ORIGINAL ARTICLE

A longitudinal 3-dimensional size and shape comparison of untreated Class I and Class II subjects

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Background: The invention of the Broadbent-Bolton cephalometer in 1925 made possible the collection of 3-dimensional data from biorthogonal plain film head radiographs. The objective of this study was to compare longitudinal changes in the shape and size of craniofacial structures between 16 untreated Class II Division 1 girls and 16 untreated Class I Bolton girls. **Methods:** Procrustes analyses were used to compare differences in 30 cephalometric landmarks that were 3-dimensional. The same methods were also used to analyze changes of 4 subsets of landmarks (maxilla, mandible, midface, and cranial vault). Comparisons included shape and size differences between adjacent age groups at ages 6, 11, and 15 in the Class II sample as well as between the Class I and Class II samples at each age. **Results:** Overall, the craniofacial complex underwent continuous shape change from ages 6 to 15 in both samples. In the Class II sample, the smallest contribution to craniofacial shape change was seen for the mandibular landmarks between ages 6 and 11. Compared with the Class I sample, the Class II sample had (1) a longer facial pattern, (2) the smallest mandibular shape difference at age 6 and the largest at age 15, and (3) more protrusive maxillary landmarks at all ages compared with the Class I sample. The Class II sample also had the largest change in size from ages 11 to 15 (6.5%), whereas the Class I sample showed the greatest size change (10.5%) from ages 6 to 11. **Conclusions:** Clinically significant size and shape differences were observed during growth and development between Class II and Class I subjects in this sample. (Am J Orthod Dentofacial Orthop 2005; 127:584-91)

The world's largest and most renowned longitudinal study of human craniofacial growth and development is the Bolton-Brush Growth Study at Case Western Reserve University in Cleveland, Ohio.[1,2] It gives orthodontic practitioners longitudinal cephalometric standards of normality for children from ages 3 to 18.

In 1975, Broadbent et al[3] published the Bolton Standards and introduced the Broadbent orientator, which was designed to convert information obtained in the biorthogonal plain film radiographs into 3-dimensional (3D) data points. To use the orientator to acquire 3D data, one must assume that the beams of the posterior and lateral tube heads orthogonally intersect in the center of the head (Fig 1). Manual use of the Broadbent orientator is cumbersome,[4,5] and 3D data collection was not routinely attempted. Recent advances in computer graphics and a computerized version of the Broadbent orientator allow for easier collection and interpretation of 3D data.[6]

Palomo et al[7] used this computerized version of the orientator and the Procrustes superimposition method to examine radiographs of the 16 Class I girls who were used to create the Bolton Standards. The Procrustes algorithm, as proposed by Rohlf and Bookstein,[8] provided optimal superimposition of 2 sets of homologous landmarks on their shared centroid. The centroid is the geometric center of the object. The remaining differences between the 2 sets of landmarks provided size, orientation, and positional information. This method has 2 advantages over traditional cephalometric superimposition techniques: size is treated as a separate variable and does not overdetermine the result, and no landmark is seen as primary or stationary during the superimposition.

Cephalometric studies of Class II malocclusions have reported conflicting results about which jaw is

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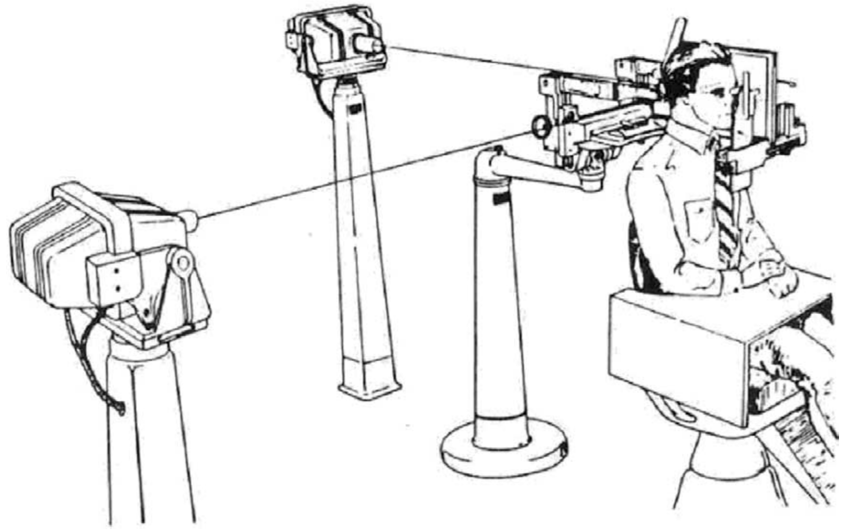

Fig 1. Broadbent-Bolton cephalometer (with permission from Bolton Brush Growth Study Center).

abnormal.[9-15] McNamara[13] reviewed 16 previous Class II studies and found 12 that supported the notion that Class II Division 1 malocclusion is the result of mandibular retrognathia. He also found 4 that reported the mandible as "normal." He then reported from his own studies that most subjects with Class II Division 1 malocclusions have mandibular skeletal retrusion (hypoplasia), and a smaller percentage showed maxillary protrusion (hyperplasia).

The objective of our study was to compare longitudinal changes in the shape and size of craniofacial structures between 16 untreated Class II Division 1 girls and 16 untreated Class I girls.

MATERIAL AND METHODS

A sample of 16 untreated Class II Division 1 girls was identified from the records of the Bolton-Brush Growth Study. Records at ages 6, 11, and 15 represented the prepubertal, circumpubertal, and postpubertal growth periods. The selection criteria were (1) no orthodontic treatment; (2) frontal and lateral cephalograms of diagnostic quality at ages 6, 11, and 15; (3) hand-wrist radiographs at ages 6, 11, and 15 to confirm skeletal maturation based on the method of Greulich and Pyle[16]; and (4) dental casts at age 6 confirming a Class II Division 1 malocclusion based on a relationship of the deciduous second molars and canines. From 147 longitudinal Class II records in the Bolton-Brush collection, 16 subjects met all criteria. An age-matched sample of 16 Class I girls was used for comparison. The growth and development of this Class I sample was analyzed in depth in a previous study.[7]

By using a template developed at the University of California at San Francisco, 4 fiducial points were punched in each cephalogram to control for distortion and enlargement.[17] The cephalograms were then scanned at 512 dpi and saved as 12-bit TIFF images. The data were analyzed by using an imaging program developed by Subramanyan and Dean at Case Western Reserve University,[6] 3dCEPH. The 3dCEPH program allowed image enhancement and identification of 30 cephalometric landmarks (22 skeletal and 8 dental) in each frontal and lateral film pair (Fig 2). The landmarks used in this study were based on the definitions of Grayson et al.[18] The same operator (D. W. H.) identified all landmarks (Fig 3). To estimate intraoperator reliability, 37.5% of the total sample was digitized 3 times. The 3dCEPH program also combined all landmarks identified in both lateral and frontal cephalograms into a 3D landmark frame by using the Broadbent orientator principles.[3] The subjects were then separated by age. An average location for each landmark was calculated, creating a grand mean landmark frame for each group (6, 11, and 15 years). The grand means were then compared chronologically (ages 6-11, 11-15, and 6-15) and between Class I and Class II groups at the same ages (6, 11, and 15). The Procrustes algorithm was used in each comparison, so that size and shape could be analyzed separately.

Because using dental landmarks during periods of rapid eruption could yield misleading values, the grand means described above were also calculated without the dental landmarks and the same comparisons performed.

After the comparisons were made, the landmarks were separated into 4 craniofacial regions for visualization.

Fig 2. Landmark identification screen of 3dCEPH program.

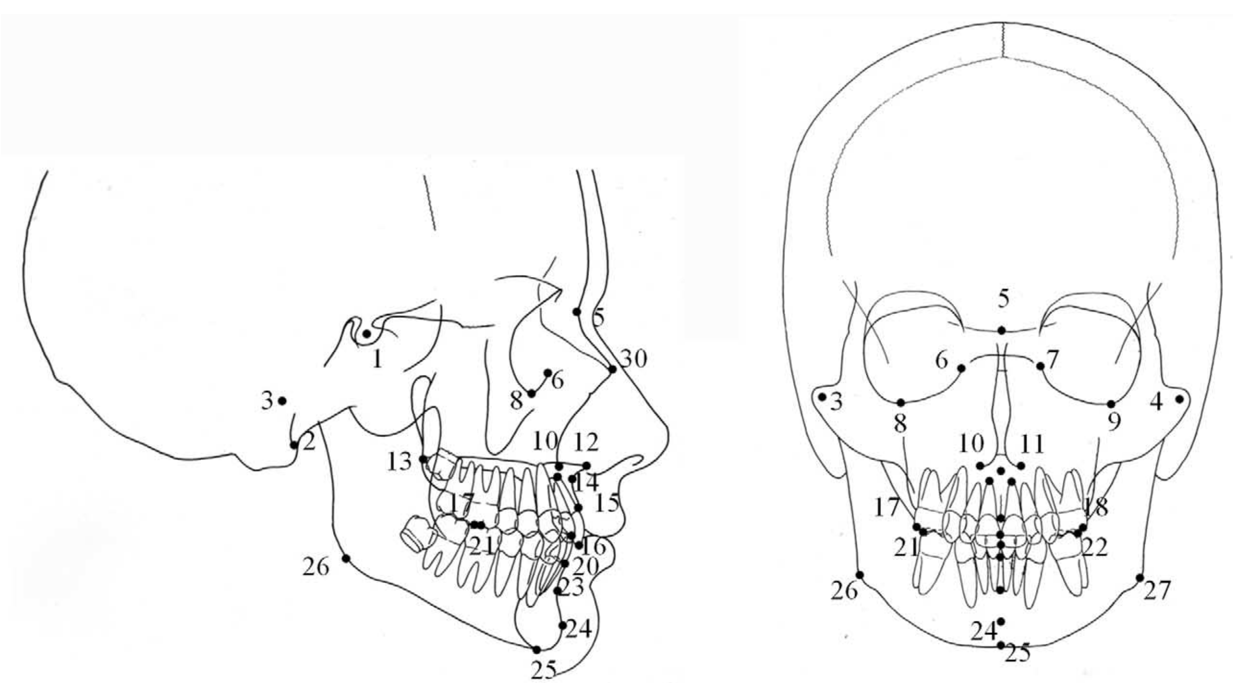

Fig 3. Landmarks used in lateral and frontal views.

These regions were the cranial vault (10 landmarks: nasion, sella, medial orbitale [right and left], orbitale [right and left], mechanical porion [right and left], rhinion, and basion), the maxilla (6 landmarks: anterior nasal spine [ANS], posterior nasal spine [PNS], A point, piriform [right and left], and supradentale), the mandible (6 landmarks: gonion [right and left], menton, pogonion, B point, and infradentale), and the dental landmarks (8 landmarks: mandibular first molar distal cusp [right and left], maxillary first molar distal cusp [right and left], maxillary central incisor root apex [right and left], maxillary central incisor edge, and mandibular central incisor edge).

RESULTS

Intraoperator reliability for the overall average difference in the 30-landmark group at 3 times was 0.627 mm. The landmark that had the most variation (right piriform, 1.37 mm) was still below the recommended maximum of 2 mm change,[19] so no alteration in the original number of landmarks used was necessary.

The results of the 22-landmark group were similar to the 30-landmark group. Because more landmarks give a better representation of the object analyzed, the 30-landmark group was used, except for size comparison.

All size comparisons were performed with the group without dental landmarks, because craniofacial size is a skeletal comparison.

The comparisons are given below. In each comparison, the total amount of shape change is mentioned in millimeters. The landmarks that showed the least and most shape changes are also mentioned, and, in addition to their actual values in millimeters, the percentage of contribution to the overall change is also given. The percentage of contribution to the overall change is calculated by dividing the change in the landmark by the total change in that comparison, multiplying it by 100 to yield a percentile value. For example, rhinion changed 2.09 mm during the 6-11 comparison, in which there was a total change of 69.29 mm. Rhinion's contribution to the overall change is 2.09/69.29 = 0.301, multiplied by 100 = 3.01%. The shape change values for all landmarks used are given in Table I, which also shows the total amount of shape modification for each comparison.

The last paragraph of each comparison reports the size information. One step of the Procrustes superimposition method is the enlargement, without distortion, of the smallest object until both objects are of equal size. The enlargement used gives the difference in size between both objects.

Class II Division 1, age 6-11

The greatest amount of shape change occurred from ages 6 to 11 (69.29 mm). Gonion right had the least shape change (0.36%); it had postero-inferior and lateral changes totaling 0.25 mm. The central incisor root apex left exhibited the greatest change, with 8.17 mm (11.8%); it changed in anterior, inferior, and medial directions.

The magnification needed to allow the Procrustes superimposition was 1.0078. This means that a 6-year-old Class II Division 1 Bolton girl's cephalogram must be magnified 0.78% to be the same size as that of an 11-year-old. This same comparison in the Class I group showed that a 6-year-old is 10.3% smaller than an 11-year-old (Table I).

Class II Division 1, age 11-15

The 11 to 15-year-old group showed a total shape change of 46.04 mm. The maxillarry incisal edge moved the least (0.38%); it had an 0.18-mm downward change. The right maxillary first molar showed the greatest change, with 4.21 mm (9.15%); it changed downward, forward, and medially.

The magnification needed to allow the Procrustes superimposition was 1.0672. This makes an 11-year-old Class II Division 1 Bolton girl 6.72% smaller than a 15-year-old. The Class I Bolton sample showed that the 11-year-old girl is 5.92% smaller than the 15-year-old (Table I).

Class II Division 1, age 6-15

The 6 to 15-year-old group showed a total shape change of 83.91 mm. Nasion moved the least (0.73%)—0.61 mm posteriorly. The left central incisor root apex moved the most, at 8.55 mm (10.2%), in superior, posterior, and medial directions (Fig 4).

The magnification needed to allow the Procrustes superimposition was 1.0752. This makes a 6-year-old 7.52% smaller than a 15-year-old. In the Class I sample, the 6-year-old was 16.81% smaller than the 15-year-old (Table I).

Class II versus Class I, age 6

Comparing the Class II Division 1 with the Class I Bolton girls at age 6 showed a total shape difference of 55.98 mm. The landmark with the least shape difference was the left mandibular first molar (0.27%); in the Class II sample, it appeared 0.15 mm more inferior, posterior, and medial than in the Class I group. Mechanical porion left had the greatest shape difference (8.16%); in the Class II sample, it appeared 4.57 mm more inferior and medial than in the Class I group (Fig 5).

The magnification to allow the Procrustes superimposition was 1.096. This means that a Class II Division 1 Bolton girl is 9.6% larger than a Class I Bolton girl at age 6 (Table I).

Class II versus Class I, age 11

The age-11 group showed an overall shape difference total of 52.98 mm between the Class II and Class I samples. The maxillary incisal edge had the least shape difference (0.46%); in the Class II sample, it appeared 0.24 mm more anterior and inferior than in the Class I sample. Mechanical porion right had the biggest shape difference (6.65%); in the Class II sam-

Table I. Shape difference in millimeters for each landmark for each comparison

	Class II			*Class I*			*Class II vs. Class I*		
	6-11	*11-15*	*6-15*	*6-11*	*11-15*	*6-15*	*Age 6*	*Age 11*	*Age 15*
A point	2.52	0.92	2.09	2.24	1.53	2.22	0.92	0.91	1.46
ANS	1.68	0.53	2.11	2.09	1.06	1.89	1.83	2.30	1.93
B point	1.53	0.33	1.67	0.72	0.34	0.99	2.86	2.52	3.20
Basion	1.51	2.40	3.53	3.45	2.51	6.11	2.10	1.98	1.81
Central incisor root apex left	8.17	0.88	8.55	5.44	1.05	5.97	3.00	2.17	2.50
Central incisor root apex right	7.79	0.67	7.99	5.95	0.49	6.04	2.67	3.04	2.93
Gonion left	0.57	1.27	1.82	0.70	2.16	2.36	2.14	3.11	3.41
Gonion right	0.25	1.38	1.41	1.18	1.86	2.03	1.81	2.40	1.69
Infradentale	1.45	0.44	1.38	1.03	0.24	0.86	1.68	1.37	1.29
Mand first molar left	3.61	3.70	2.06	3.62	3.31	2.92	0.16	0.32	0.84
Mand first molar right	2.93	3.58	2.71	3.98	3.14	2.27	2.17	0.86	0.55
Mand incisor edge	2.15	0.75	1.72	1.82	0.62	1.49	0.68	0.58	0.55
Mechanical porion left	1.63	1.95	3.30	1.69	1.93	1.24	4.57	2.29	2.46
Mechanical porion right	1.45	1.95	2.71	1.35	1.89	1.78	3.47	3.52	4.20
Medial orbit left	0.92	1.11	2.12	0.30	1.00	1.29	1.81	1.34	0.77
Medial orbit right	0.84	0.98	1.69	0.51	1.21	1.70	2.04	1.55	1.39
Menton	1.86	1.30	2.93	3.89	1.35	5.33	0.97	2.36	3.38
Nasion	0.40	0.94	0.61	0.05	1.06	1.04	2.81	3.10	2.15
Orbitale left	1.93	1.12	3.21	1.03	0.72	1.76	1.39	0.41	0.77
Orbitale right	0.91	1.19	2.18	1.25	0.93	1.98	0.54	1.49	1.48
Piriform left	1.89	2.07	2.51	1.75	1.40	2.66	1.45	1.53	1.37
Piriform right	2.23	1.89	2.82	2.14	1.02	2.57	1.88	2.00	1.93
Pogonion	1.69	1.18	2.80	3.03	1.94	5.17	1.46	2.70	4.23
PNS	1.83	0.99	0.98	1.24	1.22	0.29	0.62	0.59	0.44
Rhinion	2.09	2.03	1.88	1.13	0.41	1.46	3.10	2.12	4.02
Sella	2.25	1.48	3.57	3.03	1.44	4.60	2.24	0.89	0.92
Supradentale	2.74	0.76	2.19	1.99	1.00	1.13	2.12	2.31	2.53
Max first molar left	3.46	3.87	3.63	3.49	3.40	2.95	1.98	2.39	3.09
Max first molar right	3.35	4.21	4.04	3.91	2.87	3.18	0.82	0.60	2.02
Max incisor edge	3.64	0.18	3.72	3.85	1.20	3.19	0.69	0.24	1.31
Total*	69.29	46.04	83.93	67.86	44.28	78.47	55.98	52.99	60.62
Average*	2.31	1.53	2.80	2.26	1.48	2.62	1.87	1.77	2.02
Median*	1.88	1.18	2.35	1.90	1.21	2.13	1.86	1.99	1.87
SD*	1.79	1.07	1.71	1.51	0.87	1.66	0.98	0.94	1.12
Total skeletal only**	34.18	28.23	49.51	35.80	28.21	50.46	43.81	42.79	46.83
Size difference***	0.78%	6.72%	7.52%	10.30%	5.92%	16.81%	9.60%	0.15%	0.88%

Mand, Mandibular; *max,* maxillary.
*Four rows show statistical analysis of data.
**Row shows total difference in shape for skeletal dental landmarks only.
***Row shows size difference, in percentage, for each comparison.

ple, it appeared 3.52 mm more inferior and medial than the Class I sample (Fig 5).

The magnification for age 11 was 1.0015, making a Class II Division 1 girl 0.15% larger than a Class I Bolton girl (Table I).

Class II versus Class I, age 15

Comparison at age 15 gave a total shape difference of 60.62 mm. Skeletal components accounted for 46.83 mm, or 77.25%, of the total difference. PNS had the least difference, with 0.44 mm (0.72%) in an inferior position. Pogonion had the largest shape difference, with 4.23 mm (6.97%) in a posterior position (Fig 5).

The magnification was 1.0088, making a Class II Division 1 Bolton girl 0.88% larger than a Class I Bolton girl at age 15 (Table I).

Craniofacial groups

Craniofacial groups were created to better interpret the data. Different craniofacial groups had different numbers of landmarks. The data were normalized by dividing the total number of shape changes by the number of landmarks in that group (Table II).

The overall growth analysis showed that the greatest shape change for both Class I and Class II subjects occurred in the dental group during the age

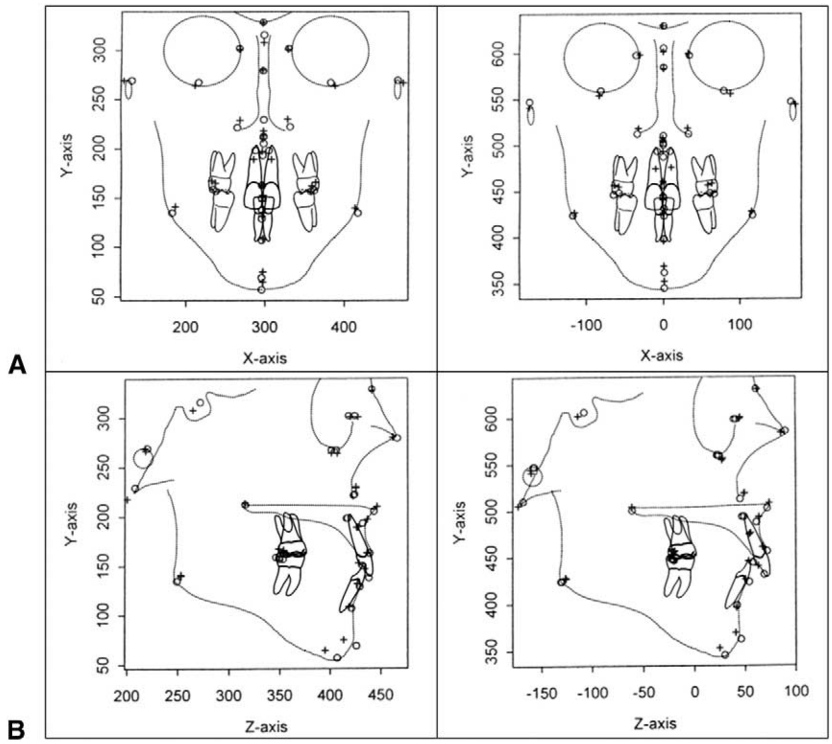

Fig 4. Procrustes fit of landmarks. **A**, (*left*) Class I, age 6 ("+") to age 15 ("o") in frontal and lateral views; **B**, (*right*) Class II, age 6 ("+") to age: 15 ("o") in frontal and lateral views.

6-11 period, followed by the maxilla, during the same period (Table II).

The least amount of change occurred in the maxilla for the Class I subjects at ages 11 to 15. For the Class II group, the mandible showed the least change at ages 11 to 15 (Table II).

Overall analysis showed that the Class II group was growing more vertically than the Class I group.

A tipping of the palatal plane (ANS-PNS) up and forward at ANS and slightly inferior at PNS throughout the age periods was noted for the Class II group compared with the Class I sample. This tipping contributed to the vertical difference in the Class II group.

The mandibular (menton, pogonion, infradentale, and B point) and maxillary (ANS, A point, piriform, and supradentale) anterior landmarks were sagittally coincident in both groups at age 6 (Fig 5). From age 11 to 15, the mandible became progressively retrusive and the maxilla protrusive in the Class II sample. This maxillary protrusion was also noted dentally (Fig 5). In the longitudinal growth comparisons for ages 6-15, both the Class I and Class II subjects showed mandibular changes, but, in Class II subjects, there was less forward and more downward displacement of the landmarks (Fig 4).

When comparing the Classes I and II groups, we see the cranial vault as the major difference at age 6, with the mandible distinctively the major difference at ages 11 and 15 (Table II).

DISCUSSION

Several studies have compared Class II with Class I subjects. It is still debatable whether the most common cause for this discrepancy lies in the maxilla or the mandible.[14,15] We used different methods from most of the previously published studies. This study is longitudinal, descriptive, and 3D, and analyzes shape and size separately. The overall results show that both the maxilla and the mandible are responsible for the skeletal discrepancy between both classifications. This is not evident at age 6 but can be easily seen at later ages.

Even though different craniofacial landmark groups were used and described in this study, it is not assumed that these landmarks fully represent a craniofacial region. The analyses were performed individually for each landmark, and they were never treated as a group that defines the total shape or size of a craniofacial region.

In a study by Buschang et al,[20] the longitudinal mandibular growth of French-Canadian children be-

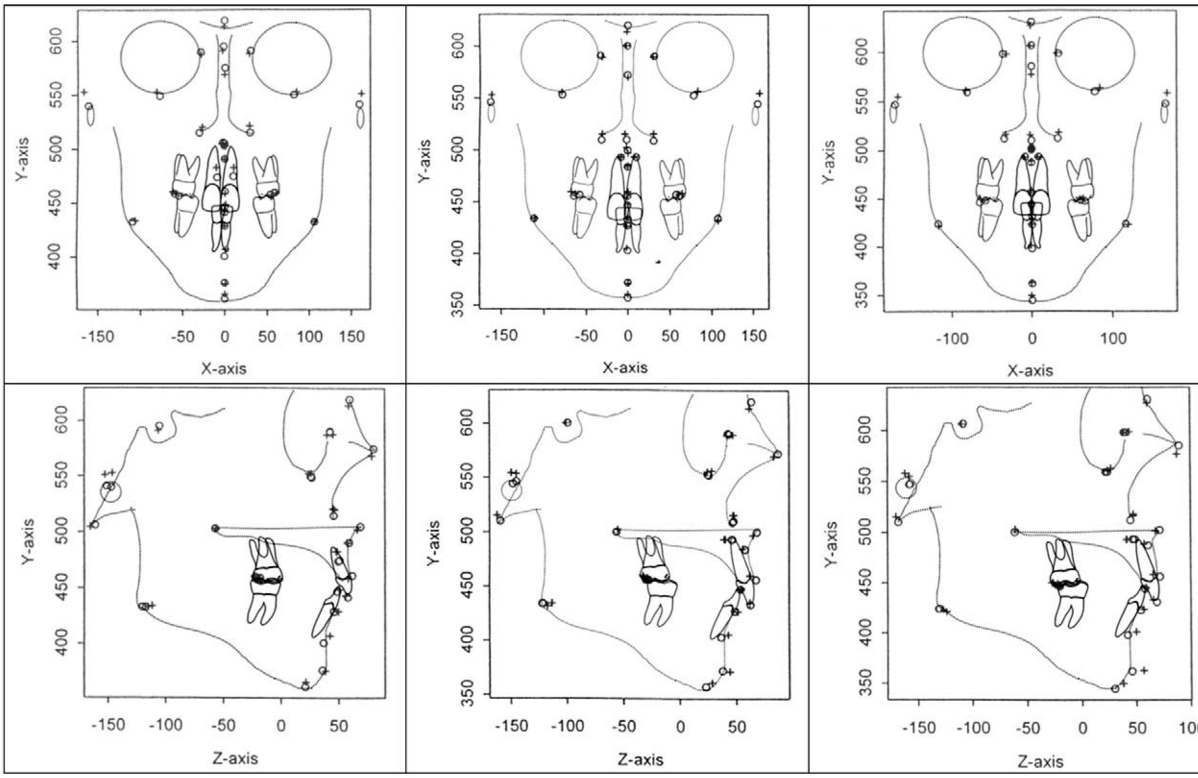

Fig 5. Procrustes fit of landmarks comparing Class II ("o") and Class I ("+") for ages 6 (*left*), 11 (*center*), and 15 (*right*) in frontal and lateral views.

Table II. Average shape change for longitudinal growth of Class I and Class II subjects, and average shape difference for the Class II and Class I comparison at ages 6, 11, and 15

	Class I			*Class II*			*Class II vs. I*		
	Age 6-11	*Age 11-15*	*Age 6-15*	*Age 6-11*	*Age 11-15*	*Age 6-15*	*Age 6*	*Age 11*	*Age 15*
Cranial vault	1.39	1.52	2.48	1.38	1.31	2.30	2.41	1.87	2.00
Maxilla	2.15	1.19	2.12	1.91	1.20	1.79	1.47	1.61	1.61
Mandible	1.23	0.98	2.00	1.76	1.32	2.79	1.82	2.41	2.87
Dental	4.39	2.23	4.30	4.01	2.01	3.50	1.52	1.28	1.72

Values are total shape change in millimeters divided by number of landmarks in that craniofacial group.

tween ages 6 and 15 with normal occlusions and untreated Class II Division 1 malocclusions was compared. The authors concluded that those with Class II Division 1 malocclusions exhibited a tendency toward a more vertical growth direction, which would further increase anteroposterior jaw discrepancies. The findings of our study agree with that conclusion, also showing an increase in the vertical dimension in a Class II subject's growth.

We found that, at age 6, a Class II subject was 9.6% bigger than the Class I girl, but, after age 11, this difference falls to less than 1% (0.15% difference at age 11, and 0.88% at age 15). When analyzing the growth rate, the Class I subjects showed 9.5% more growth from ages 6 to 11; this suggests a catching up phase in size.

Studies published in 1986[21] and 1995[22] reported a similarity in mean growth between males with Class I and II malocclusion in the postpubertal development. Our findings agree with those, indicating that from 11 to 15 years of age the size changes for both Class I and Class II girls have less than a 1% difference in growth rate.

Interestingly, the rate of shape change was very similar for both Class I and Class II at all age comparisons—less than 2 mm of difference. This suggests that shape change occurs at the same rate for both groups but in different directions. The size rate, otherwise, is different during the 6-11 age group but very similar at 11-15.

The transverse discrepancies between untreated Class I and Class II Division 1 malocclusion groups were examined by Bishara et al.[23] They found that the male and female Class I samples had a greater intermolar arch width than the Class II Division 1 malocclusion sample. The findings also indicated that the relative constriction was expressed from the earliest stages of dental arch development continuing into the mixed dentition, and it did not self correct. Our study supports these findings by noting a continuous anterior and medial shift of the maxillary molars from ages 6 to 15. In the Class II Division 1 sample, the maxillary intermolar width was less than the Class I Bolton standards.

CONCLUSIONS

In this sample, there were significant shape differences during the growth and development between Class II and Class I girls.

Overall, the craniofacial complex underwent continuous shape changes from ages 6 to 15 in both samples. In both samples, the amounts of shape change were similar, but the directions were different. Compared with the Class I sample, the Class II sample had (1) a longer facial pattern; (2) the smallest mandibular shape difference at age 6 and the largest at age 15, with mandibular anterior landmarks located inferiorly and more retrusively; (3) more protrusive maxillary landmarks at all ages compared with the Class I sample; (4) similar shape change rates from ages 6 to 15, with different directions; and (5) different size change rates from ages 6 to11, but very similar from ages 11 to 15.

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