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Three-dimensional skeletal and dentoalveolar sagittal and vertical changes associated with cantilever Herbst appliance in prepubertal patients with Class II malocclusion

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Introduction: This study aimed to assess sagittal and vertical skeletal and dentoalveolar changes through the use of 3-dimensional imaging in prepubertal Class II malocclusion patients treated with a cantilever Herbst appliance (HA). Condyle-glenoid fossa positional changes were also quantified. **Methods:** This retrospective cohort study assessed 22 children (11.2 years ± 1.2) consecutively treated with a cantilever HA for 12 months and 11 untreated children (aged 9.3 ± 0.30 years) that served as controls. Cone-beam computed tomography was performed at baseline (T1) and at the end of the observation period (T2). Movements in the regions of interest were measured as linear displacements from cone-beam computed tomography images through algebraic calculations. A Student *t* test for independent samples was used for group equivalence testing at T1, and the treatment differences between T2 and T1 were evaluated by 2 analyses of covariance, one considering the expected growth unit as a covariate and the other with an annualized factor. **Results:** The largest dental movement was a mesial movement of mandibular molars (3.70 mm), whereas the largest skeletal changes consisted of a larger relative length of the mandible (difference of 1.2 mm) in the HA group than in the control group. **Conclusions:** Within the study limitations (retrospective cohort, historical control group, and sample size), 3-dimensional imaging suggests that HA corrected Class II malocclusion in a predominantly prepubertal sample through more dental than skeletal changes. The changes were more significant in the sagittal than in the vertical direction. In addition, relative stability in the condyle-fossa relationship was noted. (Am J Orthod Dentofacial Orthop 2021;■:■-■)

The Herbst appliance (HA) is a fixed functional orthopedic appliance used to correct Class II malocclusion associated with mandibular deficiency. It does not depend on patient compliance, and treatment length ranges from 6 to 18 months.[1-3] In the dentoalveolar region, maxillary teeth tend to move distally, whereas mandibular teeth tend to move mesially.[2] Skeletal changes have also been observed.[2-4] These changes reflect a posterior force vector on the maxillary dentition and an anterior force vector on the mandibular dentition.

The majority of Herbst studies have been performed using 2-dimensional (2D) cephalometric imaging, an approach that cannot adequately assess the complex interactions of 3-dimensional (3D) changes that occur with craniofacial growth and orthopedic treatment.[5] In a recently published systematic review,[6] it was recommended that the portrayed skeletal and dental changes attributed to the HA be interpreted with caution because of the low quality of evidence and publication bias. The

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limitations of this analysis were the small number of high-quality studies and uncontrolled consideration of cephalometric magnifications.

Currently, 3D imaging is widely accessible and able to quantify skeletal and dental measurements more accurately because distortions and superimpositions are eliminated. Many studies[7-9] have attempted to develop reliable methods for assessing data from different time points using 3D imaging. Current methods rely on the voxel-based superimposition of the skull base or landmark-based superimpositions.[7,10,11]

Previous 3D studies about the HA have had some limitations, including small sample sizes,[11-13] control groups treated with fixed appliances,[12-14] and failure to report the changes in the 3 different spatial planes. This retrospective study is the first to assess 3D skeletal and dentoalveolar changes distinctly in the sagittal and vertical planes produced by a cantilever HA in Class II malocclusion, mostly in prepubertal patients using a landmark-based superimposition 3D method.[15] Changes were compared with an untreated Class II malocclusion group. Condyle-glenoid fossa positional changes were also quantified.

MATERIAL AND METHODS

This retrospective study was approved by the local Research Ethics Committee of Positivo University (process no. 2.207.562). The sample consisted of cone-beam computed tomography (CBCT) images from girls aged 9-12 years and boys aged 10-13 years consecutively treated with cantilever HA at the outpatient dental clinic affiliated with a university (Table I). As of 2010, the University's clinic started using CBCT imaging to diagnose patients with significant skeletal discrepancies. All available patients with HA (n = 22) up to 2016 that met the inclusion criteria were considered.

The following inclusion criteria were used: Class II molar relationship with at least half cusp on both sides, pronounced overjet (>4 mm), convex facial profile suggestive of mandibular retrognathia, and an improved facial profile when the mandible was positioned forward. Patients subjected to previous orthodontic treatment, tooth agenesis, and history of abnormal bone growth were excluded from the study.

The HA group included 22 patients (12 boys and 10 girls) with a mean age of 11.2 ± 1.23 years at baseline, treated with a cantilever HA (Fig 1). Seven patients required maxillary expansion with a Hyrax appliance for a mean period of 4 months. This appliance was removed before the placement of the HA. The PMA telescopic system (3M Unitek Abzil, São José do Rio Preto, São Paulo, Brazil) was used. All appliances contained Rollo bands

Table I. Sample characteristics

Characteristics	*Herbst*	*Control*
n	22	11
Boys	12	8
Girls	10	3
Initial age, y	11.2 ± 1.2	9.3 ± 0.30
Time between CBCT scans, y	1.5 ± 0.4	1.9 ± 0.5
CVM stage 1	4	1
CVM stage 2	9	8
CVM stage 3	3	2
CVM stage 4	4	0
CVM stage 5	2	0

(American Orthodontics, Sheboygan, Wis) on the 4 first molars and a cantilever on the mandibular molars. A transpalatal arch was used for the maxillary molars, and a lingual arch with occlusal rests on the deciduous second molars or the mandibular second premolars attached to the mandibular first molars. A construction bite registration was obtained for edge-to-edge incisor relationship, with a mean mandibular advancement of 7.2 mm (max: 10 mm, min: 4 mm) in a single step. The appliance was worn for at least 12 months.

The control group (CG) included 11 patients (8 boys and 3 girls) with a mean age of 9.3 ± 0.30 years at baseline, with the same characteristics as those described for the HA group. These patients underwent an examination at baseline and, for different reasons—especially lack of availability of their parents or legal guardians to bring them to the dental appointments, in addition to financial hardships associated with treatment costs—could not initiate orthodontic treatment. After approximately 18 months, new contact was made with the patients, and they underwent a new examination (including orthodontic records) and were referred to treatment.

CBCT imaging was considered appropriate by the teaching institution for patients with Class II malocclusion with significant skeletal discrepancies.

The patients were grouped on the basis of their skeletal maturation stage, determined by the cervical vertebral maturation (CVM) method proposed by McNamara and Franchi[16] (Table I).

All patients underwent a CBCT scan examination at baseline (T1) and the end of the observation period or up to 7 days after Herbst treatment (T2). The time between CBCT scans in the HA group was, on average, 1.5 years with a standard deviation of 0.4 years. This long period is due to a delay of approximately 4 months in initiating treatment, including the time for maxillary expansion. The average time in the CG was 1.9 years, with a standard deviation of 0.5 years.

Fig 1. HA treatment of a prepubertal patient. **(A)** pretreatment; **(B)** immediately after HA placement; **(C)** HA removed after 12 months of treatment. **(D)** T1 − T2 CBCT superimposition on skull base: *brown,* initial; *green*, final.

CBCT scans were performed with standard head positioning (Frankfurt horizontal plane) at these settings: 120 kVp; 8 mA; 0.3-mm voxel size; scan time, 17.8 seconds; field of view of 170 mm × 170 mm; and patient in maximum intercuspation. An i-CAT (model 9140; Imaging Sciences International, Hatfield, Pa) was used. The CBCT images were exported as digital imaging and communication in medicine files.

CBCT images were analyzed using Avizo software (version 8.1; Mercury Computer Systems, Inc, Berlin, Germany). Landmarks were located on the sagittal plane and positioned on the axial and coronal planes 3 times by a single calibrated examiner (K.L.S.). Spherical digital markers (0.5 mm) were placed to determine the center of each point. Supplementary Figure and Table II show the 3D images and the definitions of the reference points and landmarks.

The methodology employed in this study consisted of 4 steps: identification of landmarks, coordinate system transformation, a superimposition using optimization calculations, and measurement of displacement of the assessed structures.

First, reference points at the skull base were used to establish the coordinate system and plane orientation. The right and left external auditory canals, right and left foramina ovalia, foramen magnum, and a point equidistant from the points at the center of each foramen spinosum (ELSA[17]), were identified.

Later, a coordinate system transformation was performed, subtracting the vector that describes the distance between ELSA and the original position (0, 0, 0) and repositioning all the other anatomic structures.

After that, an optimization problem had to be solved for the CBCT images taken at baseline and at the end of treatment to be superimposed on the Cartesian system. The relative distance and the relationship of angles between the landmarks were calculated on each image, and then an algorithm was developed by using linear algebraic equations for the necessary corrections.

Finally, the face was marked to indicate the skeletal and dental changes and the position of the condyle and mandibular fossa. The total variation observed in the treatment period was calculated by the difference between the distances measured in different periods (T2 − T1). Distance (d) in millimeters was determined by the following equation:

$$\sqrt{(x1-x2)^2+(y1-y2)^2+(z1-z2)^2}.$$

The anatomic distances used in the present study are described in Table II.

Statistical analysis

The normality of the data was assessed by the Kolmogorov-Smirnov test. $P<0.05$ was considered statistically significant. Data were analyzed by SPSS software (version 20.0; IBM, Armonk, NY).

A Student t test for independent samples was used to compare the HA and CG with baseline (T1) values. Because of the difference in time between CBCTs in both groups, the sample had to be adjusted for the final assessment considering differences in expected growth (T2 − T1). Therefore, 2 statistical approaches were used: (1) analysis of covariance with the expected growth unit (EGU)[18] factor. EGU corresponds to an individualized estimate of growth intensity expected to occur in orthodontically untreated patients of the

Table II. Definitions of distances between anatomic structures

Dentoalveolar measurements		*Skeletal measurements*		*Temporomandibular joint measurements*	
ANTEROPOSTERIOR MEASUREMENTS					
ELSA/PC16	Maxillary right first molar at the center of the largest cross-sectional PC area	ELSA/A	Distance between ELSA and A point	ELSA/SRC	Superior right condyle
ELSA/PC26	Maxillary left first molar at the center of the largest cross-sectional PC area	ELSA/B	Distance between ELSA and B-point	ELSA/SLC	Superior left condyle
ELSA/PC36	Mandibular left first molar at the center of the largest cross-sectional PC area	ELSA/RMF	Distance between ELSA and right mental foramen	ELSA/PRC	PRC
ELSA/PC46	Mandibular right first molar at the center of the largest cross-sectional PC area	ELSA/LMF	Distance between ELSA and left mental foramen	ELSA/PLC	PLC
ELSA/IS11	Incisal edge of maxillary right central incisor	ELSA/ANS	Distance between ELSA and ANS	ELSA/SRGF	Superior right glenoid fossa
ELSA/IS21	Incisal edge of maxillary left central incisor	ELSA/PNS	Distance between ELSA and posterior nasal spine	ELSA/SLGF	Superior left glenoid fossa
ELSA/II 31	Incisal edge of mandibular left central incisor	ELSA/Pog	Distance between ELSA and pogonion	ELSA/PRGF	Posterior right glenoid fossa
ELSA/II 41	Incisal edge of mandibular right central incisor	ELSA/GoR	Distance between ELSA and right gonion	ELSA/PLGF	Posterior left glenoid fossa
ELSA/MBA16	Mesial buccal root apex of maxillary right first molar	ELSA/GoL	Distance between ELSA and left gonion	ELSA/ARGF	Anterior right glenoid fossa
ELSA/MBA26	Mesial buccal root apex of maxillary left first molar	PRC/A	Distance between posterior right condyle and A point	ELSA/ALGF	Anterior left glenoid fossa
ELSA/MA36	Mesial root apex of mandibular left first molar	PLC/A	Distance between posterior left condyle and A point		
ELSA/MA46	Mesial root apex of mandibular right first molar	PRC/Pog	Distance between PRC and Pog		
ELSA/A11	Root apex of maxillary right central incisor	PLC/Pog	Distance between PLC and Pog		
ELSA/A21	Root apex of maxillary left central incisor				
ELSA/A31	Root apex of mandibular left central incisor				
ELSA/A41	Root apex of mandibular right central incisor				
VERTICAL MEASUREMENTS					
IOF/PC16	Distance between superior most aspect of the right IOF outer border and maxillary right first molar at the center of PC	ANS/RMF	Distance between ANS and right mental foramen		
IOF/PC26	Distance between the most superior aspect of the left IOF outer border and maxillary left first molar at the center of PC	ANS/LMF	Distance between ANS and left mental foramen		
MF/PC46	Distance between right mental foramen and mandibular right first molar at the center of PC				
MF/PC36	Distance between left mental foramen and mandibular left first molar at the center of PC				

same sex and age at a specific time interval.[18] (2) Analysis of covariance with changes in annualized measurements to control the time difference between radiographs.

Based on the repeated measurements in 3 different periods by the same evaluator, the intraclass correlation coefficient (ICC) was then estimated. The images were remeasured 15 days after the first measurements. The third evaluation was carried out 30 days after the second one. All data from both groups (HA and CG) and baseline measurements for the 3 coordinates of each point (x, y, and z) were used. Dahlberg formula was used to calculate the random error.

RESULTS

For the precision of landmarks, with few exceptions, ICC values were very close to 100%, indicating good reliability. Overall, the ICCs of the landmarks were greater than 0.962, 0.959, and 0.987 on the x-, y-, and z-axes, respectively. The poorest ICC on the x- and y-axes was for B-point, measuring 0.962 and 0.959, respectively. The poorest ICC on the z-axis was for the right infraorbital foramen, measuring 0.987. The random error of most landmarks was <1 mm. The greatest error on the x-axis was for posterior right condyle, measuring 1.03 mm. The greatest error on the y-axis was for root apex of right lower central incisor, measuring 1.24 mm. The greatest error on the z-axis was for B-point, measuring 1.11 mm.

The descriptive statistics of dentoalveolar changes summarized in Table III suggest that, at baseline, the maxillary and mandibular molars were more anteriorly positioned in the HA group than in the CG, with a statistically significant difference for the crowns and roots. The maxillary incisors were more labially positioned, with a statistically significant difference for the crowns of maxillary and mandibular central incisors. The mandibular incisors were in relatively similar positions. Therefore, one can observe that, at baseline, the Class II malocclusion characteristics were more pronounced in the HA group than in the CG because the mean distance between the maxillary and mandibular molars was 5 mm vs 4 mm, whereas overjet had a difference of 7 mm vs 4 mm, respectively, indicating a more severe Class II malocclusion in HA than in the CG.

After treatment, the anterior movement of the crown of maxillary right and left first molars was more limited, with a mean difference of 1.56 mm and 1.30 mm, respectively, compared with the annualized average movement. The mean anterior displacement of the maxillary molars in the HA group was 0.12 mm vs 1.57 mm in the CG.

The mandibular molars in the CG showed a mean anterior movement of 2.01 mm for the left first molar and 2.20 mm for the right first molar. In contrast, the HA group showed a larger anterior movement (3.59 mm and 3.82 mm, respectively). The mean anterior displacement of the mandibular molars, assessed by the ELSA/pulp chamber [PC]36 and ELSA/PC46 measurements in the HA group, was 3.70 mm vs 2.10 mm in the CG.

At T2 − T1, the anterior movement of maxillary incisors was restricted in patients wearing HA. The mandibular right and left central incisors in the HA group revealed the anterior crown movement of approximately 2.0 mm when compared with the CG, with statistically significant differences. The apices of teeth moved 1.93 mm in the CG and 2.92 mm in the HA group, also with statistically significant differences (Fig 2).

In the vertical measurements (infraorbital foramina [IOF]/PC16 and IOF/PC26), the maxillary molars intruded an average of 1.0 mm in both groups with a difference of 0.04 mm in the annualized statistics and 0.28 mm in the EGU statistics, without significant difference.

Regarding vertical measurements, the CG had a mean extrusion of mandibular molars of approximately 0.12 mm (FM/PC36 of 0.01 mm and FM/PC46 of −0.24 mm), compared with extrusion of 0.98 mm (FM/PC36 of −1.08 mm and FM/PC46 of −0.88 mm) in the HA group. There were statistically significant differences in both measurements (Fig 2).

The statistical analysis of the maxillary and mandibular measurements (Table IV) suggests that the maxilla was in a similar position at baseline in both groups, whereas the mandible was anteriorly positioned in the HA group, with a difference of approximately 2.75 mm (85.98 mm for the HA group and 83.23 for the CG) at point B and 3.34 mm at the pogonion (Pog). In addition to these 2 points, the distance of ELSA from the right and left mental foramina (RMF/LMF) and the right and left gonion revealed significant differences at T1. At T2 − T1, these parameters showed no statistical difference, but there was some constraint on the maxilla in the HA group because the anterior movement from point A was significantly smaller than the CG (0.51 mm and 1.23 mm, respectively).

Mandibular length, measured by posterior right condyle (PRC)/Pog and posterior left condyle (PLC)/Pog, had a larger significant increase, with a mean difference of approximately 1.20 mm (PRC/Pog: 1.97 mm and 3.25 mm; PLC/Pog: 1.93 mm and 3.03 mm in the CG and HA group, respectively, for annualized changes), with larger, albeit nonsignificant, anterior movement from point B in the HA group (Fig 3).

The measurement from the mental foramen to the anterior nasal spine (ANS/RMF and ANS/LMF) analyzed

Table III. Dentoalveolar measurements at T1 and the difference in displacements (T2 − T1)

Measurements	Period	CG Mean	CG SD	HA Mean	HA SD	P
Anteroposterior measurements						
ELSA/PC16	T1	54.40	2.11	57.14	3.98	0.015*
	T2 − T1	3.12	0.80	0.29	2.40	0.001†
	T2 − T1	1.66	0.36	0.10	1.68	0.008‡
ELSA/MBA16	T1	54.97	2.10	57.43	3.54	0.042*
	T2 − T1	2.24	1.28	1.17	2.39	0.278†
	T2 − T1	1.15	0.59	0.73	1.58	0.633‡
ELSA/PC26	T1	54.3	1.7	57.0	4.2	0.015*
	T2 − T1	2.7	1.0	0.41	3.08	0.035†
	T2 − T1	1.44	0.46	0.14	2.02	0.073‡
ELSA/MBA26	T1	55.17	1.98	57.24	3.78	0.048*
	T2 − T1	2.74	1.75	1.35	2.42	0.165†
	T2 − T1	1.48	1.12	0.89	1.53	0.352‡
ELSA/PC36	T1	58.5	1.6	62.6	4.4	0.001*
	T2 − T1	3.72	1.35	5.10	2.52	0.060†
	T2 − T1	2.01	0.75	3.59	1.61	0.001‡
ELSA/MA36	T1	67.15	2.27	71.57	4.55	0.001*
	T2 − T1	4.12	1.24	4.77	3.15	0.292†
	T2 − T1	2.29	0.89	3.29	1.86	0.033‡
ELSA/PC46	T1	58.4	2.26	62.9	4.23	0.001*
	T2 − T1	4.03	0.90	5.26	2.14	0.060†
	T2 − T1	2.20	0.58	3.82	1.79	0.002‡
ELSA/MA46	T1	67.48	2.63	71.79	4.42	0.006*
	T2 − T1	4.41	1.31	4.69	2.46	0.614†
	T2 − T1	2.40	0.75	3.39	1.93	0.040‡
ELSA/IS11	T1	82.61	3.49	86.68	4.71	0.017*
	T2 − T1	3.64	1.91	1.13	2.12	0.031†
	T2 − T1	2.03	1.30	0.75	1.46	0.191‡
ELSA/A11	T1	67.43	2.40	70.10	4.19	0.060*
	T2 − T1	3.29	1.29	1.14	1.92	0.008†
	T2 − T1	1.76	0.71	0.80	1.36	0.089‡
ELSA/IS21	T1	82.94	2.64	86.60	5.03	0.010*
	T2 − T1	3.26	0.89	1.30	2.17	0.062†
	T2 − T1	1.79	0.65	0.86	1.50	0.350‡
ELSA/A21	T1	67.56	2.32	69.87	4.42	0.058*
	T2 − T1	2.89	0.98	1.30	1.81	0.027†
	T2 − T1	1.54	0.53	0.93	1.29	0.256‡
ELSA/II31	T1	78.15	3.04	79.1	4.44	0.531*
	T2 − T1	3.25	0.93	5.22	2.28	0.010†
	T2 − T1	1.78	0.60	3.68	1.54	0.001‡
ELSA/A31	T1	79.81	2.34	81.72	4.41	0.115*
	T2 − T1	3.57	1.28	4.06	1.93	0.364†
	T2 − T1	1.95	0.83	2.91	1.46	0.031‡
ELSA/II 41	T1	78.03	3.06	79.09	4.47	0.485*
	T2 − T1	3.30	0.86	5.42	2.37	0.007†
	T2 − T1	1.81	0.59	3.80	1.57	0.001‡
ELSA/A41	T1	79.87	2.06	81.60	4.41	0.136*
	T2 − T1	3.53	1.12	4.08	2.25	0.358†
	T2 − T1	1.92	0.71	2.93	1.64	0.034‡
Vertical measurements						
IOF/PC16	T1	29.47	1.46	30.73	2.67	0.156*
	T2 − T1	1.54	0.91	1.57	1.20	0.947†
	T2 − T1	0.81	0.46	1.05	0.81	0.355‡
IOF/PC26	T1	29.82	1.39	30.98	2.78	0.120*
	T2 − T1	2.22	2.04	1.63	1.20	0.235†
	T2 − T1	1.28	1.34	1.11	0.77	0.666‡

Table III. Continued

		CG		HA		
Measurements	*Period*	*Mean*	*SD*	*Mean*	*SD*	P
MF/PC36	T1	21.37	1.71	20.20	1.95	0.104*
	T2 − T1	−0.01	0.95	−1.56	1.90	0.001†
	T2 − T1	0.01	0.54	−1.08	1.04	0.001‡
MF/PC46	T1	21.34	1.39	19.66	2.21	0.029*
	T2 − T1	−0.43	0.65	−1.15	0.93	0.019†
	T2 − T1	−0.24	0.38	−0.88	0.78	0.018‡

*Student *t* test for independent samples, $P < 0.05$; †Comparison of groups in relation to the difference between T1 and T2, including EGU and T1 evaluation as covariates; ‡Comparison of groups regarding the difference between T1 and T2 considering annualization and including T1 assessment as a covariate.

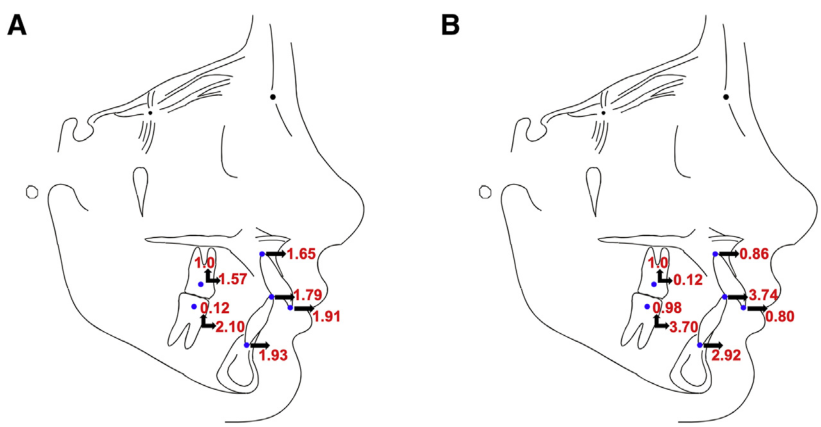

Fig 2. Results for anteroposterior and vertical dentoalveolar measurements. Image representative of the mean (right and left) dentoalveolar displacements, using the annualized mean, in CG **(A)** and HA group **(B)**.

the anteroinferior facial height. The mean difference was 1.29 mm in the HA group and 0.76 mm in the CG, with an average difference of 0.5 mm in the annualized statistics, with no significant difference (Fig 3).

The condyle-mandibular fossa relationship is shown in Table V. Descriptive statistics showed no statistically significant difference between the groups at T1 and T2 − T1, considering EGU or annualized changes.

Both points marked on the mandibular condyle (ELSA/superior right condyle and ELSA/PRC) shifted more anteriorly in the HA group. The upper condyle position was previously displaced by 0.55 mm in the HA group and 0.34 mm in the CG, with no statistical difference. The posterior point shifted by an average of 0.58 mm vs 0.46 mm, respectively, without statistical difference.

In the mandibular fossa, 3 points were marked: superior, posterior, and anterior (ELSA/superior right glenoid fossa, ELSA/posterior right glenoid fossa, and ELSA/anterior right glenoid fossa). The upper position of the mandibular fossa displaced anteriorly with a higher average in the HA group (0.54 mm) than in the CG (0.42 mm). The posterior point of the mandibular fossa was displaced anteriorly with a lower average in the HA group (0.50 mm) than in the CG (0.57 mm). The anterior region of the mandibular fossa displaced anteriorly with a higher average in the HA group (0.53 mm) than in the CG (0.45 mm).

DISCUSSION

Most studies on the effects of HA have been based on 2D images[1] and only a few on 3D imaging.[11-14] The present study is relevant because it uses a 3D method that is different from previously reported, showing skeletal and dental changes in 2 different dimensions

Table IV. Skeletal measurements at T1 and the difference in displacements (T2 − T1)

Measurements	Period	CG Mean	CG SD	HA Mean	HA SD	P
Anteroposterior measurements						
ELSA/A	T1	74.12	1.82	75.49	3.55	0.154*
	T2-T1	2.31	0.82	0.82	1.91	0.047†
	T2-T1	1.23	0.39	0.51	1.30	0.183‡
ELSA/B	T1	83.23	2.29	85.98	4.76	0.032*
	T2-T1	4.10	1.54	4.73	2.71	0.387†
	T2-T1	2.25	1.03	3.34	1.94	0.063‡
ELSA/RMF	T1	78.12	2.26	80.99	4.37	0.018*
	T2-T1	3.63	0.69	4.05	2.40	0.497†
	T2-T1	1.98	0.49	2.89	1.75	0.057‡
ELSA/LMF	T1	78.22	1.81	81.29	4.31	0.008*
	T2-T1	3.82	0.73	3.74	1.93	0.940†
	T2-T1	2.08	0.53	2.63	1.36	0.128‡
ELSA/POG	T1	91.30	2.57	94.67	5.07	0.016*
	T2-T1	3.87	1.05	4.29	2.62	0.471†
	T2-T1	2.08	0.57	3.06	1.90	0.056‡
ELSA/GoR	T1	60.58	3.43	63.64	4.31	0.049*
	T2-T1	3.08	1.61	3.29	1.84	0.642†
	T2-T1	1.75	0.96	2.40	1.52	0.124‡
ELSA/GoL	T1	60.93	20.86	64.28	4.31	0.026*
	T2-T1	2.59	1.50	2.61	2.56	0.825†
	T2-T1	1.50	0.88	1.95	2.07	0.243‡
ELSA/ANS	T1	75.01	1.71	76.38	3.66	0.155*
	T2-T1	1.63	0.81	1.20	2.73	0.863†
	T2-T1	0.85	0.36	0.79	1.86	0.500‡
ELSA/PNS	T1	32.60	1.63	33.27	2.45	0.419*
	T2-T1	0.55	0.67	0.29	1.64	0.862†
	T2-T1	0.32	0.41	0.14	1.16	0.887‡
PRC/A	T1	88.53	3.13	90.91	3.89	0.089*
	T2-T1	2.31	1.59	1.42	1.89	0.544†
	T2-T1	1.23	0.82	0.88	1.47	0.977‡
PLC/A	T1	89.31	3.60	91.14	4.07	0.217*
	T2-T1	2.12	1.50	1.31	1.81	0.399†
	T2-T1	1.11	0.72	0.89	1.23	0.939‡
PRC/POG	T1	104.03	3.45	107.56	4.94	0.042*
	T2-T1	3.72	1.11	4.65	2.23	0.112†
	T2-T1	1.97	0.51	3.25	1.44	0.003‡
PLC/POG	T1	104.20	3.95	107.13	4.66	0.084*
	T2-T1	3.60	0.80	4.32	2.28	0.159†
	T2-T1	1.93	0.42	3.03	1.49	0.007‡
Vertical measurements						
ANS/RMF	T1	50.25	2.10	51.69	4.40	0.213*
	T2-T1	1.29	1.07	1.49	1.92	0.869†
	T2-T1	0.69	0.58	1.11	1.60	0.436‡
ANS/LMF	T1	49.92	2.53	51.43	4.03	0.266*
	T2-T1	1.55	1.47	1.95	1.76	0.621†
	T2-T1	0.83	0.80	1.48	1.77	0.248‡

*Student *t* test for independent samples, $P < 0.05$; †Comparison of groups in relation to the difference between T1 and T2, including EGU and T1 evaluation as covariates; ‡Comparison of groups regarding the difference between T1 and T2 considering annualization and including T1 assessment as a covariate.

individually (sagittal and vertical planes). One of the advantages of this method[15] is the use of points at the skull base that do not change significantly after 5 years of age. Another advantage is the optimization analysis, aiming to minimize the error found in fixed reference positions, readjusting the reference coordinates on the overlay. This study does not imply that one method is better than the other, but for this study, using landmark

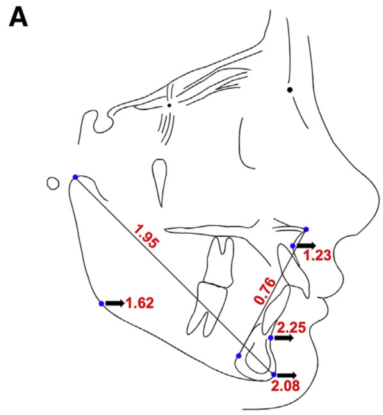

Fig 3. Results for anteroposterior and vertical skeletal measurements. Image representative of the mean (right and left) skeletal displacements, using the annualized mean, in CG **(A)** and HA group **(B)**.

superimposition in planes and determining the distances from the different coordinates to each of these planes may provide the relevant data to answer the question brought in this study. We could have used a voxel-based superimposition method, but it would have been very hard and burdensome to obtain specific coordinate changes of each landmark using such a method.

Lagravère et al[15] proposed an optimization analysis to correct examiner errors. The method is based on 9 equations and 9 variables optimized by a Newton-Raphson root-finding algorithm and used for an accurate solution. The equations determine the distances and angles between points on each image. This allows finding correction values, making the images acquired at different times similar. Thus, anteroposterior and transverse movements can be assessed quantitatively using the coordinate system. Stepanko and Lagravère[19] used this method to evaluate skeletal and dental changes in rapid maxillary expansion treatments. However, there is no report in the literature on the use of this method for evaluating the effects produced by HA. Current methods used in 3D cephalometry either use a landmark-based overall superimposition, which assesses changes in landmarks in different planes, or a voxel-based superimposition with skull base used as a reference, which assesses the differences in colors between the analyzed surfaces and movement from one point to the other, decomposing the 3 coordinate axes and calculating the distances separately.

This study revealed significant differences in dentoalveolar and mandibular measurements between groups at T1. Mandibular length in the HA group was larger than in the CG, probably because these patients were older. In addition, the HA group had a more prominent Class II molar relationship and overjet than did the CG. This difference is also considered clinically relevant because treating a patient with 7 mm of overjet is more difficult than one with 3 mm. However, clinically, all patients had mandibular retrusion and an improved facial profile when the mandible was positioned forward. Therefore, patients in both groups had an indication to be treated with the HA.

After treatment and follow-up, the present study revealed a remarkable constraint on the anterior movement of maxillary molars and mesial movement of mandibular molars during the correction of Class II malocclusion, which was more pronounced at baseline in the HA group. The CG had a mean anterior movement of 1.57 mm for the maxillary molars and 2.10 mm for the mandibular ones, whereas treated patients showed anterior movements of 0.12 mm and 3.70 mm, respectively. Pancherz[2] and Jakobsone et al[20] observed distalization of maxillary molars, whose movements were >2.7 mm. Valant and Sinclair[21] reported that Class II correction is partly because of a distal movement of 2.2 mm of maxillary molars and a mesial movement of 4.9 mm of mandibular molars.

Although the design of the device with a cantilever may suggest that the mandibular molar tended to rotate because of the force of the device on the arm of the Cantilever, this did not happen in this study. When assessing the movement of the mandibular left first molar in the HA group, it can be seen that its crown displaced anteriorly 5.1 mm and the root 4.7 mm, so this could be read as a translation movement. For the mandibular right first molar, it can be seen that its crown displaced anteriorly 5.2 mm and root 4.7 mm, therefore also without undergoing significant inclination. It can be said that the use of the lingual arch with occlusal rests on the deciduous second molars or the mandibular second premolars attached to the mandibular first molars

Table V. Temporomandibular joint measurements at T1 and the difference in displacements (T2 − T1)

Measurements	Period	CG Mean	CG SD	HA Mean	HA SD	P
Anteroposterior measurements						
ELSA/SRC	T1	44.57	2.23	45.04	2.98	0.644*
	T2 − T1	0.54	1.51	1.16	2.13	0.373†
	T2 − T1	0.28	0.79	0.76	1.38	0.279‡
ELSA/SLC	T1	45.81	2.05	45.66	2.66	0.870*
	T2 − T1	0.85	1.20	0.42	1.79	0.309†
	T2 − T1	0.41	0.58	0.34	1.32	0.858‡
ELSA/PRC	T1	44.76	2.32	45.77	2.90	0.321*
	T2 − T1	1.03	1.28	1.11	1.84	0.801†
	T2 − T1	0.54	0.62	0.72	1.21	0.562‡
ELSA/PLC	T1	46.37	2.20	46.55	2.72	0.851*
	T2 − T1	0.78	0.99	0.44	1.89	0.512†
	T2 − T1	0.38	0.45	0.38	1.35	0.977‡
ELSA/SRGF	T1	44.68	2.12	45.20	3.00	0.614*
	T2 − T1	0.57	1.32	1.13	2.10	0.404†
	T2 − T1	0.30	0.69	0.74	1.36	0.308‡
ELSA/SLGF	T1	45.82	2.05	45.78	2.64	0.964*
	T2 − T1	1.12	1.39	0.41	1.76	0.136†
	T2 − T1	0.55	0.68	0.34	1.35	0.627‡
ELSA/PRGF	T1	45.18	2.29	46.50	2.84	0.216*
	T2 − T1	1.33	1.34	0.89	1.91	0.568†
	T2 − T1	0.71	0.65	0.57	1.29	0.936‡
ELSA/PLGF	T1	47.04	2.31	47.39	2.75	0.723*
	T2 − T1	0.87	1.17	0.49	1.83	0.522†
	T2 − T1	0.44	0.57	0.43	1.33	0.936‡
ELSA/ARGF	T1	44.90	2.42	45.07	3.01	0.871*
	T2 − T1	0.42	1.29	1.15	2.32	0.326†
	T2 − T1	0.23	0.68	0.77	1.48	0.264‡
ELSA/ALGF	T1	45.34	1.98	45.47	2.56	0.890*
	T2 − T1	1.33	1.13	0.37	1.82	0.069†
	T2 − T1	0.68	0.54	0.29	1.30	0.362‡

*Student t test for independent samples, $P < 0.05$; †Comparison of groups in relation to the difference between T1 and T2, including EGU and T1 evaluation as covariates; ‡Comparison of groups regarding the difference between T1 and T2 considering annualization and including T1 assessment as a covariate.

may have prevented the molars from tilting. Such rotational movements could produce some changes in the sagittal and vertical dimensions. Moro et al[22] observed that the lingual arch without occlusal rests was not able to withstand the inclination forces placed on the mandibular molars by the cantilevers. In many patients, the lingual arch slipped down on the cingulum of the mandibular incisors and landed on the gingiva behind them. The lingual arch created sores in the gingiva and contributed to procline the mandibular incisors in these patients. Tomblyn et al[3] evaluated the effects of a cantilever Herbst and did not find any problem using a lingual arch with occlusal rests.

With respect to maxillary incisors, they had a mean anterior movement of 1.91 mm in the CG, compared with 0.80 mm in the HA group, showing a statistically significant difference. This indicates a constraint on the anterior movement of incisors in the latter group. This finding is in line with those of previous studies,[2,3,11,22,23] which have reported limited anteroposterior movement during treatment, with a minimum value of 0.5 mm[23] and a maximum value of 2.02 mm.[3] Mandibular incisors showed a protrusion of approximately 1.95 mm more than did those in the CG, with statistical significance in both measurements. The protrusion of mandibular incisors has also been described by other studies.[2,11,20,22] The design of the appliance may influence the outcome because mandibular anchorage increases with the larger number of teeth involved.[1] In the present study, the appliance contained a cantilever and a fixed lingual arch in the mandibular arch, which was not efficient enough to prevent protrusion, but this protrusion could be considered clinically negligible. For a small potential proclination, using a TAD-supported HA may be questionable.

In vertical measurements, the HA group revealed a mean intrusion of 1.0 mm of maxillary molars compared with CG, but no statistical significance was observed. A similar result was obtained by Barnett et al[23] and Flores-Mir et al[24] in their systematic reviews, in which intrusions ranged from −0.4 mm to −1 mm and 0.9 mm, respectively. The mandibular molars were remarkably extruded in the HA group (0.98 mm). Almeida et al[25] and Tomblyn et al[3] obtained the same results for mandibular molars.

The outcomes reveal maxillary constraint, as indicated by ELSA/A. The anterior movement of point A was more pronounced in the CG (1.23 mm) than in the HA group (0.51 mm), showing statistical significance compared with the EGU. The midface length was also determined by PRC/A and PLC/A. The results indicated greater constraint (1.17 mm) in the HA group than in the CG (0.88 mm), but without statistical significance. Pancherz,[4] LeCornu et al,[12] and Pancherz and Fackel[26] found some constraint on maxillary growth. Other studies have reported that HA is not so effective in restricting maxillary growth.[11,19,21,22,27]

The methodology may vary from one study to another, and different outcomes maybe therefore obtained. Wieslander[28] used HA combined with an extraoral appliance and noted a posterior movement of 1.5 mm from point A at the end of treatment and a difference of 2.3 mm when compared with the CG. LeCornu et al[12] used a cantilever HA and assessed movement from point A, corresponding to −1.22 mm for those in the HA group and 1.20 mm in the CG. Valant and Sinclair[21] used an HA with a removable acrylic mandibular splint and observed a distalization of 0.7 mm when they evaluated maxillary movement.

The findings of this study indicate greater mandibular growth (1.2 mm) compared with the CG. Considering that measurement from the posterior condyle to pogonion was evaluated and that this value refers to what remained after subtracting the value that the CG grew without treatment, it can be suggested that 1.2 mm represents greater mandibular growth than in the untreated group. Almeida et al[25] also found a modest but statistically significant increase in total mandibular length (1.6 mm) in HA patients treated during the mixed dentition stage. Barnett et al[23] and Flores-Mir et al[24] reported substantial mandibular growth with HA with bands and splint, respectively. In a retrospective study, Souki et al[14] used 3D imaging and found a 2.2-mm anterior movement of pogonion on the y-axis in the HA group and a 0.5-mm movement in the CG, with a mean 3D mandibular movement of 1.5 mm greater in the HA group in older patients (88% in CS3 or CS4). Other studies have shown larger mandibular growth using HA.[2,4,21,22,29] Lecornu et al[12] observed advancement of the mandible, but with no significant differences in the body of the mandible and the growth of the ramus.

A possible explanation for the small mandibular growth (1.2 mm) in this study may be related to the fact that most HA patients were in the stages of maturation of cervical vertebral 1 and 2, which are considered to be prepubertal. Only 3 patients were in stage 3, and 4 in stage 4, which are quite close to the pubertal growth spurt.[1,6] Nevertheless, the stage of growth assessed by CVM could be a debatable factor, and planning treatment timing-based only on CVM maybe not be fully reliable.[30] Hägg and Pancherz[31] found a steady increase in sagittal condylar growth, from 1.7 mm 3 years before the peak height velocity to 3.6 mm at the peak, followed by a steady decrease to 1.3 mm 3 years after the peak. Zymperdikas et al[32] noted that skeletal changes seem to be more pronounced in patients treated before or during the growth spurt, whereas dentoalveolar changes are more remarkable after the growth spurt. In this study, most patients in the HA group, approximately 60%, were treated before the growth spurt, presenting with more dental changes and very few skeletal changes, despite the constraint on maxillary movement and stimulation of mandibular growth. Consideration should also be given to the impact of measurement error.

Another factor that might have affected the stimulus for mandibular growth could be the mandibular form. Some authors[33] believe that a gonial angle of approximately 122° could result in a better growth response. However, a previous study[13] has not found any significant differences in the movements of the condyles and fossae in mesofacial and brachyfacial patients treated with HA. The present study did not assess the vertical facial pattern of patients, given that the sample was small and could not be further subdivided.

The clinical protocol used in this study might also have influenced the results, as according to a controlled trial carried out by Purkayastha et al,[34] who investigated the effects of HA, the largest skeletal changes occurred with gradual advancement (step by step) of the mandible when compared with single-step advancement, whereas dentoalveolar changes were more pronounced in single-step activation. At odds with these findings, other studies[32,35] have not revealed any difference between gradual and maximum activations for mandibular growth.

Treatment with HA produces anterior movement of the mandibular fossa and condyle, but when the skull base (ELSA) was used as a reference, the movement was relatively small. The anterior region of the mandibular fossa showed a 0.53-mm movement in the HA group and a 0.45-mm movement in the CG, which indicates bone resorption in the former group. The upper region of the mandibular fossa presented a difference of 0.12 mm. The movement of the mandibular condyle was similar to that of the mandibular fossa, with the larger anterior movement of the maxillary and posterior regions in the HA group than in the CG, with a mean difference of 0.21 mm and 0.12 mm, respectively, showing no statistical significance. These findings are similar to those described by Ruf and Pancherz,[36] who observed the same relationship between the movements of the mandibular fossa and condyle after HA treatment. Other authors[12,37,38] also observed anterior remodeling and posterior bone apposition in the HA group. Souki et al[14] reported a significantly larger variation in condylar movement in the HA group than in the CG, with a difference of 1.4 mm in the upper region and of 1.2 mm in the posterior region.

Recently, after evaluating condylar displacement relative to the position of the condyle within the glenoid fossa, Cheib Vilefort et al[39] also found that HA treatment did not change the original condyle-fossa relationship at the time of HA removal, regardless of the stage of skeletal maturation. The condyles remained spatially stable relative to their glenoid fossae after 8 or 12 months of treatment.

The new 3D technology used in this study allowed confirming some concepts that had been addressed in previous studies with 2D cephalometry. As Almeida et al[25] concluded, HA treatment produced a modest but statistically significant increase in total mandibular length. This increase in total mandibular length; however, it was less than that observed in adolescent HA patients in other studies.

The 3D approach did not significantly contradict what 2D studies have reported in the past. The direction and the magnitude (to some extent) of the treatment effects are relatively similar.

By comparing the regions of interest between the HA and CG, validated by the 3D method used in this study, it is possible to suggest that HA helped with the correction of Class II malocclusion and that dental changes were more prevalent, as described by 2D studies. There was an anteroposterior movement of maxillary and mandibular teeth, remarkable changes in the constraint on anterior maxillary movement, a slight increase in mandibular growth, and a negligible difference in the condyle-mandibular fossa relationship.

The changes reported herein refer to the appliance design and the sample evaluated in the present study. Appliance design may also contribute to the variability of reported changes. The bands on first molars supported only by a transpalatal bar and a lingual arch may not afford adequate rigidity for the forces applied to the appliance by the muscles of mastication. More rigid designs using full crowns (first molars and/or first premolars) with rigid cobalt-chrome, stainless steel, or Hyrax expander across the palate could produce different changes.

The major limitation of this study was the relatively small sample size in both groups because a larger study could have shed further light on the changes that occur naturally through normal growth compared with those changes caused by treatment with HA.

The follow-up time between the groups was a limiting factor for several reasons, mainly the unavailability of parents or legal guardians and treatment costs, delaying the implementation of orthodontic treatment, and causing loss to follow-up.

As this was a retrospective study with a convenience sample, similarly matching the groups regarding sex, age, and CVM was a hindrance. Therefore, prospective or retrospective 3D imaging studies with a larger sample size selected consecutively are needed in the future. Ideally, randomized clinical trials should be encouraged.

The sample size is small, as in most previous studies.

CONCLUSIONS

Within the study limitations (retrospective cohort, historical CG, and sample size), 3D imaging used in this study suggests that HA corrected Class II malocclusion in a predominantly prepubertal sample through more dental than skeletal changes.

The value of any individual treatment measurement change alone does not provide a meaningful Class II modification, but when all the relatively small changes are considered simultaneously, an overall positive treatment change is noted.

The changes were more significant in the sagittal than in the vertical dimension. In addition, there was a stable condyle-mandibular fossa relationship after treatment.

AUTHOR CREDIT STATEMENT

Kamilla Leonardo Sangalli contributed to data acquisition, data analysis, data interpretation, and original manuscript preparation; Kamile Leonardi Dutra-Horstmann contributed to data analysis, data interpretation, and original manuscript preparation; Gisele Maria Correr contributed to manuscript review and editing;

Francielle Topolski contributed to manuscript review and editing; Carlos Flores-Mir contributed to conception, study design, and manuscript review and editing; Manuel O Lagravère contributed to conception, study design, and manuscript review and editing; and Alexandre Moro contributed to conception, study design, and manuscript review and editing.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2020.11.045.

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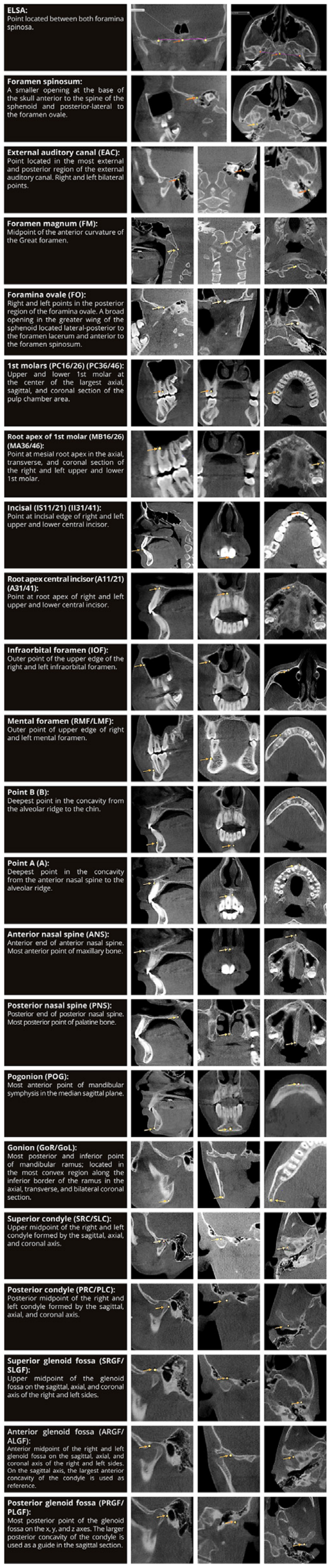

Supplementary Fig. Description of the anatomic landmarks in 3 planes.