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Stepwise advancement versus maximum jumping with headgear activator

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SUMMARY The aim of this study was to compare the effects of stepwise mandibular advancement versus maximum jumping and extended treatment versus early retention. The material was obtained prospectively and consisted of lateral cephalograms taken at the start (T0), after initial (T1), and at the end (T2) of treatment, from two groups of consecutively treated skeletal Class II patients who had undergone therapy with headgear activators. The first headgear activator group, HGA-S (n = 24; mean age 11.9 ± 1.2 years), was treated for 13 months and had 4-mm mandibular advancement every 3 months. The second headgear activator group, HGA-M (n = 31; mean age 11.2 ± 1.5 years), had maximum jumping, 6–8 mm interincisal opening, for a total of 15.4 months, and with reduced wear for the last 6.9 months. The dropout over 12 months was 41 and 46 per cent, respectively. Pre-treatment growth changes were obtained as a reference. An independent t-test was used to determine differences in baseline dentofacial morphology between the groups, a paired t-test for intra-group comparisons, and an independent t-test to evaluate differences between the groups.

The results, in both groups, showed enhanced mandibular prognathism during the initial phase (T0–T1), followed by normal growth (T1–T2), and lower face height enhancement throughout treatment (T0–T2). For both groups, the mandibular plane and occlusal angle increased, possibly enhanced by 'extrusion' of the lower molars. For both groups, maxillary forward growth was restrained only during the initial phase, but the effect remained significant at T2 for the HGA-S group. In the HGA-M group, the lower incisors were protruded, while in the HGA-S group, they were unaffected. The findings indicate that both modes of mandibular jumping resulted in skeletal and dental effects. The length of active treatment seemed to be decisive in maintaining the treatment effects; stepwise advancement had less dental effects.

Introduction

There has been growing interest in the subject of orthopaedic correction of Class II malocclusions in recent years (Graber *et al.*, 1997; Meikle, 2005). Some studies have demonstrated no significant effect, while others have shown enhanced mandibular growth with functional appliance treatment (Pancherz, 1979; Jakobsson and Paulin, 1990; Ghafari *et al.*, 1998; Illing *et al.*, 1998; Keeling *et al.*, 1998; Tulloch *et al.*, 1998, Ruf *et al.*, 2001; Basciftci *et al.*, 2003; Haralabakis *et al.*, 2003; O'Brien *et al.*, 2003a; Phan *et al.*, 2006). The addition of high-pull headgear to the functional appliance possibly combines restraint and redirection of maxillary growth with potentially more forward positioning of the mandible (van Beek, 1982; Dermaut *et al.*, 1992; Wieslander, 1993; Ömblus *et al.*, 1997; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002; Hägg *et al.*, 2003).

Recent experimental studies demonstrated that condylar growth was enhanced with mandibular advancement, and significantly more so with stepwise advancement than with maximum jumping (Rabie *et al.*, 2003a,b). Two clinical studies using fixed or removable functional appliances in combination with headgear have shown that mandibular stepwise advancement tended to result in larger enhancement of mandibular prognathism than maximum jumping (Ömblus *et al.*, 1997; Du *et al.*, 2002), whereas a study using a removable functional appliance without headgear was unable to demonstrate any significant difference between the mode of mandibular jumping (Banks *et al.*, 2004).

It has been reported that after enhancement of mandibular prognathism in a shorter active period with functional appliances, mandibular prognathism became 'subnormal' during the immediate post-treatment period (Pancherz and Hansen, 1986). However, others have found a return to normal mandibular forward growth rate during extended treatment (Hägg *et al.*, 2002). An experimental study has demonstrated that the enhancement of mandibular growth was maintained where the active treatment time was not too short (Chayanupatkul *et al.*, 2003).

The aim of this study was to compare the treatment effects of stepwise advancement versus maximum jumping of the mandible, and extended treatment time versus early retention.

Subjects and methods

The material consisted of the lateral cephalograms from two separate groups of consecutively treated patients with a skeletal Class II malocclusion, obtained at the start (T0), after the initial phase (T1), and at the end of treatment (T2). Inclusion criteria were age 8–16 years, overjet ≥6 mm, ANB ≥4 degrees, molars at least half unit Class II bilaterally, and no previous orthodontic treatment. For both groups, ethical approval was obtained from the Ethics Committee, Faculty of Dentistry, University of Hong Kong. The subjects had been treated by postgraduate students under the supervision of two designated supervisors. The length of the treatment was predetermined to approximately 12 months in both groups.

Headgear activator with stepwise advancement and extended treatment (HGA-S) group

The appliance consisted of a high-pull headgear combined with a modified activator using a screw to advance (by the operator) the mandible 4 mm every 3 months (Figure 1A). All subjects had the mandible advanced 8 mm during the initial phase (T0–T1). Thereafter, the amount of mandibular advancement was dependent on the size of the remaining overjet at T1. The majority of the patients had a third advancement and two subjects had a fourth advancement. The average mandibular advancement was 12 mm. The interincisal opening was 3–4 mm. Extraoral force of approximately 350 g each side was used. The patients were instructed to wear the appliance, with the headgear, 10–14 hours per day during the whole treatment period and compliance was evaluated from a written report. Thirty-four (83 per cent) of the 41 subjects completed the first stage of treatment (T0–T1). Twenty-four patients (6F and 18M; 59 per cent; mean age = 11.9 ± 1.2 years) completed the later phase of treatment (T0–T2) after 13.0 months, and were included in the analysis (Table 1; Figure 2). The dropout (n = 17; 41 per cent) was due to failure (resulting in no advancement of the mandible) of the appliance screw mechanism (n = 5), poor compliance (n = 9), self-discontinuation from treatment (n = 2), and poor attendance (n = 1).

Headgear activator with maximum jumping and early retention (HGA-M) group

The HGA-M, with extraoral high-pull traction, had a construction bite edge-to-edge with 6–8 mm interincisal opening and an extraoral force of approximately 500 g at each side (van Beek, 1982; Figure 1B). The amount of mandibular advancement varied from 9 to 15 mm (average 12 mm). The patients were instructed to wear the appliance 10–14 hours per day during active treatment (T0–T1) and compliance was evaluated from the patients' written reports. During retention (T1–T2), the headgear was removed and the appliance was worn at night only. Forty-three (75 per cent) of 57 subjects completed the first stage of treatment (T0–T1), while 31 (11F and 20M; 54 per cent; mean age = 11.2 ± 1.5 years) completed the retention phase (T1–T2) after a total of 15.4 months, and were subsequently included in this study (Table 1). The dropout (n = 26; 46 per cent) was due to poor compliance in the first 2 months of treatment (n = 12), respiratory problems (n = 6), poor compliance (n = 7), and emigration (n = 1).

Untreated growth data

Growth changes were obtained from lateral cephalograms of the HGA-M group 6 months prior to treatment.

Method of analysis

All radiographs were manually traced twice by one examiner (MCW) with an interval of at least 2 weeks before being digitized and measured by CASSOS software (CASSOS 2001, City University, Hong Kong) using the analysis of Björk (1947) and Pancherz (1982a, b; Figure 2). Data from the two tracings of the same radiographs were then averaged. As the treatment periods differed significantly between the groups, interpolation was undertaken on the results to

Table 1 Age, duration of treatment, and adjusted treatment intervals for headgear activator with stepwise advancement group (HGA-S; n = 24) and headgear activator with maximum jumping group (HGA-M; n = 31) at the start of treatment (T0), after the initial (T1), and late phase of treatment (T2).

	T0/(T0–T1)					T1/(T1–T2)					T2/(T0–T2)				
	HGA-S		HGA-M			HGA-S		HGA-M			HGA-S		HGA-M		
	Mean	SD	Mean	SD	Diff	Mean	SD	Mean	SD	Diff	Mean	SD	Mean	SD	Diff
Age	11.9	1.16	11.2	1.49	0.7	12.6	1.21	11.9	1.48	0.7	13.2	1.24	12.4	1.48	0.8*
Duration	7.2	2.08	8.6	1.70	1.3*	5.8	1.05	6.9	1.98	1.0*	13.0	2.57	15.4	2.64	2.4**
Adjusted duration	6.0		6.0			6.0		6.0			12.0		12.0		

SD, standard deviation.
*P < 0.05, **P < 0.01.

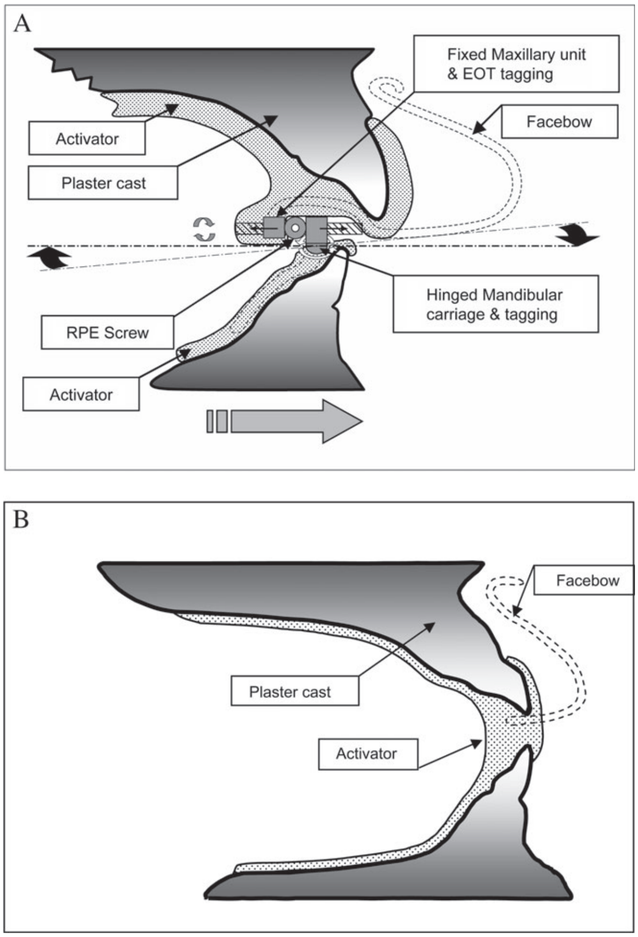

Figure 1 Schematic cross-section of (A) headgear activator appliance with screw mechanism for stepwise advancement and (B) headgear activator appliance with maximum jumping (van Beek, 1982).

represent exactly the same length of compared periods, i.e. 6 and 12 months, respectively (Table 1). Growth changes obtained from the untreated growth data were deducted from treatment changes to obtain the net treatment effects.

Statistical analysis

Statistical analysis was carried out using the Statistical Package for Social Science (SPSS Inc., Chicago, Illinois, USA) software. An independent *t*-test was used to determine differences in baseline dentofacial morphology between both groups. A paired *t*-test was used for intra-group comparisons and differences between groups were evaluated by an independent *t*-test.

Method error

Two weeks after the first measurement, 10 sets of radiographs were selected at random and retraced twice, redigitized, and remeasured. The combined method errors for landmark identification and measurement were tested using two-tailed paired *t*-tests. Differences between the first and second measurements were insignificant.

Results

Comparison of dentofacial morphology

At T0, the HGA-S group had a statistically significantly more severe Class II jaw base relationship and deeper overbite, but at T2 there was no difference in dentofacial morphology between the two groups (Table 2).

There were no statistically significant gender differences for normal growth and treatment changes in either group, except for lower permanent first molar extrusion, which was greater in males in the HGA-S group at T2. Data for both genders were therefore pooled for analysis.

'Growth changes' over 6 months were significant for linear measurement of mandibular forward growth (OLp-Pg), lower incisor, and upper molar eruption (Table 3).

Treatment changes and effects in the HGA-S group

At the end of treatment (T0–T2), the statistically significant treatment effects in the HGA-S group were a reduction of overjet and overbite, restraint of maxillary forward growth, increase of mandibular prognathism and lower face height, improvement of jaw base and molar relationship, retrusion and intrusion of upper incisors, and extrusion of lower molars (Tables 3 and 4; Figures 3 and 4). The mandibular plane angle increased, while the maxillary and mandibular occlusal plane angles decreased and increased, respectively. Most of these effects were pronounced in both the initial (T0–T1) and the late (T1–T2) phases of treatment, except for mandibular prognathism and retrusion of the upper incisors. There were no differences in treatment effects between either treatment phase except for a greater improvement in overjet and molar relationship in the initial treatment phase.

Treatment changes and effects in the HGA-M group

At the end of treatment (T0–T2), the statistically significant effects in the HGA-M group were a reduction of overjet and overbite, increased mandibular prognathism (OLp-Pg) and lower face height, improvement of jaw base and molar relationship, protrusion of lower incisors and molars, and eruption of lower molars (Tables 3 and 4; Figures 3 and 4). The mandibular plane and occlusal plane angles increased. There were statistically significant effects in the initial (T0–T1) treatment phase for these variables, and also for restraint of maxillary forward growth, retrusion of upper incisors and molars, and intrusion of upper incisors. There were statistically significant effects in the retention phase (T1–T2) for increase of lower face height, forward movement and eruption of upper incisors and molars, and eruption of lower molars. Most variables improved during T0–T1, while from T1–T2 some effects rebounded, but mostly normal growth returned.

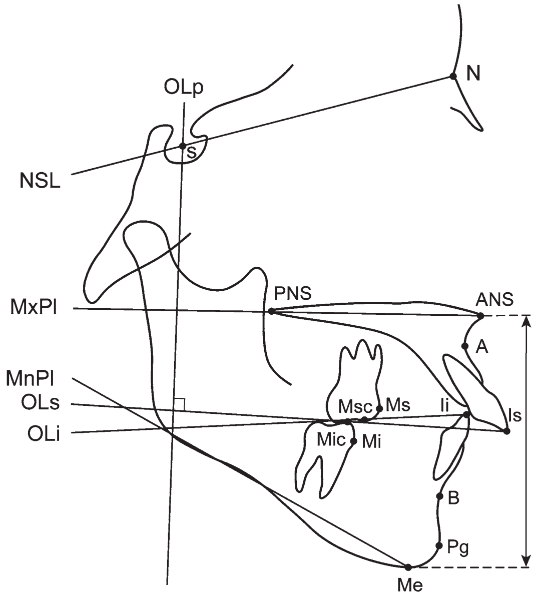

Figure 2 Overjet (mm): Is-OLp minus Ii-OLp; Maxillary prognathism: A-OLp (mm) linear position of the maxillary base, SNA (°) angular measurement of maxillary position; Mandibular prognathism: Pg-OLp (mm) linear position of the mandibular base, SNB (°) angular measurement of mandibular position; Jaw base relationship: A-Pg (mm) jaw base relationship, A-OLp minus Pg-OLp, ANB (°) sagittal jaw relationship; Upper incisor: Is-A (mm) change in the position of the maxillary central incisor, Is-OLp minus A-OLp; Lower incisor: Ii-Pg (mm) change in the position of the mandibular central incisor, Ii-OLp minus Pg-OLp; Molar changes: Ms-A (mm) change in the position of the maxillary permanent first molar, Ms-OLp minus A-OLp; Mi-Pg (mm) change in the position of the mandibular permanent first molar, Ms-OLp minus A-OLp; Ms-Mi (mm) molar relationship, Ms-OLp minus Mi-OLp; Overbite (mm): distance from Ii perpendicular to OLs, Ii-OLs; Face height: Me-MxPl (mm) lower face height; Incisor changes: Is-MxPl (mm) vertical position of the maxillary incisor; Ii-MPl (mm) vertical position of the mandibular central incisor, distance from Ii perpendicular to MnPL; Molar changes: Msc-MxPl (mm) vertical position of the maxillary permanent first molar, distance from Msc perpendicular to MxPl; Mic-MPl (mm) vertical position of the mandibular permanent first molar, distance from Mic perpendicular to MnPl; Rotational changes: SN/MnPl (°) mandibular plane angle; SN/MxPl (°) maxillary plane angle; Occlusal planes: OLs/NSL (°) maxillary occlusal plane angle; OLi/NSL (°) mandibular occlusal plane angle.

Comparison of the treatment effects between the HGA-S and HGA-M groups

There were some statistically significant differences in the treatment effects after therapy (T0–T2) between the HGA-S and HGA-M groups (Table 4). The HGA-S group showed a more pronounced reduction in overbite, improvement of jaw base (ANB) and molar relationship, upper incisor intrusion, and less lower incisor protrusion. The upper occlusal plane closed and the mandibular plane angle increased more in the HGA-S group. During T0–T1, there was a greater improvement in jaw base relationship (ANB), less upper incisor retrusion and lower incisor protrusion, and the upper occlusal plane closed in the HGA-S group. During the later treatment phase in the HGA-S group and the retention phase in the HGA-M group (T1–T2), there were statistically significant differences since treatment effects continued in the HGA-S group, while some treatment effects rebounded in the HGA-M group. The skeletal contribution to the reduction of overjet at T2 was 70 per cent in the HGA-S group and 59 per cent in the HGA-M group (Figure 3). There was no significant difference in treatment changes between the two groups for maxillary and mandibular prognathism, jaw base relationship, and lower face height (Figure 4A–D). The upper incisors were more retruded during T0–T1 in the HGA-M group, but rebounded and became more protruded at T2 than in the HGA-S group (Figure 4E). The lower incisors became protruded but only in the HGA-M group (Figure 4F).

Discussion

This was a prospective study based on two separate groups of consecutive skeletal Class II patients treated with a headgear activator, with two different modes of mandibular jumping. The sampling criteria used were similar but the dentofacial morphology of the groups differed at the start of treatment (T0) for jaw base relationship and overbite, which was more severe in the HGA-S group (Table 3). However, these differences were probably not clinically relevant, and consequently do not affect the validity of this study. The dentofacial morphology of the patients was generally in agreement with that of Caucasian samples treated with the HGA-M appliance (Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002), except that the protrusion of the upper and lower incisors was more pronounced in the present Chinese subjects, which is a documented ethnic difference, also in Class II subjects (Lau and Hägg, 1999).

Interpolations were made to represent intervals of exactly 6 and 12 months, which enables a direct comparison to be made between the two groups and age with the results of previous studies on functional appliances (Ömblus *et al.*, 1997; Bendeus *et al.*, 2002; Du *et al.*, 2002; Hägg *et al.*, 2002, 2003), and a general comparison to be made with other studies on the headgear activator, where the patients were treated on average for 9–11 months (Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998).

The findings suggest that during the actual period neither growth rate nor treatment response differed between the genders, which might indicate that the majority of the patients were pre-pubertal when treated (Pancherz and Hägg, 1985). Since the growth reference data were obtained prior to treatment, the average basic growth rate measured might differ slightly to that observed during the respective treatment periods, but probably to a negligible extent, since the observation periods were short. Growth data obtained prior to treatment of the HGA-M group showed growth in respect of mandibular prognathism and face height, which is consistent with that observed in controls in some previous studies on functional appliances (Nelson *et al.*, 1993; Wieslander, 1993; O'Brien *et al.*, 2003a). However, it

Table 2 Comparison of dentofacial morphology at the start (T0), after 6 months (T1), and after 12 months (T2) of treatment between the headgear activator with stepwise advancement group (HGA-S; $n = 24$) and the headgear activator with maximum jumping group (HGA-M; $n = 31$).

Variables	T0					T1					T2				
	HGA-S		HGA-M			HGA-S		HGA-M			HGA-S		HGA-M		
	Mean	SD	Mean	SD	Difference	Mean	SD	Mean	SD	Difference	Mean	SD	Mean	SD	Difference
Sagittal															
Overjet (mm)	11.0	2.53	10.2	2.32	0.8	7.7	1.84	5.8	2.00	1.9***	5.2	3.38	5.6	2.93	−0.4
Maxillary prognathism															
A-Olp (mm)	77.9	3.91	75.5	4.75	2.4	77.6	4.09	75.4	4.85	2.2	77.8	4.81	76.2	4.78	1.6
SNA (°)	80.8	2.86	79.4	4.34	1.4	80.0	3.27	78.8	4.18	1.3	79.4	4.18	78.9	4.11	0.5
Mandibular prognathism															
Pg-Olp (mm)	78.6	5.20	78.2	5.03	0.5	80.7	5.04	79.9	5.36	0.8	82.6	5.35	81.6	4.87	1.0
SNB (°)	75.0	2.81	74.8	3.58	0.2	75.7	3.01	75.2	3.68	0.6	76.1	2.98	75.7	3.43	0.3
Jaw base relationship															
A-Pg (mm)	−0.8	3.19	−2.7	1.67	1.9*	−3.1	2.92	−4.5	3.18	1.4	−4.8	3.69	−5.4	3.53	0.6
ANB (°)	5.8	1.46	4.6	2.65	1.2*	4.3	1.72	3.6	2.80	0.7	3.3	2.48	3.2	3.05	0.1
Upper Incisor															
Is-A (mm)	14.8	2.13	15.4	2.44	−0.6	14.0	2.13	13.7	2.83	0.3	13.3	2.32	14.5	2.82	−1.2
Lower Incisor															
Ii-Pg (mm)	3.1	3.22	2.5	2.90	0.5	3.1	3.35	3.3	2.85	−0.2	3.3	3.31	3.5	2.78	−0.2
Molar changes															
Maxillary molar (mm)	−21.3	2.21	−20.3	2.73	−1.0	−21.6	2.49	−21.2	2.83	−0.4	−21.7	2.37	−20.3	3.02	−1.5
Mandibular molar (mm)	−24.7	3.44	−25.3	2.29	0.6	−24.4	3.44	−24.6	2.32	0.2	−24.1	3.63	−24.6	2.47	0.5
Molar relationship (mm)	2.6	1.36	2.3	1.52	0.4	−0.3	1.40	−1.0	2.19	0.7	−2.5	3.36	−1.2	2.50	−1.3
Vertical															
Overbite (mm)	5.1	1.52	4.0	1.27	1.0**	3.5	1.74	2.3	1.15	1.2**	2.3	1.63	2.4	1.33	−0.1
Me-MxPl (mm)	63.1	4.14	63.2	4.41	−0.1	65.2	4.10	65.2	4.61	0.1	67.4	4.40	66.7	5.17	0.7
Incisor changes															
Is-MxPl (mm)	30.4	2.52	29.9	2.80	0.5	29.9	2.69	29.4	2.77	0.4	29.5	2.83	30.6	2.95	−1.1
Ii-MPl (mm)	44.0	3.34	43.5	3.15	0.5	44.4	3.60	43.6	3.06	0.8	45.1	3.74	44.2	3.18	0.9
Molar changes															
Msc-MxPl (mm)	23.2	2.20	22.9	2.23	0.4	23.7	2.28	23.1	2.23	0.6	24.3	2.54	23.8	2.37	0.4
Mic-MPl (mm)	32.3	2.57	32.5	2.34	0.2	33.1	2.75	33.3	2.31	−0.2	34.1	3.01	34.2	2.68	−0.1
Rotational changes															
SN/MnPl (°)	33.9	6.22	34.8	4.75	−0.9	34.1	6.53	34.8	4.88	−0.7	34.3	6.60	34.9	4.65	−0.6
SN/MxPl (°)	9.9	2.00	10.5	3.49	−0.6	10.1	2.47	10.7	3.39	−0.6	10.6	2.41	10.4	3.45	0.2
Occlusal planes															
OLs/NSL (°)	22.0	4.46	22.6	4.20	−0.5	21.3	4.50	22.5	3.92	−1.2	20.7	5.30	22.5	4.17	−1.8
OLi/NSL (°)	10.6	5.23	12.4	5.58	−1.9	11.3	4.88	14.0	5.19	−2.6	12.2	5.42	14.8	5.35	−2.7

SD, standard deviation.
$*P < 0.05$; $**P < 0.01$; $***P < 0.0001$.

Table 3 Dentofacial growth and treatment changes during the initial (T0–T1), late (T1–T2), and both phases combined (T0–T2) in the headgear activator with stepwise advancement group (HGA-S; $n = 24$) and headgear activator with maximum jumping group (HGA-M; $n = 31$).

Variables	Growth changes 6 months		HGA-S						HGA-M					
			T0–T1		T1–T2		T0–T2		T0–T1		T1–T2		T0–T2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sagittal														
Overjet (mm)	−0.2	1.43	−3.3***	1.82	−2.3***	2.17	−5.8***	3.65	−4.3***	2.34	−0.3	1.54	−4.6***	3.14
Maxillary prognathism														
A-OLp (mm)	0.8	1.11	−0.3	0.97	0.3	1.72	−0.1	2.50	0.0	0.85	0.7***	1.01	0.7***	0.99
SNA (°)	0.2	1.03	−0.8***	0.95	−0.6	1.46	−1.4**	2.30	−0.6***	0.88	0.2	0.67	−0.4**	0.85
Mandibular prognathism														
Pg-OLp (mm)	1.0*	1.27	2.1***	1.20	1.9***	2.28	3.9***	2.37	1.8***	1.55	1.6***	1.75	3.4***	2.05
SNB (°)	0.2	0.70	0.7***	0.73	0.3**	0.83	1.0***	1.00	0.4**	0.65	0.6***	0.74	0.9***	0.99
Jaw base relationship														
A-Pg (mm)	−0.3	1.45	−2.3***	1.30	−1.6**	2.66	−4.0***	2.88	−1.8***	1.67	−0.9**	1.49	−2.7***	1.96
ANB (°)	0.0	0.99	−1.5***	0.85	−0.9*	1.81	−2.5***	2.30	−1.0***	1.00	−0.4**	0.85	−1.4***	1.18
Upper Incisor														
Is-A (mm)	−0.1	1.30	−0.9***	1.08	−0.6*	1.41	−1.5***	1.64	−1.7***	1.16	0.8***	0.83	−0.9**	1.50
Lower Incisor														
Ii-Pg (mm)	−0.1	0.65	0.1	1.05	0.1	1.48	0.2	1.46	0.8***	1.09	0.2	1.03	1.0***	1.33
Molar changes														
Maxillary molar (mm)	0.2	1.10	−0.2	1.03	−0.1	1.52	−0.4	1.53	−0.8***	1.03	0.9***	0.77	0.0	1.38
Mandibular molar (mm)	0.1	0.59	0.4*	0.76	0.2	0.79	0.7*	1.23	0.7***	0.72	0.1	0.79	0.7***	0.87
Molar relationship (mm)	−0.1	0.95	−2.9***	1.48	−2.0***	2.27	−5.1***	3.56	−3.3***	1.72	−0.1	1.22	−3.4***	2.09
Vertical														
Overbite (mm)	0.3	0.88	−1.6***	1.14	−1.1**	1.66	−2.8***	1.81	−1.7***	1.18	0.1	0.89	−1.6***	1.30
Me-MxPl (mm)	0.5	1.03	2.1***	1.17	2.2***	1.96	4.3***	2.05	2.1***	0.98	1.5***	0.95	3.5***	1.34
Incisor changes														
Is-MxPl (mm)	0.3	0.63	−0.6**	0.96	−0.3*	0.77	−0.9**	1.24	−0.5**	0.88	1.2***	0.93	0.7***	0.93
Ii-MPl (mm)	0.4*	0.49	0.4**	0.71	0.7**	1.00	1.0***	1.27	0.1	0.64	0.6***	0.69	0.7***	0.83
Molar changes														
Msc-MxPl (mm)	0.5*	0.49	0.4**	0.67	0.7**	1.13	1.0***	1.10	0.2	0.66	0.8***	0.57	1.0***	0.71
Mic-MPl (mm)	0.4	0.54	0.8***	0.71	1.0***	0.71	1.8***	1.03	0.8***	0.49	0.9***	0.80	1.7***	0.84
Rotational changes														
SN/MnPl (°)	−0.3	0.68	0.2	0.84	0.1	1.49	0.4	1.60	0.0	0.81	0.1	0.97	0.1	1.00
SN/MxPl (°)	0.1	0.75	0.2	1.25	0.6*	1.08	0.7	1.40	0.2	0.77	−0.2	0.73	0.0	0.91
Occlusal planes														
OLs/NSL (°)	0.2	1.11	−0.7*	1.28	−0.6	1.53	−1.3**	2.11	0.0	0.99	−0.1	1.06	−0.1	1.40
OLi/NSL (°)	−0.6	1.39	0.8	2.04	0.7	2.57	1.6*	2.87	1.5***	1.74	0.9*	2.22	2.4***	2.60

SD, standard deviation.
$^*P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Table 4 Dentofacial treatment effects during the (initial T0–T1, late T1–T2, and combined T0–T2 phases) in the headgear activator with stepwise advancement group (HGA-S; $n = 24$) and headgear activator with maximum jumping group (HGA-M; $n = 31$).

Variables	HGA-S							HGA-M							HGA-S versus HGA-M		
	T0–T1		T1–T2		T0–T1 versus T1–T2	T0–T2		T0–T1		T1–T2		T0–T1 versus T1–T2	T0–T2		T0–T1	T1–T2	T0–T2
	Mean	SD	Mean	SD	Difference	Mean	SD	Mean	SD	Mean	SD	Difference	Mean	SD	Mean	Mean	Mean
Sagittal																	
Overjet (mm)	−3.1***	1.63	−2.1***	1.79	−1.0*	−5.4***	2.63	−4.1***	3.10	−0.1	2.22	−4.1***	−4.2***	4.86	1.0	−2.0***	−1.2
Maxillary prognathism																	
A-OLp (mm)	−1.0***	1.06	−0.5	1.41	−0.1	−1.6*	1.84	−0.8*	1.68	0.0	1.36	−0.8*	−0.8	2.59	−0.2	−0.5	−0.8
SNA (°)	−1.0***	1.01	−0.8*	1.24	−0.2	−1.9**	1.69	−0.8**	1.55	−0.1	1.32	−0.7**	−0.9	2.57	−0.2	−0.7*	−1.0
Mandibular prognathism																	
Pg-OLp (mm)	1.1**	1.25	0.8	1.78	−0.3	1.9**	1.83	0.7*	1.94	0.6	2.46	0.1	1.4*	3.66	0.4	0.2	0.5
SNB (°)	0.5**	0.70	0.1	0.76	−0.4	0.7*	0.82	0.2	0.96	0.4	1.23	−0.2	0.5	1.67	0.3	−0.3	0.2
Jaw base relationship																	
A-Pg (mm)	−2.1***	1.39	−1.4*	2.06	−0.7	−3.5***	2.19	−1.5**	2.47	−0.7	2.19	0.8	−2.2**	4.02	−0.6	−0.7	−1.3
ANB (°)	−1.5***	1.56	−0.9*	1.41	−0.6	−2.6***	1.71	−1.0**	1.68	−0.4	1.33	0.5**	−1.4**	2.69	−0.5*	−0.5	−1.2*
A,B on OP (mm)	−1.5***	0.93	−0.6	2.02	−0.9	−2.3*	2.59	−1.4**	2.82	−0.6	2.72	0.8	−2.0*	4.96	−0.1	0.0	−0.3
Upper Incisor																	
Is-A (mm)	−0.8*	1.21	−0.5	1.35	−0.3	−1.4*	1.46	−1.7***	1.98	0.9**	1.51	2.6***	−0.7	3.20	0.9**	−1.4***	−0.7
Lower Incisor																	
Ii-Pg (mm)	0.2	0.86	0.2	1.09	0.0	0.5	1.08	0.9***	1.35	0.3	1.17	0.6*	1.3***	1.90	−0.7**	−0.1	−0.8*
Molar changes																	
Maxillary molar (mm)	−0.5	1.07	−0.4	1.30	0.1	−0.9	1.30	−1.1**	1.68	0.6*	1.41	1.7***	−0.5	2.83	0.6*	−1.0***	−0.4
Mandibular molar (mm)	−0.3	0.68	0.2	0.68	−0.1	0.5	0.93	0.6**	1.00	0.0	0.87	−0.6*	0.5*	1.43	−0.3	0.2	0.0
Molar relationship (mm)	−2.8***	1.22	−1.9***	1.66	0.9*	−4.9***	2.45	−3.2***	2.04	0.0	1.80	3.2***	−3.2***	3.27	0.3	−1.9***	−1.7*
Vertical																	
Overbite (mm)	−1.9***	1.00	−1.4***	1.28	−0.5	−3.4***	1.36	−2.0***	1.74	−0.2	1.13	−1.8***	−2.2***	2.46	0.1	−1.2**	−1.2**
Me-MxPl (mm)	1.6***	1.10	1.7***	1.51	−0.1	3.3***	1.56	1.6***	1.56	1.0***	1.34	0.6*	2.5***	2.59	0.0	0.7	0.8
Incisor changes																	
Is-MxPl (mm)	−0.9***	0.76	−0.6**	0.69	−0.3	−1.6***	0.95	−0.8***	1.19	0.9***	1.09	−1.7***	0.1	1.70	−0.1	−1.5***	−1.7***
Ii-MPl (mm)	0.0	0.60	0.3	0.75	−0.3	0.3	0.91	−0.3	0.95	0.2	0.84	0.9*	−0.1	1.45	0.3	0.1	0.4
Molar changes																	
Msc-MxPl (mm)	0.0	0.55	0.2	0.83	0.2	0.1	0.81	−0.2	0.84	0.3*	0.76	0.6**	0.1	1.23	0.2	−0.1	0.1
Mic-MPl (mm)	0.4*	0.61	0.7***	0.62	0.3	1.1***	0.79	0.4**	0.75	0.5**	1.02	0.1	1.0**	1.49	0.0	0.2	0.2
Rotational changes																	
SN/MnPl (°)	0.5*	0.76	0.5	1.11	0.0	1.0*	1.20	0.3	1.07	0.4	1.29	−0.1	0.7*	1.88	0.2	0.1	0.3
SN/MxPl (°)	0.0	0.96	0.4	0.91	−0.4	0.4	1.06	0.1	1.25	−0.4	1.13	0.5*	−0.3	2.04	−0.1	0.8**	0.7*
Occlusal planes																	
OLs/NSL (°)	−0.9**	1.16	−0.8*	1.31	−0.1	−1.7**	1.62	−0.2	1.61	−0.3	1.62	−0.1	−0.5	2.86	−0.7*	−0.5	−1.2**
OLi/NSL (°)	1.3**	1.65	1.3*	1.99	0.0	2.7***	2.16	2.1***	2.58	1.5*	3.06	0.6	3.6***	4.74	−0.8	−0.2	−0.9

SD, standard deviation.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

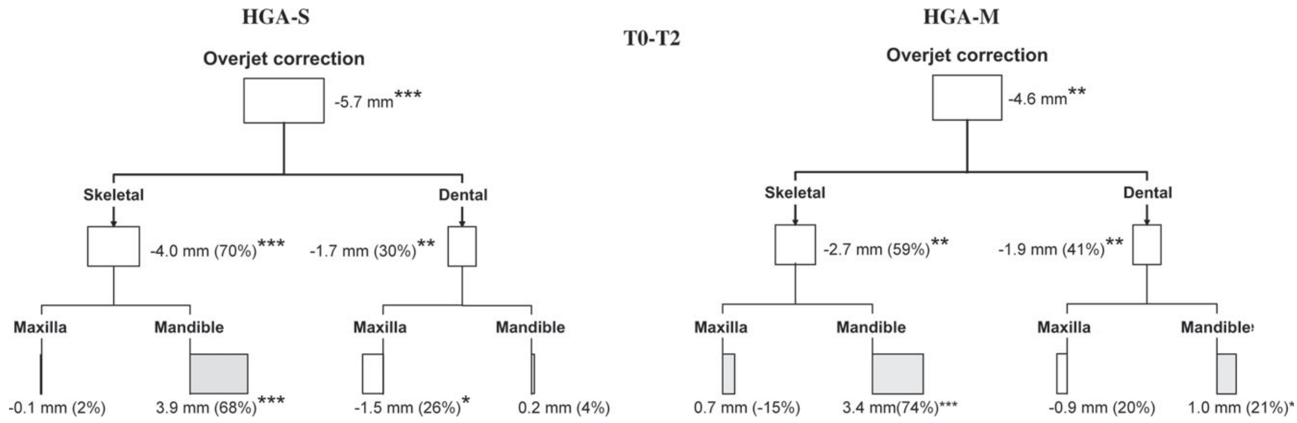

Figure 3 Maxillary and mandibular skeletal and dental treatment changes contributing to overjet correction (Pancherz, 1982a) for the total treatment period (T0–T2). **P* < 0.05, ***P* < 0.01, and ****P* < 0.001.

should be noted that in other studies the controls showed practically no mandibular growth (Ömblus *et al.*, 1997; Illing *et al.*, 1998).

Metric cephalometric measurements are demonstrably more accurate (Bookstein, 1997), but angular measurements are more commonly reported in the orthodontic literature, and have therefore been included.

In any functional appliance treatment, whether with fixed or removable devices, there is a dropout rate. The dropout figure sometimes represents only patients who have left the study (Tulloch *et al.*, 1998) but it often includes, as in the present research, non-compliant patients (Ömblus *et al.*, 1997; Ghafari *et al.*, 1998; Bendeus *et al.*, 2002; O'Brien *et al.*, 2003a,b). The dropout rate in the initial treatment phase of this study (T0–T1) was 17 per cent in the HGA-S group and 25 per cent in the HGA-M group. These figures are comparable with other investigations with similar observation periods (Ömblus *et al.*, 1997; Illing *et al.*, 1998; Bendeus *et al.*, 2002; Banks *et al.*, 2004). However, the dropout rate at the end of the present study (T2) was over 40 per cent in both samples. This was towards the higher end of that reported in other studies on removable functional appliances, which varied from 6 to 40 per cent (Nelson *et al.*, 1993; Ömblus *et al.*, 1997; Altenburger and Ingervall, 1998; Illing *et al.*, 1998; Keeling *et al.*, 1998; Bendeus *et al.*, 2002). Dropout usually increases with time, but the age of the sample seems to be an important factor, as observed from a comparison between two recent studies on the Twin Block (TB; O'Brien *et al.*, 2003a,b). In that investigation, the younger sample had a dropout rate of 18 per cent, whereas 3-year-old subjects had a dropout rate almost twice as large. In the later study, it was also reported that the dropout rate of patients treated with the fixed functional Herbst appliance was approximately half that of those treated with the TB appliance. There might be fewer dropouts in a patient sample treated by a single, 'committed', clinician than in a one treated by a larger number of clinicians. The patients analysed in this study were definitely compliant and submitted written reports throughout the study, but still it has to be borne in mind that orthodontic patients have been stated to over report compliance (Brandão *et al.*, 2006).

The treatment effect on overjet was statistically significant with both devices after both 6 (T1) and 12 (T2) months of treatment (Table 4), which is consistent with previous studies of the HGA-M appliance (Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002). However, the overjet continued to decrease in the late phase in the HGA-S group only, and at the end of treatment (T2) there was no difference between the two groups (Figure 4G). Restraint on maxillary forward growth was found with both devices after 6 months (T1) and while this disappeared, after 6 months of retention (T2) in the HGA-M group, it became more pronounced in the HGA-S group after extended treatment. In one study, there was no restraint of maxillary growth after 6 months of treatment, whereas after a further 6 months of treatment there was an effect (Bendeus *et al.*, 2002) similar to that reported after 9–11 months of treatment (Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998). In the present study, mandibular growth was accelerated with both devices after 6 and 12 months of treatment, which is in agreement with all but one of the other studies, which indicated that mandibular growth was unaffected (Bendeus *et al.*, 2002). However, the enhancement of mandibular prognathism reached a statistically significant level only during T0–T1 similar to that reported for the Herbst appliance (Hägg *et al.*, 2002). The upper incisors were retruded with both devices during T0–T1, but relapsed during T1–T2 in the HGA-M group. This was similar to the pattern observed by Bendeus *et al.* (2002) that there was no lasting effect after 12 months of treatment with HGA-M. At T2, the upper incisors were retruded in the HGA-S group, which is in agreement with the observations made after 9 and 11 months with the HGA-M appliance in two previous studies (Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998). The mandibular incisors became protruded with the HGA-M appliance in this study at T1 and T2, but no such

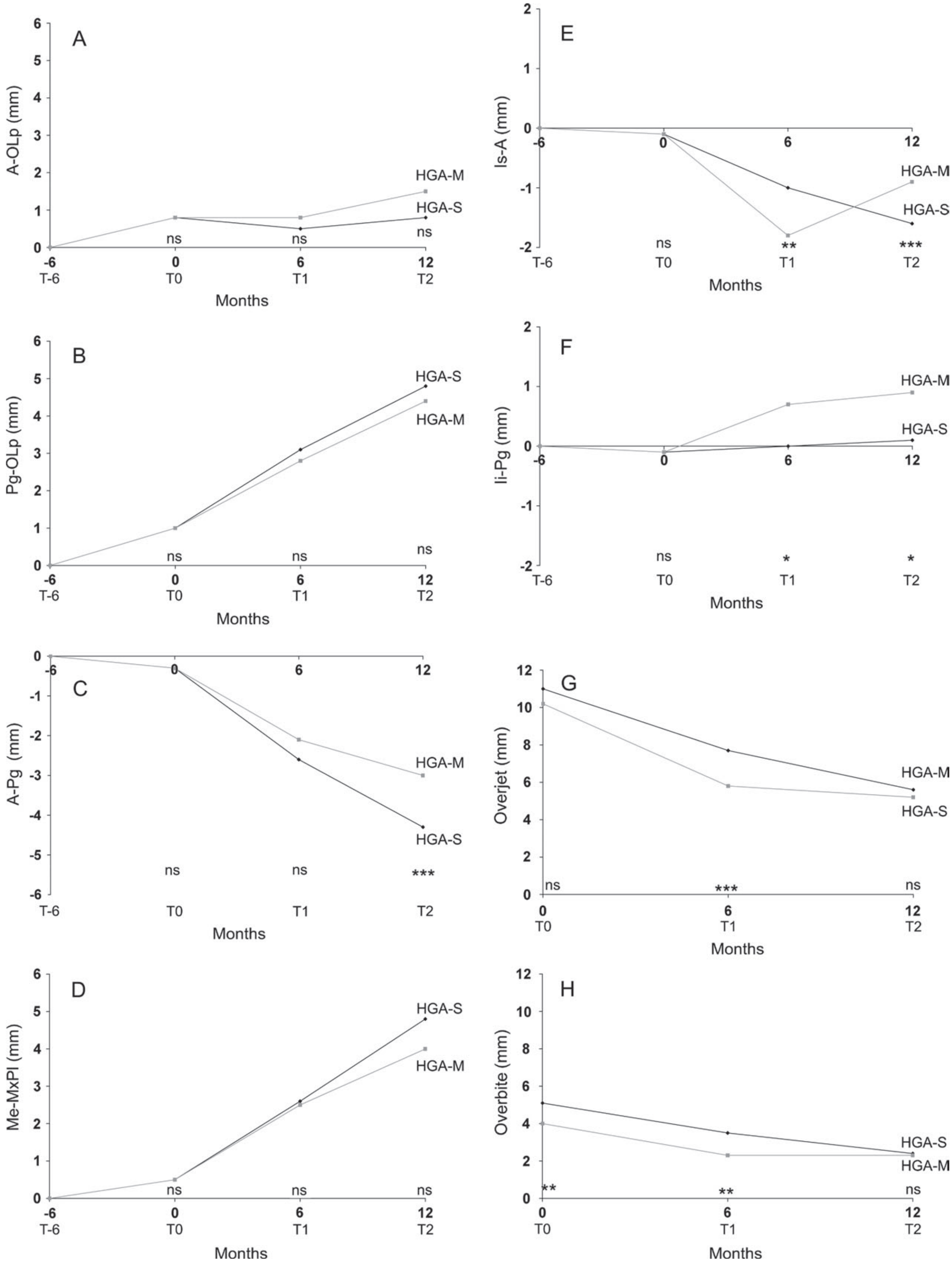

Figure 4 Cumulative changes of (A) mandible, (B) maxilla, (C) jaw base, (D) lower face height, (E) maxillary incisors, (F) mandibular incisors, (G) overjet, and (H) overbite. Growth changes 6 months and treatment changes 0–6 months (T0–T1) and 6–12 months (T1–T2) with the headgear activator with stepwise advancement group (HGA-S; n = 24) and headgear activator with maximum jumping group (HGA-M; n = 31). $^{*}P < 0.05$, $^{**}P < 0.01$, and $^{***}P < 0.001$.

effect was observed in the HGA-S group or with HGA-M in previous studies (Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002). This difference in effect on the lower incisors might depend on the degree of labial lower incisor capping rather than stepwise advancement. The skeletal changes contributing to the overjet reduction was larger with the HGA-S than the HGA-M, being 70 and 59 per cent, respectively, after treatment (Figure 3).

There was an increase of lower face height during both the initial and the late phases with both devices in this study, whereas two previous reports found no effect on lower face height with high-pull headgear (Dermaut *et al.*, 1992; Bendeus *et al.*, 2002). The increase in lower face height may be partly due to the lower molars having been extruded during treatment with both devices and in both treatment phases, whereas in one previous study (Bendeus *et al.*, 2002) they were unaffected. The extrusion of the lower molars in the HGA-S group could be explained by the fact that this two-piece device did not prevent eruption, while in HGA-M group, there was no occlusal stop at the lower first molars. The maxillary occlusal plane angle closed in the HGA-S group only, due to continuous intrusion of the upper incisors, but in the HGA-M group there was no net effect on intrusion of the upper incisor and no lasting effect on the maxillary occlusal plane. In both groups, the mandibular occlusal plane angle increased due to extrusion of the lower molars, whereas there was no significant effect on the lower incisors in the vertical plane. Stepwise versus maximum jumping of the mandible produced no significantly different skeletal effect on mandibular prognathism compared with maximum jumping.

There were fewer dental effects in the HGA-S group, which might be a reflection of the lower force transmitted to the dentition when the mandible was gradually advanced by 8 mm (2 × 4 mm) over the first 6 months, compared with an average jumping of the mandible of 12 mm in the HGA-M group at the start of treatment. A comparison of two groups treated with the TB for 7 months (Banks *et al.*, 2004) found no difference in sagittal maxillary and mandibular treatment changes between stepwise advancement and maximum jumping of the mandible. This was in general agreement with the findings of Illing *et al.* (1998) who compared the effects of stepwise versus maximum jumping using Bass versus Bionator and TB. A tendency to a greater increase in mandibular prognathism was observed with gradual advancement (3 × 2 mm) of the mandible with the Bass appliance compared with maximum jumping with the Herbst appliance after 6 months of treatment (Ömblus *et al.*, 1997) and with stepwise advancement (3 × 2 mm) with the Herbst appliance (Hägg *et al.*, 2002). In an experimental study, it has been demonstrated that stepwise advancement of the mandible resulted in significantly more condylar bone formation (2 + 1.5 mm) than a similar amount of single advancement (3.5 mm), even though fixed appliances were used in both cases (Rabie *et al.*, 2003b).

It has been claimed, from a survey of clinical studies, that increased mandibular growth during active treatment will be followed by a period of subnormal growth, and that this 'enhancement effect' is merely temporary (Pancherz and Michailidou, 2004). In many studies on functional appliances, the active treatment period was comparatively short, e.g. 5–7 months (Pancherz, 1979; Pancherz and Hansen, 1986; Wieslander, 1993; Ömblus *et al.*, 1997; Wong *et al.*, 1997), i.e. a potentially unfavourable growth pattern was affected for a brief period but then returned to its original pattern (Pancherz and Fackel, 1990). In the present study, the HGA-M treatment lasted for 8.6 months (T0–T1), and was followed by retention (T1–T2) using the same device at night only and without the headgear for nearly 6 months. During the retention period, there were no further significant positive effects, and the skeletal changes did not differ from those of normal growth, but relapse of dental effects and increase in lower face height continued. With continued treatment with the HGA-S, the effects achieved during the initial phase of treatment were maintained, and some further improvement occurred, which is in agreement with previous studies of extended treatment with the HGA-M and Herbst appliance, respectively (Bendeus *et al.*, 2002; Hägg *et al.*, 2002). It has also been demonstrated that early removal of a functional appliance does not allow the new condylar bone to mature, and subsequently the treatment gain in bone is not fully maintained, whereas prolonged use of the functional appliance results in permanent gain of the newly formed condylar bone (Chayanupatkul *et al.*, 2003). Consequently, the length of active treatment seems to be a crucial factor in achieving more pronounced and lasting effects.

Conclusions

The findings indicate that stepwise mandibular advancement does not affect mandibular prognathism differently from maximum mandibular jumping. With both modes of mandibular jumping, there is enhanced mandibular growth in the initial phase only, and the effect is maintained in the late phase, indicating that extended treatment is of importance. There was a significant increase in lower face height with both devices but neither device prevented extrusion of the lower molars. With stepwise advancement, the dental effects were less pronounced, and there was no protrusion of the lower incisors. The length of active treatment tended to be decisive in maintaining and further enhancing the treatment effects.

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References

Altenburger E, Ingervall B 1998 The initial effects of the treatment of Class II, division 1 malocclusions with the van Beek activator compared with the effects of the Herren activator and an activator-headgear combination. European Journal of Orthodontics 20: 389–397

Banks P, Wright J, O'Brien K 2004 Incremental versus maximum bite advancement during twin-block therapy: a randomized controlled clinical trial. American Journal of Orthodontics and Dentofacial Orthopedics 126: 583–588

Basciftci F A, Uysal T, Buyukerkmen A, Sari Z 2003 The effects of activator treatment on the craniofacial structures of Class II division 1 patients. European Journal of Orthodontics 25: 87–93

Bendeus M, Hägg U, Rabie B 2002 Growth and treatment changes in patients treated with a headgear-activator appliance. American Journal of Orthodontics and Dentofacial Orthopedics 121: 376–384

Björk A 1947 The face in profile: an anthropological X-ray investigation on Swedish children and conscripts. Berlingska Boktryckeriet, Lund, Sweden

Bookstein F L 1997 Landmark methods for forms without landmarks: morphometrics of group differences in outline shape. Medical Image Analysis 1: 225–243

Brandão M, Pinho H S, Urias D 2006 Clinical and quantitative assessment of headgear compliance: a pilot study. American Journal of Orthodontics and Dentofacial Orthopedics 129: 230–244

Chayanupatkul A, Rabie A B, Hägg U 2003 Temporomandibular response to early and late removal of bite-jumping devices. European Journal of Orthodontics 25: 465–470

Dermaut L R, van den Eynde F, de Pauw G 1992 Skeletal and dento-alveolar changes as a result of headgear activator therapy related to different vertical growth patterns. European Journal of Orthodontics 14: 140–146

Du X, Hägg U, Rabie A B 2002 Effects of headgear Herbst and mandibular step-by-step advancement versus conventional Herbst appliance and maximal jumping of the mandible. European Journal of Orthodontics 24: 167–174

Ghafari J, King G J, Tulloch J F 1998 Early treatment of Class II, division 1 malocclusion—comparison of alternative treatment modalities. Clinical Orthodontics and Research 1: 107–117

Graber T M, Rakosi T, Petrovic A G 1997 Dentofacial orthopedics with functional appliances. Mosby, St Louis

Hägg U, Du X, Rabie A B 2002 Initial and late treatment effects of headgear-Herbst appliance with mandibular step-by-step advancement. American Journal of Orthodontics and Dentofacial Orthopedics 122: 477–485

Hägg U, Du X, Rabie A B, Bendeus M 2003 What does headgear add to Herbst treatment and to retention? Seminars in Orthodontics 9: 57–66

Haralabakis N B, Halazonetis D J, Sifakakis I B 2003 Activator versus cervical headgear: superimpositional cephalometric comparison. American Journal of Orthodontics and Dentofacial Orthopedics 123: 296–305

Illing H M, Morris D O, Lee R T 1998 A prospective evaluation of Bass, Bionator and Twin Block appliances. Part I—the hard tissues. European Journal of Orthodontics 20: 501–516

Jakobsson S O, Paulin G 1990 The influence of activator treatment on skeletal growth in Angle Class II:1 cases. A roentgenocephalometric study. European Journal of Orthodontics 12: 174–184

Keeling S D *et al*. 1998 Anteroposterior skeletal and dental changes after early Class II treatment with bionators and headgear. American Journal of Orthodontics and Dentofacial Orthopedics 113: 40–50

Lau J W, Hägg U 1999 Cephalometric morphology of Chinese with Class II division 1 malocclusion. British Dental Journal 186: 188–190

Meikle M C 2005 What do prospective randomized clinical trials tell us about the treatment of Class II malocclusions? A personal viewpoint. European Journal of Orthodontics 27: 105–114

Nelson C, Harkness M, Herbison P 1993 Mandibular changes during functional appliance treatment. American Journal of Orthodontics and Dentofacial Orthopedics 104: 153–161

O'Brien K *et al*. 2003a Effectiveness of early orthodontic treatment with the Twin-block appliance: a multicenter, randomized, controlled trial. Part 1: dental and skeletal effects. American Journal of Orthodontics and Dentofacial Orthopedics 124: 234–243; quiz 339

O'Brien K *et al*. 2003b Effectiveness of treatment for Class II malocclusion with the Herbst or Twin-block appliances: a randomized, controlled trial. Part 2. Psychosocial effects. American Journal of Orthodontics and Dentofacial Orthopedics 124: 128–137

Ömblus J, Malmgren O, Pancherz H, Hägg U, Hansen K 1997 Long term effects of Class II correction in Herbst and Bass therapy. European Journal of Orthodontics 19: 85–193

Pancherz H 1979 Treatment of Class II malocclusions by jumping the bite with the Herbst appliance. A cephalometric investigation. American Journal of Orthodontics 76: 423–442

Pancherz H 1982a The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. American Journal of Orthodontics 82: 104–113

Pancherz H 1982b Vertical dentofacial changes during Herbst appliance treatment. Swedish Dental Journal 15 (Supplement): 189–196

Pancherz H, Fackel U 1990 The skeletofacial growth pattern pre- and post-dentofacial orthopaedics. A long-term study of Class II malocclusions treated with the Herbst appliance. European Journal of Orthodontics 12: 209–218

Pancherz H, Hägg U 1985 Dentofacial orthopedics in relation to somatic maturation. American Journal of Orthodontics 88: 273–287

Pancherz H, Hansen K 1986 Occlusal changes during and after Herbst treatment: a cephalometric investigation. European Journal of Orthodontics 8: 215–228

Pancherz H, Michailidou C 2004 Temporomandibular joint growth changes in hyperdivergent and hypodivergent Herbst subjects. A long-term roentgenographic cephalometric study. American Journal of Orthodontics and Dentofacial Orthopedics 126: 153–161; quiz 254–255

Phan K L D, Bendeus M, Hägg U, Hansen K, Rabie A B M 2006 Comparison of the headgear activator and Herbst appliance—effects and post-treatment changes. European Journal of Orthodontics 28: 594–604

Rabie A B, She T T, Hägg U 2003a Functional appliance therapy accelerates and enhances condylar growth. American Journal of Orthodontics and Dentofacial Orthopedics 123: 40–48

Rabie A B, Tsai M J, Hägg U, Du X, Chou B W 2003b The correlation of replicating cells and osteogenesis in the condyle during stepwise advancement. The Angle Orthodontist 73: 457–465

Ruf S, Baltromejus S, Pancherz H 2001 Effective condylar growth and chin position changes in activator treatment: a cephalometric roentgenographic study. The Angle Orthodontist 71: 4–11

Tulloch J F, Phillips C, Proffit W R 1998 Benefit of early Class II treatment: progress report of a two-phase randomized clinical trial. American Journal of Orthodontics and Dentofacial Orthopedics 113: 62–72; quiz 73–74

van Beek H 1982 Overjet correction by a combined headgear and activator. European Journal of Orthodontics 4: 279–290

Wieslander L 1993 Long-term effect of treatment with the headgear-Herbst appliance in the early mixed dentition. Stability or relapse? American Journal of Orthodontics and Dentofacial Orthopedics 104: 319–329

Wong G W, So L L, Hägg U 1997 A comparative study of sagittal correction with the Herbst appliance in two different ethnic groups. European Journal of Orthodontics 19: 195–204