Sanders stage 7b: using the ulna physis improves decision-making for brace weaning in adolescent idiopathic scoliosis

Abstract

Aims

To investigate whether including the stages of ulnar physeal closure in Sanders stage(SS) 7 aids in more accurate assessment for brace weaning for patients with adolescent idiopathic scoliosis(AIS).

Methods

This was a retrospective analysis of patients who weaned brace-wear and consulted from June 2016 to December 2018. Patients who weaned brace-wear at Risser stage ≥4, static standing body height and arm span for at least 6 months and ≥2-years post-menarche were included. Skeletal maturity at weaning was assessed using Sanders staging with SS7 subclassified into SS7a (all phalangeal physes are fused and only distal radial physes are open, with narrowing of medial physeal plate of the distal ulna) and SS7b (those with >50 % fusion of the medial growth plate of distal ulna), and the distal radius and ulna (DRU) classification. Weaning maturity grading and any curve progression were analyzed using Fisher's exact test, with Cramer's V and Goodman and Kruskal's tau.

Results

A total of 179 AIS patients (83.2% females) were studied with mean age of 14.8±1.1 years and Cobb angle of 34.6±7.7° at weaning. Follow-up period was 3.4±1.8 years. At post-weaning 6-months, curve progression rates for patients weaning at SS7a versus SS7b were 11.4% and 0%

respectively for <40° curves. Similarly, curve progression rate for weaning at U7 was 13.5% versus 0% for weaning at U8. The use of SS6, SS7a/b, SS8 for maturity assessment at weaning strongly associated (Cramer's V: 0.326, p=0.016) with whether curve progressed at post-weaning 6-months. Weaning with SS7 subclassification allowed a 10.6% reduction of error in predicting curve progression.

Conclusion

The use of SS7a and SS7b allows accurate maturity assessment for guiding brace weaning. Weaning at SS7b, that is at U8, is more appropriate without any curve progression cases immediately post-weaning for small curves (<40°). This makes reaching full fusion of both distal radius and ulna physis (SS8) not necessary and brace weaning can be initiated approximately 9.0 months earlier.

Keywords: Brace weaning, skeletal maturity, Sanders staging, distal radius and ulna classification, DRU, curve progression

Take home message (3 bullet points summing clinical relevance)

- Subclassification of SS7 into SS7a and SS7b allows more accurate assessment for guiding brace weaning in patients with AIS.
- Weaning at SS7b and U8 is appropriate for patients whose major curve Cobb angle is <40°.
- For large curves of ≥40° at weaning, curve progression can occur regardless of the skeletal maturity status at which weaning takes place.

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Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity diagnosed between the age of 10 to 18 years. This spinal deformity progresses rapidly during the pubertal growth spurt,[1] and stabilizes near skeletal maturity.[2] When the Cobb angle reaches 25° to 40° Cheung et al. reveals that 46% of study subjects experienced curve progression if bracing is weaned at Sanders stage (SS) 7, with SS8 having the least risk of curve progression.[3] A study by Grothaus et al. also discovers that SS7 is not predictive of no curve progression even for curves less than 40 degrees at SS7, with the rate of increase in curve magnitude greater than that of natural history.[4] SS7 represents the early mature stage at which all phalangeal physes are fused and only distal radial physes are open, but only until complete fusion that SS8 is graded.[5] By these definitions, there can be a wide range of radiographic appearance from open to fusion of the distal radius and ulna physis between SS7 and SS8. This warrants the investigation of whether further subclassification of SS7 can allow more accurate identification of skeletal maturity which provides an earlier and safer timing for brace weaning. The radiographic appearance of both the distal radius and ulna are utilized in details by the DRU classification and gradings are readily available for assessing decelerating growth and growth cessation.[6] With the ulnar epiphyseal closure slightly earlier than distal radius,[7] the ulnar appearance with reference to the DRU classification may be useful for further subclassification of SS7.

Thus, the aim of this study is to subclassify SS7 using the appearance of the ulna physis particularly for patients undergoing brace weaning. We hypothesize that the ulna physis provides a more precise appreciation of the growth cessation phase thereby providing a better indicator for brace weaning with minimal risk for future curve progression.

Patients and Methods

Study Design

This study was based on a retrospective analysis of a prospectively collected cohort of patients who weaned brace-wear and consulted at a tertiary scoliosis specialist clinic in the period of June 2016 to December 2018. Inclusion criteria were patients diagnosed with AIS and had good brace compliance (> 16 hours of wearing brace per day) prior to discontinuation of brace-wear. Our centre adopted an alternate in-brace and out-of-brace radiograph protocol at each subsequent follow-up. Out-of-brace radiographs were obtained with patients having removed the brace for 24 hours prior to the follow-up visit. Brace weaning was initiated at Risser ≥ 4, without any interval bodily growth (no increase of standing body height and arm span) as compared to last visit at least 6 months ago, and post-menarche for 2 years for girls. Included subjects must have post-weaning follow-up of at least 2 years. Exclusion criteria included patients who had a follow-up period of less than two years after weaning, no out-of-brace spine radiographs at the time of weaning to identify the baseline weaning Cobb angle, and no left hand and wrist radiograph at the time of weaning (**Figure 1**). Ethics approval was obtained from the local ethics committee.

Data Collection

Data including patient demographics (age at weaning, gender, onset of menarche for girls) were recorded. Growth parameters included standing body height and arm span (both in centimetres) measured by a designated nurse at every clinic visit. Cobb angles were measured on the posteroanterior whole spine radiographs. Skeletal maturity was assessed using Risser staging,[8] as well as Sanders staging[14] and the DRU classification[9] based on the left hand and wrist radiograph taken on the same day of consultation.

The growth parameters and the magnitude of curves were collected at the time of brace weaning (referred as baseline), post-weaning 6-months, and post-weaning 2 years.

Subclassification of SS7

For further description of SS7, ulnar gradings of DRU classification were referenced. As previously reported, brace weaning at ulnar grade (U) 7 carries a risk of curve progression as compared to U8 which has a protective effect in terms of odds ratio for curve deterioration.[3] U7 represents the narrowing of the medial physeal plate of the distal ulna whereas U8 refers to those with greater than 50% fusion of the medial growth plate with unfused part just proximal to the styloid process, and U9 occurs when the distal ulnar physis is fully fused (**Figure 2**). Therefore, SS7 could be subclassified into: SS7a – all phalangeal physis are completely closed and the medial physeal plate of the distal ulna exhibiting narrowing or some extent of fusion (≤ 50%) at the medial side; and SS7b – all phalangeal physis are completely closed with greater than 50% fusion of the medial growth plate (**Figure 2**).

Statistical Analysis

The main focus of this study was to refine the brace weaning recommendations for the initiation of weaning, knowing that patients who were skeletally mature should not have further curve progression. Therefore, the first follow-up at 6 months immediately post-weaning was the crucial time-point to determine any further growth and curve progression occurred. Any curve progression at 2-years post-weaning was also assessed. Bodily growth was based on any increase in standing body height or arm span between brace weaning and first subsequent follow-up, despite static height and arm span were observed at weaning from 6 months prior. Subjects were allowed a growth difference of ≤ 0.15cm/month as it was reported as the rate of growth cessation for both boys and girls in this population.[6] Post-weaning curve progression at 6-months and 2-years follow-up was defined as any increase in the coronal Cobb angle of the major curve by greater than 5° at those time-points in comparison to the Cobb angle at baseline.[10, 11]

Descriptive statistics including mean values with standard deviations (SDs) or standard errors (SEs), percentages and ranges were presented according to the types of data. Bodily growth and curve progression were assessed for each patient, and whether curve progressed with any concurrent bodily growth was examined. The occurrence of subjects experiencing post-weaning bodily growth and curve progression in terms of frequency counts were tested for any association with the skeletal maturity grades at weaning (for Sanders staging and DRU classification) using Fisher's exact test of independence. According to the natural history of scoliosis, 40° is the threshold for adult deterioration.[12] Therefore, the role of curve magnitude at weaning, with the Cobb angle of major curve < 40° versus ≥ 40°, was specifically explored. Chi-square test of independence was used to test for any relationship between weaning major curve Cobb angle (< 40° versus ≥ 40°) and the prevalence of curve progression post-weaning.

The association of Sanders staging with subclassification was tested with the occurrence of curve progression using Fisher's exact test, and the strength of any relationship found was assessed by Cramer's V as there were uneven spans between each SS[5] and we could not assume equal intervals between grades. A Cramer's V value of > 0.10 indicates a moderate relationship and a value of > 0.25 indicates a very strong relationship.[13] Additional information was gained by examining the Goodman and Kruskal's tau (*τ*), which is based on conditional proportions and quantifies the reduction of error in prediction.[14, 15] It measures the percentage improvement in predictability of post-weaning curve progression given the information of the skeletal maturity grade at which the patient weaned brace-wear. The mean difference of the age at weaning between each SS was also calculated.

All statistical analyses were performed using SPSS Windows 26.0 (IBM SPSS Inc., Chicago, Illinois). A p-value of < 0.05 was considered as statistically significant.

Results

This study examined a total of 179 patients (83.2% females), who weaned bracing at the mean age of 14.8 years (SD 1.1). First follow-up since weaning was at 7.5 months (SD 2.5). The mean Cobb angles of major and minor curves at weaning was 34.6° (SD 7.7°, range: 18.0° to 50.0°) and 29.3° (SD 7.8°, range: 6.8° to 49.0°) respectively. At 2-years post-weaning, the Cobb angles of the major curve was 37.9° (SD 9.8°, range: 19.0° to 60.4°) and the minor curve was 30.8° (SD 9.1°, range: 10.3° to 52.3°). The mean duration of follow-up was 3.4 years (SD 1.8). After final follow-up, 8 patients (4.5%) had eventually undergone surgery. At 2-years post-menarche, 26.2% of female patients were at SS7a while 64.4% reached SS7b. The remaining belonged to SS6 (2.7%) and SS8 (6.7%). Patients' baseline characteristics are presented in **Table I**.

For the whole study cohort, the overall mean value of growth rate based on standing body height and arm span indicated no bodily growth occurred at post-weaning 6-months (**Table II**). However, when examining individual growth rates of each patient, it was revealed that 17.9% of the study population experienced growth based on standing body height, and 26.2% experienced growth based on arm span (**Table II**) according to the previously reported rate of growth cessation (growth rate ≤ 0.15cm/month for both body height and arm span). Curve progression occurred in 8.4% of the study cohort at post-weaning 6-months, among whom 66.7% were weaned at major curve Cobb angle of ≥ 40°. At post-weaning 2-years or more, 32.4% of patients had curve progression as compared to baseline, with 41.4% of these deteriorated patients weaned at ≥ 40°. There was no association between post-weaning curve progression and bodily growth based on body height (p=0.734) or arm span (p=0.543). Concurrent growth changes occurred in only 20% (based on body height, n=3) and 33.3% (based on arm span, n=5) of curve progression cases. Curve types were not associated with the curve progression rate (p=0.416).

For bodily growth, the presentation of cases with any residual increase in body height (> 0.15cm/month) was found associated with Sanders staging with SS7a/SS7b (p=0.048) and with the ulnar grades (p=0.009) at weaning (**Table III**). As the curve magnitude at weaning (<40° and ≥ 40°) was associated with the outcome of curve progression (at post-weaning 6-months, p=0.002; at post-weaning 2-years, p=0.017), the relationship of Sanders staging, DRU grades and the outcome of curve progression were stratified according to curve magnitude (**Table IV**). For patients with Cobb angle < 40°, weaning at SS6/7a/7b/8 (p=0.003) or at U6/U7/U8/U9 (p=0.006) was each associated with the occurrence of curve progression at 6-months post-weaning. The curve progression rate for those weaned at SS7a was 11.4%, whereas those weaned at SS7b and SS8 were 0%. The mean difference between weaning at SS7b and SS8 was 9.0 months (SE 4.6) for patients weaned at < 40°, and the mean difference was 7.4 months (SE 3.4) for the whole cohort. Similarly, curve progression rates for weaning at U7 versus those weaning at U8 and U9 were 13.5% and 0% (both U8 and U9) respectively, for < 40° curves at post-weaning 6-months. For larger curves, the curve progression rate post-weaning was not associated with any of the skeletal maturity indices.

There was a lack of relationship between curve progression and weaning maturity of SS6/SS7/SS8 (p=0.188). With the introduction of SS7 subclassification, weaning at SS6, SS7a, SS7b and SS8 had a significant association with whether curve progression occurred post-weaning for those patients with curves < 40° (p=0.003). (**Table V**) This relationship was strong (Cramer's V= 0.326, p=0.016). The significant improvement of error was 10.6% in the prediction of curve progression/no progression when factoring maturity status.

Discussion

As one of determinants for the success of bracing is precise timing of brace weaning at skeletal maturity, the accuracy of skeletal maturity assessment in capturing growth cessation is of utmost importance. The ossification of various epiphyseal plates allows prediction for different phases of pubertal growth, such as the growth acceleration phase before peak growth using the olecranon.[16, 17] To avoid overuse of braces, accurate identification of skeletal maturity provides a good recommendation for brace weaning. This study reclassifies SS7 with the ulnar appearance for better guidance in initiating brace weaning in patients with AIS.

Our findings reveal that SS7b is an effective guide for the end of skeletal growth (**Figure 3**), and also for any curve progression after brace weaning. By subclassifying SS7, we found clear associations between the timing of weaning and curve progression (**Figure 4**), as reflected by the immediate post-weaning curve progression rate. Subclassifications SS7a and SS7b are sensitive to any remaining growth just prior to skeletal maturity. Maturity status can be assessed more accurately with the associated curve progression rate using these additional SS7 grades. Clinical parameters lack accuracy as seen by the variability in bone age according to 2-years post-menarche. Previous studies observed that the deceleration phase of pubertal growth allows many

DRU grades for maturity assessment,[3, 17] thus the descriptor from ulnar grading is a useful tool for subclassifying SS7.

The key differentiation is the degree of medial physeal plate closure on radiographs. Identifying > 50% closure (SS7b) is adequate for brace weaning. None of the patients with curves < 40° who weaned at this stage progressed. By weaning at SS7b instead of SS8, there is a benefit of weaning at approximately 9 months earlier. For the whole cohort, weaning at SS7b leads to similar rates of curve progression (6.3%, same as for weaning at SS8) while avoiding at least 7 to 9 months of unnecessary brace-wear. The use of the radiographic appearances of U7 and U8 demonstrates that U8 used alone can also be a good indicator for brace weaning.

The close examination of curve progression at immediate 6-months post-weaning captures any premature brace weaning that can be avoided by precise skeletal maturity assessment. Accurate skeletal maturity assessment is also important to avoid prolonged bracing which may be detrimental to patients' mental and physical health.[18] This cohort exhibits a relatively lower curve progression rate of 8.4% at post-weaning 6-months as compared to 25.0% as reported by Shi et al.[19] The average increase in Cobb angle at post-weaning 6-months was 2.0° (SD 2.4°), which is comparable to their deterioration of 2.6° (SD 5.8°). Both studies had higher curve progression rate at ≥ 2-years follow-up (32.4% as compared to 46.5% for Shi's study). Among these patients who deteriorated over longer follow-up period, 41.4% had weaned brace at ≥ 40°. These large curves were associated with higher rates of curve progression. Despite weaning brace-wear at skeletal maturity, some patients experienced curve progression at post-weaning 2-years. Long-term monitoring is therefore recommended for patients with large deformities.

In this study, some curve progression occurred after final body height and arm span were attained. There is a mismatch between curve progression and skeletal growth, with peak curve progression occurring after peak growth.[20] This may possibly explain why some patients experienced curve progression despite no concurrent gains in body height or arm span. However, whether conceptually these two phenomena are the same requires further investigation. Even at SS7 which was predictive of the end of spinal growth,[4] curve progression may still occur. For this study cohort, 50% of those who weaned brace-wear at SS7a had curve progression 6-months post-weaning without concurrent bodily growth. As weaning at SS7a/SS7b was evaluated for all patients who experienced curve progression regardless of any concurrent residual bodily growth, SS7b should be used instead of SS7a for curves < 40°. For the users of DRU classification, U8 alone may be adequate for weaning. This is consistent with the results of weaning at U7 having significantly higher odds of curve progression as reported by Cheung et al.[3]

Limitations of this study include the uneven distribution of males and females as per prevalence of AIS, with a ratio of females to males being 4.5 : 1 for curves of ≥ 20°.[21] This limited the number of subjects in subgroup analyses for curve progression rate. Moreover, as this study and data collected were of retrospective nature, the measurement of sitting height,[22] which may be more useful for assessing spine growth, was not readily available. In addition, the brace compliance prior to weaning was self-reported and a more objective measure may be more accurate. Curve flexibility at pre-bracing should also be examined as a factor of curve progression after weaning. Those that are less flexible may be more prone to further deterioration.[23] Future prospective study can address these issues, and parameters should be included and used effectively as outcome measures of any residual growth.

Significant differences in curve progression rates were observed between SS7a and SS7b distinguished by 50% ulnar medial physeal closure. SS7b is recommended for brace weaning especially for curves < 40° at weaning to maximize the outcomes of reduced post-weaning curve progression. For clinicians using the DRU classification for skeletal maturity assessment, U8 is demonstrated as a good indicator for brace weaning. This study further delineates the importance of accurate bone age assessment which weans brace-wear earlier thereby avoiding overuse of bracing while limiting the risk of curve progression. Prospective study is required for comparing the outcomes of weaning at SS7a versus SS7b in terms of health-related quality of life, and for validation in other cohorts.

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Figure Legends

Figure 1. Patient recruitment flowchart

Figure 2. Radiographic appearance of ulnar medial growth plate in SS7a versus SS7b

Figure 3. Association of Sanders Staging with subclassification and occurrence of growth at post-weaning 6-months

Figure 4. Association of curve progression rate at post-weaning 6-months and Sanders staging with subclassification

Figure 1. Patient recruitment

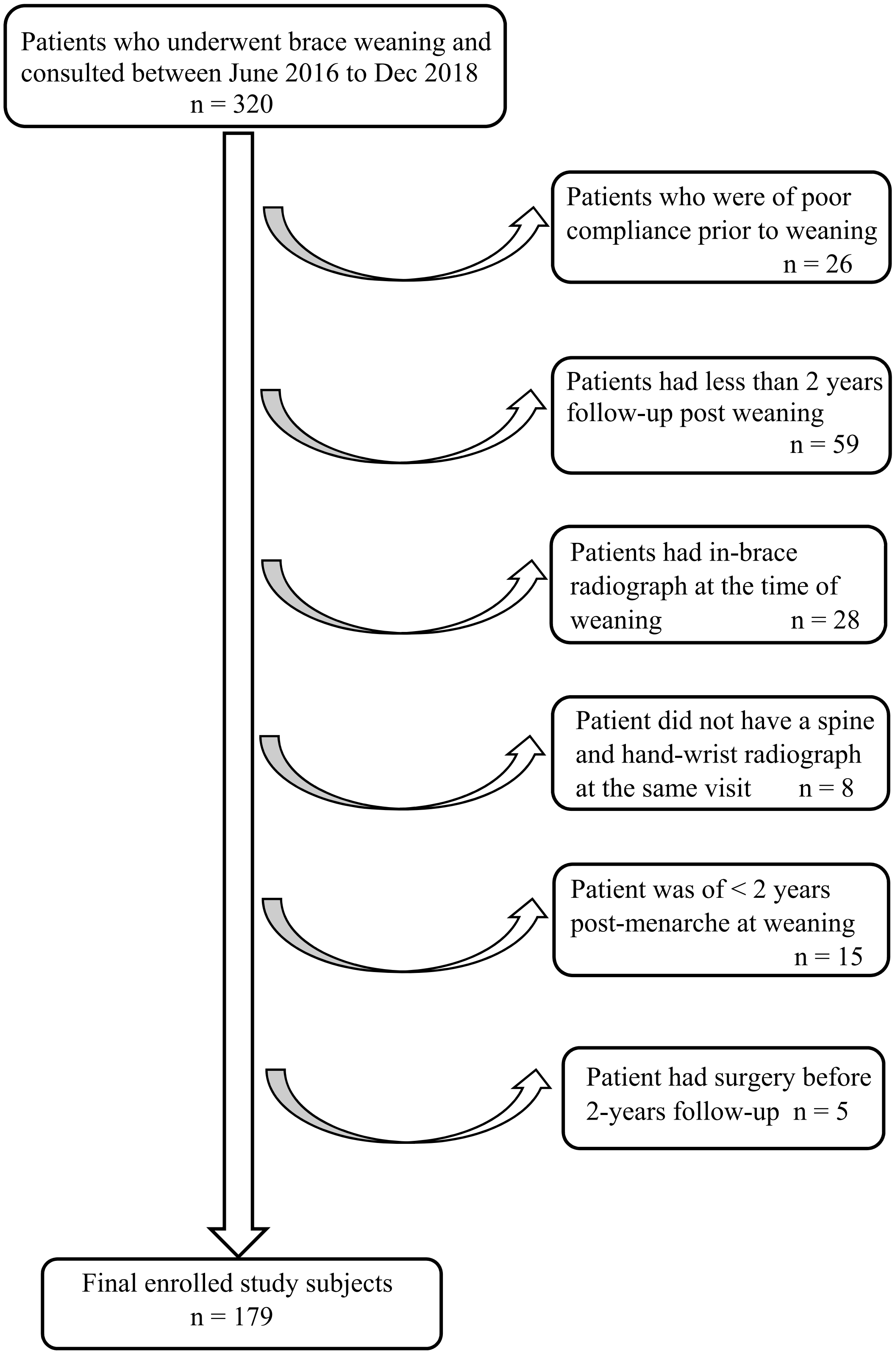

Figure 2. Radiographic appearance of ulnar medial growth plate in SS7a versus SS7b

Figure 3. Association of Sanders Staging with subclassification and occurrence of growth at post-weaning 6-months

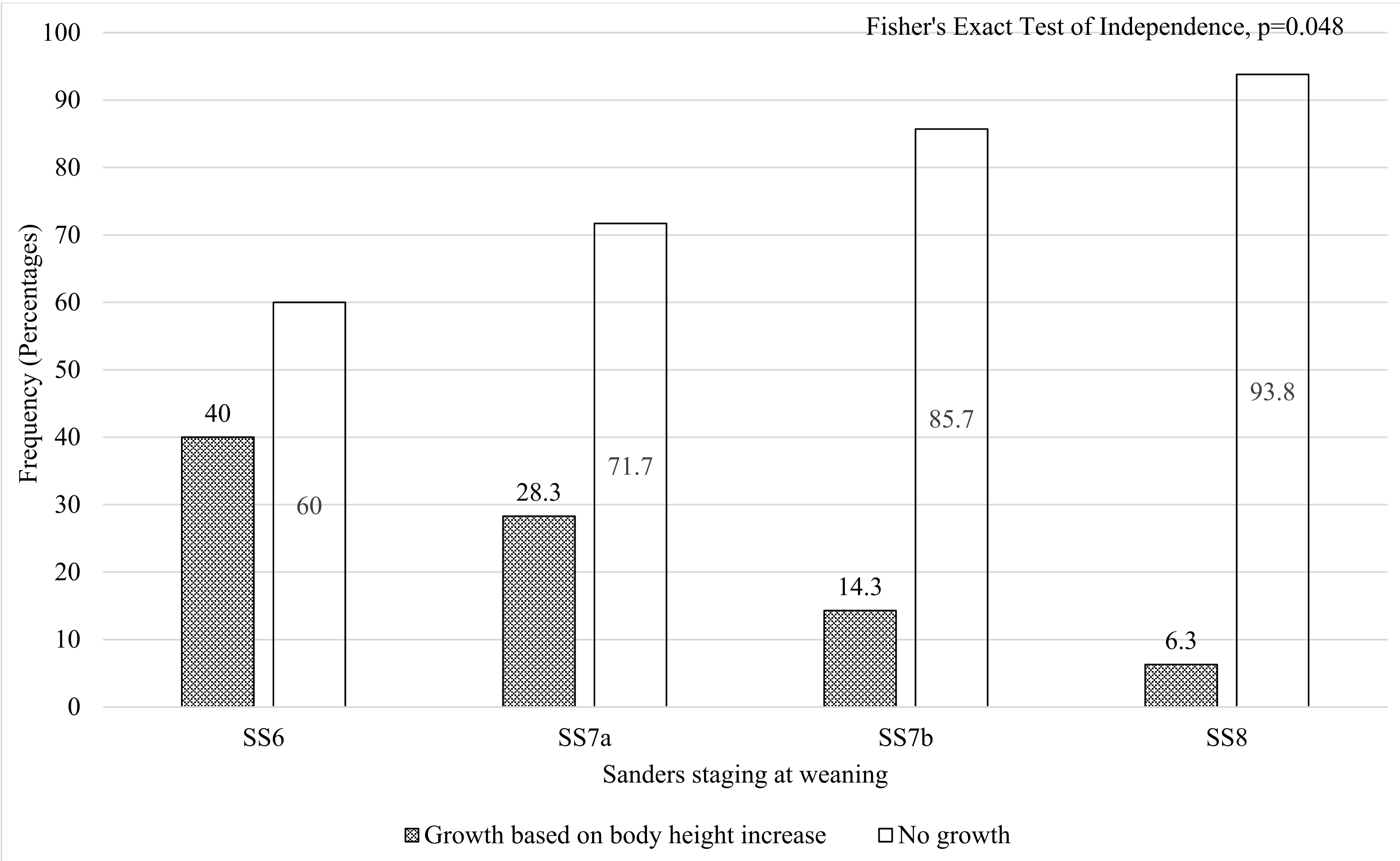

Figure 4. Association of curve progression rate at post-weaning 6-months and Sanders staging with subclassification

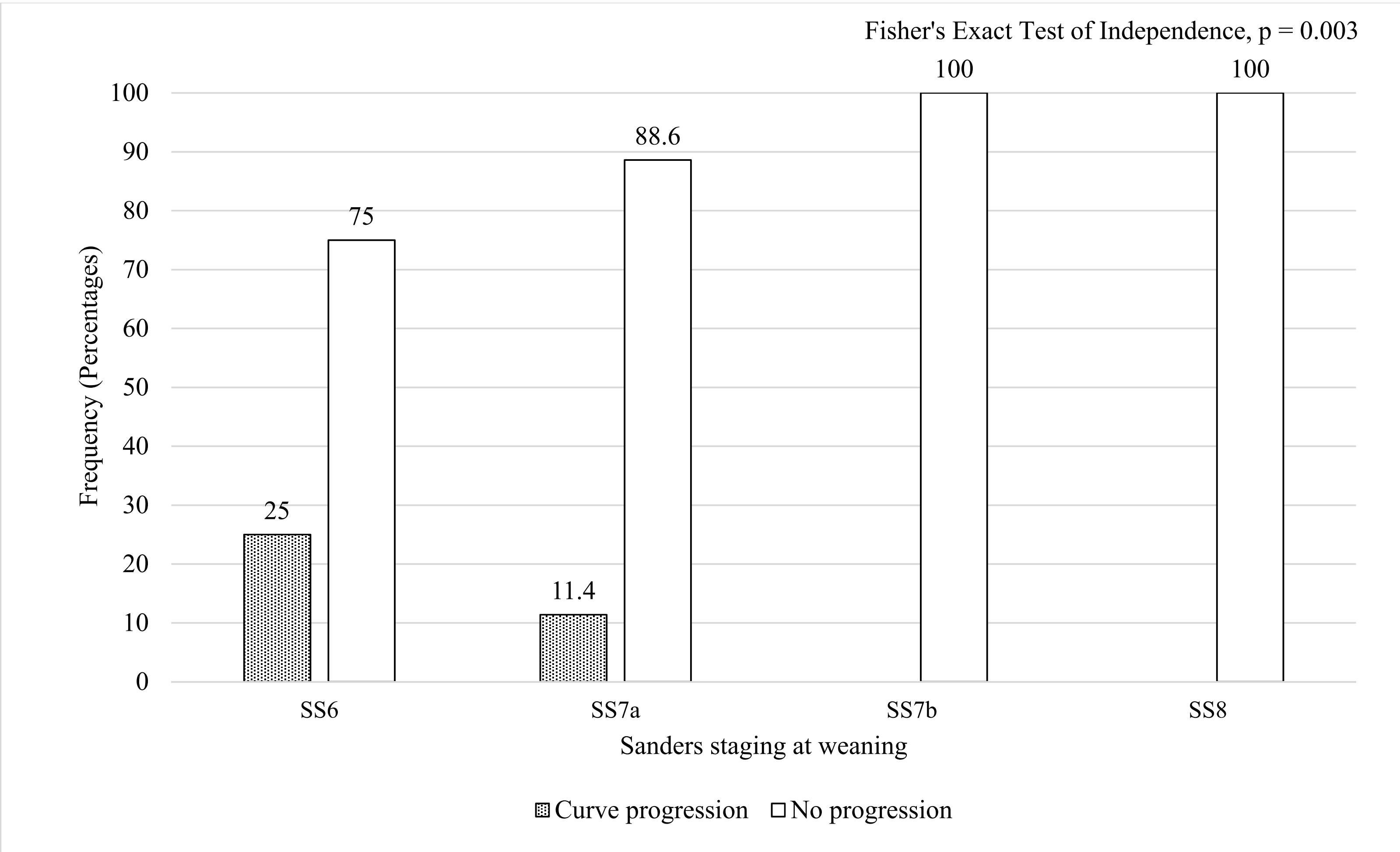

Table I. Patient Characteristics at baseline (at the time of initiation of brace weaning)

	Overall	Females (n=149)	Males (n=30)
Growth parameters at brace weaning - Mean (SD)			
Age at weaning (years)	14.8 (1.1)	14.6 (1.0)	16.0 (0.8)
Standing body height (cm)	161.4 (7.0)	159.6 (5.3)	170.4 (7.3)
Arm span (cm)	161.9 (7.9)	159.8 (6.2)	172.2 (7.4)
Months post-menarche		26.7 (9.8)	
Skeletal maturity (n)			
Risser sign			
4	70	60	10
4+	99	84	15
5	10	5	5
Sanders stage (SS)			
SS6	5	4	1
SS7a	46	39	7
SS7b	112	96	16
SS8	16	10	6
Distal radius and ulna (DRU) classification			
R8	5	4	1
R9	85	74	11
R10	76	61	15
R11	13	10	3
U6	2	1	1
U7	48	41	7
U8	109	93	16
U9	20	14	6
Curve types (n)			
Double/triple curve	74	63	11
Single thoracic curve	47	42	5
Single thoracolumbar/lumbar curve	58	44	14
Curve magnitude			
Coronal Cobb angle of major curve (°) Mean (SD)	34.6 (7.7)	34.7 (7.5)	34.2 (8.5)
Coronal Cobb angle of minor curve (°) Mean (SD)	29.3 (7.8)	29.3 (7.2)	29.3 (10.7)
Large curve > 40° at weaning (n, column %)	53 (29.6%)	47 (31.5%)	6 (20.0%)

SD: standard deviation, cm: centimetres, %: percentage, n: number of subjects

Table II. Change of growth parameters and curve magnitudes at 6-months and 2-years post-weaning

Growth parameters Mean (SD, range)			
Parameters	At post-weaning 6 months vs weaning		
Change of standing body height (cm)	0.5 (SD 0.8, range: 0.0 to 3.5)		
Change of arm span (cm)	0.8 (SD 1.0, range: 0.0 to 0.9)		
Growth rate Change of BH/AS per month, cm/month, mean (SD, range)			
Based on standing body height	0.08 (SD 0.12, range: 0.0 to 0.7)		
Based on arm span	0.11 (SD 0.15. range: 0.0 to 1.0)		
Patients with bodily growth^ (n, %)			
Based on body height growth rate	32 (17.9%)		
Based on arm span growth rate	45 (26.2%)		
Curve magnitude Mean (SD, range)			
	At post-weaning 6-months vs weaning	At 2 years vs 6 months follow-up	2-year follow-up vs time of weaning
Change of coronal Cobb angle of major curve (°)	2.0 (SD 2.4, range: 0.0 to 12.8)	2.4 (SD 3.2, range: 0.0 to 15.3)	3.9 (SD 4.1, range: 0.0 to 19.0)
Change of coronal Cobb angle of minor curve (°)	1.6 (SD 2.5, range: 0.0 to 10.5)	1.9 (SD 2.6, range: 0.0 to 9.5)	2.8 (SD 3.6, range: 0.0 to 16.3)
Curve progression (n, %)			
Curve progression#	15 (8.4%)	30 (16.8%)	58 (32.4%)
Large curve (≥ 40°) among progression cases	10 (66.7%)	12 (40.0%)	24 (41.4%)

BH: Standing body height, AS: arm span, SD: standard deviation, cm: centimetres, %: percentage, n: number of subjects

^ > 0.15cm/month: bodily growth

curve progression: an increase of > 5° of major curve Cobb angle at specific post-weaning time-points in comparison

Table III. Bodily growth per skeletal maturity system

Skeletal Maturity at weaning	Bodily growth – n (%)					
	At post-weaning 6-months					
	Growth based on BH	No growth	p-value^	Growth based on AS	No growth	p-value^
Sanders stage (SS)						
SS6	2 (40%)	3 (60%)	0.048*	0	5 (100%)	0.473
SS7a	13 (28.3%)	33 (71.7%)		12 (26.7%)	33 (73.3%)	
SS7b	16 (14.3%)	96 (85.7%)		31 (28.7%)	77 (71.3%)	
SS8	1 (6.3%)	15 (93.8%)		2 (14.3%)	12 (85.7%)	
Distal radius and ulna (DRU) classification						
R8	2 (40%)	3 (60%)	0.158	2 (40%)	3 (60%)	0.328
R9	19 (22.4%)	66 (77.6%)		26 (31.3%)	57 (68.7%)	
R10	10 (13.2%)	66 (86.8%)		15 (20.8%)	57 (79.2%)	
R11	1 (7.7%)	12 (92.3%)		2 (16.7%)	10 (83.3%)	
U6	2 (100%)	0	0.009*	0	2 (100%)	0.738
U7	13 (27.1%)	35 (72.9%)		12 (25.5%)	35 (74.5%)	
U8	15 (13.8%)	94 (86.2%)		30 (28.6%)	75 (71.4%)	
U9	2 (10.0%)	18(90%)		3 (16.7%)	15 (83.3%)	

BH: Standing body height, AS: arm span, n: number of subjects, %: percentage per skeletal maturity grade (row percentages)
^ Fisher's exact test with 2-sided significance

Table IV. Curve progression per skeletal maturity system

At post-weaning 6-months – n (%)

Skeletal Maturity at weaning	Cobb angle at weaning <40°		p-value^	Cobb angle at weaning ≥ 40°		p-value^	Whole cohort		p-value^
	Curve progression	No progression		Curve progression	No progression		Curve progression	No progression	
Sanders stage (SS)									
SS6 SS7a SS7b SS8	1 (25.0%) 4 (11.4%) 0 0	3 (75.0%) 31 (88.6%) 78 (100%) 9 (100%)	0.003*	1 (100%) 1 (9.1%) 7 (20.6%) 1 (14.3%)	0 10 (90.9%) 27 (79.4%) 6 (85.7%)	0.287	2 (40.0%) 5 (10.9%) 7 (6.3%) 1 (6.3%)	3 (60.0%) 41 (89.1%) 105 (93.8%) 15 (93.8%)	0.077
Distal radius and ulna (DRU) classification									
R8 R9 R10 R11	1 (50.0%) 3 (4.9%) 1 (1.8%) 0	1 (50.0%) 59 (95.2%) 55 (98.2%) 6 (100%)	0.110	2 (66.7%) 5 (21.7%) 3 (15.0%) 0	1 (33.3%) 18 (78.3%) 17 (85.0%) 7 (100%)	0.115	3 (60.0%) 8 (9.4%) 4 (5.3%) 0	2 (40.0%) 77 (90.6%) 72 (94.7%) 13 (100%)	0.007*
U6 U7 U8 U9	0 5 (13.5%) 0 0	1 (100%) 32 (86.5%) 75 (100%) 13 (100%)	0.006*	1 (100%) 1 (9.1%) 7 (20.6%) 1 (14.3%)	0 10 (90.9%) 27 (79.4%) 6 (85.7%)	0.287	1 (50.0%) 6 (12.5%) 7 (6.4%) 1 (5.0%)	1 (50.0%) 42 (87.5%) 102 (93.6%) 19 (95.0%)	0.118

At post-weaning 2-years – n (%)

Skeletal Maturity at weaning	Cobb angle at weaning <40°		p-value	Cobb angle at weaning ≥ 40°		p-value	Whole cohort		p-value
	Curve progression	No progression		Curve progression	No progression		Curve progression	No progression	
Sanders stage (SS)									
SS6 SS7a SS7b SS8	2 (50.0%) 11 (31.4%) 21 (26.9%) 0	2 (50.0%) 24 (68.6%) 57 (73.1%) 9 (100%)	0.152	1 (100%) 6 (54.5%) 14 (41.2%) 3 (42.9%)	0 5 (45.5%) 20 (58.8%) 4 (57.1%)	0.710	3 (60.0%) 17 (37.0%) 35 (31.2%) 3 (18.7%)	2 (40.0%) 29 (63.0%) 77 (68.8%) 13 (81.3%)	0.304
Distal radius and ulna (DRU) classification									

R8	2 (100%)	0	0.008*	3 (100%)	0	0.120	5 (100%)	0	<0.001*
R9	22 (35.5%)	40 (64.5%)		12 (52.2%)	11 (47.8%)		34 (40.0%	51 (60.0%)	
R10	9 (16.1%)	47 (83.9%)		6 (30.0%)	14 (70.0%)		15 (19.7%)	61 (80.3%)	
R11	1 (16.7%)	5 (83.3%)		3 (42.9%)	4 (57.1%)		4 (30.8%)	9 (69.2%)	
U6	0	1 (100%)	0.227	1 (100%)	0	0.710	1 (50.0%)	1 (50.0%)	0.358
U7	13 (35.1%)	24 (64.9%)		6 (54.5%)	5 (45.5%)		19 (39.6%)	29 (60.4%)	
U8	20 (26.7%)	55 (73.3%)		14 (41.2%)	20 (58.8%)		34 (31.2%)	75 (68.8%)	
U9	1 (7.7%)	12 (92.3%)		3 (42.9%)	4 (57.1%)		4 (20.0%)	16 (80.0%)	

n: number of subjects, %: percentage per skeletal maturity grade (row percentages)

^ Fisher's exact test with 2-sided significance

Table V. Test of association and directional measures for curve progression at post-weaning 6-months and skeletal maturity using Sanders staging

Major curve magnitude	Skeletal Maturity at weaning	Curve Progression	No Progression	Association test p-value^	Directional measure				
		n (%)			Cramer's V	p-value	Goodman and Kruskal's tau	Value	p-value
Cobb angle <40° (n=126)	SS6 SS7a SS7b SS8	1 (25.0%) 4 (11.4%) 0 0	3 (75.0%) 31 (88.6%) 78 (100%) 9 (100%)	0.003* X^2 value: 11.752	0.326	0.016*	Sanders dependent	0.053	0.002*
							Curve progression dependent	0.106	0.016*
Cobb angle ≥40° (n=53)	SS6 SS7a SS7b SS8	1 (100%) 1 (9.1%) 7 (20.6%) 1 (14.3%)	0 10 (90.9%) 27 (79.4%) 6 (85.7%)	0.287	0.312	0.202	Sanders dependent	0.010	0.644
							Curve progression dependent	0.097	0.202

n: number of subjects, SS: Sanders stage, %: percentage per each Sanders stage (row percentages)
^ Fisher's exact test with 2-sided significance