0±6.7	6.1 (5.2-6.9)	**<0.001**	28.3±5.5	16.8±6.7	11.5 (9.6- 13.4)	**<0.001**
Lumbar	27.3±6.4	23.9±5.5	3.4 (1.6-5.2)	**0.007**	29.0±5.1	14.8±6.6	14.1 (12.2-16.1)	**<0.001**
Apical vertebral rotation (°)								
Primary curve	10.9±7.2	8.4±7.4	2.5 (1.3- 3.7)	**<0.001**	11.5±7.0	7.1±5.8	4.4 (3.3-5.6)	**<0.001**
Thoracic	10.9±7.1	8.5±8.1	2.4 (1.2-3.6)	**<0.001**	11.7±7.1	6.8±5.3	4.9 (3.4-6.4)	**<0.001**
Lumbar	7.8±6.5	5.7±4.3	2.1 (0.3-3.8)	**0.029**	10.9±6.2	6.7±5.9	4.1 (2.7-5.5)	**<0.001**
Coronal spinal parameters								
Pelvic asymmetry (°)	1.6±1.4	1.2±1.1	0.33 (-0.1- 0.8)	0.214	1.5±1.2	1.1±1.08	0.34 (0.0-0.6)	0.098
Biacromial slope (°)	2.1±1.7	1.9±1.8	0.18 (-0.5-0.9)	0.844	2.3±2.06	2.3±2.1	-0.01 (-0.5-0.4)	0.781
Lateral trunk shift (mm)								
Thoracic	20.5±9.9	15.3±9.6	5.2 (2.6- 7.7)	**<0.001**	21.2±10.7	12.9±8.9	7.98 (4.9-10.9)	**<0.001**
Lumbar	24.3±9.01	19.6±7.5	4.7 (1.9- 7.5)	**0.005**	23.8±8.8	13.4±7.0	10.7 (7.8-13.6)	**<0.001**
Coronal alignment (mm)	12.05±8.3	10.1±9.7	1.9 (-1.5- 5.3)	0.262	12.5±7.5	11.4±8.5	1.06 (-1.4-3.5)	0.174
Thoracic cage parameters								
T1-T12 height (mm)	252±39.3	249±20	3.7 (-8.1- 15.6)	0.090	244±30.8	250±30.8	-5.3 (-7.8 -2.8)	**<0.001**
T1-S1 height (mm)	412±63.1	411±36	1.07 (-17- 20)	**0.015**	405±42.9	416±46.4	-10.2 (-13.8 -6.6)	**<0.001**
Thoracic transverse diameter (mm)	222±37.3	212±22	10.3 (-0.8-21.5)	**0.007**	222±24.1	214±23.1	8.5 (6.1-10.8)	**<0.001**
Apical vertebral body-rib ratio	1.4±0.2	1.45±0.2	0.02(-0.03-0.08)	0.232	1.3±0.1	1.2±0.2	0.11 (0.05-0.16)	**<0.001**

MD: mean difference, SD: standard deviation, CI: confidence interval. Wilcoxon signed-rank test.

Supplementary Table I. — Comparison of pre-brace and in-brace radiographic measures in early-onset scoliosis and adolescent idiopathic scoliosis

	EOS (n=3)			**AIS (n=86)**			**EOS versus AIS**
	Pre-brace	**In-brace**	**MD (%95 CI)**	**Pre-brace**	**In-brace**	**MD (%95 CI)**	**p***
Cobb angle (°)	30.2 (20-36)	14.9 (2-22)	15.7 (-0.9- 32.4)	28.6 (25-33)	19.5 (15-25)	9.6 (8.2-10.9)	0.103
AVR (°)	8 (2-12)	2 (0-6)	4.6 (-1.07- 10.4)	10 (6-18)	6 (2-10)	4.2 (3.0-5.4)	0.552
Coronal spinal parameters							
Pelvic asymmetry	0.5 (0-1.3)	1 (0.3-1.2)	-0.23 (-1.4- 1.0)	1.3 (0.5-2.4)	1.1 (0.3-1.8)	0.28 (-0.07- 0.6)	0.345
Biacromial slope	5 (0.5-5.9)	4 (1.4-4.2)	0.6 (-2.7- 3.9)	2 (0.8-3.2)	1.6 (0.6-3.5)	0.01 (-0.5-0.5)	0.570
Lateral trunk shift	22.2 (8.2-27)	0.4 (0-8)	16.3 (-1.5- 34.1)	22.5 (14.2-28.7)	14.4 (7.7-20)	6.3 (4.3-8.2)	**0.047**
Coronal alignment	8.6 (2.4-25)	12 (9.4-13.6)	0.3 (-27.0- 27.6)	11.7 (6-17)	8.2 (4-15)	0.6 (-1.9-3.1)	0.617
Thoracic cage parameters							
T1-T12 height	189 (167-193)	203 (175-208)	-12.3 (-25.5-0.9)	250 (233-270)	256 (238-269)	-3.5 (-10-3)	0.067
T1-S1 height	324 (293-343)	333 (296-374)	-14.3 (-50.8- 22.1)	414 (394-435)	422 (399-439)	-5.5(-13.4- 2.3)	0.617
Thoracic transverse diameter	181 (169-218)	173 (160-220)	4.7 (-11.6- 21.0)	224 (205-238)	215 (201-229)	9.3 (4.7-14)	0.750
Apical vertebral body-rib ratio	1.37 (1.2-1.6)	1.39 (1.0-1.4)	0.1 (-0.2- 0.5)	1.41 (1.3-1.5)	1.35 (1.2-1.4)	0.07 (0.03-0.1)	0.524
In-brace correction rate (%)	58.6 (27.1- 90.0)			30.3 (20.5-45.8)			0.152

AVR: apical vertebral rotation, EOS: early-onset scoliosis, AIS: adolescent idiopathic scoliosis. Values are frequency (%) or median (interquartile range). *Mann-Whitney U test.

(p = 0.713 and p = 0.074, respectively). The thoracic cage parameters, including the T1-12 height and the T1-S1 height, increased significantly (p < 0.001), and the thoracic transverse diameter and the AVB-R decreased significantly ($p < 0.001$). The pre-brace and in-brace data and the changes in the radiographic measures are shown in Table II.

The Cobb angle, AVR, and lateral trunk shift decreased significantly both when the in-brace correction rate was below 30% and above 30% ($p < 0.001$). Also in both conditions, no statistically significant difference was found in the pelvic asymmetry, biacromial slope, and coronal alignment ($p > 0.05$). However, when the in-brace correction rate was above 30%, the vertical parameters of the thoracic cage, including the T1-12 height ($p < 0.001$), increased and the AVB-R decreased ($p < 0.001$). The coronal spinal and thoracic cage parameters of the patients with respect to in-brace correction are compared in Table III.

In supplementary Table I, a comparison of pre-brace and in-brace radiographic measures in EOS and AIS is presented. No significant difference was found in terms of coronal spinal and thoracic cage parameters between groups except for lateral trunk shift. Lateral trunk shift was significantly decreased in the EOS compared to the AIS ($p=0.047$).

DISCUSSION

This study found that the spinal bracing immediately decreased the Cobb angle and the AVR of the IS patients with an in-brace correction of 37% for the primary curve. The brace decreased the lateral trunk shift but did not change the pelvic asymmetry, biacromial slope, and coronal alignment in the coronal plane, and improved the thoracic cage parameters, including the thoracic height, spine height, and AVB-R, but decreased the thoracic transverse diameter. When the in-brace correction ratio was above 30%, the thoracic height and the AVB-R significantly improved, unlike when the in-brace correction ratio was below 30%.

According to a recent systematic review by van den Bogaart et al., in-brace correction is the strongest predictor of successful brace treatment[9]. Several studies have suggested that braces must correct the curve by at least 30-50% to prevent significant curve progression[16-18]. Ng et al. found that an in-brace correction lower than 10% was associated with an increased rate of failure of brace treatment, whereas an in-brace correction higher than 40-50% was associated with an increased rate of brace treatment success[35]. Despite several studies, there is no consensus yet on the cut-off percentage for minimal immediate in-brace correction[9]. In this study, the brace provided an immediate radiological correction of 37±21% (range = 10-100%) for the primary curve, consistent with previous studies.

Previous studies have investigated brace biomechanics in scoliosis. Lebel et. al. evaluated differences in in-brace radiographic correction with the use of a custom TLSO brace and a Chêneau-type TLSO brace by utilizing the 3D EOS reconstruction technology to determine the 3D effect of braces on the spine and in particular, on the AVR. They showed that the Chêneau brace reduced the AVR more significantly than did the TLSO brace (average corrections = 8.2° and 4.9°, respectively), but the coronal and sagittal corrections did not differ significantly between the two groups[36]. Mahaudens et al. evaluated the very short-term effect of brace wearing on gait in adolescent girls with IS and found that the apical rotation did not significantly differ[37]. However, only Lenke type-5 patients were included in the study, unlike in this study, and the Cobb angle of the patients was lower than in this study. We think the difference may be related to the differences in the curve type, brace design, and lower Cobb angle of the subjects of the two studies. Our findings are consistent with the data of Lebel et al. In addition, we found that in the in-brace correction condition, derotation occurred with an immediate 3.7° change in the AVR. The clinical significance of the change in AVR was reported to be 5° and above[38]. Although the change in the AVR was statistically significant, the clinical significance was questionable. However, positive change in AVR in-brace condition showed that bracing is a promising approach to treating patients with IS. Also, we know that angular correction has better results 6 to 8 weeks after the orthosis fitting[39], so it's more effective to wait 2 months before doing the x-ray to see in-brace correction. Due to the nature of a retrospective study, an in-brace X-ray was taken the day of the orthosis fitting. This condition may affect the moderate results of in-brace correction.

Bassett et al. showed that the Wilmington brace decreased the lateral trunk shift in adolescent IS[40]. Korovessis et al. documented immediate and late changes in the shape and balance of the thoracic and lumbar spines and the lower rib cage on the frontal plane induced by treatment with a TLSO brace. They showed that bracing improved the frontal appearance of the trunk by reducing the lateral trunk shift[41]. Similarly, this study showed that the brace significantly reduced the lateral trunk shift. Mahaudens et. al.[37] compared immediate in-brace and out-brace conditions related to frontal imbalance and found no changes in coronal imbalance, which is consistent with our data.

Zheng et al. studied the effect of a TLSO brace versus exercise on the spinal curvature, body symmetry, and quality of life and found that the shoulder balance significantly improved only in the bracing group after 12 months[42]. Studies on the immediate effect of bracing on pelvic asymmetry and shoulder balance are limited. This study showed that the pelvic asymmetry and shoulder balance did not change immediately in an in-brace correction condition, which is consistent with the results of previous studies. These results suggest that IS patients, when wearing braces, may need time to develop body awareness and proprioception.

Based on Dimeglio data for normal spine growth, Dimeglio et. al. determined that the T1-12 length averaged 18 cm at 5 years of age, 22 cm at 10 years of age, and 26.5-28 cm in adults[43]. Karol et al. also showed that a thoracic spine height of 18-22 cm or more is necessary to avoid severe respiratory insufficiency[15]. Glotzbecker et al., in their study on the relationship between the thoracic dimensions and the pulmonary function in EOS, found that the T1-12 height was a significant predictor of forced air volume expelled in a 1-second percentile and of total forced air volume percentiles[14]. To our knowledge, studies on the immediate effects of braces on the thoracic cage parameters are limited in literature. This study showed that bracing increased the trunk height and the spine height by correcting the lateral deviation of the spine on the frontal plane with the brace's three-point force system. Moreover, the thoracic height significantly improved when the in-brace correction ratio was above 30%, unlike when it was below 30%. We also found that bracing decreased the thoracic transverse diameter, likely due to the increased compression or derotational forces caused by the brace, but that the thoracic transverse diameter decreased less when the in-brace correction was above 30% than when it was below 30%. These findings suggest that higher in-brace correction may help to preserve the thoracic transverse diameter. Future studies shall investigate the relationship between the brace design, the in-brace correction ratio, and the thoracic diameter.

In addition, only three of the patients had early-onset scoliosis due to idiopathic causes, and their ages were seven, eight, and nine years. The present study found that coronal spinal and thoracic cage parameters were similar in patients with EOS and AIS in-brace condition. However, lateral trunk shift was more reduced in the EOS compared to the AIS. These results may be related to differences in the treatment approach or spine flexibility in patients with EOS. Further studies with larger sample sizes are needed in patients with EOS due to thoracic development and spine growth would differ significantly from patients with AIS.

This study mainly differed from previous studies in that it evaluated the immediate effect of bracing on both the coronal spinal and thoracic cage parameters. Also, our subjects had a wide age range (7-18 years). In particular, we obtained important data regarding the effects of in-brace correction on the thoracic cage. However, this study had a few limitations. First, it was designed to evaluate only the immediate effects of braces on coronal spinal and thoracic cage parameters. Further studies are required to determine the effect of long-term treatment with braces on thoracic cage parameters in IS patients. Second, we were not able to assess the sagittal plane because the patients did not have lateral spine radiographs. Third, the study included patients treated with a modified Boston brace. The results might have been different with a different brace design. Further studies should investigate differences in in-brace correction and the thoracic cage parameters identified in this study with different brace designs. Moreover, 3D biomechanical analysis is suggested to investigate how corrective forces act on the thoracic diameter.

CONCLUSION

In conclusion, a modified custom-made Boston brace improve the trunk shift, the thoracic and spine heights. However, the brace has a negative impact on thoracic transverse diameter. The in-brace correction rate above 30% seems useful for thoracic cage parameters.

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