Received: 14 June 2020 | Revised: 21 October 2020 | Accepted: 11 November 2020

DOI: 10.1111/ocr.12442

ORIGINAL ARTICLE

Orthodontics & Craniofacial Research WILEY

Changes in the upper airway, hyoid bone and craniofacial morphology between patients treated with headgear activator and Herbst appliance: A retrospective study on lateral cephalometry

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Abstract

Background: The present study compared the treatment changes in the upper airway, hyoid bone position and craniofacial morphology between two groups of children with skeletal class II malocclusion treated with the headgear activator (HGA) and Herbst appliance (Herbst).

Setting and sample population: Orthodontic population from the Faculty of Dentistry of the University of Hong Kong.

Methods: Thirty-four skeletal class II patients treated with the HGA (17 patients, mean age 10.6 ± 1.5 years) and the Herbst (17 patients, mean age 11.0 ± 1.4 years) were matched for sex, age, overjet, skeletal class and mandibular divergence. The patients received lateral cephalometric radiographs (LCRs) at the beginning of treatment (T_1), after treatment (T_2) and at follow-up (T_3). In the HGA group, patients underwent LCRs 7 months before the beginning of treatment (T_0), which were used as growth reference for intra-group comparison. Paired Student's *t* tests were used for intra- and inter-group comparisons ($\alpha = .05$).

Results: Treatment changes (T_2-T_1) did not differ significantly between the groups. However, at follow-up (T_3-T_1) the Herbst group showed a smaller increase than the HGA group in the vertical position of the hyoid bone relative to the Frankfort plane ($P = .013$) and mandibular plane ($P = .013$).

Conclusions: There were no significant differences in the upper airway, hyoid bone position and craniofacial morphology between the groups at the end of treatment. However, the Herbst may provide better long-term control of the vertical position of the hyoid bone than the HGA in children with skeletal class II malocclusion.

KEYWORDS

airway, cephalometrics, class II, functional appliances, hyoid bone

1 | INTRODUCTION

Children with skeletal class II and retrognathic mandible have smaller upper airway than skeletal class I patients,[1] and adults with retruded mandible may have narrower pharyngeal airway than those with mandibular prognathism.[2]

In adults, mandibular advancement devices (MADs) are used to enlarge the upper airway by positioning the mandible anteriorly and, subsequently, the hyoid bone and tongue.[3] However, mandibular growth is not affected, and the effect is present only when the device is used.

The attempt to treat growing patients with airway problems by advancing the mandible dates back to the work of Robin (1934), who suggested orthostatic feeding and use of a mono-block in infants with mandibular hypoplasia.[4] Accordingly, the treatment of children with sleep-disordered breathing (SDB) should aim to increase the airway size while improving the dentoskeletal relationship.[5] Nowadays, functional appliances similar to MADs are also used in children to correct skeletal class II.[6] Although their effects on the airway of growing patients are variable, with studies reporting both an increase in oropharyngeal depth[7] and lack of significant changes,[8] functional appliances are commonly used for correcting craniofacial anomalies and the analysis of their consequences on the airway is relevant.[9,10] In fact, different functional appliances used for the correction of skeletal class II may influence the morphology of both the upper airway and their supporting structures,[8,11,12] which is relevant to treatment planning.[13]

In addition, although some functional appliances may induce a long-term increase in the upper airway size,[8,11] their ability to treat SDB seems to be supported only in the short term.[9,14] Still, skeletal class II deformities are often corrected independently of SDB, and it is important that the treatment is coherent with favourable craniofacial development.[15]

Both the headgear activator (HGA) and the Herbst appliance (Herbst) are used to stimulate mandibular growth and generate different dentoskeletal effects.[16,17] Although the changes in the airway[11,14,18] and hyoid bone position[14,18] related to the HGA and Herbst have been investigated independently, to the best of our knowledge, no study in the literature has compared the two treatments. Thus, the aim of the present study was to compare the changes in the upper airway, hyoid bone position and craniofacial morphology between patients treated with the HGA and the Herbst.

2 | METHODS

2.1 | Subjects

A convenient sample of 34 patients treated by post-graduate students with either the HGA or the Herbst was selected from the patients of the orthodontic department (Faculty of Dentistry, the University of Hong Kong). Patients presenting with skeletal class II (defined either as ANB angle > 5.0° or Wits > −1.5 mm, according to norms for Southern Chinese[19,20]), class II division 1 malocclusion, overjet >5.0 mm and no history of orthodontic treatment were included. Lateral cephalometric radiographs (LCRs), collected retrospectively, were taken in the natural head posture (the patients looked at the reflection of their eyes in a mirror at a distance of 200 cm, and ear posts were used to stabilize the position), at the beginning of treatment (T_1), end of treatment (T_2) and at follow-up (T_3).

The first group consisted of 17 patients (11 boys, 6 girls; mean age, 10.6 ± 1.5 years) consecutively treated with the HGA,[21] with construction bite edge-to-edge (6.0 to 8.0 mm inter-incisal opening) and extra-oral high-pull headgear traction (approximately 500 g on each side).[22] The second group consisted of 17 patients (11 boys, 6 girls; mean age, 11.0 ± 1.4 years) treated with casted splint Herbst, with stepwise advancement and no retention. The patients were matched for sex, age at T_1 (±1.0 years), overjet (±1.0 SD), skeletal class (ANB angle ± 1.0 SD) and mandibular divergence (MP-SN angle ± 1.0 SD).

The sample size was calculated using the retroglossal oropharyngeal airway space as the primary outcome because of its relevance in breathing disorders related to upper airway obstruction,[23] with a power of 80% and statistical significance of 5%, capable of detecting a difference of 2.0 mm and an SD of 2.6 mm (from a previous study[11]) that led to a sample of 16 patients per group.

Ethical approval was obtained from the Institutional Review Boards of the University of Hong Kong and Hospital Authority Hong Kong West Cluster (Reference Number: UW 12-405). The requirement for informed consent was waived by the IRB.

2.2 | Measurements

Lateral cephalometric radiographs were digitized and measured (CASSOS©; Soft Enable Technology Limited). The measurements included three variables for the soft palate, four for the upper airway and three for the hyoid bone. Analysis of the dentofacial morphology included conventional cephalometric measurements, and craniocervical inclination was added to assess changes in vertebral posture (Figure 1).

Measurements were carried out by one orthodontist (M. G.) calibrated by another orthodontist (Y. Y.) experienced in airway image assessment. After a wash-out period of two weeks, 25 cephalograms were randomly chosen and re-assessed by the same operator.

2.3 | Data analysis

The intraclass correlation coefficient (ICC) and Dahlberg's formula[24] were used to assess the reliability and method error, respectively.

Raw values did not account for different treatment durations between the HGA and Herbst groups (for inter-group comparison)

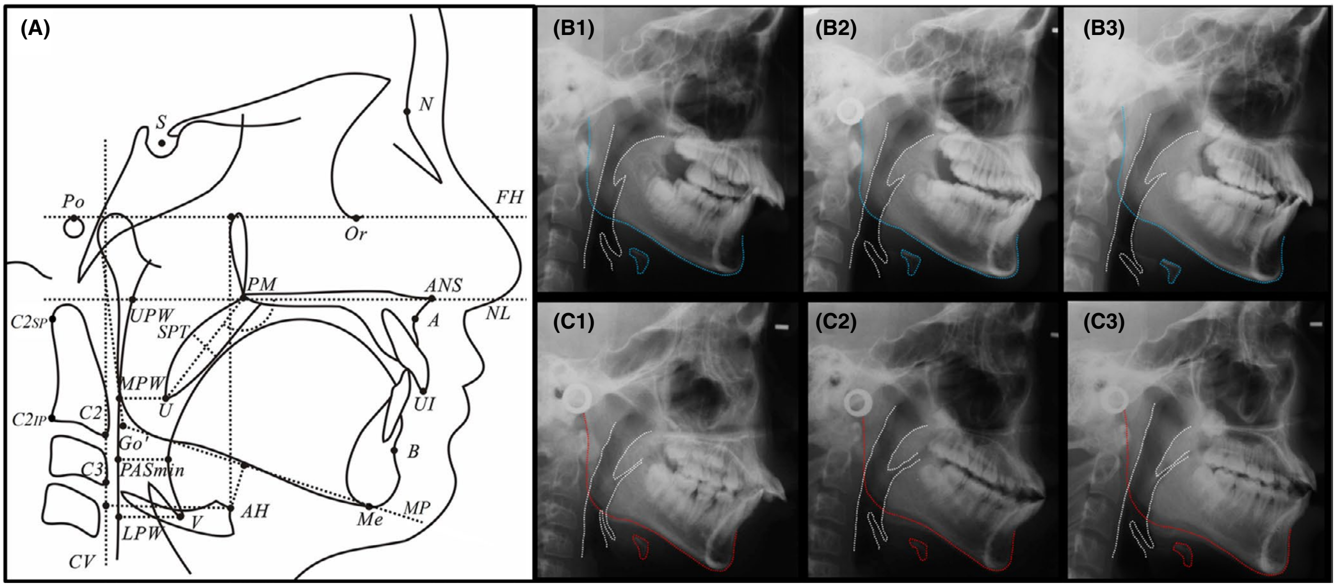

FIGURE 1 Graphical illustration of cephalometric landmarks, reference lines and variables. PM-UPW, nasopharyngeal airway space (distance from PM to UPW); U-MPW, retropalatal oropharyngeal airway space (distance from U to MPW); PASmin, retroglossal oropharyngeal airway space (distance from base of tongue and posterior pharyngeal wall); V-LPW, hypopharyngeal airway space (distance from V to LPW); PM-U, soft palate length (distance from PM to U); SPT, soft palate thickness (maximum thickness of soft palate perpendicular to PM-U); NL/PM-U, soft palate inclination (angle between long axis of soft palate and NL); AH-FH, vertical position of the hyoid bone (distance from AH to FH); AH-CV, horizontal position of the hyoid bone (distance from AH to CV, parallel to FH); AH-MP (distance from AH to MP); SNA (angle between S, N and A); SNB (angle between S, N and B); ANB (angle between A, N and B); MP/SN (angle between SN and MP); TAFH, total anterior face height (distance from N to Me); TPFH, total posterior face height (distance from S to Go′); Overjet (distance from UI to lower incisor labial surface); OPT-SN, craniocervical inclination (angle between SN and OPT, which joins $C2_{SP}$ and $C2_{IP}$) (A). Examples of patients treated with headgear activator (HGA) (B) and Herbst (C) at T_1, T_2 and T_3. Maintenance of a higher position of the hyoid bone can be observed in the patient treated with Herbst than that treated with HGA [Colour figure can be viewed at wileyonlinelibrary.com]

or for growth changes (for intra-group comparison). Thus, growth reference values were obtained from LCRs of the HGA group during a period of 7.0 ± 2.1 months before treatment (T_1-T_0), which were used to estimate the growth changes to be deducted from treatment changes to obtain the net treatment effect.[16,25] In addition, data interpolation was used to compare periods of the same length between the two groups,[16,25] normalizing them at 6.0 months (T_1-T_0)′, 12.0 months (T_2-T_1)′, 21.6 months (T_3-T_2)′ and 36.8 months (T_3-T_1)′ (Table 1).

First, intra-group and inter-group comparisons were performed using non-normalized values at each stage, which did not account for pre-treatment differences between the two groups (Table 2). Then, normalized values of changes during treatment were compared with the expected growth at each stage, representing the net treatment effect in each group (Table 3). Lastly, inter-group comparisons were performed at each stage using normalized values, representing the actual inter-group comparison (Table 4).

The Shapiro-Wilk test was used to evaluate the normality of data distribution. Paired Student's *t* tests were used to determine intra- and inter-group differences. Spearman's coefficient was used to determine the correlation between significant changes in the airway or hyoid bone position and dentofacial parameters. Statistical significance was set at $\alpha = .05$. Statistical analysis was performed using the SPSS software (SPSS© Statistics 20; IBM Corp., USA).

3 | RESULTS

Both groups completed the treatments. In the HGA group, patients used the HGA 10 to 15 hour/d for 8.2 ± 1.5 months. Thereafter, the headgear was removed, and the activator was used at night-time only for retention for 6.9 ± 2.9 months. The total treatment duration was 15.2 ± 2.9 months (T_2-T_1). During follow-up (T_3-T_2), 11 patients received fixed appliance treatment. The average overall observation in the HGA group was 36.8 ± 15.6 months (Table 1).

In the Herbst group, at T_1, the mandible advanced by 4.0 mm, and subsequent advancement(s) eliminated any residual overjet. The total treatment duration was 19.2 ± 6.1 months (T_2-T_1). During follow-up (T_3-T_2), 10 patients received fixed appliance treatment. The average overall observation in the Herbst group was 38.8 ± 12.5 months (Table 1). The cervical posture of patients did not significantly change during the observation period or between the HGA and Herbst groups.

Data were normally distributed, and the results were reported as mean ± SD. The intra-assessor ICCs ranged from 0.897 to 0.996,

TABLE 1 Age of the patients at the beginning of each phase and duration of each phase

	HGA				Herbst			HGA vs Herbst		
	T_0[a]	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*P* value	*P* value	*P* value
Age (years)	10.1 ± 1.6	10.6 ± 1.5	12.0 ± 1.5	13.5 ± 2.0	11.0 ± 1.4	12.6 ± 1.5	14.2 ± 1.6	.069	.004**	.078
	$(T_1\text{-}T_0)$[a]	$(T_2\text{-}T_1)$	$(T_3\text{-}T_2)$	$(T_3\text{-}T_1)$	$(T_2\text{-}T_1)$	$(T_3\text{-}T_2)$	$(T_3\text{-}T_1)$	$(T_2\text{-}T_1)$	$(T_3\text{-}T_2)$	$(T_3\text{-}T_1)$
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*P* value	*P* value	*P* value
Duration (months)	7.0 ± 2.1	15.2 ± 2.9	21.6 ± 15.5	36.8 ± 15.6	19.2 ± 6.1	19.5 ± 9.7	38.8 ± 12.5	.039*	.454	.365
Adjusted duration (months)[b]	6.0	12.0	21.6	36.8	12	21.6	36.8	NA	NA	NA

Note: Growth observation before treatment (T_1-T_0, applicable only to the HGA group), treatment (T_2-T_1) and follow-up (T_3-T_2), in the HGA group (n = 17) and Herbst group (n = 17), respectively. The adjusted duration obtained by interpolation is also reported. The treatment of the HGA consisted of an active phase (8.2 ± 1.5 mo) and a retention phase (6.9 ± 2.9 mo), corresponding to the total treatment phase (T_2-T_1, 15.2 ± 2.9 mo).

Abbreviations: HGA, headgear activator; NA, not applicable.

**P* < .05; ***P* < .01; ****P* < .001.

[a]Applicable only to HGA.

[b]Normalized at 6 mo (for easy comparison with previous studies), 12 mo (for easy comparison with previous studies), and 21.6 and 36.8 mo to consider the Herbst treatment as it would have lasted the same time of the HGA treatment.

and the random errors ranged from 0.4 mm to 0.8 mm for linear measurements and from 0.7 ° to 0.9 ° for angular measurements.

3.1 | Comparison of HGA and Herbst groups at the beginning of treatment, after treatment and at follow-up

At T_1, significant inter-group differences were observed in the nasopharyngeal (*P* = .011), retropalatal oropharyngeal (*P* = .006) and retroglossal oropharyngeal (*P* = .015) depths, which were narrower in the HGA group than in the Herbst group. Furthermore, the hyoid bone had moved to a significantly forward position in the Herbst group (*P* = .042). However, at T_2, differences were found only in the overjet (*P* < .001), which was higher in the HGA group than in the latter. At T_3, only the nasopharyngeal depth (*P* < .001) and overjet (*P* = .030) remained significantly different between the groups. Furthermore, in the HGA group, no significant changes were observed between the beginning of treatment (T_1) and seven months pre-treatment (T_0), except for an increase in the total anterior (*P* = .027) and posterior (*P* = .040) facial height (Table 2). Figure 2 illustrates the changes over time in the airway and hyoid bone position for each appliance.

3.2 | Net treatment effects in each group

During the HGA treatment $(T_2\text{-}T_1)'$, the effect on the airway was not significantly different compared with the expected growth changes. Conversely, significant changes were observed in the dentofacial morphology, such as reduction in the ANB angle (*P* = .001) and overjet (*P* < .001) and an increase in the total posterior facial height (*P* = .002). No significant changes in hyoid bone position were observed at any treatment stage (Table 3).

During the Herbst treatment $(T_2\text{-}T_1)'$, a significant decrease in the soft palate inclination (*P* = .037) was noticed among the airway variables as compared to the expected growth changes. A decrease in the ANB angle (*P* = .005) and overjet (*P* < .001), and an increase in the posterior facial height (*P* = .002) were observed among the dentofacial variables. Similar to the HGA group, no differences were observed with regard to the hyoid bone position (Table 3).

3.3 | Comparison of treatment effects between the HGA and the Herbst

Over the entire observation period $(T_3\text{-}T_1)'$, the Herbst group showed a shorter distance of the hyoid bone from the Frankfort plane (*P* = .013) and mandibular plane (*P* = .013) than the HGA group. Although a smaller increase in these distances appeared during treatment $(T_2\text{-}T_1)'$, significant differences were reached only in a later stage. It is noticeable that both the anterior (*P* = .031) and posterior (*P* = .032) facial height showed a significant decrease in the

TABLE 2 Upper airway, hyoid bone, dentofacial morphology and craniocervical inclination

	HGA				Herbst			HGA vs Herbst		
	T_0[a]	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
Variables	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*P* value	*P* value	*P* value
Upper airway										
PM-UPW (mm)	21.2 ± 2.9	21.2 ± 2.3	21.7 ± 2.9	21.8 ± 1.9	23.6 ± 3.6	23.7 ± 3.7	25.3 ± 1.8	.011*	.114	<.001***
U-MPW (mm)	8.6 ± 1.8	8.7 ± 1.7	10.1 ± 1.4	10.2 ± 2.7†	10.8 ± 2.3	11.5 ± 2.8	11.7 ± 3.1	.006**	.059	.094
PASmin (mm)	7.8 ± 2.1	7.9 ± 2.1	9.6 ± 2.5	9.7 ± 3.4†	9.9 ± 2.7	11.0 ± 3.6	10.9 ± 3.3	.015*	.175	.228
V-LPW (mm)	11.7 ± 3.2	13.1 ± 2.5	15.4 ± 2.3	15.7 ± 3.3††	14.5 ± 3.4	15.6 ± 3.4	16.4 ± 3.2†	.218	.779	.547
Soft palate										
PM-U (mm)	28.6 ± 3.7	29.1 ± 4.0	29.6 ± 3.5	31.7 ± 4.0††	29.3 ± 4.2	30.3 ± 5.0	31.8 ± 5.0†	.814	.540	.910
SPT (mm)	8.2 ± 1.0	8.2 ± 1.0	9.3 ± 1.0	8.9 ± 1.2†	8.1 ± 4.0	9.1 ± 1.4††	8.9 ± 1.9†	.759	.635	.852
NL/PM-U (°)	131.4 ± 4.4	132.1 ± 4.4	129.6 ± 4.5††	127.5 ± 5.4††	132.8 ± 6.9	129.3 ± 6.6†	129.4 ± 7.1	.705	.869	.410
Hyoid bone										
AH-FH (mm)	71.8 ± 5.6	73.6 ± 6.7	76.6 ± 7.0	85.7 ± 8.5†††	76.0 ± 6.7	79.5. ± 7.1†	84.0 ± 9.6†††	.434	.290	.582
AH-CV (mm)	28.7 ± 2.5	29.6 ± 3.3	31.7 ± 3.4†	33.8 ± 3.4†††	31.8 ± 3.4	33.5 ± 4.1††	35.0 ± 4.8†††	.042*	.127	.364
AH-MP (mm)	8.2 ± 5.4	9.4 ± 5.0	8.7 ± 4.6†	13.4 ± 5.3†††	11.9 ± 5.0	9.7 ± 5.3†	11.1 ± 5.7	.273	.610	.317
Dentofacial morphology										
SNA (°)	80.6 ± 4.6	81.0 ± 4.7	80.5 ± 4.6	80.4 ± 4.8	81.4 ± 4.7	81.7 ± 3.9	81.1 ± 4.7	.789	.358	.635
SNB (°)	75.0 ± 4.1	75.1 ± 3.5	76.8 ± 3.3††	76.8 ± 3.9††	76.1 ± 4.0	78.1 ± 4.1†††	77.7 ± 4.8††	.356	.280	.516
ANB (°)	5.6 ± 2.7	5.9 ± 3.2	3.6 ± 3.3†††	5.9 ± 3.0†††	5.4 ± 1.8	3.6 ± 2.2††	3.5 ± 2.4††	.491	.966	.868
MP/SN (°)	34.6 ± 4.8	34.2 ± 3.8	33.9 ± 4.1	34.1 ± 5.1	33.9 ± 4.1	33.5 ± 4.5	32.9 ± 5.6	.783	.777	.479
TAFH (mm)	108.4 ± 6.6	110.0 ± 6.9‡	114.8 ± 7.6†††	121.0 ± 9.2†††	110.2 ± 6.9	117.3 ± 7.5†††	120.4 ± 7.5†††	.915	.331	.821
TPFH (mm)	71.9 ± 4.8	72.6 ± 5.5‡	76.9 ± 5.9†††	82.2 ± 7.8†††	73.4 ± 6.2	79.0 ± 6.8†††	81.9 ± 8.0†††	.744	.362	.901
Overjet (mm)	8.2 ± 2.1	8.4 ± 2.2	3.3 ± 2.5†††	4.5 ± 2.1†††	8.5 ± 2.5	0.1 ± 3.6†††	2.8 ± 2.2†††	.862	<.001***	.030*
Craniocervical inclination										
OPT-SN	100.0 ± 8.3	102.5 ± 8.0	103.1 ± 6.6	103.9 ± 6.1	103.3 ± 10.3	101.8 ± 11.0	102.4 ± 11.6	.636	.725	.671

Note: Non-interpolated values are presented at the beginning of the treatment (T_1), at the end of treatment (T_2) and at the end of follow-up (T_3) in the HGA and Herbst groups, respectively. Inter-group comparison is also shown at T_1, T_2 and T_3. The data presented in the table were not normalized by interpolation, and the expected growth changes were not deducted.

Abbreviation: HGA, headgear activator.

Significant differences respect to T_0: ‡*P* < .05; ‡‡*P* < .01; ‡‡‡*P* < .001.

Significant differences respect to T_1: †*P* < .05; ††*P* < .01; †††*P* < .001.

Significant differences between the two treatments: **P* < .05; ***P* < .01; ****P* < .001.

[a]Applicable only to HGA.

TABLE 3 Intra-group comparison of the upper airway, hyoid bone and dentofacial morphology

	Growth reference	Net HGA changes	Net Herbst changes	Expected growth changes vs HGA changes	Expected growth changes vs Herbst changes
	$(T_1\text{-}T_0)'$	$(T_2\text{-}T_1)'$ ‡	$(T_2\text{-}T_1)'^{a}$	$(T_1\text{-}T_0)'$ vs $(T_2\text{-}T_1)'$	$(T_1\text{-}T_0)'$ vs $(T_2\text{-}T_1)'$
Variables	Mean ± SD	Mean ± SD	Mean ± SD	*P* value	*P* value
Upper airway					
PM-UPW (mm)	0.1 ± 2.2	0.2 ± 2.1	−0.5 ± 2.2	.862	.606
U-MPW (mm)	0.0 ± 1.5	1.1 ± 1.1	0.3 ± 1.7	.222	.676
PASmin (mm)	0.0 ± 1.4	1.5 ± 1.3	0.0.8 ± 2.0	.106	.183
V-LPW (mm)	1.1 ± 3.1	−0.4 ± 2.4	−1.4 ± 2.2	.837	.372
Soft palate					
PM-U (mm)	0.3 ± 1.6	−0.2 ± 1.8	0.1 ± 2.5	.835	.954
SPT (mm)	0.0 ± 1.1	1.0 ± 0.8	0.6 ± 1.1	.124	.406
NL/PM-U (°)	0.6 ± 3.0	−3.2 ± 3.4	−3.6 ± 3.9	.107	.037*
Hyoid bone					
AH-FH (mm)	1.8 ± 4.3	−0.6 ± 3.9	−1.0 ± 4.0	.840	.694
AH-CV (mm)	0.7 ± 1.7	0.3 ± 1.2	−0.3 ± 1.3	.704	.724
AH-MP (mm)	0.9 ± 5.1	−2.3 ± 2.4	−3.1 ± 2.4	.430	.242
Dentofacial morphology					
SNA (°)	0.4 ± 1.8	−1.2 ± 1.4	−0.5 ± 1.7	.278	.596
SNB (°)	0.0 ± 1.2	1.3 ± 1.2	1.4 ± 1.6	.096	.050
ANB (°)	0.4 ± 1.1	−2.5 ± 0.9	−1.8 ± 1.2	.001**	.005**
MP/SN (°)	−0.3 ± 1.7	0.4 ± 1.4	0.5 ± 1.1	.689	.535
TAFH (mm)	1.2 ± 2.3	1.5 ± 1.7	1.8 ± 1.7	.234	.179
TPFH (mm)	0.5 ± 1.1	2.5 ± 1.6	2.5 ± 1.0	.002**	.002**
Overjet (mm)	0.4 ± 1.4	−4.7 ± 2.1	−6.7 ± 3.7	<.001***	<.001***

Note: Comparisons are reported between expected growth changes (calculated based on the pre-treatment changes in the HGA group, and proportional to the duration of each phase) and changes during treatment $(T_2\text{-}T_1)'$ in the HGA and Herbst groups, respectively. Growth comparison was not reported for the follow-up $(T_3\text{-}T_1)'$ because of its excessive duration compared with the growth reference period. Values were normalized by interpolation to an equal duration of each phase between the two treatments.

Abbreviation: HGA, headgear activator.

′Normalized by interpolation.

*$P < .05$; ** $P < .01$; *** $P < .001$.

[a]Adjusted by deducting the expected growth changes.

follow-up $(T_3\text{-}T_2)'$ although changes were not significant during the overall observation period $(T_3\text{-}T_1)'$ (Table 4).

Spearman's correlation coefficient revealed that the vertical changes in the hyoid bone position (AH-FH) were positively related to changes in anterior ($r = .7$, $P < .001$) and posterior ($r = .6$, $P < .001$) facial height during both the follow-up $(T_3\text{-}T_2)'$ and the entire observation period $(T_3\text{-}T_1)'$.

4 | DISCUSSION

4.1 | Effects of treatment on craniofacial morphology

The present study analysed patients with similar skeletal class II, as shown by the pre-treatment ANB values. Patients presented with similar overjet so that similar mandibular advancement could be achieved during treatment. As condylar growth during Herbst treatment may differ between hyperdivergent and hypodivergent skeletal patterns,[26] patients with similar mandibular rotation were selected in the HGA and Herbst groups. Accordingly, at the beginning of treatment, there were no differences in craniofacial morphology between the two groups, and the variables were expected to change equally in the two groups because of growth. However, at the end of treatment, the HGA group showed greater overjet than the Herbst group, which remained significantly different during follow-up. Similarly, greater overjet was observed with the HGA than with the Herbst by Phan et al,[17] who reported significant differences at 6-month and 12-month observations. Nevertheless, the treatment phase was shorter in the HGA group than in the Herbst group, justifying the smaller correction of overjet in the former than in the latter.

TABLE 4 Changes in the upper airway, hyoid bone and dentofacial morphology

	HGA changes			Herbst changes			HGA changes vs Herbst changes					
	$(T_2\text{-}T_1)'$	$(T_3\text{-}T_2)'$	$(T_3\text{-}T_1)'$	$(T_2\text{-}T_1)'$	$(T_3\text{-}T_2)'$	$(T_3\text{-}T_1)'$	$(T_2\text{-}T_1)'$		$(T_3\text{-}T_2)'$		$(T_3\text{-}T_1)'$	
Variables	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Δ	*P* value	Δ	*P* value	Δ	*P* value
Upper airway												
PM-UPW (mm)	0.4 ± 2.1	0.2 ± 2.9	0.6 ± 1.9	−0.3 ± 2.2	1.6 ± 3.4	1.8 ± 5.3	0.7	.352	−1.4	.283	−1.2	.395
U-MPW (mm)	1.2 ± 1.1	0.2 ± 2.3	1.6 ± 2.8	0.4 ± 1.7	0.2 ± 2.8	0.6 ± 2.2	0.8	.101	0.0	.994	1.0	.193
PASmin (mm)	1.4 ± 1.3	0.1 ± 2.4	1.8 ± 3.1	0.7 ± 2.0	−0.1 ± 2.7	0.9 ± 3.3	0.7	.305	0.2	.857	0.9	.416
V-LPW (mm)	1.8 ± 2.4	0.3 ± 3.8	2.6 ± 3.2	0.8 ± 1.8	0.8 ± 1.9	1.7 ± 2.3	1.1	.123	−0.5	.666	1.0	.413
Soft palate												
PM-U (mm)	0.3 ± 1.8	2.1 ± 2.1	2.6 ± 2.5	0.6 ± 2.5	1.5 ± 2.2	2.6 ± 3.9	−0.3	.693	0.6	.440	0.0	.995
SPT (mm)	0.9 ± 0.8	−0.4 ± 1.4	0.7 ± 1.1	0.5 ± 1.1	−0.2 ± 1.5	0.9 ± 1.4	−0.4	.261	−0.2	.714	−0.1	.645
NL/PM-U (°)	−2.0 ± 3.4	−2.1 ± 5.5	−4.5 ± 5.1	−2.4 ± 3.9	0.2 ± 5.9	−3.0 ± 6.5	0.4	.788	−2.2	.315	−1.5	.452
Hyoid bone												
AH-FH (mm)	2.6 ± 3.9	9.2 ± 6.5	12.2 ± 6.6	2.2 ± 4.0	4.4 ± 4.8	7.4 ± 6.3	0.4	.769	4.7	.016*	4.8	.013*
AH-CV (mm)	1.7 ± 1.2	2.1 ± 3.1	4.2 ± 3.2	1.0 ± 1.3	1.4 ± 2.9	2.9 ± 2.8	0.6	.227	0.7	.541	1.3	.187
AH-MP (mm)	−0.4 ± 2.4	4.7 ± 4.3	4.0 ± 4.5	−1.2 ± 2.4	1.4 ± 4.1	−0.8 ± 4.5	0.8	.384	3.3	.069	4.8	.013*
Dentofacial morphology												
SNA (°)	−0.4 ± 1.4	−0.1 ± 2.3	−0.7 ± 2.5	0.3 ± 1.7	−0.5 ± 2.7	−0.2 ± 2.2	−0.7	.208	0.4	.644	−0.4	.627
SNB (°)	1.4 ± 1.2	−0.1 ± 1.6	1.7 ± 2.0	1.4 ± 1.6	−0.4 ± 2.1	1.6 ± 2.3	−0.1	.883	0.3	.628	0.1	.952
ANB (°)	−1.8 ± 0.9	−0.1 ± 2.0	−2.4 ± 1.4	−1.1 ± 1.2	−0.1 ± 1.7	−1.9 ± 1.8	−0.7	.053	0.1	.844	−0.5	.333
MP/SN (°)	−0.3 ± 1.4	0.3 ± 2.1	−0.1 ± 2.4	−0.2 ± 1.1	−0.6 ± 3.1	−0.6 ± 2.3	−0.1	.635	0.9	.252	0.5	.518
TAFH (mm)	3.9 ± 1.7	6.2 ± 4.8	11.0 ± 5.5	4.3 ± 1.7	3.1 ± 3.0	9.7 ± 4.2	−0.3	.454	3.1	.031*	1.4	.154
TPFH (mm)	3.5 ± 1.6	5.3 ± 4.0	9.6 ± 4.1	3.6 ± 1.0	2.9 ± 3.7	8.1 ± 4.7	0.0	.920	2.4	.032*	1.5	.137
Overjet (mm)	−3.9 ± 2.1	1.2 ± 2.4	−3.9 ± 4.4	−5.9 ± 3.7	2.7 ± 4.1	−5.1 ± 3.3	2.0	.085	−1.6	.135	1.3	.198

Note: Changes are reported for each phase in each group, and comparison of the changes during treatment $(T_2\text{-}T_1)'$, follow-up $(T_3\text{-}T_2)'$ and total observation period $(T_3\text{-}T_1)'$ between the HGA and Herbst groups are also reported. Expected growth changes were not deducted from the values reported in the present table. Values were normalized by interpolation to an equal duration of each phase between the two treatments.

Abbreviation: HGA, headgear activator.

′Normalized by interpolation.

P* < .05; ** *P* < .01; * *P* < .001.

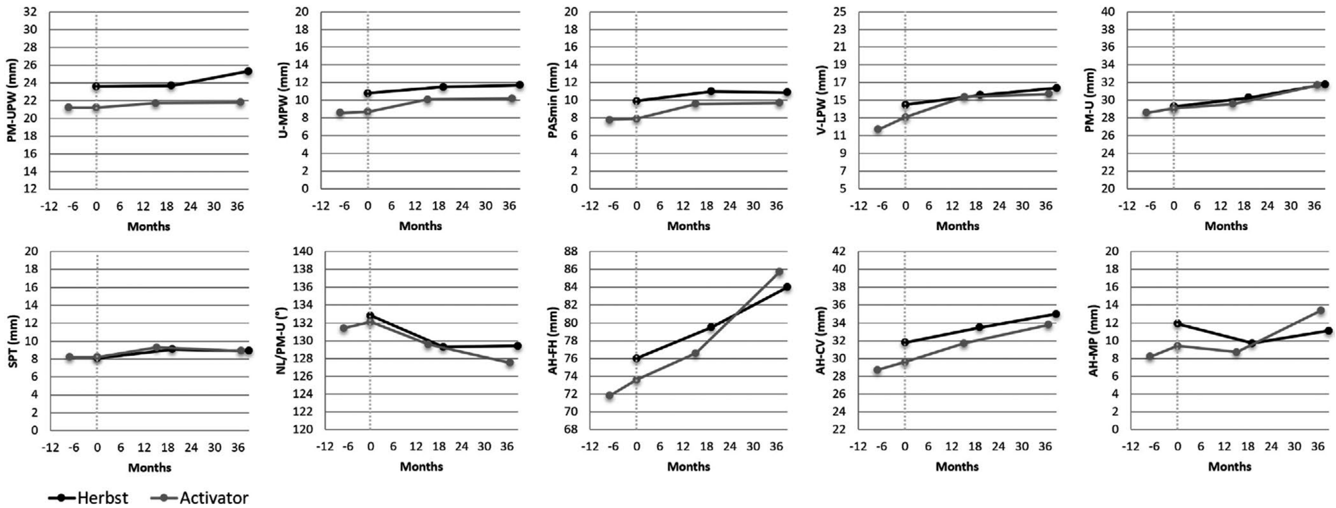

FIGURE 2 Cumulative changes in the upper airway and hyoid bone position with headgear activator (HGA) and Herbst. Values are presented for the baseline of the growth reference period (T_0, applicable only to HGA), beginning of treatment (T_1, 0 mo for both treatments), end of treatment (T_2, 15.2 mo for HGA and 19.2 mo for Herbst) and end of follow-up (T_3, 36.8 mo for HGA and 38.8 mo for Herbst)

Compared with the growth reference, only the decrease in the ANB angle, increase in posterior facial height and decrease in overjet were significant throughout the HGA treatment. Accordingly, Hänggi et al[11] reported a significant decrease in the ANB angle in the HGA group as compared to in the controls, but facial height changes and overjet were not assessed. Similar results were noticed in the Herbst group regarding the ANB angle, posterior facial height and overjet. These findings support the results of Iwasaki et al,[18] who reported a reduction in the ANB angle in the Herbst group as compared to in the control group. These effects were also clinically relevant with respect to growth, represented by changes of −4.7 mm to −6.7 mm in overjet and −1.8° to −2.5° in ANB angle. Thus, both appliances reduced overjet and ANB angle.

Although each treatment generated significant changes in the afore-mentioned parameters, no differences were present between the two appliances at the end of treatment when the normalized changes generated by the two treatments were compared. However, at follow-up, the Herbst group showed a significantly lower increase in the anterior and posterior facial height than the HGA, so the Herbst may offer better skeletal vertical control than the HGA.

4.2 | Treatment effects on airway

Previous studies have reported that the HGA[11,12] and Herbst[18] increased the pharyngeal airway space.

In the present study, at the beginning of treatment, the nasopharyngeal, retropalatal oropharyngeal and retroglossal oropharyngeal spaces were significantly narrower in the HGA group than in the Herbst group. However, at the end of treatment and at follow-up, only the nasopharyngeal space remained significantly different between the groups. In fact, the high-pull headgear of the HGA may have restrained maxillary growth, leading to a rather caudal position of the posterior nasal spine, which affected the nasopharyngeal space.

In particular, when the changes in each group during treatment were compared with the estimated growth, there was no significant change in the airway morphology with either of the appliances. These results are in agreement with those of Ulusoy et al[8] who reported no difference in growth after functional appliance treatment, but showed favourable effects on the nasopharyngeal and oropharyngeal areas throughout the retention period. However, in the present study, comparison with expected growth was not applied to the follow-up phase because extending a 6.0-month growth reference to a 21.6-month follow-up was considered inappropriate. Interestingly, the inclination of the soft palate showed a decrease of 3.6° in the Herbst group, which was significantly different from the expected growth change. This fact can be explained by the mandibular advancement effect, which may have led to a more anterior positioning of the tongue and, subsequently, lower pressure on the soft palate than normally observed. Although a similar effect was probably present in the HGA group, the 3.2° reduction in the inclination of the soft palate was not statistically significant.

However, when the changes generated by the two treatments were compared in terms of airway and soft palate parameters, no significant differences were observed at any treatment phase.

4.3 | Treatment effects on the hyoid bone position

Inferior positioning of the hyoid bone may be related to obstructive sleep apnoea (OSA) in children,[27,28] and it has also been associated with breathing disorders in adults.[29] Thus, functional appliances should also aim to promote favourable development of the airway and their supporting structures in order to reduce the risk of developing OSA later in life.[28]

In the present study, the vertical position of the hyoid bone at the beginning of treatment did not differ between the groups. However, it was significantly more forward in the Herbst group than in the HGA group.

Schutz et al[14] found increased airway space in patients treated with the Herbst and maxillary expansion, despite a stable position of the hyoid bone. In contrast, the present study showed a significant downward position of the hyoid bone after treatment and follow-up, as compared to at the beginning of treatment. Unfortunately, no control group was present in the study of Schutz et al,[14] so it is not possible to determine whether the appliance had any effect compared with normal growth.

The present study showed that both the Herbst and HGA groups did not differ in terms of expected growth changes. Ulusoy et al[8] compared patients treated with an activator without a headgear and untreated controls, finding no significant changes in the vertical position of the hyoid bone.

However, during follow-up, the Herbst maintained the hyoid bone in a more upward position relative to the Frankfurt plane (4.4 ± 4.8 mm) than the HGA (9.2 ± 6.5 mm), which was maintained throughout the 36.8 months of observation. Thus, the Herbst may allow better vertical control of the hyoid bone than the HGA, especially during follow-up. A delayed onset of the treatment effects was previously reported by Ozbek et al[12] and Ulusoy et al[8] who reported no significant effects during treatment with the HGA, and increased pharyngeal airway dimensions only after retention. Perhaps, the HGA led to a greater amount of vertical growth[25] than the Herbst because during the retention phase of the HGA a bilateral open bite is often present, which was probably corrected by dental eruption,[16] whereas the Herbst created a more horizontal vector with smaller vertical effects than the HGA.[16] Overall, since the inferior position of the hyoid bone is an apparent feature of OSA in both children[27,28] and adults,[29] maintaining the hyoid bone in a superior position early in life may be beneficial in preventing predisposed children from developing breathing disorders during adulthood.

4.4 | Limitations

Although head posture, cervical posture and swallowing may affect airway morphology,[30] the natural head posture method has demonstrated good reproducibility.[31] Moreover, data on craniocervical inclination showed no significant variation at different time points, and no swallowing action was present on LCRs. Chronological age may not be representative of skeletal maturity, and inter-group differences in growth velocity could not be excluded.[32] Because of intrinsic differences between the two appliances, the treatment duration differed between groups, and interpolation was necessary to equalize the observation intervals and carry out a direct comparison. In addition, the effect of growth was estimated rather than being calculated from a control group.[25] However, the primary aim of the present study was to compare the HGA with the Herbst, which was not affected by such limitations. Furthermore, the use of an untreated group of patients affected by skeletal class II and dental class II was not possible because of ethical concerns, and healthy subjects may not have been suitable because of different skeletal growth patterns.[16]

Although the initial phases included only functional appliance treatment, some patients in both the HGA and Herbst groups received fixed appliance treatment during follow-up, as also reported by previous studies including a long-term observation of growing patients.[11] However, since a similar number of patients in both groups were treated with fixed appliances, the effect should have been equally distributed. Lastly, despite LCRs offering good reproducibility in the measurement of airway dimensions and hyoid bone position,[30,33] it is a static 2D examination with limitations in the assessment of oropharyngeal movements, and investigating the efficacy of functional appliances in the treatment of SDB was beyond the scope of the present study. Further studies with longer follow-up are needed to understand whether the described effects are stable throughout the years.

5 | CONCLUSIONS

Although no differences were present in the effects of the two appliances at the end of treatment, the Herbst achieved better long-term control of the vertical position of the hyoid bone than the HGA in children with skeletal class II. Even though the primary aim of functional treatments is mandibular growth modification, these results may help orthodontists to choose the most suitable functional appliance also by considering the effects on the structures supporting the upper airway.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. Nabil Samman and Dr Winnie W. S. Choi (Faculty of Dentistry, HKU) for their support, and Ms Samantha K. Y. Li (Faculty of Dentistry, HKU) for her assistance in the statistical analysis.

CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

AUTHOR CONTRIBUTIONS

MG and FS designed the study, and drafted and revised the manuscript. EYLC, CSKT and MTWL acquired the data. MG, FS and UH analysed and interpreted the data. YY, UH and MCW critically revised the manuscript. All authors corrected and approved the final version of the manuscript.

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How to cite this article: Gu M, Savoldi F, Chan EYL, et al. Changes in the upper airway, hyoid bone and craniofacial morphology between patients treated with headgear activator and Herbst appliance: A retrospective study on lateral cephalometry. *Orthod Craniofac Res*. 2021;24:360–369. https://doi.org/10.1111/ocr.12442