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Comparison of the headgear activator and Herbst appliance—effects and post-treatment changes

Kok Leong Dale Phan, Margareta Bendeus, Urban Hägg, Ken Hansen and A. Bakr M. Rabie
Orthodontics, Faculty of Dentistry, The University of Hong Kong, China

SUMMARY The aim of this study was to evaluate the effects of the headgear activator (HGA) and Herbst appliance during active treatment and retention and at follow-up in children with a skeletal Class II malocclusion. The two groups comprised 16 consecutive male patients (mean age 11.6 ± 1.42 years) treated with a HGA and 16 male patients (mean age 12.6 ± 1.13 years) treated with a Herbst appliance and Andresen activator (HAA) sampled from a larger pool using similar selection criteria. Growth data were obtained for the two groups. Lateral cephalograms taken at the start, after 6 months of treatment, after 12 months of active treatment or 6 months of retention, and at the 24-month follow-up were analysed.

The total changes over the whole observation period (T0–T3) did not differ significantly between the groups; there was, however, a statistically significant increase in jaw prognathism ($P < 0.05$) and improvement of the molar relationship ($P < 0.05$) in the HAA group as compared with the HGA group. During the initial treatment phase (T0–T1), the overall treatment effects were statistically more pronounced in the HAA group than in the HGA group.

Despite significant differences in treatment effects and changes between the two devices, there were no significant overall changes at follow-up except for the prognathism, i.e. maxillary prognathism decreased with treatment with the HGA while mandibulars prognathism continued to increase with HAA treatment.

Introduction

A large number of functional appliances of different designs, fixed and removable, have been used to correct Class II division 1 malocclusions (Graber *et al.*, 1997). Two commonly used devices are the Herbst appliance—a fixed functional appliance (Pancherz, 1979), and the headgear activator (HGA)—a removable functional appliance (van Beek, 1982).

The immediate treatment changes reported with the use of the Herbst were restraint of maxillary growth and enhanced growth of the mandible (Pancherz, 1979, 1982a). It has been demonstrated that condylar and glenoid fossa remodelling seemed to contribute significantly to the increase in mandibular prognathism when investigated using a magnetic resonance imaging technique (Ruf and Pancherz, 1998). The improvement in occlusal relationship during Herbst treatment resulted almost equally from skeletal and dental changes (Pancherz, 1982a). The effect of the Herbst appliance on the maxillary first molar (i.e. distalization and intrusion) was comparable with that of a high-pull headgear (Pancherz and Anehus-Pancherz, 1993).

After short-term follow-ups, the maxilla in Herbst patients has shown a period of catch-up growth, whereas the mandible demonstrated a period of minor reduction in growth (Pancherz, 1981; DeVincenzo, 1991; Pancherz and Anehus-Pancherz, 1993). It has also been reported that the amount and direction of temporomandibular joint (TMJ) changes were affected favourably but only temporarily by Herbst treatment, as all desirable TMJ changes reverted approximately 7 months after treatment (Pancherz and Fischer, 2003).

A long-term follow-up study on headgear-Herbst treatment (Wieslander, 1993) found that there was a significant relapse both in mandibular advancement and in the gain in mandibular length obtained during initial treatment, while another similar study of the Herbst appliance (Hansen and Pancherz, 1992) concluded that in spite of the improvement of the jaw–base relationship during initial treatment and long-term follow-up, Herbst treatment did not normalize the sagittal skeletal relationship at the end of the observation period.

The findings from studies on the treatment changes of the HGA are disputable. However, the general consensus is that there is a reduction of maxillary prognathism in patients treated with this regimen (Ozturk and Tankuter, 1994; Cura *et al.*, 1996; Bendeus *et al.*, 2002). Other immediate treatment changes reported include enhancement of mandibular growth (Cura *et al.*, 1996; Sari *et al.*, 2003) and retrusion of the upper incisors (Ozturk and Tankuter, 1994; Weiland *et al.*, 1997; Altenburger and Ingervall, 1998; Bendeus *et al.*, 2002; Sari *et al.*, 2003). A study which followed a group of patients treated with HGAs for 5 years (Lehman *et al.*, 1988) reported that one out of six subjects experienced a relapse of the treated Class II malocclusion.

A retrospective study that compared the treatment outcome of the Herbst appliance and the Andresen activator (HAA) in terms of effective TMJ growth changes and their influence on the position of the chin (Baltromejus *et al.*, 2002) found that effective TMJ and chin changes were greater with both activator and Herbst treatment than in the control subjects. However, the Herbst appliance produced more favourable sagittally orientated treatment effects in a much shorter time than the activator.

Although numerous studies have been conducted on the effects of the Herbst appliance and HGA in isolation, no comparison of the effectiveness of the two therapies seems to have been undertaken. Due to certain limiting factors in the designs of investigations, such as varied subject sampling procedures and duration of treatment, it is difficult to use existing studies to draw a direct comparison between the two different treatment regimens.

The aim of this study was to evaluate and compare the effects of a removable and fixed functional appliance during active treatment and retention and at follow-up in children with a skeletal Class II malocclusion.

Subjects and methods

The original sample comprised of 20 consecutive Caucasian male patients with a skeletal Class II division 1 malocclusion, treated with a HGA devised by van Beek (1982) for 12 months (T0–T2) and followed for 24 months (T2–T3; Bendeus *et al.*, 2002). Four subjects were excluded due to poor compliance or incomplete records. The selection criteria were mixed dentition, good shape of the dental arches, mild to moderate skeletal Class II (ANB 4.5 degrees ≤ 8.0 degrees), mandibular plane angle (NSL/ML) greater than 39.0 degrees, no previous orthodontic treatment, and acceptable co-operation (evaluated after 2 months). The initial average overjet and overbite were 8.6 and 3.9 mm, respectively. The second sample consisted of 16 Caucasian male patients who received active treatment with a banded Herbst appliance (Pancherz, 1985) for 7 months (T0–T1) followed by 6 months of retention with an Andresen activator with moderate bite opening (T1–T2), and were subsequently followed for 24 months (T2–T3). These subjects were recruited from a large pool of patients treated with the Herbst appliance, whose records were obtained prospectively. The lengths of the observation intervals are given in Table 1. No retention or further treatment was provided between T2 and T3 in either group.

Growth data were obtained for two groups of male subjects, which were sampled using similar selection criteria. One group included 14 subjects (mean age = 11.0 ± 1.5 years) from the HGA group, and the second consisted of 17 male patients (mean age = 12.9 ± 1.3 years) taken from another prospective study (Nelson *et al.*, 1999), who were comparable with the Herbst appliance group. The growth changes in these subjects were followed for 6 months before commencement of any active treatment. The data from both groups were pooled to obtain the 6-month growth changes. Treatment effects were calculated by subtracting the growth changes from the treatment changes.

Lateral cephalograms in centric occlusion were taken at the start of treatment (T0), after initial (T1) and late (T2) treatment, and at the 24-month follow-up (T3; Table 1). The HGA group was on average 1 year younger than the HAA group ($P < 0.05$). Interpolations were made to obtain data from both groups, representing exactly the same length of observation periods (Table 1). All lateral cephalograms were analysed (Figure 1) according to Björk (1947) and Pancherz (1982a,b) by one investigator (PKLD) twice, with a 1-week interval, and the two sets of data were averaged in order to reduce the measurement error (Miethke, 1989). Using Pancherz's method, superimposition was undertaken on the structures of the anterior base rather than only on the nasion-sella line.

Method error study

Prior to the analysis, the treatment changes for 10 patients were assessed twice with a 2-week interval to determine the method error. A paired *t*-test was carried out and no systematic error was found. The size of the combined method error in locating, superimposing, and measuring the

Table 1 Age at the start (T0), after 6 months (T1), and 12 months (T2) of treatment, and 24 months of follow-up (T3), and duration of observation periods of Headgear activator (HGA) group (n = 16) and Herbst appliance and Andresen activator (HAA) group (n = 16).

	T0/T0–T1					T1/T1–T2					T2/T2–T3					T3				
	HGA		HAA		Diff	HGA		HAA		Diff	HGA		HAA		Diff	HGA		HAA		Diff
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Age	11.6	1.42	12.6	1.13	−1.0*	12.1	1.42	13.1	1.14	−1.0*	12.6	1.4	13.7	1.20	−1.1*	14.6	1.4	15.6	1.14	−1.0*
Duration	6.0	0.39	6.8	1.11	−0.8*	6.1	1.00	6.3	0.73	−0.2	23.7	1.20	23.8	0.99	−0.1	35.8	0.80	36.9	1.30	−1.1***
Adjusted duration			[6.0]					[6.1]										[35.8]		

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

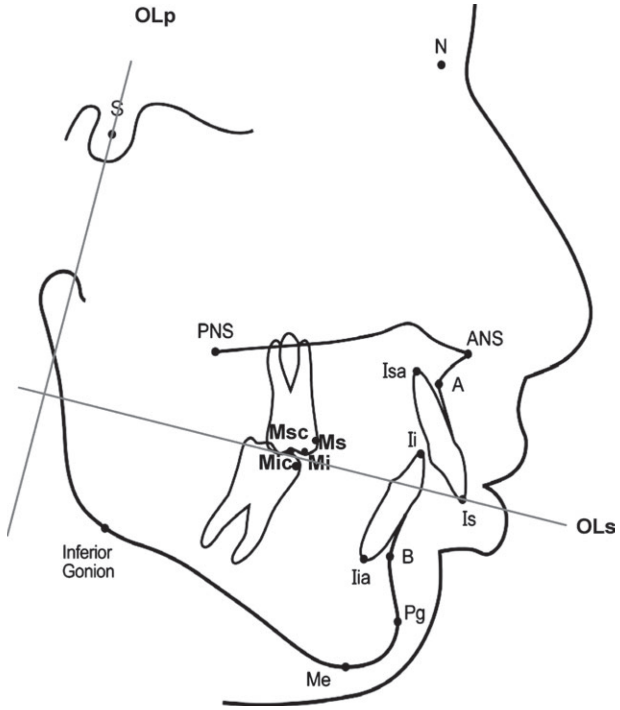

Figure 1 Cephalometric variables: OLs (OP, Maxillary occlusal plane, joining Is and the distobuccal cusp tip of the maxillary permanent first molar), and OLp (Occlusal plane perpendicular, reference line from S perpendicular to the maxillary occlusal plane). Sagittal—overjet (mm), Is-OLp minus Ii-OLp; maxillary prognathism: A-OLp (mm), Linear position of maxillary base; SNA (°), angular measurement of maxillary position; mandibular prognathism: Pg-OLp (mm), linear position of 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; A,B on OP (mm), sagittal jaw relationship on occlusal plane measurement; upper incisor: Is-A (mm), change of maxillary central incisor, Is-OLp minus A-OLp; lower incisor: Ii-Pg (mm), change of mandibular central incisor, Ii-OLp minus Pg-OLp; molar changes: Ms-A (mm), change of the maxillary permanent first molar, Ms-OLp minus A-OLp; Mi-Pg (mm), change of the mandibular permanent first molar, Ms-OLp minus A-OLp; Ms-Mi (mm), molar relationship, Ms-OLp minus Mi-OLp. Vertical—overbite (mm), distance from Ii perpendicular to OLs, Ii-OLs; lower face height: Me-MxPl (mm), distance from MxPl perpendicular to Me; incisor changes: Is-NL (mm), lower face height, distance from Is perpendicular to MxP; Ii-ML (mm), vertical position of mandibular central incisor, distance from Ii perpendicular to MnPl; molar changes: Msc-NL (mm), vertical position of the maxillary permanent first molar, distance from Msc perpendicular to MxPl; Mic-ML (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.

changes of the different landmarks was calculated using the formula $\sqrt{\frac{\sum d^2}{2n}}$. The combined error did not exceed ±0.4 (mm or degree) for any of the variables investigated.

Statistical analysis

A Student's *t*-test for unpaired sample and Welch correction were used. The level of statistically significant difference was set at $P = 0.05$.

Results

Dentofacial morphology of the patient groups

There was a minimal statistically significant difference in the dentofacial morphology at the start of treatment (T0) between the two patient groups, except for the position of the maxillary incisors and first molars in the sagittal plane (Table 2). After the initial treatment phase (T1), some statistically significant differences in dentofacial morphology were observed, but these became less pronounced at T2 and had virtually vanished at T3, except for maxillary and mandibular prognathism, which became more pronounced in the Herbst group ($P < 0.01$).

Growth changes

Six months of growth resulted in statistically significant changes such as an increase of lower face height, maxillary and mandibular prognathism, improvement of jaw–base relationship, and some dental changes (Table 3).

HGA treatment and follow-up

The statistically significant treatment effects (Table 3) during the total treatment period (T0–T2) were a decrease of overjet and overbite, improvement of the jaw base and molar relationship, restraint of maxillary forward growth, increase of lower face height, retrusion of the maxillary incisors and molars, protrusion of the mandibular incisors, and opening of the occlusal planes (Figure 2). During T0–T1, the treatment effects were more pronounced than at T1–T2. During the follow-up period (T2–T3; Table 4), the following statistically significant changes were noted in the sagittal plane: maxillary and mandibular prognathism increased (without a statistically significant improvement of the jaw base relationship and overjet) and the mandibular incisors and maxillary molars re-bounded. In the vertical plane, there was an increase in lower face height, eruption of the teeth, and closing of the mandibular plane angle. During T0–T3 (Table 4), there were statistically significant changes in the sagittal plane with a reduction of overjet, due to retrusion of the maxillary incisors, and improvement of the jaw base relationship (the increase of mandibular prognathism was more pronounced than that of the maxilla), with a reduction of the overbite, an increase in face height, and eruption of the teeth.

Herbst treatment and follow-up

The statistically significant treatment effects (Table 3) observed during the total treatment period (active treatment with Herbst and retention with activator, T0–T2) were a decrease of overjet and overbite, improvement of the jaw base and molar relationship, enhanced forward mandibular growth, an increase of lower face height, retrusion of the maxillary incisors and molars, protrusion of the mandibular molars and incisors, intrusion of the maxillary molars and

Table 2 Comparison of dentofacial morphology at start (T0), after 6 months (T1), and 12 months (T2) of treatment and after 24 months of follow-up (T3) between Headgear activator (HGA) and Herbst appliance plus Andresen activator (HAA).

Variables	T0					T1					T2					T3				
	HGA (n = 16)		HAA (n = 16)		Diff	HGA (n = 16)		HAA (n = 16)		Diff	HGA (n = 16)		HAA (n = 16)		Diff	HGA (n = 16)		HAA (n = 16)		Diff
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Sagittal																				
Overjet (mm)	8.6	2.78	9.2	2.96	−0.6	6.6	2.11	1.5	3.22	5.1***	5.7	2.10	4.0	2.22	1.7*	5.0	1.39	4.2	2.15	0.9
Maxillary prognathism																				
A-Olp (mm)	79.2	3.41	81.2	4.42	−1.9	79.4	3.17	81.3	4.24	−1.9	79.5	3.32	82.1	4.60	−2.5	81.3	3.21	85.2	3.54	−4.0**
SNA (°)	81.0	3.22	82.4	4.73	−1.4	80.8	2.62	81.8	4.49	−1.0	80.3	2.92	82.1	4.71	−1.8	80.0	3.00	82.9	4.44	−2.9*
Mandibular prognathism																				
Pg-Olp (mm)	80.1	4.10	83.4	5.59	−3.3	81.2	4.17	86.0	5.99	−4.9*	82.3	4.11	86.4	6.01	−4.2*	84.9	4.10	90.5	5.86	−5.7**
SNB (°)	75.8	2.47	76.9	3.55	−1.1	76.1	2.43	78.1	3.76	−2.0	76.5	2.67	78.2	3.79	−1.7	76.6	2.42	78.8	3.77	−2.2
Jaw base relationship																				
A-Pg (mm)	−0.8	2.02	−2.3	4.46	1.4	−1.8	2.59	−4.8	4.11	2.9*	−2.7	2.69	−4.4	4.33	1.6	−3.6	3.00	−5.3	5.20	1.7
ANB (°)	5.2	1.24	5.5	2.29	−0.3	4.7	1.07	3.6	2.14	1.0	3.9	1.31	3.9	2.36	0.0	3.4	1.37	4.1	2.60	−0.7
A,B on OP (mm)	2.3	1.74	1.8	3.29	0.6	1.3	2.05	−2.7	3.11	4.0***	0.6	1.98	−1.7	2.81	2.3*	0.1	1.65	−0.9	3.18	1.0
Upper incisor																				
Is-A (mm)	8.7	1.67	9.9	1.72	1.3*	7.9	1.27	7.5	2.02	0.4	7.8	1.47	7.9	1.74	−0.1	7.1	1.54	7.9	1.84	−0.8
Lower incisor																				
Ii-Pg (mm)	−0.8	2.82	−1.5	3.78	0.7	−0.5	2.76	1.3	3.27	−1.8	−0.5	2.94	−0.5	3.75	−0.1	−1.6	3.05	−1.6	3.97	0.0
Molar changes																				
Maxillary molar (mm)	−25.7	1.79	−23.4	2.09	−2.3**	−26.2	1.64	−25.5	2.42	−0.7	−26.4	1.99	−24.8	2.12	−1.6	−25.2	2.27	−24.7	2.41	−0.5
Mandibular molar(mm)	−27.1	2.18	−27.6	3.29	0.5	−27.1	2.11	−26.1	3.38	−1.0	−27.1	2.4	−26.2	3.31	−1.0	−26.4	2.71	−26.7	3.41	0.2
Molar relationship (mm)	0.6	1.49	2.0	2.37	−1.4	−1.0	1.91	−4.2	2.78	3.2***	−2.0	2.01	−3.0	2.60	0.9	−2.4	1.57	−3.3	2.67	0.9
Vertical																				
Overbite (mm)	3.9	1.02	4.8	1.71	−0.8	3.4	1.30	1.4	1.73	2.0***	3.1	1.32	2.9	1.66	0.2	3.0	1.42	3.2	1.89	−0.3
Me-MxPl (mm)	60.0	4.03	62.9	4.66	−2.9	61.2	4.28	65.7	5.30	−4.5*	62.6	4.19	65.6	5.09	−3.0	66.6	4.88	68.8	6.28	−2.2
Incisor changes																				
Is-NL (mm)	28.3	2.74	29.9	3.25	−1.6	28.3	2.73	30.1	3.18	−1.9	28.5	2.99	30.6	3.16	−2.1	30.1	3.02	31.6	3.52	−1.5
Ii-ML (mm)	40.2	2.86	41.8	1.69	−1.7	40.7	3.06	40.3	1.63	0.3	41.1	3.02	41.3	1.77	−0.2	42.6	3.33	43.6	2.11	−1.0
Molar changes																				
Msc-NL (mm)	20.6	2.01	22.8	2.29	−2.2	20.9	2.04	22.1	2.38	−1.3	21.4	2.11	23.1	2.47	−1.8*	23.5	1.87	24.5	2.73	−1.0
Mic-ML (mm)	29.9	2.12	31.3	2.18	−1.4	30.6	2.29	32.7	2.17	−2.1*	31.1	2.24	33.1	2.29	−2.0*	33.6	2.50	35.4	2.77	−1.7
Rotational changes																				
SN/MnPl (°)	31.0	4.66	30.2	5.30	0.8	30.8	4.78	30.4	5.87	0.5	31.0	4.95	30.0	5.97	1.0	30.1	5.20	28.2	6.12	1.9
SN/MxPl (°)	5.8	2.55	6.1	2.37	−0.4	5.6	2.23	7.0	2.31	−1.4	6.1	2.50	6.8	2.47	−0.7	6.3	2.50	6.4	2.21	−0.1
Occlusal planes																				
OLs/NSL (°)	18.5	3.98	18.6	4.99	0.0	18.8	3.82	20.8	4.96	−2.0	18.4	3.77	19.8	4.60	−1.4	18.2	3.85	18.2	4.30	0.1
OLi/NSL (°)	9.8	4.34	8.7	4.79	1.1	9.9	4.33	15.1	6.07	−5.2**	10.2	5.27	12.7	5.78	−2.6	10.3	5.24	10.6	5.44	−0.2

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

mandibular incisors, extrusion of the maxillary incisors and mandibular molars, and opening of the maxillary and occlusal planes (Figure 2). During T0–T1, the treatment effects included almost all cephalometric variables, whereas during T1–T2 practically all those variables re-bounded. During T2–T3 (Table 4), the following statistically significant changes were noted in the sagittal plane. Overjet and maxillary and mandibular prognathism increased (without a statistically significant change in the jaw–base relationship), and the mandibular incisors uprighted. In the vertical plane, there was an increase in face height, eruption of the teeth, closing of the maxillary and mandibular plane angles, and re-bounded occlusal planes. During T0–T3 (Table 4), there were statistically significant changes in the sagittal plane with a reduction of overjet, due to retrusion of the maxillary incisors and improvement of the jaw base relationship (the increase of mandibular prognathism was more pronounced than that of the maxilla), and in the vertical plane a reduction of the overbite, an increase of face height, eruption of the teeth, and closure of the mandibular plane.

Comparison of HGA and Herbst appliance

The total changes from T0–T3 (Table 4) did not differ significantly between the two groups, except that there was a greater increase in jaw prognathism and improvement of

Table 3 Dentofacial growth changes of 31 subjects, and treatment effects during initial phase (T0–T1), late phase (T1–T2), and both phases combined (T0–T2) of headgear activator group (HGA; $n = 16$) and Herbst activator group (HAA; $n = 16$). Comparison of the dentofacial effects between HGA and HAA during the various treatment phases.

Variables	Growth change		HGA						HAA						HGA vs. HAA		
	6 months		T0–T1		T1–T2		T0–T2		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	Mean	Mean	Mean
Sagittal																	
Overjet (mm)	−0.1	0.97	−1.9***	1.54	−0.8*	1.16	−2.7***	1.98	−7.6***	2.39	2.6***	1.68	−5.0***	1.70	5.7***	−3.4***	2.2**
Maxillary prognathism																	
A-OLp (mm)	0.6**	1.02	−0.5	1.00	−0.4	0.96	−0.9**	1.03	−0.5	1.01	0.2	0.96	−0.3	1.02	0.0	−0.6	−0.6
SNA (°)	0.1	0.71	−0.3	0.89	−0.5*	0.71	−0.9**	0.94	−0.7**	0.73	0.2	0.71	−0.5*	0.80	0.3	−0.7**	−0.4
Mandibular prognathism																	
Pg-OLp (mm)	1.1***	1.03	0.0	1.18	0.0	1.36	0.0	1.49	1.6***	1.41	−0.7	1.53	0.9*	1.19	−1.6**	0.7	−0.8
SNB (°)	0.3*	0.64	0.0	0.80	0.0	0.85	0.0	1.01	0.9***	0.90	−0.3	0.87	0.7**	0.71	−0.9**	0.3	−0.6(*)
Jaw base relationship																	
A-Pg (mm)	−0.5*	1.02	−0.5	1.10	−0.4	1.38	−0.9*	1.39	−2.0***	1.39	0.9*	1.44	−1.2***	1.09	1.5**	−1.3*	0.2
ANB (°)	−0.2	0.69	−0.3	0.74	−0.6*	0.85	−0.9**	0.92	−1.6***	0.83	0.5*	0.79	−1.1***	0.70	1.3***	−1.0**	0.2
A,B on OP (mm)	0.3	1.21	−1.3***	1.17	−1.0**	1.31	−2.3***	1.50	−4.8***	1.75	0.7	1.50	−4.1***	1.37	3.5***	−1.7***	1.8**
Upper incisor																	
Is-A (mm)	0.1	0.88	−0.9**	0.87	−0.2	1.01	−1.1**	1.25	−2.5***	1.62	0.3	0.99	−2.2***	1.45	1.6**	−0.5	1.1*
Lower incisor																	
Ii-Pg (mm)	−0.2	0.70	0.5*	0.83	0.1	0.68	0.7**	0.86	3.0***	0.93	−1.6***	0.78	1.5***	0.75	−2.5***	1.6***	−0.8*
Molar changes																	
Maxillary molar (mm)	0.2	1.13	−0.7*	1.02	−0.3	1.12	−1.1**	1.12	−2.3***	1.13	0.6	1.17	−1.7***	1.09	1.6***	−0.9*	0.6
Mandibular molar (mm)	0.1	0.83	−0.1	0.85	−0.1	0.83	−0.2	1.03	1.4***	0.94	−0.2	0.93	1.2***	0.80	−1.5***	0.1	−1.4***
Molar relationship (mm)	−0.4*	1.19	−1.2**	1.28	−0.6	1.26	−1.8***	1.54	−5.7***	1.64	1.7**	1.72	−4.1***	1.34	4.6***	−2.3***	2.3***
Vertical																	
Overbite (mm)	−0.1	0.44	−0.4*	0.59	−0.3	0.57	−0.7**	0.77	−3.3***	0.85	1.6***	0.58	−1.7***	0.86	2.9***	−1.8***	1.0**
Me-MxPl (mm)	0.9***	1.07	0.3	1.06	0.5	1.08	0.8**	1.11	1.9*	3.34	−1.0***	0.98	0.9**	0.99	−1.6	1.5***	−0.1
Incisor changes																	
Is-NL (mm)	0.1	1.02	−0.1	0.96	0.2	1.03	0.0	1.11	0.2	0.94	0.4	0.88	0.6*	0.94	−0.3	−0.2	−0.6
Ii-ML (mm)	0.5***	0.63	0.3*	0.64	0.3*	0.57	0.0	0.70	−1.9***	0.87	0.5**	0.59	−1.5***	0.78	2.0***	−0.5*	1.5***
Molar changes																	
Msc-NL (mm)	0.5*	1.08	−0.3	1.01	0.0	0.98	−0.3	1.01	−1.2***	1.01	0.5	1.08	−0.7*	1.08	0.9*	−0.5	0.4
Mic-ML (mm)	0.4***	0.63	0.2	0.80	0.6*	0.88	0.8**	0.95	0.9***	0.59	0.0	0.66	1.0***	0.70	−0.7**	0.1	−0.6*
Rotational changes																	
SN/MnPl (°)	−0.4*	0.88	0.0	1.23	0.7	1.31	0.7	1.43	0.5	0.96	0.1	0.92	0.5	0.96	−0.3	0.5	0.2
SN/MxPl (°)	−0.2	1.28	0.2	1.24	−0.1	1.16	0.1	1.33	1.0**	1.12	0.0	1.12	1.0**	1.18	−1.0*	0.7	−0.3
Occlusal planes																	
OLs/NSL (°)	−1.0***	1.20	1.3***	1.22	0.6	1.25	1.9***	1.15	3.3***	1.36	0.0	1.24	3.2***	1.37	−2.0***	0.6	−1.4**
OLi/NSL (°)	−0.6*	1.34	0.8*	1.32	0.9*	1.50	1.7**	1.88	7.0***	2.02	−1.7***	1.48	5.3***	2.07	−6.2***	2.6***	−3.6***

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

molar relationship in the HAA than in the HGA group (Tables 3 and 4, Figure 2). During T0–T1 (Table 3), the overall treatment effects were more pronounced in the HAA than in the HGA group. During T1–T2 and T2–T3, some treatment changes re-bounded in the HAA group, and there was continuation of progress in the HGA group, leading to the disappearance of almost all the differences observed during the initial treatment at the end of the observation period.

Discussion

In this prospective study, a sample of consecutive young male patients with skeletal Class II division 1 malocclusions was treated with a specific type of HGA (van Beek, 1982). Another group of young male patients with similar cephalometric dentofacial morphology (Table 2) treated with HAA was selected from a large prospective study and compared with the former group. Linear cephalometric measurements are known to be more reliable than angular measurements (Baumrind and Frantz, 1971; Bookstein, 1997), but angular measurements were also investigated to facilitate comparisons with other studies. Interpolations were carried out to equalize the observation intervals for both groups and to allow direct comparison. An important feature of this study was the long follow-up period to enable

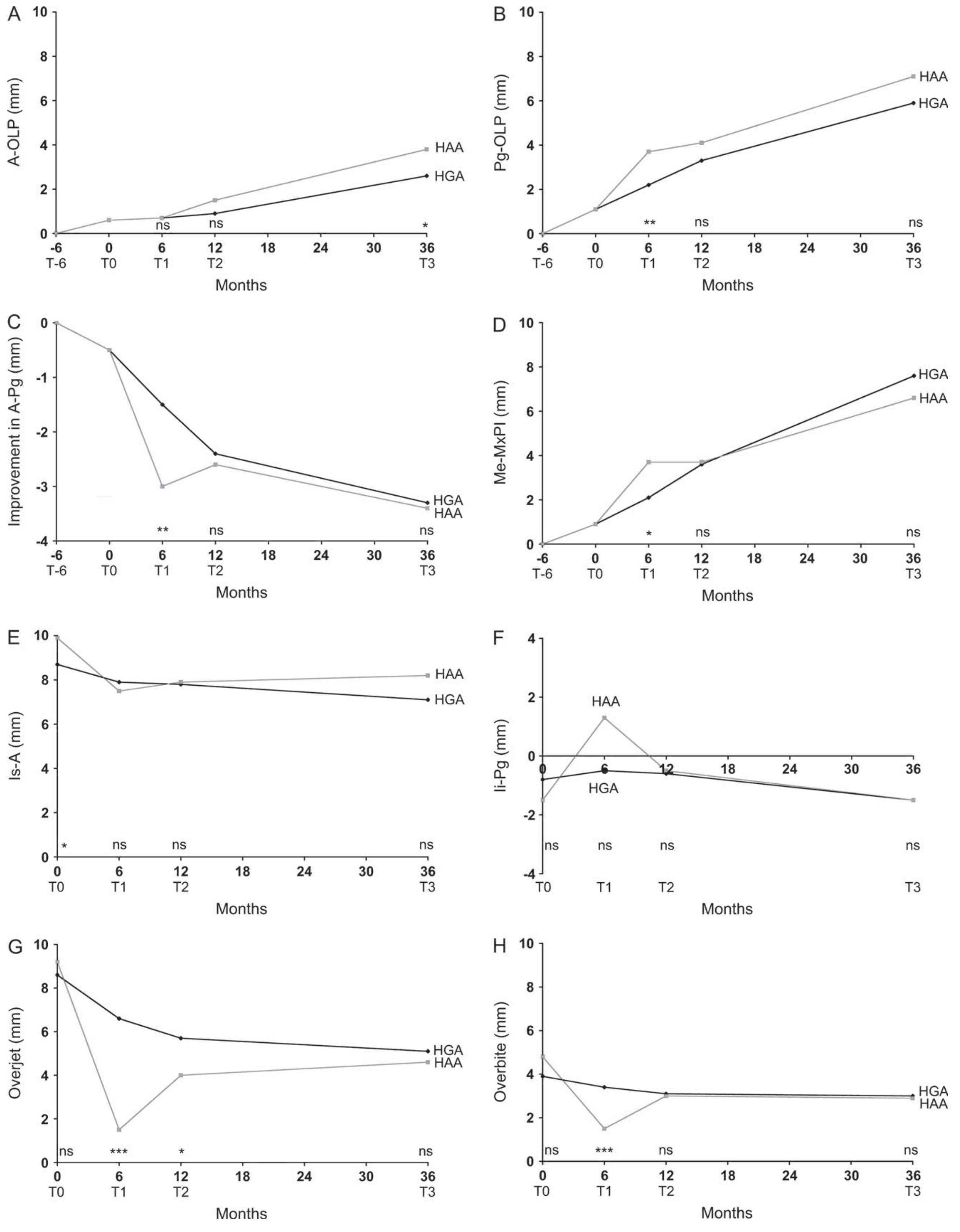

Figure 2 Cumulative changes (A) maxilla, (B) mandible, (C) jaw base, (D) lower face height, (E) maxillary incisors, (F) mandibular incisors, (G) overjet, and (H) overbite. Growth changes: 6 months; treatment changes: 0–6 months (T0–T1), 6–12 months (T1–T2); follow-up: 24 months (T2–T3); HGA (headgear activator); HAA (Herbst 6 months and activator 6 months).

Table 4 Comparison of dentofacial changes during treatment (initial phase T0–T1, late phase T1–T2, both phases combined T0–T2), follow-up period (T2–T3), and total observation period (T0–T3) of headgear activator group (HGA; n = 16) and Herbst activator group (HAA; n = 16).

Variables	HGA										HAA										HGA vs. HAA	
	T0–T1		T1–T2		T0–T2		T2–T3		T0–T3		T0–T1		T1–T2		T0–T2		T2–T3		T0–T3		T2–T3	T0–T3
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	Mean
Sagittal																						
Overjet (mm)	−2.0**	2.29	−0.9*	1.48	−2.9**	3.14	−0.6	2.24	−3.6***	2.17	−7.7***	3.90	2.5**	2.58	−5.2***	2.60	0.6*	1.03	−5.1***	2.56	−1.2	1.6
Maxillary prognathism																						
A-OLp (mm)	0.1	0.98	0.2	0.84	0.3	1.04	1.7***	1.56	2.0***	1.74	0.1	1.00	0.8**	0.84	0.9**	1.02	2.3***	0.90	3.4***	1.27	−0.6	−1.3*
SNA (°)	−0.2	1.17	−0.4**	0.72	−0.7	1.28	−0.3	1.60	−1.0	1.85	−0.6**	0.76	0.3	0.71	−0.3	0.95	0.6**	0.72	0.4	1.05	−0.9	−1.3*
Mandibular prognathism																						
Pg-OLp (mm)	1.1**	1.44	1.1*	1.85	2.2***	2.13	2.6***	2.08	4.8***	2.34	2.6***	1.96	0.4	2.22	3.0***	1.44	3.0***	1.58	6.3***	2.19	−0.4	−1.5
SNB (°)	0.3	1.04	0.3	1.17	0.7	1.50	0.2	1.30	0.8	1.60	1.3**	1.28	0.0	1.21	1.3***	0.83	0.5*	0.81	2.0***	0.98	−0.4	−1.1*
Jaw base relationship																						
A-Pg (mm)	−1.0**	1.24	−0.9	1.91	−1.9***	1.94	−0.9	1.82	−2.8***	1.75	−2.5***	1.93	0.4	2.03	−2.1***	1.21	−0.7	1.42	−2.9***	1.94	−0.2	0.2
ANB (°)	−0.6*	0.84	−0.8*	1.09	−1.3***	1.26	−0.5	1.11	−1.8***	1.08	−1.8***	1.05	0.3	0.95	−1.6***	0.72	0.0	0.60	−1.6***	1.05	−0.5	−0.2
A,B on OP (mm)	−1.0**	1.09	−0.7	1.51	−1.7**	1.97	−0.5	1.83	−2.2***	1.60	−4.5***	2.51	1.0	1.95	−3.4***	1.64	1.1***	0.96	−2.5***	1.89	−1.6**	0.4
Upper incisor																						
Is-A (mm)	−0.8**	0.85	−0.1	1.22	−0.9	1.78	−0.7	1.64	−1.6**	2.06	−2.4**	2.51	0.4	1.19	−2.0**	2.19	0.3	1.10	−2.1**	2.46	−0.9	0.5
Lower incisor																						
Ii-Pg (mm)	0.3	1.04	−0.2	0.66	0.2	1.11	−0.9*	1.65	−0.8	1.86	2.8***	1.28	−1.8***	0.93	1.0***	0.85	−1.0***	0.82	0.1	1.08	0.1	−0.9
Molar changes																						
Maxillary molar (mm)	−0.6**	0.79	−0.2	1.11	−0.8*	1.11	1.2***	1.21	0.4	1.23	−2.1***	1.13	0.7*	1.25	−1.4***	1.00	0.4	1.43	−1.1*	2.04	−0.7	−1.5
Mandibular molar (mm)	0.1	0.89	0.0	0.83	0.0	1.34	0.7*	0.98	0.7	1.66	1.5***	1.14	−0.1	1.11	1.4***	0.73	−0.3	0.87	1.3***	1.07	−1.0	0.5
Molar relationship (mm)	−1.6***	1.46	−1.1**	1.39	−2.7***	2.08	−0.3	2.05	−3.0***	1.43	−6.2***	2.30	1.2	2.46	−4.9***	1.60	0.1	0.88	−5.3***	2.18	0.4	−2.3*
Vertical																						
Overbite (mm)	−0.5*	0.81	−0.3	0.78	−0.8*	1.17	−0.1	1.40	−0.9*	1.36	−3.3***	1.33	1.5***	0.79	−1.8***	1.35	−0.1	1.40	−1.7***	1.16	−0.5	0.8
Me-MxPl (mm)	1.2***	1.04	1.5***	1.11	2.7***	1.19	4.0***	2.22	6.7***	1.84	2.8***	1.12	0.0	0.78	2.8***	0.82	2.9***	2.01	6.0***	2.19	1.1	0.1
Incisor changes																						
Is-NL (mm)	−0.1	0.80	0.2	1.04	0.2	1.26	1.6***	0.71	1.8***	1.32	0.3	0.74	0.5**	0.49	0.7***	0.73	0.8**	0.85	1.6***	0.90	0.8**	0.2
Ii-ML (mm)	0.5**	0.66	0.5***	0.43	0.9***	0.82	1.5***	0.99	2.4***	1.01	−1.5**	1.22	0.9***	0.51	−0.5*	1.00	2.3***	1.20	1.7***	1.27	−0.9*	0.7
Molar changes																						
Msc-NL (mm)	0.2	0.84	0.5**	0.74	0.8**	0.85	2.1***	0.89	2.9***	1.15	−0.7**	0.83	1.0**	1.08	0.3	1.07	1.2***	0.98	1.7***	0.99	0.8	1.2*
Mic-ML (mm)	0.6**	0.61	0.6**	0.61	1.2***	1.05	2.5***	1.22	3.7***	1.38	1.3***	0.50	0.5	0.70	1.8***	0.81	1.9***	1.16	4.0***	1.22	0.6	−0.3
Rotational changes																						
SN/MnPl (°)	−0.2	0.62	0.2	0.86	0.0	1.08	−0.9*	1.59	−0.8	1.82	0.1	1.09	−0.3	1.00	−0.2	1.11	−1.7***	1.43	−2.0**	2.03	0.9	1.1
SN/MxPl (°)	−0.2	1.13	0.5	1.37	0.4	1.70	0.1	1.29	0.5	1.67	0.8***	0.72	−0.2	0.72	0.7*	0.94	−0.8*	1.21	−0.1	1.41	0.9	0.6
Occlusal planes																						
OLs/NSL (°)	0.3	1.24	−0.4	1.34	−0.2	1.05	−0.1	1.76	−0.3	1.89	2.2***	1.62	−1.1**	1.30	1.2*	1.65	−2.0***	1.07	−0.9	2.19	1.9**	0.6
OLi/NSL (°)	0.1	1.28	0.3	1.78	0.4	2.64	0.2	3.07	0.6	2.64	6.4***	2.94	−2.3***	1.71	4.1***	3.03	−2.8***	1.68	1.8	2.69	3.0**	−1.3

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

the permanent effects of the treatment to be adequately assessed. Most previous studies (Pancherz, 1979; Dermaut *et al.*, 1992; Cura *et al.*, 1996; Wong *et al.*, 1997; Altenburger and Ingervall, 1998; Illing *et al.*, 1998; Du *et al.*, 2002) only reported the immediate treatment changes, and did not consider the long-term effects of treatment.

A recent randomized clinical trial (RCT; O'Brien *et al.*, 2003) that studied the differences in treatment outcome after treatment with Twin Block and Herbst appliances concluded that there were no differences in skeletal and dental changes between the appliances at completion of the second phase of treatment with fixed appliance therapy. Although it was reported that there was no difference in total treatment time (functional phase plus fixed appliance phase) between the appliances, a closer scrutiny of the study design revealed that there was a statistically significant difference in the duration of treatment in the functional phase. This lasted 11.2 months with the Twin Block appliance and 5.8 months with the Herbst ($P < 0.001$). Furthermore, in the case of the Herbst appliance treatment, once the overjet was fully corrected the appliance was removed and treatment was continued with a fixed appliance. No retainers were used to maintain the correction achieved and allow the occlusion to settle before the commencement of the second phase with fixed appliances. It has been demonstrated that 90 per cent of occlusal relapse occurs during the first 6 months post-treatment (Pancherz and Hansen, 1986), and an experimental study (Chayanupatkul *et al.*, 2003) has shown that sufficient time is required for newly formed bone to mature into more stable bone. Furthermore, this RCT only reported on the immediate treatment changes, and presented no follow-up data to reflect the true outcome of treatment. The present study dramatically demonstrates the importance of follow-up, as the immediate treatment effects differed markedly between the two therapeutic groups, but after a period of retention and settling the eventual differences at follow-up were limited to only jaw prognathism (Table 2). Thus, the conclusions of a retrospective study that compared the effects of the HAA (Baltromejus *et al.*, 2002) are also questionable, as the duration of treatment with the two appliances differed significantly (2.6 years for activator versus 0.6 years for Herbst appliance), and the analysis of the treatment effects of the Herbst appliance was undertaken immediately after treatment, before a period of retention to allow for stabilization and settling of the occlusion to take place.

The inherent weakness of the present study is the small size of the groups. However, the subjects were all males, and it has been shown that the growth rate between the genders differs significantly closer to the pubertal maximum (Pancherz and Hägg, 1985). However, the age difference between the groups at the start of treatment was 1 year which might indicate that the basic growth differed somewhat between the two groups. The reason for the age difference was mainly due to the fact that the Herbst group was more dentally mature, since anchorage required the first premolars to have erupted fully (Pancherz, 1985). By comparing the effects of treatment rather than treatment changes only, this problem might have been reduced since effects of a certain treatment seem to be consistent and not directly related to growth status (Hägg *et al.*, 1987).

The two appliances investigated in this study produced different treatment effects on maxillary and mandibular growth (Figure 2). At T2, there was restraint of maxillary growth in the HGA group ($P < 0.01$), but not in the HAA group. After initial treatment (T0–T1), the amount of maxillary growth restraint was statistically insignificant (−0.5 mm) with both HGA and Herbst appliance. Six months of retention with the Andresen activator in this study did not affect maxillary growth, which seemed to have re-bounded to the normal level. However, the Andresen activator has been shown to restrain maxillary growth when used for active treatment for 12 months (Jakobsson and Paulin, 1990), and after an extensive period of retention following early treatment with the Herbst appliance (Wieslander, 1993). Previous studies of HGA with active treatment of 9–11 months have shown restraint of maxillary forward growth (Lehman *et al.*, 1988; Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998). In general, this finding is in agreement with the results from two studies on headgear treatment, which reported a marked increase in the treatment changes on the maxilla in patients treated for 2 years compared with those treated for approximately half as long (Ghafari *et al.*, 1998; Tulloch *et al.*, 1998). By interpolating the results from two previous studies of the Herbst appliance (Hägg *et al.*, 2002, 2003), it was demonstrated that 6 months of treatment with a conventional Herbst did not significantly affect forward growth of the maxilla, but after an additional 6 months of treatment there was a statistically significant effect. The combination of headgear and a fixed functional appliance, headgear-Herbst appliance, further enhanced the restraint of maxillary growth, and the effects were already evident after 6 months of treatment (Hägg *et al.*, 2003). These findings seem to indicate that the length of treatment is an essential factor in the modification of maxillary growth with headgear and functional appliances.

Mandibular growth was accelerated ($P < 0.01$) during Herbst treatment (T0–T1), but tended to become slower than normal during the retention period (T1–T2; $P = 0.08$), but the gain in mandibular growth at T2 was still statistically significant ($P < 0.05$; Table 3). Consequently, the use of an Andresen activator as a retainer for a 6-month period after active treatment with the Herbst appliance for 7 months only indicated that the Andresen activator was unable to maintain the treatment effect achieved by the acceleration of mandibular growth, or even the normal rate of mandibular growth to prevent deceleration of growth after active treatment. A previous study of Herbst treatment showed that acceleration of mandibular growth only occurred during the initial 6-month phase of treatment, and after 6 more months of extended treatment mandibular growth did not differ from normal growth, a level which was maintained during 6 months of retention with a HGA (Hägg *et al.*, 2003). A recent experimental study demonstrated that sufficient time after forward positioning with a fixed jumping device was necessary to allow the newly formed condylar bone to mature and become stable, and hence enable normal growth to be maintained post-treatment (Chayanupatkul *et al.*, 2003). By contrast, mandibular growth appeared to be unaffected by treatment with the HGA (Table 3). This might be because the activator is a removable device which holds the mandible in a forward position for part of the day only. This finding is also consistent with the results of 12 months of treatment with an Andresen activator, which also had no effect on the mandible (Jakobsson and Paulin, 1990). However, other studies using the same HGA for 9–11 months have reported that mandibular growth was enhanced (Lehman *et al.*, 1988; Dermaut *et al.*, 1992; Altenburger and Ingervall, 1998). Difference in compliance may partly account for these outcomes, and it is also possible that the reference values of normal growth in the studies concerned were not obtained in a similar fashion for the treated samples, as in the present investigation.

During T2–T3, there was no significant difference in growth changes in either the mandible or the maxilla between the two groups (Table 4). There was less increase in maxillary and mandibular prognathism during the 3-year observation period (T0–T3) in the HGA than in the HAA group. Apparently the decrease in maxillary prognathism during active treatment with HGA had a lasting effect, and this might also have contributed to possible sub-normal growth of the mandible. In the HAA group, maxillary growth had already re-bounded during the retention period. Despite some deceleration of mandibular growth in the HAA group during T1–T2, the increase in mandibular prognathism during the total observation period appeared to be close to that expected from normal growth. Consequently, there seemed to be a temporary acceleration of mandibular growth during treatment with the Herbst appliance, which was followed by a possible sub-normal or deceleration of growth in the sagittal plane. Deceleration of normal growth is unlikely, since the male patients during the follow-up period (T2–T3) were on average 12.6–14.6 years of age and 13.7–15.6 years in the HGA and HAA groups, respectively, which were close to the pubertal maximum of mandibular growth (Björk, 1972). Another possibility was that mandibular growth became sub-normal after functional appliance treatment in both groups. Two recent reports on treatment with the Twin Block (O'Brien *et al.*, 2003; Banks *et al.*, 2004) showed that the maxillary and mandibular treatment changes were indeed very similar in the subjects treated with a Twin Block for 7 months only, compared with the sample that had 22 months of treatment with the Twin Block followed by comprehensive orthodontic treatment. This would indicate that limited growth occurred after the initial phase of functional appliance treatment in the later sample. In other words, growth could have become sub-normal or close to zero after the initial phase of functional appliance therapy, or the growth direction became 'purely' vertical during the later phase of treatment with fixed appliance.

It was reported from a RCT (Tulloch *et al.*, 2004) that there was no difference in the final outcome between the one- and two-phase treatment groups. The figures published in two separate reports (Tulloch *et al.*, 1995, 2004) were used in the present study in order to calculate the changes in mandibular (SNB) and maxillary (SNA) prognathism in the three 'experimental groups' which would represent the changes displayed over an entire estimated observation period of 40–50 months, and compared them with those obtained from the two groups investigated in the present study over a period of 36 months (Table 5). In the present study, the findings showed that maxillary prognathism in the HGA group tended to decrease (P = 0.052), but there was no marked change in the HAA group. The difference between the two groups was marginally statistically significant (P = 0.056). Mandibular prognathism tended to increase in the HGA group (P = 0.052) but increased even more markedly in the HAA group (P < 0.001), the difference between the two groups being statistically significant. The calculated figures from that RCT study confirmed that the

Table 5 Comparison of the differences of maxillary and mandibular prognathism at the start and end of the present study and in the randomized controlled trial (RCT) by Tulloch *et al.* (1995, 2004). (HGA, headgear activator; HAA, Herbst appliance + Andresen activator; 1-Phase, one-phase fixed appliance; 2-Phase B, bionator + fixed appliance; 2-Phase HG, headgear + fixed appliance).

Variables	Present study				RCT					
	HGA		HAA		1-Phase		2-Phase B		2-Phase HG	
	Diff	*P* value	Diff	*P* value	Diff	*P* value	Diff	*P* value	Diff	*P* value
SNA	−1.0	0.052	0.4	0.207	−0.8	0.281	−0.6	0.496	−1.5	0.028
SNB	0.8	0.052	2.0	0.001	1.1	0.123	1.9	0.035	0.5	0.439

headgear group (two-phase treatment) had reduced maxillary prognathism ($P < 0.028$) with no increase in mandibular prognathism. The bionator group (two-phase treatment) experienced an increase in mandibular prognathism ($P < 0.035$) but no change in maxillary prognathism, whereas in the fixed appliance group (one-phase treatment) there was no significant change in jaw prognathism. Hence, these findings contradict the conclusion of the authors of the RCT (Tulloch *et al.*, 2004) that there was no difference between the outcomes of the three different treatment regimens. Based on the calculated figures from the previous RCT study (Tulloch *et al.*, 1995, 2004) and the findings from the present investigation, prognathism of the jaws was affected differently in the short and the long terms, depending on which treatment device was used.

Conclusions

Maxillary prognathism decreased with treatment with the HGA, while mandibular prognathism continued to increase with HAA. This might indicate that the use of headgear also has an indirect restraining effect on mandibular prognathism.

Address for correspondence

Dr Urban Hägg
Orthodontics, Faculty of Dentistry
The University of Hong Kong
Prince Philip Dental Hospital
34 Hospital Road
Hong Kong SAR
China
E-mail: euohagg@hkusua.hku.hk

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