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Clinical Study

Coronal deformity angular ratio may serve as a valuable parameter to predict in-brace correction in patients with adolescent idiopathic scoliosis

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Abstract

BACKGROUND CONTEXT: In-brace correction (IBC) plays an important role in curve progression of patients with adolescent idiopathic scoliosis (AIS) under brace treatment. We evaluated the coronal deformity angular ratio (C-DAR) as a potential predictor of IBC. Based on our experience, we postulated that a high C-DAR may result in low IBC. This relationship had not been previously studied.
PURPOSE: To evaluate the relationship of C-DAR and IBC in patients with AIS.
STUDY DESIGN/SETTING: A retrospective study.
PATIENT SAMPLE: A total of 119 patients with AIS treated with a Gensingen brace in our scoliosis center from July 2015 to October 2017 were included.
OUTCOME MEASURES: In-brace correction.
METHODS: Data were collected before and upon brace placement. Correlation analyses between study variables and IBC were performed. A linear regression model was established on the basis of C-DAR.
RESULTS: At brace fitting, the average age was 12.62±1.16 (range, 10−15) years and mean major curve Cobb angle was 32.14±4.66° (range, 25−40°). Mean IBC was 59.62%±22.03% (range, 16.2−100%). IBC had significant correlation with C-DAR ($r=-0.69$; 95% confidence interval, −0.77 to −0.61; $p<.001$). IBC was not significantly correlated with age, sex, height, weight, BMI, menstrual status, or Risser sign. A simple linear regression model established that in-brace correction=115.4−10.7×C-DAR.
CONCLUSIONS: C-DAR has strong negative correlation with IBC and may estimate the expected IBC. The usage of C-DAR may obviate the need for flexibility radiographs, such as supine or supine lateral bending radiographs.

Keywords: In-brace correction; Coronal deformity angular ratio; Adolescent idiopathic scoliosis; Gensingen brace; Linear regression model; Correlation analysis

FDA device/drug status: Not applicable

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Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformity of the spine [1]. It is characterized by a coronal curvature>10° and rotation on the axial plane. AIS affects approximately 2−3% of adolescents [2]. The management strategies for AIS according to the Cobb angle and the skeletal maturity of the patient are primarily observation, brace, and surgery. Bracing is the primary nonsurgical treatment for AIS, and its efficacy has been confirmed by the Bracing in Adolescent Idiopathic Scoliosis Trial (BrAIST) [3,4]. Brace treatment in skeletally immature patients with a curve size of 25−40° has been shown to be superior to observation [4].

In-brace correction (IBC) refers to the percentage decrease in curve size at initial brace prescription. IBC and compliance are the main predictors for the outcome of brace treatment in patients with AIS. Some studies have demonstrated a high prevalence of noncompliance to be associated with a poor outcome [3,4]. Reports have confirmed the importance of IBC to predict the outcome of long-term treatment in AIS patients [5−12]. Although the cut-off points of IBC for a positive outcome of brace treatment reported by different scholars have been inconsistent [6,7,9,12−14], it is commonly accepted that a 50% IBC can act as an ideal cut-off value contributing to a brace success [7,15]. In-brace corrections of different patients [1,15,16] and brace fabrication methods [12,15,17,18] may be variable. But ideally maximal curve correction should be achieved. So, some radiographs to assess spinal flexibility, such as supine or supine lateral bending radiographs (SLBR), are routinely taken before brace fabrication and fitting. Previous studies proposed several methods which could predict IBC [1,15]. A close estimate of IBC in advance is great importance to brace fabrication and fitting.

Intuitively, a sharp, angulated curve is more likely to result in lower IBC than a more global, rounded curve, but this relationship has never been tested. Therefore, we used a parameter, coronal deformity angular ratio (C-DAR) to assess the angulation of coronal curve. Deformity angular ratio (DAR) defined as the maximum Cobb angle divided by number of vertebrae involved in the curve is a measure of curve magnitude per level of deformity. In 1962, Harrington et al. proposed the Harrington factor, which refers to the maximum Cobb measurement divided by number of levels involved in the curve in the coronal plane [11]. The Harrington factor was employed to identify a potentially progressive curve. Lenke et al. and Lewis et al. proposed DAR, which is similar in terms of measurement with the Harrington factor [19,20]. However, they extended its scope to include C-DAR, sagittal DAR (S-DAR), and total DAR (T-DAR, the sum of C-DAR and T-DAR) to describe deformity severity and predict the risk of neurologic deficit in surgical procedures for spinal deformity.

In this study, we performed a retrospective analysis of patients with AIS under Gensingen brace treatment to determine the relationship between C-DAR and IBC.

Materials and methods

Patients

A total of 119 AIS patients with brace treatment in our scoliosis center from July 2015 to October 2017 were included in this retrospective study. Seven hundred twelve patients who did not meet the inclusion criteria were excluded. Ethics was approved by our institutional review board. All patients met the inclusion criteria set by the Scoliosis Research Society for bracing studies: age≥10 years; Risser sign 0−2; primary curve angle 25−40°; no prior treatment; and, if female, either premenarchal or less than 1 year postmenarchal [21]. All patients were managed with Gensingen brace, a Cheneau-style TLSO used to address all possible curve patterns [22]. Fabrication and fitting of Gensingen brace were performed by a same orthotist who had no knowledge of the study according to the instructions described in previous reports [22].

Data collection

Radiographic and clinical parameters were recorded before and upon brace placement. Study variables were age, sex, height, weight, body mass index (BMI), Risser sign, major curve Cobb angle, curve type, menstrual status, C-DAR, and IBC. C-DAR was calculated as the Cobb angle of the major curve divided by the number of vertebral levels involved (Fig. 1). IBC was

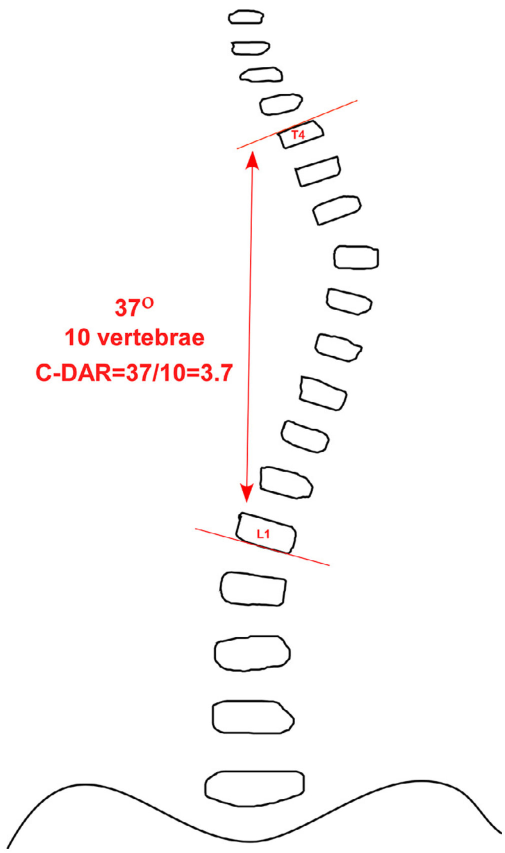

Fig. 1. The measurement of C-DAR. The major curve Cobb angle is 37°. Ten vertebrae are involved in the major curve. So, C-DAR=37/10=3.7.

Table 1
Baseline characteristics of the study cohort

Variables	Age (y)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Risser sign	C-DAR	Major curve Cobb angle (°)
Value	12.62±1.16	41.25±8.02	155.49±11.27	16.92±1.99	1.16±0.78	5.19±1.42	32.14±4.66
Range	10−15	20−62	110−180	11.2−24.2	0−2	2.08−9.25	25−40

BMI, body mass index; C-DAR, coronal deformity angular ratio; y, year.

calculated using the following formula: *(Cobb angle at prebrace−Cobb angle at initial in-brace)/Cobb angle at prebrace* × *100%.* The IBC value was recorded as 0 or 100% for a value <0 or >100%, respectively. The standing anteroposterior radiographs of the entire spine were taken for all patients before and after brace placement. All radiographs were measured by two experienced spinal surgeons (the third and fifth authors). The measurements of prebrace and in-brace radiographs were 2 weeks apart. The observers were blinded to patient details and the measurement results of prebrace radiographs. The interobserver reliability was as follows: 0.960 for Cobb angle, 0.935 for C-DAR, and 0.944 for Risser sign. The mean values of Cobb angle and C-DAR were reported. When there was a discrepancy in Risser sign, a consensus between individuals was determined.

The time frame between prebrace radiograph and in-brace radiograph was within 6 weeks. All in-brace radiographs were obtained on the day of brace fitting after at least 2 hours of brace wear [23]. In-brace radiograph needed to reach three conditions: (1) patients felt tight but had no pain or difficult breathing; (2) the skin around where the corrective force had been applied (rib level of the thoracic apex and level of the lumbar apex) turned red after wearing the brace for 10 min; (3) fingers could not be inserted in the area between the brace and skin where corrective force had been applied.

Statistical analyses

Statistical analyses were undertaken using SPSS v20.0 (IBM, Armonk, NY). Data are reported as mean and standard deviation. Data distribution was assessed by histograms. The mean values of two variables with a normal distribution were compared using the independent sample Student's *t* test. For variables with a non-normal distribution, the Wilcoxon rank-sum test was used. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test. Pearson correlation coefficient was calculated to identify the association between study variables and IBC. If the data did not meet the conditions of Pearson correlation analysis, Spearman correlation analysis was performed. The strength of association is considered weak with correlation coefficient of <0.39, moderate with 0.40−0.59, strong for 0.60−0.79, and very strong of 0.80−1.00 [24]. Subgroup (thoracic and lumbar curves groups) analysis was performed. The curve classification was according to the location of the apical vertebra of the major curve. Thoracic curves referred to curves with an apex which was located between the second thoracic vertebral body and the 11th and 12th thoracic intervertebral disc (T2−T11/12 disc). The apex of lumbar curves was located between the 12th thoracic vertebral body and the caudad border of the fourth lumbar vertebra (T12−L4). An IBC of ≥50% was defined as ideal IBC predicting a positive brace outcome. $p<.05$ was considered significant.

Results

The 119 patients with AIS reviewed in the present study comprised 18 boys and 101 girls. Baseline characteristics of the study population were presented in Table 1. The major curve Cobb angle of 32.14±4.66° (range, 25−40°) was reduced to 13.25±7.87° (0−31°) after brace prescription with an IBC of 59.62±22.03% (range, 16.2−100%). There were six patients with IBC>100%.

Correlation analyses showed that IBC had no significant relationship with age, sex, weight, height, BMI, menstrual status, and Risser sign (Table 2). A strong negative correlation was observed between C-DAR and IBC ($r=-0.69$, $p<.001$). Two representative cases were used to illustrate the negative correlation between C-DAR and IBC in Fig. 2. Major curve Cobb angle was significantly correlated with IBC ($r=-0.29$, $p=.001$). Hence, C-DAR and major curve Cobb angle were used for linear regression model. Only the effects from C-DAR remained significant ($p<.001$). The simple linear regression model created was: *In-brace correction=115.4−10.7×C-DAR*. R^2 of the model was 0.482, suggesting that 48.2% of the variance in IBC was explained by C-DAR ($F=108.816$, $p<.001$, Fig. 3).

Table 2
Correlation analysis between IBC and related variables

Variables	Correlation coefficient (95% CI)	p
Age	0.12 (−0.19 to 0.23)	.900
Sex	0.11 (−0.05 to 0.26)	.219
Height	0.15 (−0.05 to 0.36)	.125
Weight	0.17 (−0.05 to 0.37)	.083
BMI	0.08 (−0.14 to 0.29)	.421
Risser sign	−0.06 (−0.29 to 0.13)	.513
Menstrual status	−0.11 (−0.33 to 0.16)	.298
Major curve Cobb angle	−0.29 (−0.47 to −0.14)	.001
C-DAR	−0.69 (−0.77 to −0.61)	<.001

IBC, in-brace correction; CI, confidence interval; BMI, body mass index; C-DAR, coronal deformity angular ratio

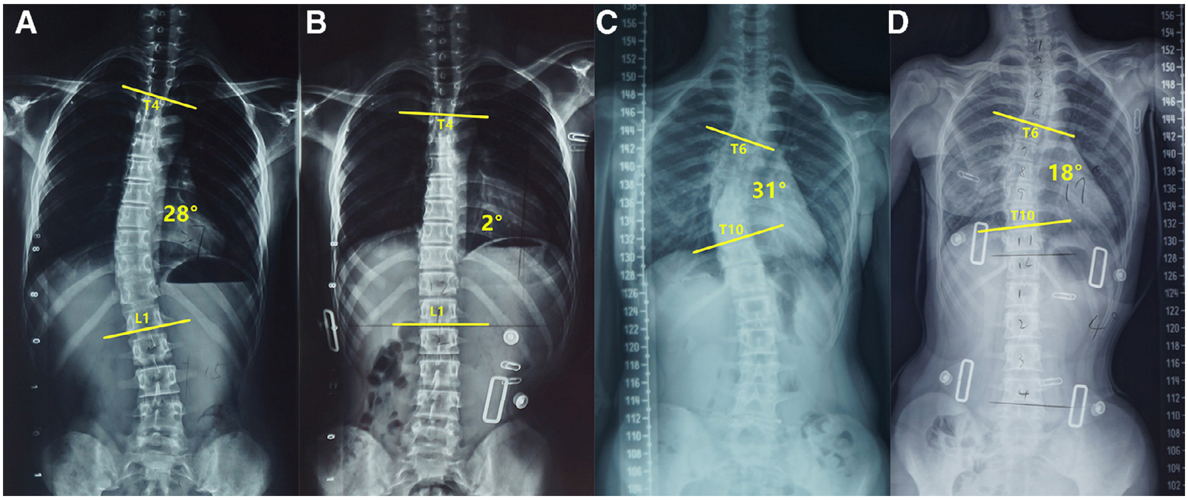

Fig. 2. Case 1: a 12-year-old female patient with a thoracic curve; prebrace (A) and in-brace (B) anteroposterior radiographs. Case 2: a 12-year-old female patient with a thoracic curve; prebrace (C) and in-brace (D) anteroposterior radiographs. These two representative cases with similar age, sex, Risser sign, curve type, and major curve Cobb angle were used to illustrate the negative correlation between C-DAR and IBC. Due to different C-DAR, case 1 with C-DAR of 3.11 had higher IBC compared with case 2 with C-DAR of 6.20 (92.86% vs. 41.94%).

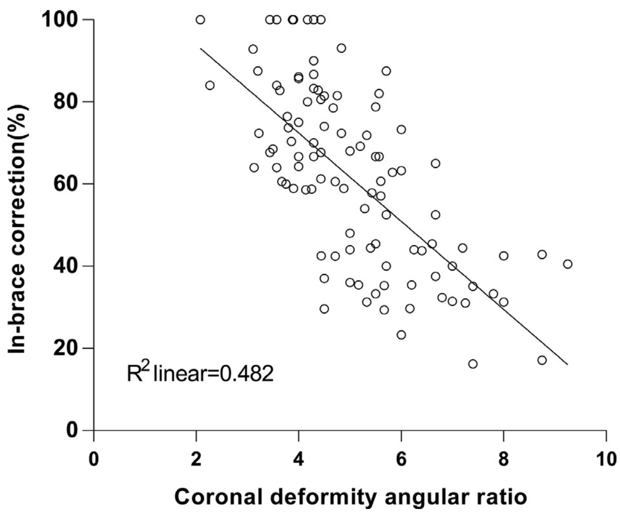

Fig. 3. Coronal deformity angular ratio and in-brace correction with the fitted line for the simple linear regression model.

In this study, a 50% IBC was selected as a target for curve correction. Notably, when C-DAR was more than 6, only 6.7% patients had an IBC of ≥50%. In contrast, while C-DAR was less than 5, there were 93.0% patients with an IBC of ≥50% (Table 3).

Given the potential differences between thoracic and lumbar (including thoracolumbar and lumbar curves) curves, subgroup analysis was performed. There were 58 patients with thoracic curve and 61 patients with lumbar curve, of which basic data were shown in Table 4. Differences by curve type distribution regarding major curve Cobb angle, in-brace Cobb angle, and IBC were not significant. Interestingly, significant difference was found between thoracic and lumbar curves in terms to C-DAR (p=.020). Significant correlation between C-DAR and IBC was also found in thoracic (r=−0.73, p<.001) and lumbar (r=−0.71, p<.001) curve. Linear regression models for thoracic and lumbar curves were presented in Table 5, which could predict 53.1% and 50% of the variance with good fit of data, respectively.

Table 3
Related variables according to C-DAR distribution

C-DAR	≤4	4< to <5	5≤ to ≤6	6< to ≤7	7<
Number of patients (percentage*)	28 (23.5%)	29 (24.4%)	32 (26.9%)	17 (14.3%)	13 (10.9%)
Number of thoracic curves (percentage*)	21 (36.2%)	11 (19.0%)	13 (22.4%)	10 (17.2%)	3 (5%)
Number of lumbar curves (percentage*)	7 (11.5%)	18 (29.5%)	19 (31.1%)	7 (11.5%)	10 (16.4%)
Major curve Cobb angle (°, pre-brace)	30.43±4.46	30.55±3.79	32.25±5.05	34.24±3.91	36.38±3.23
Major curve Cobb angle (°, in-brace)	6.71±4.45	8.45±6.19	15.25±5.86	20.76±3.73	23.31±3.50
IBC (%)	78.16±13.68	72.52±18.76	52.29±17.14	39.14±9.30	35.68±9.74
Number of IBC≥50% (percentage†)	28 (100%)	25 (86.2%)	16 (50%)	2 (11.8%)	0 (0%)
	53/57 (93.0%)‡		16/32 (50%)§	2/30 (6.7%)‖	

C-DAR, coronal deformity angular ratio; IBC, in-brace correction.
* Indicated percentage of patients of each group compared to total patients in the study.
† Indicated percentage of patients with IBC≥50% of each group compared to total patients of this group.
‡ Indicated percentage of patients with IBC≥50% in patients with C-DAR<5.
§ Indicated percentage of patients with IBC≥50% in patients with 5≤C-DAR≤6.
‖ Indicated percentage of patients with IBC≥50% in patients with C-DAR>6.

Table 4
Differences by curve type distribution

Variables	Thoracic curve	Lumbar curve	p
C-DAR	4.88±1.31	5.49±1.47	.020
Major curve Cobb angle (°)	31.93±4.80	32.34±4.56	.631
In-brace Cobb angle (°)	13.34±7.56	13.16±8.22	.901
IBC (%)	59.05±21.35	60.15±22.82	.786

C-DAR, coronal deformity angular ratio; IBC, in-brace correction.

Table 5
Linear regression analysis

Curve type	Model	R^2	F	p
Thoracic curve	IBC=116.9−11.8×C-DAR	0.531	63.307	<.001
Lumbar curve	IBC=120.4−11.0×C-DAR	0.500	58.899	<.001

IBC, in-brace correction; C-DAR, coronal deformity angular ratio.

Discussion

The effect of brace treatment in AIS has been debated for several years. The vast majority of studies have supported its effectiveness [4−6,9,21], even though some have reported the negative influence of a brace on quality of life [25]. However, after the BrAIST reported by Weinstein et al., the effectiveness of bracing for the treatment of AIS was confirmed [4]. In the BrAIST, the success rate of brace management was 72% as compared with 48% for observation. This denoted a failure rate of 28% for braced AIS patients [4], which varied in different studies due to the different criteria employed, such as inclusion criteria, definition of brace failure, or brace type [4,12,26−28]. Some contributory factors of bracing failure have been reported, including age, sex, BMI, curve type, pelvic tilt, spinopelvic inclination angles, rotation of vertebrae, Risser sign, compliance, and IBC [3,10,12,26,29,30]. IBC has been reported to have a significant positive correlation with bracing success [6−9,12]. Our experience suggests that AIS patients with high C-DAR will probably have low IBC. However, the relationship between C-DAR and IBC has not been elucidated in previous studies. This is the first study to demonstrate that C-DAR has a negative correlation with IBC and can be used to predict IBC to some extent.

In the present study, mean IBC of Gensingen brace was 59.62% (range, 16.2−100%). No end result studies on IBC of Gensingen brace which was similar to the inclusion criteria of this study are available in this stage. Weiss et al. reported that IBC with the Chêneau light brace exceeded 50% in a sample of patients with an average Cobb angle of 36° [18]. Furthermore, they thought that since the Gensingen brace was adjusted according to the same principles of correction as the Chêneau light brace, similar results could be expected in both brace types [22]. IBC varies considerably according to the different designs employed [1,8,12,22]. Even if the same type of brace is used, IBC has been shown to differ among studies, such as the Boston brace with IBC of 13% to 50% [7,10,12]. A high IBC is positively correlated with bracing success. Hence, brace fabrication and fitting should be individualized to achieve maximal IBC. Our study revealed the negative relationship between C-DAR and IBC, and proposed a linear regression model to predict IBC. Jason et al. reported that in-brace Cobb angle had a significant correlation with supine Cobb angle, and established a univariate regression model: *In-brace Cobb angle=0.809×supine Cobb angle* [15]. This model predicted 54.8% of the variability in IBC, which was slightly higher than ours (48.2%). Ohrt-Nissen et al. found a mean difference of <1° in the Cobb angle between the in-brace radiograph and SLBR, which implied SLBR could provide a close estimate of IBC [1]. But, in line with our experience, some scholars thought that SLBR depended on patient effort and technician expertise, which limited its reliability and reproducibility [15,31−35]. What's more, routine SLBR and supine radiographs are more time-consuming before brace prescription as compared with C-DAR and may increase the radiation exposure and economic burden for patients.

It is generally acknowledged that there is potential difference between thoracic and lumbar curves. Hence, we performed the subgroup analysis. A noteworthy finding is that lumbar curve had significantly higher C-DAR than thoracic curve. The number of vertebrae involved in lumbar curve is less than that in thoracic curve, which may explain the finding. Thoracic and lumbar curves were similar in IBC in line with the study performed by Chueng et al. [15]. Ohrt-Nissen et al. found that lumbar curve had higher IBC than thoracic curve [1]. Different concepts applied in braces may account for this phenomenon [1]. R^2 for the models of thoracic and lumbar curves was slightly higher than that in total study cohort, implying that we can use these two models to predict IBC more accurately.

Guidelines on a definitive value of IBC to predict the outcome of brace treatment are lacking, as is the cut-off point of IBC for Gensingen brace. Landauer et al. reported that IBC>40% would result in an ideal outcome [9]. Olafsson et al. proposed an optimal IBC≥50% could prevent curve progression during brace treatment [6]. In addition, two cut-off points of IBC, 30% and 60% (corresponding to 88% and 100% brace success, respectively) for the Charleston brace, were reported by Gepstein et al. [13]. In the study of Xu et al., the best cut-off value of IBC was 10% [12]. However, it is commonly accepted that IBC≥50% can predict a successful outcome of bracing [7,14]. So, combined with our clinical experience, we defined ≥50% as the value of IBC that could expect a positive outcome for brace treatment. In this study, when C-DAR exceeded 6, the incidence for patients with an IBC of ≥50% was 6.7%. Meanwhile, when C-DAR was less than 5, there were 93% of patients presenting an IBC≥50%. Our results indicate that these two points (5 and 6) can be used to stratify patients with different IBC.

DAR is used mainly to evaluate the risk of neurologic deficit in surgical procedures for spinal deformity (especially in spinal osteotomy) and describe curvature severity. Lewis et al. reported that DAR correlated with high-risk cases for electrophysiology monitoring alerts undergoing 3-column osteotomies for spinal deformity correction [20]. The study by Fan et al. demonstrated that S-DAR had a significant positive correlation with osteotomy grade, which could aid preoperative planning [36]. Our study found a new application of C-DAR in predicting IBC. Since patients with high IBC could have larger probability of successful bracing outcome in previous studies [6,9,12,13] and IBC had a negative correlation with C-DAR in this study, we hypothesized that C-DAR may be a prognostic factor for final bracing outcome. However, further studies are needed to assess the prognostic ability of C-DAR for brace treatment.

The most meaningful finding in the present study is that C-DAR has a negative correlation with IBC and can be applied to estimate IBC. In current practice, some clinicians estimate IBC by clinical experience to assist brace fabrication and fitting. This empirical practice makes initial curve correction under brace less scientific and evidence-based, which would affect the treatment outcome. IBC usually varies among patients due to individualized spinal conditions. Therefore, quantitative estimation of IBC could optimize the treatment effectiveness. Our easy-to-use model based on prebrace radiographs can provide an estimation of IBC before brace fabrication and fitting, which may help patients achieve the expected curve correction under brace wear. Meanwhile, radiation exposure should be reduced. The application of C-DAR may avoid additional use of flexibility radiographs.

There are several limitations to our study. First, its retrospective nature may result in inherent biases. Second, since this was a single-institution study using a Gensingen brace, our results may not be applicable to other types of brace. Third, there was no comparison in estimating IBC between C-DAR and other already established methods, such as supine and SLBR. Future studies should focus on investigating that which method is more effective. Fourth, only univariate analysis was performed in this study. In further studies, a multivariate analysis including more variables may have a better estimate of IBC. Fifth, the lack of final follow-up outcome means that some hypothesis is unverified at the moment. Finally, due to the IBC measurements based on initial brace fabrication, the curve correction may have been suboptimal, and brace adjustments may provide further curve correction in some patients. Future studies should address the impact of brace adjustments on curve correction.

Conclusions

C-DAR has strong negative linear correlation with IBC in this study. The application of C-DAR may estimate the expected IBC in the brace, which may obviate the need for flexibility radiographs, such as supine or SLBR.

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