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How the curve morphology differs between curve types in patients with adolescent idiopathic scoliosis during brace treatment?

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Abstract

Background Changes in coronal curve type and curve span may be linked to spinal and rib cage deformities. Therefore, it is crucial to comprehend the potential impact of these changes on brace treatment. This study aims to investigate the relationship between curve progression and change in coronal curve type and curve span in braced patients, and to compare the coronal balance and change in apical vertebral between patients with and without curve pattern change.

Methods Two hundred seventeen patients who fulfilled the Scoliosis Research Society brace referral criteria were recruited. Radiographs at prebrace and brace weaning were assessed. Patients were classified into three groups based on the curve pattern at prebrace: major thoracic (MT), major lumbar (ML) and double major (DM). Change in coronal curve referred to curve of the greatest magnitude changes from thoracic to lumbar or vice versa. Change in curve span defined as change of at least two vertebral levels in the end vertebra of the curve. Change in apical vertebrae referred to change of at least one vertebral level. The association between coronal imbalance, major curve progression and regression, change in coronal curve type, change in curve span, change in apical vertebrae, and curve type were studied using Chi-square test. Multivariable logistic regression was used to predict curve progression at brace wean in each curve type.

Results The major lumbar group exhibited a higher risk of coronal imbalance (Listing-MT: 5.6% vs ML: 37.7% vs DM: 23.5%, $p < 0.001$ and truncal shift-MT: 6.9% vs ML: 27.3% vs DM: 2.9%, $p < 0.001$) and changes in apical vertebrae (MT: 30.6% vs ML: 58.4% vs DM: 45.6%, $p = 0.003$). The double major group had a greater likelihood of experiencing changes in the coronal curve type (MT: 0% vs ML: 15.6% vs DM: 25%, $p < 0.001$) and major curve progression (MT: 23.6% vs ML: 22.1% vs DM: 52.9%, $p < 0.001$). In the major thoracic group, predictive factors for curve progression included being female, having poor brace compliance, and no change in curve span. However, no significant relationships were found for the major lumbar group. Patients with a larger prebrace major Cobb angle, larger thoracic kyphosis and poor brace compliance from double major group were more likely to experience curve progression.

Conclusions This study suggests that each curve type undergoes distinct changes during bracing. Future studies should consider the influence of curve type in study design and address the challenges associated with each type.

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Keywords Adolescent idiopathic scoliosis, Brace, Coronal balance, Curve progression, Coronal curve type change, Curve span change

Introduction

Bracing remains the most common nonoperative treatment for adolescent idiopathic scoliosis (AIS) which is a spinal deformity with a prevalence rate of 3–4% in the local population [1–3] and 0.47–5.2% worldwide [4].

To make appropriate and timely clinical decisions, it is crucial to comprehend the risk factors that contribute to curve progression. According to Wong et al. [5], poor flexibility and correction, high apical vertebral rotation, large rib vertebra angle difference, small rib vertebra angle on the convex side, low pelvic tilt, and thoracic curve were predictors of curve progression in braced patients. Other studies have also found a higher risk of curve progression in right-sided thoracic curves [6–16]. However, accurate prediction remains challenging due to the multifactorial nature of AIS. Limited documentation of the change in spinal morphology during bracing for each curve type makes it difficult to comprehend the spine's mechanism during bracing and the heterogeneous nature of AIS.

Change in coronal curve type and change in end vertebrae are not uncommon. Change in curve morphology is found in both braced and unbraced populations [6, 17–21]. The transition of the major curve location from thoracic to lumbar or vice versa as the spine grows signifies a shift in the deformity of both the spine and the rib cage. It is unknown whether the brace, which is fabricated based on the initial curve, can effectively maintain correction of the new major curve. Curve type change may also affect postural or coronal balance [22]. Brace treatment is based on mechanical forces. Incorrect positioning of the pads can exert force in an undesired direction [23]. When the curve span (length of the curvature) changes, the apex and the apical vertebral rotation (AVR) may also change. Since pressure pads should be placed on the apex of the curve, the brace may need to be revised when the curve span changes. AVR represents the axial plane deformity and can predict curve progression [24] and is related to frontal malalignment [25]. It is important to understand the impact of curve span change on axial plane rotation. Currently, only Zheng et al. [17] investigated the effect of change of curve patterns in a braced population, showing that patients with these changes had a higher possibilities of curve progression and the need for surgery compared to those without. However, the individual effect of change in coronal curve type and curve span was not reported.

Previous research has not investigated the change in spinal morphology during bracing and explored the impact of changes in coronal curve type and curve span separately on patients who received brace treatment in each curve type. Gaining a better understanding of these changes would enhance our knowledge about the heterogeneous nature of AIS and also the brace mechanism. This study aims to compare the spinal morphology at prebrace and brace wean in patients with major thoracic, major lumbar, and double major curves and to identify factors predicting major curve progression in each curve type.

Methods

This was a retrospective study of consecutive patients with brace prescription attending our tertiary referral spine clinic. Ethics was approved by the local institutional review board. Patients who were prescribed with bracing in December 2016 and completed brace treatment in or before December 2022 were studied. Inclusion criteria were: (1) fulfilled the brace referral criteria set by the Scoliosis Research Society at the initiation of brace: between 10 to 18 years old, Risser stage 0 to 2, major curve magnitude from 25 to 40 degrees, no prior treatment and less than 1 year post-menarchal for girls [26], (2) weaned bracing when they were Risser stage $\geq$4, and with no body height gain within 6 months, >2 years post-menarche for girls, (3) or received surgery [27]. Patients with left-sided thoracic and/or right-sided lumbar curve**s** were excluded to eliminate the impact of curve convexity on the results.

Data collection

Demographic data including sex, age and menarche status were recorded. Prebrace and brace wean standing posteroanterior and lateral radiographs and supine whole spine radiographs were collected and Cobb angle of the major curve was calculated. Radiological parameters included Risser staging, listing (differences between C7 plumb line and central sacral vertical line, CSVL [28]), truncal shift (differences between midpoints of the two widest point of the rib cage along a horizontal line which passed through the midpoint of the apical vertebra and CSVL [28]), major curve apical vertebra and AVR were calculated from the prebrace and brace wean radiographs. Sagittal parameters such as pelvic tilt (PT), pelvic incidence (PI), sacral slope (SS), T5/T12 thoracic kyphosis (TK), and L1/S1 lumbar lordosis (LL) were measured at pre-brace, during brace weaning, and the changes observed during bracing (brace weaning minus pre-brace). T5 was chosen over T1 or T4 due to challenges in visualizing the vertebrae in the lateral radiograph [29, 30]. Cobb angle of the major curve obtained from the supine whole spine radiograph was used to calculate curve flexibility using the formulae: (pre-brace Cobb angle – supine Cobb angle)/pre-brace Cobb angle *100% [31, 32]. AVR was measured using the Nash-Moe method by a customized MATLAB code (The MathWorks, Inc., Natick, Massachusetts) [33]. The code identified the center of the convex pedicle and measured the width of the vertebral body (Fig. 1). Brace compliance was monitored with the aid of Thermochron iButtons thermal sensors (Maxim Integrated Products, USA) and average hours of wearing throughout the whole treatment were calculated. Patients with brace revision due to addition of padding, outgrowth/fitting, discomfort or other reasons were collected. Patients with underarm brace changed to Milwaukee brace were documented. Curve progression is defined as an increase of more than 5 degrees (^{o}) in Cobb angle between two timepoints. Curve regression refers to a reduction of 5^{o} in Cobb angle [26, 34]. A listing or truncal shift greater than or equal to 2 cm was considered as coronal imbalance [28].

As the Lenke classification system of curve type is designed for surgical cases, it was not used in this study of braced patients. A minor curve is considered structural if the curve magnitude is > 80% of the magnitude of the major curve [6, 21].

Definition of change in coronal curve type, curve span and apical vertebrae

Change in coronal curve referred to curve of the greatest magnitude changes from thoracic to lumbar or vice versa (Fig. 2). Change in curve span occurred when the end vertebra of the curve changes by at least two vertebral level [17] (Fig. 3). Change in apical vertebrae referred to change of at least one vertebral level.

Statistical analysis

Descriptive data were presented as mean ± standard deviation with 95% confidence intervals. All analyses were performed using SPSS v. 27.0 (IBM, Armonk, NY, USA). Patients were classified into three groups based on the curve pattern at the time of brace initiation: the major thoracic group, where the proximal thoracic curve and/or main thoracic curve was structural, and the thoracolumbar/lumbar curve was nonstructural; the major lumbar group, where only the thoracolumbar/lumbar curve was structural; and the double major group, where both the thoracic and lumbar curves were structural. Kolmogorov–Smirnov test was used to test the normality of the data. Sagittal parameters, flexibility, change of listing and truncal shift and brace compliance were compared between patients with different curve types using ANOVA or Kruskal–Wallis test. Post-hoc Bonferroni adjusted z-tests was applied if there was a significant difference between three groups. The association between coronal imbalance, major curve progression and regression, change in coronal curve type, change in curve span, change in apical

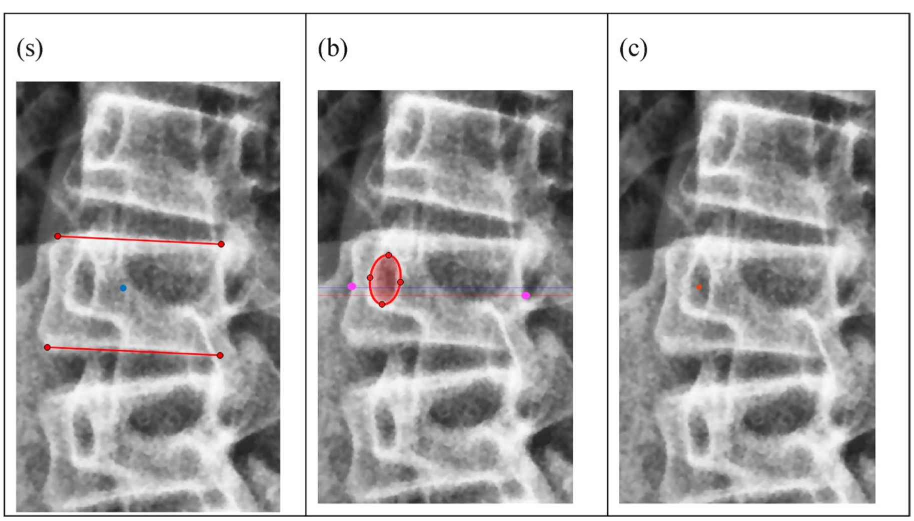

Fig. 1 Apical vertebrae rotation measurement by a customized MATLAB code. **a** The upper and lower endplate of the apical vertebra were marked, and the four corners of the vertebrae were identified. **b** An ellipse was drawn to encompass the entire pedicle. Since the vertebra is not a rectangle, the code automatically drew the middle line of the left side (blue line) and right side (red line) of the vertebra based on the four corners. A purple dot was marked to calculate the width of the vertebra. **c** The system automatically located the center of the pedicle

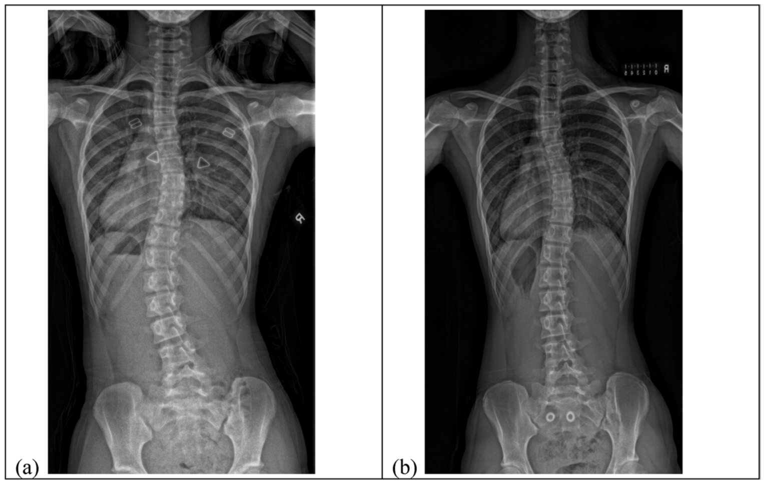

Fig. 2 Change in coronal curve type. **a** A Female subject with T6-T11 17.6° and T11-L3 30° at pre-brace. **b** At brace weaning, the curve became 22.4° and 16.9° respectively

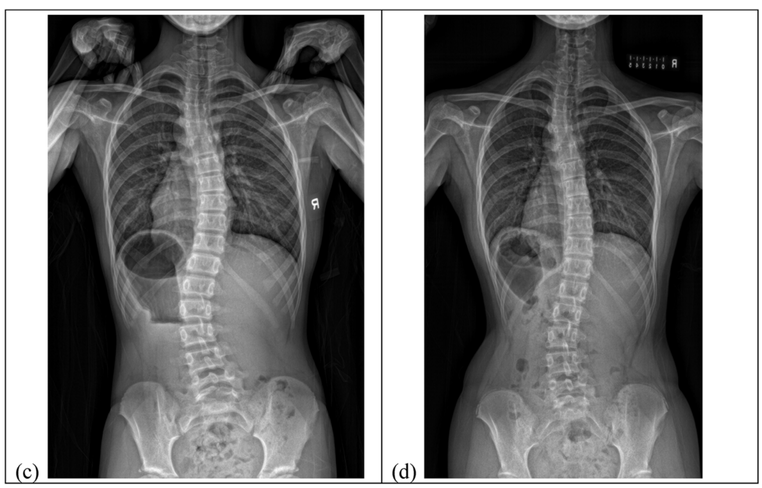

Fig. 3 Change in curve span. **a** A Female subject with T1-T6 19.2°, T6-T12 23.1° and T12-L4 27.3° at pre-brace. **b** At brace wean, the curve became T1-T6 25°, T6-L2 24.2° and L2-L5 17.4°

vertebrae, change from underarm bracing to Milwaukee bracing, and brace revision and curve type were studied using Chi-square test. Fisher exact test was used if the expected cell count was <5 in at least 80% of cells. Univariate logistic regression was first used to detect association between the radiological parameters (Cobb angle, listing, truncal shift, AVR and flexibility), sagittal parameters (PT, PI, SS, TK, LL), curve patterns (change in coronal curve type, curve span and apical vertebrae), and brace related factors (brace revision and brace compliance) and major curve progression at brace wean. Any variables that had a statistical significance <0.15 were included in multivariable logistic regression [35]. Statistical significance was defined by a significance level of 5% for all tests.

Results

A total of 794 patients who completed brace treatment were screened, and 217 patients were included in the study. Of these, 72 (33.2%) had major thoracic curves, 77 (35.5%) had major lumbar curves, and 68 (31.3%) had double major curves. Descriptive statistics of patients are listed in Table 1.

Table 1 Cohort characteristics of the patients

		Major thoracic (n=72)	Major lumbar (n=77)	Double major (n=68)
Sex n (%)	Male	17 (23.6%)	15 (19.5%)	19 (27.9%)
	Female	55 (76.4%)	62 (80.5%)	49 (72.1%)
Prebrace Mean±SD	Age (year)	12.1±1.2	12.3±1.3	12±1.3
	Major Cobb Angle (°)	32.3±4.6	30.6±4.4	30.8±4.5
	Listing (cm)	−0.4±1.0	−1.7±1.0	−1.2±1.0
	Truncal shift (cm)	0.6±0.9	−1.4±1.0	−0.2±0.9
	AVR (°)	4.9±3.7	16.6±4.9	7.9±5.7
	Pelvic tilt (°) (95% CI)	9.59±8.52 [7.59,11.6]	7.46±8.14 [5.61,9.31]	7.13±8.25 [5.1,9.16]
	Pelvic incidence (°) (95% CI)	52.0±13.1 [48.9,55.0]	47.4±17.0 [43.6,51.3]	46.2±14.2 [42.7,49.7]
	Sacral slope (°) (95% CI)	42.4±10.2 [40.0,44.8]	40.0±13.6 [36.9,43.1]	39.1±13.1 [35.0,42.3]
	T5/T12 thoracic kyphosis (°) (95% CI)	16.0±10.6 [13.6,18.5]	17.4±9.70 [15.2,19.6]	16.5±9.47 [14.2,18.8]
	L1/S1 lumbar lordosis (°) (95% CI)	52.9±12.3 [50.0,55.8]	51.0±12.2 [48.2,53.8]	50.7±11.1 [48.0,53.4]
Brace wean Mean±SD	Major Cobb Angle (°)	35.1±11.2	30.6±9.1	37.8±11.2
	Listing (cm)	−0.4±1.2	−1.2±0.9	−0.9±1.2
	Truncal shift (cm)	0.6±1.1	−0.8±0.9	0.3±1.1
	AVR (°)	5.1±5.4	16.6±7.8	8.7±7.6
	Pelvic tilt (°) (95% CI)	12.2±8.44 [10.2,14.2]	11.0±7.38 [9.28,12.6]	9.34±8.24 [7.32,11.4]
	Pelvic incidence (°) (95% CI)	51.3±11.7 [48.5,54.1]	48.0±11.8 [45.3,50.7]	47.5±10.2 [45.0,50.0]
	Sacral slope (°) (95% CI)	39.1±8.3 [37.1,41.0]	37.1±9.38 [34.9,39.2]	38.2±8.43 [36.1,40.3]
	T5/T12 thoracic kyphosis (°) (95% CI)	13.3±9.26 [11.2,15.5]	14.1±8.62 [12.1,16.0]	13.3±10.6 [10.6,15.9]
	L1/S1 lumbar lordosis (°) (95% CI)	46.3±10.4 [43.9,48.8]	44.7±12.7 [41.8,47.6]	45.4±11.4 [42.6,48.2]
Change between prebrace and brace wean	Pelvic tilt (°) (95% CI)	2.64±6.28 [1.16,4.11]	3.49±6.40 [2.04,4.94]	2.21±6.08 [0.72,3.70]
	Pelvic incidence (°) (95% CI)	−0.67±6.60 [−2.22,0.88]	0.59±12.2 [−2.19,3.36]	1.31±10.7 [−1.32,3.94]
	Sacral slope (°) (95% CI)	−3.31±8.07 [−5.20,−1.41]	−2.90±11.5 [−5.51,−0.28]	−0.90±10.4 [−3.46,1.67]
	T5/T12 thoracic kyphosis (°) (95% CI)	−2.67±7.28 [−4.38,−0.96]	−3.32±8.62 [−5.28,−1.36]	−3.23±10.38 [−5.78,−0.68]
	L1/S1 lumbar lordosis (°) (95% CI)	−6.57±10.3 [−8.99,−4.15]	−6.30±9.91 [−8.55,−4.05]	−5.36±10.3 [−7.88,−2.84]
	Listing (cm)	−0.02±1.3	0.4±1.1	0.3±1.1
	Truncal shift (cm)	0.04±1.1	0.6±1.0	0.5±1.1
Flexibility of the major curve (%)		20.6±13.5	32.1±14.7	20.2±16.0
Brace compliance (hours)		15.5±5.1	15.0±4.9	13.5±6.5

n Number of patients, *SD* Standard deviation, ^{o}Degrees, *AVR* Apical vertebrae rotation, *CI* Denotes confidence interval

Comparison of spinal morphology across different curve types

There were no significant differences in terms of sagittal parameters, change in listing and brace compliance between groups. The major thoracic group had a significantly smaller change in truncal shift compared to the major lumbar and double major groups (0.04 cm vs 0.6 cm vs 0.5 cm). Additionally, the flexibility of the major curve of the major lumbar group was significantly larger than that of the major thoracic and double major groups (32.1% vs 20.6% vs 20.2%) (Table 2).

The major thoracic group had a high likelihood of requiring brace revision (X^2 (2, N= 217) =6.91, p= 0.001), whereas the major lumbar group had a higher possibility of experiencing coronal imbalance at prebrace (Listing: X^2 (2, N= 217) =22.0, p< 0.001; Truncal shift: X^2 (2, N= 217) =22.4, p< 0.001), regression of the major curve (X^2 (2, N= 217) =13.6, p= 0.001), change in apical vertebrae (X^2 (2, N= 217) =11.7, p= 0.003), having both curve progression and change in coronal curve type (p = 0.012) and having both curve regression and change in curve span (X^2 (2, N= 217) =13.4, p= 0.001). On the other hand, the double major group had a higher likelihood of experiencing major curve progression (X^2 (2, N= 217) =19.4, p< 0.001) and change in coronal curve type (X^2 (2, N= 217) =19.4, p< 0.001) (Table 3).

Table 2 Comparison of sagittal parameters, change of listing, truncal shift and flexibility between patients with different curve types

		p-value			
		3-group comparison	**ML vs D**	**MT vs D**	**MT vs ML**
At pre-brace	Pelvic tilt (°) (95% CI)	0.148	/	/	/
	Pelvic incidence (°) (95% CI)	0.057	/	/	/
	Sacral slope (°) (95% CI)	0.356	/	/	/
	T5/T12 thoracic kyphosis (°) (95% CI)	0.503	/	/	/
	L1/S1 lumbar lordosis (°) (95% CI)	0.397	/	/	/
At immediate brace wean	Pelvic tilt (°) (95% CI)	0.101	/	/	/
	Pelvic incidence (°) (95% CI)	0.042*	1	0.074	0.105
	Sacral slope (°) (95% CI)	0.297	/	/	/
	T5/T12 thoracic kyphosis (°) (95% CI)	0.578	/	/	/
	L1/S1 lumbar lordosis (°) (95% CI)	0.708	/	/	/
Change between prebrace and brace wean	Pelvic tilt (°) (95% CI)	0.487	/	/	/
	Pelvic incidence (°) (95% CI)	0.237	/	/	/
	Sacral slope (°) (95% CI)	0.22	/	/	/
	T5/T12 thoracic kyphosis (°) (95% CI)	0.979	/	/	/
	L1/S1 lumbar lordosis (°) (95% CI)	0.593	/	/	/
	Listing (cm)	0.094			
	Truncal shift (cm)	0.002*	1	0.022*	0.004*
Flexibility of the major curve (%)		<0.001*	<0.001*	1	<0.001*
Brace compliance (hours)		0.048*	0.21	0.054	1

n denotes number of patients, * denotes statistical significance $p<0.05$, ^ denotes significance values have been adjusted by the Bonferroni correction for multiple tests, CI denotes confidence interval, ML vs D denotes Major Lumbar vs Double, MT vs D denotes Major Thoracic vs Double, MT vs ML denotes Major Thoracic vs Major Lumbar

Table 3 Comparison between patients with different curve types

n (%)		**Major thoracic (*n*=72)**	**Major lumbar (*n*=77)**	**Double major (*n*=68)**	***p*-value^**
Prebrace	Listing >2 cm	4(5.6%)	29(37.7%)	16(23.5%)	<0.001*
	Truncal shift >2 cm	5(6.9%)	21(27.3%)	2(2.9%)	<0.001*
Brace wean	Listing >2 cm	7(9.7%)	18(23.4%)	10(14.7%)	0.07
	Truncal shift >2 cm	7(9.7%)	8(10.4%)	7(10.3%)	>0.99
Progression of major curve		17(23.6%)	17(22.1%)	36(52.9%)	<0.001*
Percentage of patients having major curve progression and change in coronal curve type among patients with curve progression		0(0.0%)	4(23.5%)	7(19.4%)	0.012*
Percentage of patients having major curve progression and change in curve span with curve progression		5(29.4%)	9(52.9%)	12(33.3%)	0.149
Regression of major curve		12(16.7%)	17(22.1%)	1(1.5%)	<0.001*
Percentage of patients having major curve regression and change in coronal curve type with curve regression		0(0.0%)	4(23.5%)	0(0.0%)	/
Percentage of patients having major curve regression and change in curve span with curve regression		4(33.3%)	12(70.6%)	0(0.0%)	0.001*
Change in coronal curve type		0(0.0%)	12(15.6%)	17(25.0%)	<0.001*
Change in curve span		5(6.9%)	10(13.0%)	4(5.9%)	0.26
Change in apical vertebrae (one vertebrae)		22(30.6%)	45(58.4%)	31(45.6%)	0.003*
Change from Underarm to Milwaukee brace		2(2.8%)	0(0.0%)	2(2.9%)	0.394
Brace revision		26(36.1%)	14(18.2%)	23(33.8%)	0.033*

n Number of patients

*Denotes statistical significance $p<0.05$

^Denotes Chi-square test of independence or Fisher exact test

Factors affecting curve progression

In the major thoracic group, a multivariable logistic regression was performed to examine the effects of sex, change in curve span, brace revision and brace compliance on the likelihood of curve progression based on the result from univariable logistic regression (Table 4). The logistic regression model was statistically significant, χ^2 (4) = 21.52, $p < 0.001$. Female patients without good brace compliance and change in curve span were more likely to experience curve progression (Table 5).

While the univariable logistic regression showed a significant relationship between major curve progression and brace revision and brace compliance for major lumbar group, the multivariable logistic regression did not yield a significant relationship between these factors.

In the double curve group, a multivariable logistic regression was conducted to investigate the effects of prebrace major Cobb angle, thoracic kyphosis, listing greater than or equal to 2 cm at prebrace, flexibility, change in apical vertebrae and brace compliance on the likelihood

Table 4 Univariate logistic regression model of major curve progression

Predictors	Major thoracic (*n*=72)		Major lumbar (*n*=77)		Double major (*n*=68)	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Age	0.70 (0.43–1.16)	0.17	0.73 (0.46–1.17)	0.19	0.90 (0.62–1.30)	0.57
Sex	3.15 (0.96–10.3)	0.058^	0.86 (0.21–3.47)	0.83	1.79 (0.60–5.30)	0.30
Major CA	1.00 (0.89–1.13)	0.91	1.03 (0.91–1.17)	0.63	1.11 (0.99–1.25)	0.08^
Pelvic tilt	0.99 (0.92–1.05)	0.64	0.98 (0.92–1.05)	0.62	1.00 (0.94–1.06)	0.88
Pelvic incidence	1.00 (0.96–1.04)	0.94	1.01 (0.98–1.05)	0.56	1.01 (0.98–1.05)	0.49
Sacral slope	1.00 (0.96–1.06)	0.77	1.03 (0.98–1.09)	0.29	1.02 (0.98–1.06)	0.42
T5-T12 Thoracic kyphosos	0.99 (0.93–1.04)	0.58	0.98 (0.92–1.03)	0.41	1.06 (1.01–1.12)	0.029*^
L1-S1 Lumbar lordosis	0.99 (0.94–1.03)	0.54	1.01 (0.97–1.06)	0.59	1.02 (0.97–1.06)	0.46
Listing	0.74 (0.43–1.30)	0.30	0.82 (0.48–1.38)	0.45	1.20 (0.73–1.97)	0.48
Trunal shift	0.67 (0.36–1.26)	0.21	0.69 (0.38–1.27)	0.23	1.23 (0.73–2.09)	0.44
AVR	1.03 (0.89–1.18)	0.69	1.03 (0.93–1.15)	0.56	0.96 (0.89–1.05)	0.41
Listing >=2 cm	1.08 (0.11–11.2)	0.95	1.21 (0.40–3.63)	0.74	0.31 (0.093–1.02)	0.053^
Truncal >=2 cm	0 (-)	0.99	0.78 (0.22–2.73)	0.70	0.89 (0.053–14.8)	0.93
Flexibility of the major curve	0.97 (0.93–1.01)	0.20	0.97 (0.94–1.01)	0.18	0.97 (0.94–1.0)	0.10^
Change in coronal curve type	/	/	2.00 (0.52–7.68)	0.31	0.53 (0.17–1.62)	0.27
Change in curve span	5.68 (0.86–37.4)	0.071^	0.87 (0.17–4.52)	0.87	0.28 (0.027–2.80)	0.28
Change in apical vertebrae	0.93 (0.28–3.06)	0.91	0.75 (0.25–2.21)	0.60	0.34 (0.13–0.92)	0.034*^
Brace revision	0.30 (0.077–1.16)	0.081^	3.55 (1.02–12.3)	0.046*^	1.24 (0.45–3.42)	0.67
Brace compliance	0.84 (0.75–0.94)	0.003*^	0.89 (0.80–1.00)	0.04*^	0.86 (0.78–0.95)	0.003*

OR Odds ratio, *CI* Confidence interval, *CA* Cobb angle, *AVR* Apical vertebrae rotation

*Denotes statistical significance

^denotes variables included in multivariable logistic regression analysis

Table 5 Multivariable logistic regression of major curve progression

Parameters	Regression coefficient	OR (95% CI)	*p*-value
Major thoracic group			
Sex (Female)	−1.57	0.21 (0.047–0.92)	0.039*
Change in curve span (without)	2.65	14.08 (1.53–129.63)	0.020*
Brace revision (without)	−0.93	0.40 (0.086–1.82)	0.234
Brace compliance	−0.21	0.81 (0.70–0.93)	0.002*
Major lumbar group			
Brace revision (without)	1.10	2.99 (0.84–10.71)	0.092
Brace compliance	−0.11	0.9 (0.80–1.01)	0.072
Double major group			
Prebrace Major CA	0.17	1.19 (1.01–1.39)	0.036*
T5-T12 Thoracic kyphosis	0.092	1.10 (1.02–1.18)	0.013*
Prebrace listing>=2 cm (no)	0.99	2.68 (0.60–11.9)	0.20
Flexibility	−0.022	0.98 (0.94–1.02)	0.25
Change in apical vertebrae (with)	−0.88	0.42 (0.12–1.41)	0.16
Brace compliance	−0.16	0.86 (0.76–0.97)	0.016*

OR Odds ratio, *CI* Confidence interval, *CA* Cobb angle

*Denotes statistical significance

of curve progression. The logistic regression model was statistically significant, $\chi^2(6) = 27.8$, $p = < 0.001$. Patients with larger major curve magnitude and greater thoracic kyphosis at prebrace and poor brace compliance were more likely to have curve progression.

Discussion

In this study, we have demonstrated significant differences between patients with major thoracic, major lumbar, and double major curves in terms of coronal imbalance, flexibility, change in apical vertebrae, change in coronal curve type and progression of the major curve. In addition, the factors predicting major curve progression were found to be different between curve types. If patients with major thoracic curves exhibited poor brace compliance and experienced a change in curve span during treatment, they would have a higher risk of curve progression. The impact of curve span on the efficacy of bracing is more pronounced in the major thoracic group compared to the other two groups due to the underarm-to-pelvic brace coverage. In addition to inadequate brace compliance, curve magnitude and thoracic kyphosis at pre-brace were identified as factors associated with curve progression in the double curve group. This observation may be attributed to the increased complexity of managing double curves with thoracic kyphosis compared to single curve. Hence, each curve type experiences distinct changes during bracing.

Our study revealed that the percentage of patients with coronal imbalance was highest in the major lumbar group, followed by the double curve group, and lastly the major thoracic group at prebrace. During bracing, the change in truncal shift was smallest in the major thoracic group compared to the other two groups. At brace weaning, the percentage of coronal imbalance did not differ between the groups. Therefore, the results indicate the effectiveness of bracing in controlling the coronal balance in patients with different curve types.

Gauchard et al. [22] reported that patients with a double major curve exhibited the best static balance, followed by those with a major thoracic curve, and finally those with a major lumbar curve. When combining the findings of the two studies, it can be concluded that the major lumbar group had the poorest coronal balance and static balance. The percentage of patients with poor listing was higher in the double major group compared to the major thoracic group, but both groups exhibited similar truncal shift. However, the former group demonstrated better static balance. This implies that static balance is more strongly associated with truncal shift rather than listing. Given that truncal shift is based on the apical thoracic vertebra, it can be inferred that the apical thoracic vertebra was stable in the major thoracic group, resulting in the smallest changes in truncal shift and apical vertebrae in this group.

A previous study [36] reported that the major lumbar group exhibited greater flexibility compared to the major thoracic group. Our study further supports this finding and reveals that the major lumbar group had greater flexibility than the double major group. In line with another study by Cheung et al. [31], which found that reduced flexibility predicted an increased likelihood of curve progression, our study also demonstrated that the major lumbar group had the highest flexibility and the largest percentage of patients with curve regression. Additionally, the major lumbar group exhibited the greatest change in apical vertebrae, which may be related to the flexibility of the curve.

The occurrence of changes in coronal curve type was found to be associated with the specific curve type. The highest number of patients experiencing these changes was observed in the double major group, followed by the major lumbar group, while no changes were observed in the major thoracic group. Changes in coronal curve type can occur when the original major curve regresses or the original minor curve progresses. The results indicated that patients with a double major curve had a higher likelihood of the original minor curve progressing, leading to changes in coronal curve type. This finding aligned with a study conducted by Zheng, who reported that patients who experienced changes in curve pattern had a significantly higher percentage of curve progression compared to those without changes [17].

There are some limitations that must be acknowledged in this study. Firstly, this study found that three patients in the major thoracic group had major curve changed between proximal thoracic and main thoracic. According to the defined criteria for change in coronal curve type, these cases were categorized as having no change. However, the findings from the former two patients indicated that the use of bracing can result in a downward shift of the major curve. It would be valuable to investigate the differences between patients whose major curve changed from upper thoracic to main thoracic or vice versa. On the other hand, this study employed Nash-Moe system in calculating the AVR which was found to be less accurate [37]. However, not all patients have access to computed tomography/magnetic resonance imaging which provide axial data. Moreover, incorporating 3D measurements is crucial for comprehensively understanding scoliosis [38–40]. 3D AVR can be calculated using SterEOS, but the measurement error is associated with the 3D reconstruction technique [37]. Since not all patients underwent EOS scanning, we chose the Nash-Moe system for this study. Lastly, future studies should be conducted in a prospective manner to prevent any selection bias. Additionally, it is recommended to include additional parameters such as wedging [41] and flatback deformity [42, 43] to gain a better understanding of how changes in curve patterns occur.

Conclusion

To our knowledge, this is the first study to compare spinal morphology in patients who received brace treatment. We found that in addition to radiological parameters, factors predicting curve progression also differed among patients in the major thoracic, major lumbar, and double major groups. As a result, it is crucial for future studies to consider curve type in study design and to address the challenges associated with curve progression in each curve type.

Abbreviations

AIS Adolescent idiopathic scoliosis
AVR Apical vertebral rotation
CSVL C7 plumb line and central sacral vertical line, CSVL

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Clinical trial

Not applicable.

Authors' contributions

CPY conceived the study. CWK analyzed and interpreted the patient data and draft the manuscript. CPY and CWH interpreted the data and revised the manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethics was approved by the Institutional Review Board of The University of Hong Kong/Hospital Authority Hong Kong West Cluster (UW 15-596). Informed and signed consent was obtained from all recruited subjects or from guardians/LARs of participants younger than 16 years of age. All methods were carried out in accordance with relevant guidelines and regulations (declaration of Helsinki).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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