Original Article

Long-Term Dentoskeletal Changes with the Bionator, Herbst, Twin Block, and MARA Functional Appliances

Nicole J. Siara-Olds[a]; Valmy Pangrazio-Kulbersh[b]; Jeff Berger[c]; Burcu Bayirli[d]

ABSTRACT

Objective: To determine if the long-term dentoskeletal changes in patients treated with tooth-borne functional appliances were comparable to each other and to matched controls.

Materials and Methods: The experimental sample consisted of 80 consecutively treated patients who were equally divided into Bionator, Herbst, Twin Block, and mandibular anterior repositioning appliance (MARA) groups. The control group comprised 21 children with untreated skeletal Class II malocclusions. Lateral cephalograms were taken for the treated group at T_1 (initial records), T_2 (completion of functional therapy), and T_3 (completion of fixed appliance therapy). A repeated measure analysis of variance (ANOVA) was used to assess the differences between and within groups. If ANOVA results were significant, Tukey-Kramer tests were used to determine where the significant differences occurred.

Results: (1) Temporary restriction of maxillary growth was found in the MARA group (T_2–T_1). (2) SNB increased more with the Twin Block and Herbst groups when compared with the Bionator and MARA groups. (3) The occlusal plane significantly changed in the Herbst and Twin Block groups. (4) The Twin Block group expressed better control of the vertical dimension. (5) The overbite, overjet, and Wits appraisal decreased significantly with all of the appliances. (6) The Twin Block group had significant flaring of the lower incisors at the end of treatment. (7) Over the long-term, there were no significant soft tissue changes among treated and untreated subjects.

Conclusions: No significant dentoskeletal differences were observed long-term, among the various treatment groups and matched controls. (*Angle Orthod* 2010;80:18–29.)

KEY WORDS: MARA; Long-term changes; Functional appliances

INTRODUCTION

The most common skeletal problem in orthodontics is the Class II malocclusion characterized by mandibular retrognathia.[1–5] In addition, most subjects with this type of malocclusion exhibit narrow maxillary arches.[4,6]

The effects and stability of early Class II treatment with functional appliances has been surrounded by much controversy and uncertainty. It has been shown in histologic studies with laboratory animals that when the mandible is brought forward there is an increase in cellular activity at the condylar head as well as an increase in mandibular length.[7–10] Numerous studies have shown condylar and glenoid fossa remodeling following the use of various types of functional appliances.[11–37] Questions that still remain are: (1) Are these findings substantiated with clinical research in humans; (2) Is the growth of the mandible different with functional treatment than that of similar controls; and (3) Is this treatment stable over the long-term?

There are multiple factors that influence the stability of early Class II treatment including mandibular rotational growth patterns,[38,39] airway obstructions,[40,41] proper manipulation of appliances, treatment timing,[11,12] and retention.[13–15] There are few investigators who have studied the long-term stability with functional appliances, and most have reported favorable findings with prolonged retention.[11,14–16]

[a] Private Practice, Warren, Mich.

[b] Private Practice, Sterling Heights, Mich, Adjunct Professor, Department of Orthodontics, University of Detroit Mercy, Detroit, Mich.

[c] Private Practice, Windsor, ON, Canada, Adjunct Professor, Department of Orthodontics, University of Detroit Mercy, Detroit, Mich.

[d] Associate Professor, Department of Orthodontics, University of Detroit Mercy, Detroit, Mich.

Corresponding author: Dr Jeff Berger, Department of Orthodontics, Graduate Orthodontics University of Detroit Mercy, 2700 Martin Luther King Jr Blvd, Detroit, MI 48208-2576 (e-mail: drjeff.berger@gmail.com)

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The present study was designed to assess the treatment outcome of tooth-borne functional appliances (Bionator, acrylic splint Herbst, Twin Block, and mandibular anterior repositioning appliance [MARA]) and their stability over time and after fixed appliance therapy, when compared to each other and to untreated controls with similar Class II malocclusions.

MATERIALS AND METHODS

Sample Selection

The treatment sample consisted of 80 patients, with similar Class II skeletal characteristics. The patients were divided equally among Bionator, removable acrylic Herbst, Twin Block, and MARA functional appliance groups. They were treated by two orthodontists who followed the same functional treatment philosophies and selected the appliances for each group based on anticipated patient cooperation and stability of the existing mixed dentition. The distribution of sexes was closely matched in all treatment groups. The initial mean age for the Bionator group was 10 years 7 months (range, 8 years 7 months to 13 years 9 months), for the acrylic Herbst group, 12 years 2 months (range, 10 years 6 months to 14 years 1 month), for the Twin Block group 10 years 11 months (range, 8 years 2 months to 13 years 9 months), and for the MARA group 11 years 1 month (range, 9 years 0 months to 14 years 4 months). Although there appears to be a discrepancy between the chronologic ages between the samples, they were all matched carefully for growth stages by cervical vertebral maturation (CVM) evaluation.[42,43]

Lateral cephalograms were taken for the treated groups at T_1 (initial records), T_2 (completion of functional therapy), and T_3 (completion of fixed appliance therapy). The inclusion criteria for the treated sample were: (1) Class II division 1 malocclusions characterized by a retrognathic mandible (SNA $\geq 80^\circ$, SNB $< 76^\circ$, and SN-GoGn $\leq 35^\circ$), (2) CVM between stage 2 and 3 at initial records, (3) landmarks were identifiable on all of the radiographs, and (4) treatment of functional appliance therapy was not combined with a headgear. All patients wore the functional appliances until full eruption of the permanent dentition, at which time the second phase of fixed appliance treatment commenced.

The mean treatment time from the start of functional appliance therapy to the completion of comprehensive orthodontics was 49.0 months for the Bionator, 41.6 months for the Herbst, 41.6 months for the Twin Block, and 43.7 months for the MARA. In addition, Bionator and Twin Block appliances were fabricated according to the patient's vertical dimension. The overall mean treatment time with functional appliances was 18.7 months (range, 9 months to 30 months) and the overall mean treatment time of fixed appliance therapy was 25.4 months (range, 14 months to 38 months). At the completion of orthodontic treatment, the mean age was 15 years 3 months (range, 13 years 0 months to 17 years 9 months).

The untreated control group comprised 21 children from the Michigan and Denver Growth Study samples. The selection criteria were similar to the treatment groups. Control group lateral cephalograms were also matched to the treated groups at T_1, T_2, and T_3 by CVM,[42,43] and comparisons of treatment outcomes were made.

In this retrospective long-term investigation, the treatment groups were chosen strictly based upon the appliance used for the correction of the Class II malocclusion and not upon their treatment responses. The untreated Class II control sample was selected on the time interval between cephalograms and progression of growth.[42,43] Since these criteria were not always matched to the treatment time of the groups, an analysis of the annualized increments of change was performed and reported.

Cephalometric Analysis

Lateral cephalograms were manually traced and digitized by one investigator (Dolphin Imaging Version 9.0, Chatsworth, Calif). The data were generated and the magnification was corrected for the control and treatment groups. To determine the accuracy of the measurements, intraclass correlations were calculated for the various cephalometric measurements and ranged from 85% to 97% (Figures 1 and 2).

Statistical Analysis

Repeated measures analysis of variance (ANOVA) assessed if the groups were comparable at the outset and if there were significant differences between and within groups for the various increments of change. When ANOVA results were significant, Tukey-Kramer tests were used to determine the individual differences. An analysis of the annualized increments of change among the time intervals was performed, since there were differences within the time spans between the groups. Bonferroni correction was calculated and a statistical significance was set at $P \leq .002$.

RESULTS

Comparison of Starting Forms

No statistically significant differences were found in the craniofacial configuration at T_1 between the treatment and control groups in most of the measure-

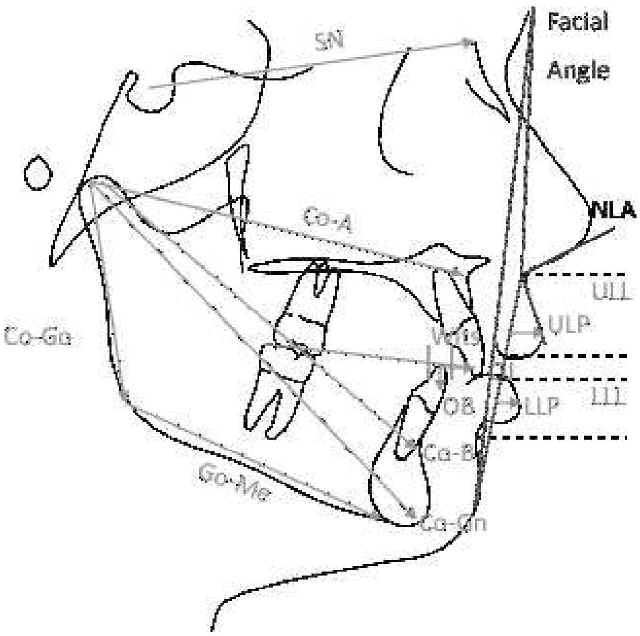

Figure 1. Linear and soft tissue measurements: grey indicates the cephalometric outline and black the lines and letters.

ments studied. Of the 25 measurements, 5 showed statistically significant differences, Table 1a,b.

Comparison of Treatment Effects

Comparison of the different treatment groups with the controls depicted no statistically significant difference in most of the measurements associated with growth at all time points studied. It is interesting to note that when significant differences were observed, they were all confined to the T_2–T_1 treatment span. Most of these differences dissipated long term (Tables 2 through 4).

The overbite, overjet, and the Wits values were the only measurements that demonstrated significant differences at the end of the observation period, (T_3–T_1).

When comparing the treatment groups among themselves, the Herbst appliance, followed by the MARA, demonstrated a significant effect on restricted maxillary growth and produced a steeper occlusal plane. The Twin Block was most effective in controlling

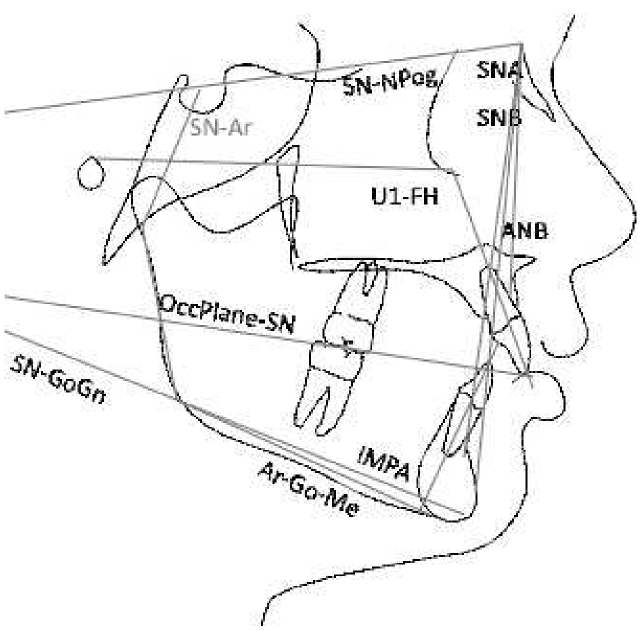

Figure 2. Angular measurements: grey indicates the cephalometric outline and black the lines and letters.

Table 1a. Comparison of Initial Angular Measurements[a]

Measurement	T_1 (B)	T_1 (H)	T_1 (TB)	T_1 (M)	T_1 (C)
Angular, degrees					
Ar-Go-Me	X	X	X	X	X
SN-Ar	122.83	X	X	X	127.37*
	X	125.92	X	122.11*	X
	X	X	X	122.11	127.37**
IMPA	X	X	X	X	X
U1-FH	X	X	X	X	X
SNA	X	X	80.34	X	83.08*
	X	X	80.34	83.36*	X
SNB	X	X	75.16	77.66*	X
ANB	X	X	X	X	X
OccPlane-SN	X	X	X	X	X
SN-NPog	X	X	75.91	78.47*	X
SN-GoGn	32.11	X	36.23*	X	X
	X	32.17	36.23*	X	X
	X	X	36.23	30.56**	X

[a] B indicates Bionator group; H, Herbst group; TB, Twin Block group; M, MARA group; and C, control group. X indicates no difference.

* $P \leq .05$; ** $P \leq .002$.

Table 1b. Comparison of Initial Linear Measurements[a]

Measurement	T_1 (B)	T_1 (H)	T_1 (TB)	T_1 (M)	T_1 (C)
Linear, mm					
Co-Go	46.50	50.35*	X	X	X
	46.50	X	X	50.23*	X
Co-A	X	82.70	78.00*	X	X
	X	X	78.00	81.87*	X
Co-B	97.05	102.47*	X	X	X
	X	102.47	97.61*	X	X
Co-Gn	101.54	107.86*	X	X	X
	X	107.86	102.60*	X	X
Go-Me	59.04	63.54*	X	X	X
	X	63.54	59.17*	X	X
Overbite	3.67	X	X	X	2.36*
	X	X	X	3.51	2.36*
Overjet	X	X	X	X	X
Wits	X	2.61	X	X	3.96*
	X	X	X	2.10	3.96*

[a] B indicates Bionator group; H, Herbst group; TB, Twin Block group; M, MARA group; and C, control group. X indicates no difference.

* $P \leq .05$; ** $P \leq .002$.

Table 2. Linear Differences Among Control and Treatment Groups Annualized[a]

Measurement	Treatment	ΔT_2–T_1 (T)	ΔT_2–T_1 (C)	Diff of Δ	Treatment–Control *t* Value	*P* Value	ΔT_3–T_2 (T)	ΔT_3–T_2 (C)	Diff of Δ	Treatment–Control *t* Value	*P* Value	ΔT_3–T_1 (T)	ΔT_3–T_1 (C)	Diff of Δ	Treatment–Control *t* Value	*P* Value
Linear, mm																
Co-Go	Bionator	2.29	2.01	0.28	0.43	.67	0.96	0.49	0.47	0.73	.46	1.38	1.10	0.28	0.44	.66
	Herbst	2.50		0.49	0.77	.44	1.08		0.59	0.92	.36	1.54		0.44	0.68	.50
	Twin Block	2.64		0.63	0.99	.33	0.94		0.45	0.70	.49	1.85		0.76	1.18	.24
	MARA	2.44		0.43	0.66	.51	1.45		0.97	1.50	.14	1.87		0.77	1.20	.23
Co-A	Bionator	0.98	1.80	−0.82	−1.32	.19	0.49	0.04	0.45	0.72	.47	0.65	0.74	−0.09	−0.15	.88
	Herbst	0.13		−1.67	−2.68	.01*	0.74		0.70	1.13	.26	0.49		−0.25	−0.41	.68
	Twin Block	1.50		−0.30	−0.47	.64	0.33		0.29	0.47	.64	0.94		0.20	0.32	.75
	MARA	1.75		−0.05	−0.08	.94	0.97		0.94	1.50	.13	1.30		0.56	0.90	.37
Co-B	Bionator	3.48	3.08	0.40	0.50	.61	1.67	0.92	0.75	0.95	.35	2.31	1.78	0.52	0.66	.51
	Herbst	3.99		0.91	1.15	.25	1.45		0.53	0.67	.50	2.23		0.45	0.57	.57
	Twin Block	4.37		1.29	1.63	.11	1.38		0.46	0.58	.56	2.88		1.10	1.38	.17
	MARA	3.87		0.79	1.00	.32	1.95		1.03	1.30	.20	2.76		0.98	1.23	.22
Co-Gn	Bionator	3.84	3.31	0.53	0.62	.54	1.68	1.21	0.46	0.54	.59	2.47	2.05	0.42	0.49	.63
	Herbst	4.40		1.09	1.27	.20	1.41		0.19	0.23	.82	2.34		0.29	0.33	.74
	Twin Block	4.78		1.47	1.72	.09	1.26		0.05	0.06	.95	2.99		0.94	1.10	.27
	MARA	4.25		0.94	1.10	.27	2.22		1.00	1.18	.24	3.08		1.03	1.20	.23
Go-Me	Bionator	1.70	2.18	−0.48	−0.76	.45	1.26	0.60	0.65	1.03	.30	1.46	1.23	0.65	1.03	.30
	Herbst	2.18		0.00	0.00	1.00	0.95		0.35	0.55	.58	1.32		0.35	0.55	.58
	Twin Block	2.54		0.36	0.56	.58	0.74		0.13	0.21	.84	1.51		0.13	0.21	.84
	MARA	1.95		−0.23	−0.37	.71	1.03		0.42	0.67	.50	1.42		0.42	0.67	.50
Overbite	Bionator	−0.99	0.29	−1.27	−4.61	<.0001**	−0.31	−0.18	−0.13	−0.47	.64	−0.65	0.01	−0.65	−2.36	.02*
	Herbst	−2.12		−2.40	−8.71	<.0001**	0.13		0.31	1.11	.27	−0.66		−0.66	−2.40	.02*
	Twin Block	−0.92		−1.21	−4.38	<.0001**	−0.26		−0.08	−0.28	.78	−0.55		−0.56	−2.02	.04*
	MARA	−1.32		−1.60	−5.81	<.0001**	0.22		0.41	1.47	.14	−0.43		−0.44	−1.59	.11
Overjet	Bionator	−1.80	−0.47	−1.36	−5.13	<.0001**	−0.15	−0.09	−0.06	−0.22	.83	−0.70	−0.24	−0.45	−1.75	.08
	Herbst	−2.46		−1.99	−7.68	<.0001**	0.07		0.16	0.63	.53	−0.80		−0.56	−2.15	.03*
	Twin Block	−1.54		−1.07	−4.14	<.0001**	−0.31		−0.22	−0.85	.40	−0.92		−0.67	−2.60	.01*
	MARA	−1.76		−1.29	−4.97	<.0001**	−0.06		0.03	0.13	.90	−0.78		−0.54	−2.08	.04*
Wits	Bionator	−1.28	0.03	−1.31	−4.27	<.0001**	−0.08	−0.03	−0.05	−0.17	.87	−0.58	0.00	−0.58	−1.87	.06
	Herbst	−2.71		−2.74	−8.92	<.0001**	0.03		0.06	0.19	.85	−0.97		−0.97	−3.14	.002**
	Twin Block	−1.38		−1.41	−4.60	<.0001**	−0.09		−0.07	−0.22	.83	−0.70		−0.69	−2.25	.03*
	MARA	−0.98		−1.01	−3.28	.001**	0.10		0.13	0.42	.68	−0.36		−0.35	−1.15	.25
Ratio																
Go-Me:SN	Bionator	1.00	2.34	−1.35	−1.76	.08	0.67	0.34	0.34	0.44	.66	0.82	1.14	−0.32	−0.42	.68
	Herbst	1.85		−0.50	−0.65	.52	0.85		0.51	0.67	.51	1.21		0.08	0.10	.92
	Twin Block	2.10		−0.25	−0.32	.75	0.56		0.22	0.29	.77	1.11		−0.03	−0.04	.97
	MARA	−0.72		−3.06	−3.99	<.0001**	1.87		1.54	2.00	.05*	0.77		−0.37	−0.48	.63

[a] T indicates treatment group; C, control group; and Diff of Δ, difference of delta.
* $P \leq .05$; ** $P \leq .002$.

Table 3. Angular Differences Among Control and Treatment Groups Annualized[a]

Measurement	Treatment	ΔT_2–T_1 (T)	ΔT_2–T_1 (C)	Diff of Δ	Treatment–Control *t* Value	*P* Value	ΔT_3–T_2 (T)	ΔT_3–T_2 (C)	Diff of Δ	Treatment–Control *t* Value	*P* Value	ΔT_3–T_1 (T)	ΔT_3–T_1 (C)	Diff of Δ	Treatment–Control *t* Value	*P* Value
Angular, degrees																
Ar-Go-Me	Bionator	1.41	−0.60	2.01	3.48	.0006**	−0.07	−0.22	0.15	0.26	.79	0.52	−0.37	0.89	1.55	.12
	Herbst	0.17		0.77	1.34	.18	−0.73		−0.51	−0.89	.38	−0.49		−0.12	−0.20	.84
	Twin Block	0.51		1.11	1.92	.06	−0.94		−0.72	−1.25	.21	−0.15		0.23	0.39	.70
	MARA	0.12		0.72	1.24	.21	−0.24		−0.02	−0.03	.98	−0.09		0.29	0.50	.62
SN-Ar	Bionator	0.21	0.85	−0.64	−1.09	.28	0.35	−0.92	1.27	2.17	.03*	0.24	−0.22	0.46	0.78	.44
	Herbst	0.40		−0.45	−0.77	.44	0.16		1.08	1.85	.07	0.13		0.34	0.59	.56
	Twin Block	−0.16		−1.01	−1.73	.08	−0.25		0.68	1.16	.25	0.11		0.11	0.19	.85
	MARA	0.52		−0.33	−0.56	.58	1.45		2.38	4.07	<.0001**	1.05		1.27	2.17	.03*
IMPA	Bionator	−0.53	−0.28	−0.25	−0.35	.73	1.00	−0.43	1.44	2.02	.04*	0.17	−0.37	0.54	0.76	.45
	Herbst	0.32		0.61	0.85	.40	−0.45		−0.02	−0.03	.98	−0.06		0.31	0.44	.66
	Twin Block	0.71		0.99	1.39	.17	2.59		3.02	4.25	<.0001**	1.60		1.97	2.78	.01*
	MARA	2.46		2.74	3.86	.0002**	1.83		2.26	3.19	.002**	0.28		0.66	0.92	.36
U1-FH	Bionator	−2.64	−1.22	−1.42	−1.32	.19	0.51	0.65	−0.13	−0.13	.90	−0.72	−0.10	−0.62	−0.58	.57
	Herbst	−1.95		−0.73	−0.68	.50	0.57		−0.08	−0.07	.94	−0.15		−0.05	−0.04	.96
	Twin Block	−0.25		0.97	0.91	.37	1.05		0.40	0.38	.71	0.27		0.37	0.34	.73
	MARA	1.07		2.30	2.14	.03*	0.47		−0.18	−0.17	.87	0.72		0.82	0.76	.45
SNA	Bionator	−0.48	−0.45	−0.03	−0.06	.95	−0.26	−0.26	0.00	0.01	.99	−0.36	−0.34	−0.02	−0.05	.96
	Herbst	−0.59		−0.14	−0.32	.75	−0.18		0.08	0.19	.85	−0.18		0.16	0.37	.71
	Twin Block	−0.19		0.27	0.62	.53	−0.28		−0.02	−0.04	.91	−0.25		0.09	0.20	.84
	MARA	−1.39		−0.93	−2.17	.03*	−0.83		−0.57	−1.32	.19	−1.06		−0.73	−1.69	.09
SNB	Bionator	0.43	−0.05	0.47	1.50	.13	−0.06	0.14	−2.07	−0.66	.51	0.11	0.07	0.04	0.13	.90
	Herbst	0.56		0.60	1.91	.06	0.18		0.04	0.12	.90	0.41		0.34	1.09	.28
	Twin Block	0.83		0.88	2.79	.01*	0.04		−0.11	−0.34	.73	0.41		0.34	1.08	.28
	MARA	−0.43		−0.39	−1.23	.22	−0.48		−0.63	−2.00	.05*	−0.46		−0.53	−1.68	.09
ANB	Bionator	−0.92	−0.40	−0.51	−1.93	.05*	−0.21	−0.41	0.21	0.78	.43	−0.48	−0.41	−0.07	−0.25	.80
	Herbst	−1.17		−0.76	−2.86	.005*	−0.36		0.05	0.19	.85	−0.60		−0.19	−0.71	.48
	Twin Block	−1.02		−0.62	−2.32	.02*	−0.31		0.11	0.40	.69	−0.41		−0.25	−0.93	.35
	MARA	−0.93		−0.53	−1.97	.05*	−0.36		0.06	0.21	.83	−0.60		−0.19	−0.71	.48
OccPlane-SN	Bionator	0.57	−0.28	0.85	1.77	.08	−0.07	−0.63	0.56	1.18	.24	0.38	−0.49	0.87	1.82	.07
	Herbst	1.81		2.09	4.37	<.0001**	−0.36		0.27	0.57	.57	0.27		0.76	1.59	.11
	Twin Block	0.02		0.30	0.62	.53	0.33		0.96	2.01	.05*	0.14		0.63	1.31	.19
	MARA	0.65		0.93	1.95	.05*	−0.14		0.49	1.02	.31	0.20		0.69	1.44	.15
SN-NPog	Bionator	0.39	−0.02	0.42	1.36	.18	0.10	0.26	−0.16	−0.51	.61	0.18	0.14	0.04	0.12	.90
	Herbst	0.59		0.61	1.99	.05*	0.21		−0.04	−0.14	.89	0.43		0.29	0.94	.35
	Twin Block	1.00		1.02	3.31	.001**	0.11		−0.14	−0.46	.64	0.50		0.35	1.15	.25
	MARA	−0.38		−0.36	−1.17	.24	−0.35		−0.61	−1.98	.05*	−0.37		−0.51	−1.66	.10
SN-GoGn	Bionator	0.60	−0.04	0.64	1.65	.10	0.09	0.04	0.05	0.12	.91	0.31	0.01	0.30	0.77	.44
	Herbst	0.79		0.83	2.14	.03*	−0.43		−0.47	−1.22	.22	−0.10		−0.11	−0.28	.78
	Twin Block	−0.19		−0.15	−0.38	.70	−0.15		−0.19	−0.50	.62	−0.13		−0.14	−0.36	.72
	MARA	0.93		0.97	2.49	.01*	0.22		0.18	0.46	.65	0.52		0.51	1.32	.19

[a] T indicates treatment group; C, control group; and Diff of Δ, difference of delta.
* $P \leq .05$; ** $P \leq .002$.

the mandibular plane angle and had the greatest long-term effect on the labial version of the mandibular incisors (Tables 5a,b and 6).

DISCUSSION

The Bionator group showed significant opening of the gonial angle (Ar-Go-Me) after functional treatment. This 2.0° per year increase in the gonial angle was greater than any of the untreated and treated samples and is most likely attributed to the growth direction of the condyle[11] and remodeling of the posterior border of the ramus. The significant reduction in the overbite in the Bionator group is to be anticipated, as the mandible migrates forward along the lingual inclines of the maxillary incisors. The greatest amount of lingual crown tipping of the maxillary incisors was shown in this treatment group and could be attributed to pressure from the labial bow. This finding has been reported by other investigators.[18,19]

The Herbst group had a significant decrease of the Wits over time, possibly due to maxillary growth restriction and change in the occlusal plane. Pancherz et al[21] and Berger et al[22] reported similar findings with forward and downward movement of pogonion (0.8° per year) and opening of the mandibular plane angle. The decrease in overbite and overjet was consistently significant at the end of treatment and parallels the findings of the previous studies.[21,22] Although the Herbst appliance is a tooth-borne appliance, there were no adverse effects on the dentition. This can be directly associated with the full acrylic coverage splint design of the appliance used in this study.

The Twin Block, Herbst, and MARA patients showed an increase in mandibular length of 1.5 mm per year, 1.2 mm per year, and 0.94 mm per year, respectively. Similar trends were noted by Baccetti et al,[12] Wieslander et al,[15] and Berger et al[22] for these appliances. It has been suggested that the most effective timing for treatment with the Bionator,[11] Twin Block,[12] and Herbst[23] appliances is during or slightly after the onset of the pubertal peak in growth velocity. The mean age of the patients in this study at the start of functional appliance treatment was 10 years 7 months for the Bionator group and 10 years 11 months for the Twin Block group. The Herbst and MARA groups began 1–2 years thereafter. This difference in chronologic age could not be explain the larger increments of growth experienced with the Twin Block, Herbst and MARA, since all of the patients were matched by their growth maturation status. The greatest change in mandibular length occurred during functional appliance treatment when compared with the controls. After this initial growth surge, only the MARA patients sustained a longer mandibular growth length of 1.0 mm per year when compared with the controls. This finding is in agreement with that reported by Livieratos and Johnston[25] who suggested that functional appliances place a mortgage on mandibular growth. Control clinical trials[26] also found no significant alteration of mandibular length long term with the utilization of functional appliances.

The maxillary length measurement was significantly larger when comparing the Herbst and MARA groups to the Twin Block sample at T_1. Therefore, it can be appreciated as to how much restriction of maxillary growth occurred during treatment with the Herbst appliance when compared with the Twin Block, MARA, and control groups. Temporary restriction in maxillary growth by the Herbst appliance is well documented in multiple investigations.[15,22,27–29] and may be due to the posterior direction of the force generated by the pistons on the maxilla. In addition, the posterior direction of force caused the maxilla to rotate in a clockwise manner, as demonstrated in this study and by von Bremen and Pancherz.[23] The Herbst group also demonstrated the most upper lip retrusion compared with any group after appliance wear, as previously reported by Pancherz and Anehus-Pancherz.[30]

The Twin Block group demonstrated stability of the skeletal changes as exhibited through the decrease in the Wits appraisal and the displacement of pogonion in a more anterior position. After appliance therapy, the ANB angle decreased (−0.6° per year), while the SNB angle increased (0.9° per year) when compared with the controls. These findings are consistent with multiple studies, which noted the favorable changes in ANB.[31,32] Patel et al[33] noted forward movement of B-point and pogonion while Baccetti et al[12] found pogonion to move forward 2.5 mm per year with Twin Block therapy. The Twin Block group exhibited the best vertical control when compared with all treatment groups, especially taking into account that the mean SN-GoGn angle was initially greater in this group at the outset. The Twin Block also showed clockwise rotation of the occlusal plane after phase II therapy and the most flaring of the mandibular incisors at the end of treatment. These findings could be explained by the bite block effect of the appliance on the buccal segments and pressure of the lingual acrylic on the lower incisors. Possibly, this side effect could have been prevented using a labial bow to support the lower anteriors as designed by McNamara and Brudon.[44] Mills and McCulloch[13] reported similar findings. The Twin Block appliance also decreased the overbite and overjet significantly over the long term when compared with the controls, showing the stability of the treatment effect.

The MARA group illustrated a combination of skeletal and dentoalveolar changes that were stable

Table 4. Soft Tissue Differences Among Control and Treatment Groups Annualized[a]

		ΔT_2–T_1	ΔT_2–T_1		Treatment–Control		ΔT_3–T_2	ΔT_3–T_2		Treatment–Control		ΔT_3–T_1	ΔT_3–T_1		Treatment–Control	
Measurement	Treatment	(T)	(C)	Diff of Δ	*t* Value	*P* Value	(T)	(C)	Diff of Δ	*t* Value	*P* Value	(T)	(C)	Diff of Δ	*t* Value	*P* Value
Soft tissue																
LLL, mm	Bionator	1.05	0.31	0.74	1.44	.15	0.25	−0.22	0.47	0.90	.37	0.41	−0.01	0.42	0.81	.42
	Herbst	0.60		0.29	0.56	.58	−0.09		0.12	0.23	.82	0.14		0.14	0.28	.78
	Twin Block	1.11		0.80	1.54	.13	0.66		0.88	1.69	.09	0.80		0.81	1.56	.12
	MARA	1.36		1.05	2.02	.05*	−0.04		0.18	0.35	.73	0.56		0.56	1.08	.28
ULP, mm	Bionator	−0.29	−0.14	−0.16	−0.54	.59	−0.37	−0.10	−0.27	−0.92	.36	−0.30	−0.11	−0.19	−0.64	.52
	Herbst	−0.98		−0.84	−2.91	.004*	−0.32		−0.22	−0.76	.45	−0.48		−0.36	−1.25	.21
	Twin Block	−0.53		−0.40	−1.37	.17	−0.06		0.04	0.14	.89	−0.30		−0.19	−0.64	.52
	MARA	−0.27		−0.13	−0.46	.65	−0.31		−0.21	−0.74	.46	−0.29		−0.18	−0.62	.54
LLP, mm	Bionator	0.16	−0.26	0.43	1.29	.20	−0.29	0.13	−0.42	−1.25	.21	−0.10	−0.03	−0.07	−0.22	.83
	Herbst	−0.20		0.06	0.19	.85	−0.32		−0.45	−1.35	.18	−0.19		−0.16	−0.49	.63
	Twin Block	0.02		0.28	0.84	.40	0.06		−0.07	−0.21	.83	−0.01		0.01	0.04	.97
	MARA	0.39		0.65	1.96	.05*	−0.24		−0.36	−1.09	.28	0.03		0.06	0.18	.86
ULL, mm	Bionator	0.46	0.86	−0.40	−1.05	.29	0.05	0.04	0.01	0.03	.97	0.25	0.37	−0.12	−0.32	.75
	Herbst	0.64		−0.21	−0.56	.58	−0.35		−0.39	−1.03	.30	−0.05		−0.42	−1.10	.27
	Twin Block	0.04		−0.81	−2.15	.03*	−0.37		−0.41	−1.09	.28	−0.16		−0.53	−1.40	.16
	MARA	0.47		−0.39	−1.02	.31	0.37		0.33	0.86	.39	0.41		0.04	0.12	.91
NLA, degrees	Bionator	−2.47	−0.81	−1.66	−0.86	.39	0.43	0.23	0.21	0.11	.91	−1.23	1.07	−2.30	−1.20	.23
	Herbst	1.62		2.43	1.27	.21	−0.53		−0.76	−0.39	.69	−0.23		−1.30	−0.68	.50
	Twin Block	0.41		1.22	0.64	.53	−1.28		−1.50	−0.78	.43	−0.21		−1.27	−0.66	.51
	MARA	−1.15		−0.34	−0.18	.86	2.46		2.23	1.16	.25	0.92		−0.15	−0.08	.94
Facial angle, degrees	Bionator	1.99	−0.31	2.30	3.15	.002*	−0.18	1.33	−1.51	−2.06	.04*	0.98	0.68	0.30	0.41	.68
	Herbst	1.04		1.35	1.85	.07	0.69		−0.64	−0.87	.39	0.99		0.32	0.44	.66
	Twin Block	0.19		0.50	0.68	.50	−0.06		−1.39	−1.91	.06	0.02		−0.65	−0.89	.38
	MARA	−0.55		−0.24	−0.33	.74	−0.21		−1.54	−2.10	.04*	−0.36		−1.03	−1.41	.16

[a] T indicates treatment group; C, control group; and Diff of Δ, difference of delta.
* $P \leq .05$; ** $P \leq .002$.

Table 5a. Significant Angular Differences Between Treatment Groups Annualized[a]

		ΔT_2–T_1	ΔT_2–T_1		T–OT		ΔT_3–T_2	ΔT_3–T_2		T–OT		ΔT_3–T_1	ΔT_3–T_1		T–OT	
Measurement	OT	(OT)	(T)	Diff of Δ	*t* Value	*P* Value	(OT)	(T)	Diff of Δ	*t* Value	*P* Value	(OT)	(T)	Diff of Δ	*t* Value	*P* Value
Bionator (T) vs other treatment (OT) groups																
Ar-Go-Me	Herbst	0.17	1.41	1.24	2.12	.04*	−0.73	−0.07	0.66	1.14	.26	−0.49	0.52	1.01	1.73	.09
	MARA	0.12		1.29	2.21	.03*	−0.24		0.17	0.29	.77	−0.09		0.61	1.04	.30
IMPA	Herbst	0.32	−0.53	−0.85	−1.19	.24	−0.45	1.00	1.46	2.02	.04*	−0.06	0.17	0.23	0.32	.75
	Twin Block	0.71		−1.23	−1.72	.09	2.59		−1.58	−2.20	.03*	1.60		−1.43	−2.00	.05*
	MARA	2.46		−2.99	−4.16	<.0001**	1.83		−0.83	−1.15	.25	0.28		−0.12	−0.16	.87
U1-FH	Twin Block	−0.25	−2.64	−2.39	−2.20	.03*	1.05	0.51	−0.54	−0.49	.62	0.27	−0.72	−0.98	−0.90	.37
	MARA	1.07		−3.72	−3.42	.0008**	0.47		0.05	0.04	.97	0.72		−1.44	−1.32	.19
SNA	MARA	−1.39	−0.48	0.91	2.09	.04*	−0.83	−0.26	0.57	1.31	.19	−1.06	−0.36	0.70	1.62	.11
SNB	MARA	−0.43	0.43	0.86	2.70	.01*	−0.48	−0.06	0.42	1.32	.19	−0.46	0.11	0.57	1.78	.08
OccPlane-SN	Herbst	1.81	0.57	−1.24	−2.57	.01*	−0.36	−0.07	0.29	0.60	.55	0.27	0.38	0.11	0.23	.82
SN-NPog	MARA	−0.38	0.39	0.78	2.50	.01*	−0.35	0.10	0.45	1.46	.15	−0.37	0.18	0.55	1.76	.08
SN-GoGn	Twin Block	−0.19	0.60	0.79	2.01	.05*	−0.15	0.09	0.24	0.61	.54	−0.13	0.31	0.44	1.12	.26
NLA	Herbst	1.62	−2.47	−4.09	−2.11	.04*	−0.53	0.43	0.97	0.50	.62	−0.23	−1.23	−1.00	−0.51	.61
Facial angle	Twin Block	0.19	1.99	1.81	2.44	.02*	−0.06	−0.18	−0.11	−0.15	.88	0.02	0.98	0.95	1.29	.20
	MARA	−0.55		2.55	3.44	.0007**	−0.21		0.03	0.04	.97	−0.36		1.33	1.80	.07
Herbst (T) vs other treatment (OT) groups																
Ar-Go-Me	Bionator	1.41	0.17	−1.24	−2.12	.04*	−0.07	−0.73	−0.66	−1.14	.26	0.52	−0.49	−1.01	−1.73	.09
SN-Ar	MARA	0.52	0.40	−0.12	−0.20	.84	1.45	0.16	−1.30	−2.19	.03*	1.05	0.13	−0.93	−1.56	.12
IMPA	Bionator	−0.53	0.32	0.85	1.19	.24	1.00	−0.45	−1.46	2.02	.04*	0.17	−0.06	−0.23	−0.32	.75
	Twin Block	0.71		−0.38	−0.53	.60	2.59		−3.04	−4.23	<.0001**	1.60		−1.66	−2.32	.02*
	MARA	2.46		−2.14	−2.97	.003*	1.83		−2.28	−3.17	.002**	0.28		−0.35	−0.48	.63
U1−FH	MARA	1.07	−1.95	−3.03	−2.79	.01*	0.47	0.57	0.11	0.10	.92	0.72	−0.15	−0.46	−0.42	.68
SNA	MARA	−1.39	−0.59	0.79	1.83	.07	−0.83	−0.18	0.65	1.49	.14	−1.06	−0.18	0.89	2.03	.04*
SNB	MARA	−0.43	0.56	0.99	3.10	.002**	−0.48	0.18	0.67	2.09	.04*	−0.46	0.41	0.87	2.74	.01*
OccPlane-SN	Bionator	0.57	1.81	1.24	2.57	.01*	−0.07	−0.36	−0.29	−0.60	.55	0.38	0.27	−0.11	−0.23	.82
	Twin Block	0.02		1.79	3.70	.0003**	0.33		−0.69	−1.42	.16	0.14		0.13	0.27	.78
	MARA	0.65		1.16	2.39	.02*	−0.14		−0.21	−0.44	.66	0.20		0.07	0.15	.88
SN-NPog	MARA	−0.38	0.59	0.97	3.13	.002**	−0.35	0.21	0.56	1.81	.07	−0.37	0.43	0.80	2.57	.01*
SN-GoGn	Twin Block	−0.19	0.79	0.98	2.49	.01*	−0.15	−0.43	−0.28	−0.71	.48	−0.13	−0.10	0.03	0.08	.93
NLA	Bionator	−2.47	1.62	4.09	2.11	.04*	0.43	−0.53	−0.97	−0.50	.62	−1.23	−0.23	1.00	0.51	.61
Facial angle	MARA	−0.55	1.04	1.59	2.15	.03*	−0.21	0.69	0.90	1.22	.22	−0.36	0.99	1.35	1.82	.07

[a] OT indicates other treatment group; T, treatment group; and Diff of Δ, difference of delta.

* $P \leq .05$; ** $P \leq .002$.

Table 5b. Significant Angular Differences Between Treatment Groups Annualized[a]

		ΔT_2–T_1	ΔT_2–T_1		T–OT		ΔT_3–T_2	ΔT_3–T_2		T–OT		ΔT_3–T_1	ΔT_3–T_1	ΔT_3–T_1		T–OT	
Measurement	OT	(OT)	(T)	Diff of Δ	*t* Value	*P* Value	(OT)	(T)	Diff of Δ	*t* Value	*P* Value	(OT)	(T)	(OT)	Diff of Δ	*t* Value	*P* Value
Twin Block (T) vs other treatment (OT) groups																	
SN-Ar	MARA	0.52	−0.16	0.69	1.16	.25	1.45	−0.25	1.70	2.87	.005*	1.05	−0.11	1.05	1.16	1.96	.05*
IMPA	Bionator	−0.53	0.71	−0.85	−1.19	.24	1.00	2.59	−1.58	−2.20	.03*	0.17	1.60	0.17	−1.43	−2.00	.05*
	Herbst	0.32		−0.38	−0.53	.60	−0.45		−3.04	−4.23	<.0001**	−0.06		−0.06	−1.66	−2.32	.02*
	MARA	2.46		1.75	2.44	.02*	1.83		−0.76	−1.05	.29	0.28		0.28	−1.32	−1.83	.07
U1-FH	Bionator	−2.64	−0.25	−2.39	−2.20	.03*	0.51	1.05	−0.54	−0.49	.62	−0.72	0.27	−0.72	−0.98	−0.90	.37
SNA	MARA	−1.39	−0.19	−1.20	−2.76	.01*	−0.83	−0.28	−0.55	−1.26	.21	−1.06	−0.25	−1.06	−0.81	−1.87	.06
SNB	MARA	−0.43	0.83	−1.27	−3.97	.0001**	−0.48	0.04	−0.52	−1.64	.10	−0.46	0.41	−0.46	−0.87	−2.73	.01*
OccPlane-SN	Herbst	1.81	0.02	1.79	3.70	.0003**	−0.36	0.33	−0.69	−1.42	.16	0.27	0.14	0.27	0.13	0.27	.78
SN-NPog	MARA	−0.38	1.00	−1.38	−4.44	<.0001**	−0.35	0.11	−0.47	−1.50	.14	−0.37	0.50	−0.37	−0.86	−2.77	.01*
SN-GoGn	Bionator	0.60	−0.19	0.79	2.01	.05*	0.09	−0.15	0.24	0.61	.54	0.31	−0.13	0.31	0.44	1.12	.26
	Herbst	0.79		0.98	2.49	.01*	−0.43		−0.28	−0.71	.48	−0.10		−0.10	0.03	0.08	.93
	MARA	0.93		1.11	2.84	.005*	0.22		0.37	0.94	.35	0.52		0.52	0.65	1.66	.10
Facial angle	Bionator	1.99	0.19	1.81	2.44	.02*	−0.18	−0.06	−0.11	−0.15	.88	0.98	0.02	0.98	0.95	1.29	.20
MARA (T) vs other treatment (OT) groups																	
Ar-Go-Me	Bionator	1.41	0.12	1.29	2.21	.03*	−0.07	−0.24	0.17	0.29	.77	0.52	−0.09	0.52	0.61	1.04	.30
SN-Ar	Herbst	0.40	0.52	−0.12	−0.20	.84	0.16	1.45	−1.30	−2.19	.03*	0.13	1.05	0.13	−0.93	−1.56	.12
	Twin Block	−0.16		−0.69	−1.16	.25	−0.25		−1.70	−2.87	.005*	−0.11		−0.11	−1.16	−1.96	.05*
IMPA	Bionator	−0.53	2.46	−2.99	−4.16	<.0001**	1.00	1.83	−0.83	−1.15	.25	0.17	0.28	0.17	−0.12	−0.16	.87
	Herbst	0.32		−2.14	−2.97	.003*	−0.45		−2.28	−3.17	.002**	−0.06		−0.06	−0.35	−0.48	.63
	Twin Block	0.71		−1.75	−2.44	.02*	2.59		0.76	1.05	.29	1.60		1.60	1.32	1.83	.07
U1-FH	Bionator	−2.64	1.07	−3.72	−3.42	.0008**	0.51	0.47	0.05	0.04	.97	−0.72	0.72	−0.72	−1.44	−1.32	.19
	Herbst	−1.95		−3.03	−2.79	.01*	0.57		0.11	0.10	.92	−0.15		−0.15	−0.46	−0.42	.68
SNA	Bionator	−0.48	−1.39	0.91	2.09	.04*	−0.26	−0.83	0.57	1.31	.19	−0.36	−1.06	−0.36	0.70	1.62	.11
	Herbst	−0.59		0.79	1.83	.07	−0.18		0.65	1.49	.14	−0.18		−0.18	0.89	2.03	.04*
	Twin Block	−0.19		1.20	2.76	.01*	−0.28		0.55	1.26	.21	−0.25		−0.25	0.81	1.87	.06
SNB	Bionator	0.43	−0.43	0.86	2.70	.01*	−0.06	−0.48	0.42	1.32	.19	0.11	−0.46	0.11	0.57	1.78	.08
	Herbst	0.56		0.99	3.10	.002**	0.18		0.67	2.09	.04*	0.41		0.41	0.87	2.74	.01*
	Twin Block	0.83		1.27	3.97	.0001**	0.04		0.52	1.64	.10	0.41		0.41	0.87	2.73	.01*
OccPlane-SN	Herbst	1.81	0.65	1.16	2.39	.02*	−0.36	−0.14	−0.21	−0.44	.66	0.27	0.20	0.27	0.07	0.15	.88
SN-NPog	Bionator	0.39	−0.38	0.78	2.50	.01*	0.10	−0.35	0.45	1.46	.15	0.18	−0.37	0.18	0.55	1.76	.08
	Herbst	0.59		0.97	3.13	.002**	0.21		0.56	1.81	.07	0.43		0.43	0.80	2.57	.01*
	Twin Block	1.00		1.38	4.44	<.0001**	0.11		0.47	1.50	.14	0.50		0.50	0.86	2.77	.01*
SN-GoGn	Twin Block	−0.19	0.93	−1.11	−2.84	.005*	−0.15	0.22	−0.37	−0.94	.35	−0.13	0.52	−0.13	−0.65	−1.66	.10
Facial angle	Bionator	1.99	−0.55	2.55	3.44	.0007**	−0.18	−0.21	0.03	0.04	.97	0.98	−0.36	0.98	1.33	1.80	.07
	Herbst	1.04		1.59	2.15	.03*	0.69		0.90	1.22	.22	0.99		0.99	1.35	1.82	.07

[a] OT indicates other treatment group; T, treatment group; and Diff of Δ, difference of delta.
* $P \leq .05$; ** $P \leq .002$.

Table 6. Significant Linear Differences Between Treatment Groups Annualized[a]

		ΔT_2–T_1	ΔT_2–T_1		T–OT		ΔT_3–T_2	ΔT_3–T_2		T–OT		ΔT_3–T_1	ΔT_3–T_1		T–OT	
Measurement	OT	(OT)	(T)	Diff of Δ	*t* Value	*P* Value	(OT)	(T)	Diff of Δ	*t* Value	*P* Value	(OT)	(T)	Diff of Δ	*t* Value	*P* Value
Bionator (T) vs other treatment (OT) groups																
Overbite	Herbst	−2.12	−0.99	1.13	4.05	<.0001**	0.13	−0.31	−0.44	−1.57	.12	−0.66	−0.65	0.01	0.04	.97
Overjet	Herbst	−2.46	−1.80	0.66	2.52	.01*	0.07	−0.15	−0.22	−0.84	.40	−0.80	−0.70	0.10	0.40	.69
Wits	Herbst	−2.71	−1.28	1.43	4.59	<.0001*	0.03	−0.08	−0.11	−0.36	.72	−0.97	−0.58	0.39	1.26	.21
Go-Me:SN	MARA	−0.72	1.00	1.71	2.21	.03*	1.87	0.67	−1.20	−1.55	.12	0.77	0.82	0.05	0.07	.95
ULP, mm	Herbst	−0.98	−0.29	0.69	2.34	.02*	−0.32	−0.37	−0.05	−0.16	.87	−0.48	−0.30	0.18	0.60	.55
Herbst (T) vs other treatment (OT) groups																
Co-A	Twin Block	1.50	0.13	−1.37	−2.18	.03*	0.33	0.74	0.41	0.65	.52	0.94	0.49	−0.45	−0.72	.47
	MARA	1.75		−1.62	−2.57	.01*	0.97		−0.23	−0.37	.71	1.30		−0.82	−1.29	.20
Overbite	Bionator	−0.99	−2.12	−1.13	−4.05	<.0001**	−0.31	0.13	0.44	1.57	.12	−0.65	−0.66	−0.01	−0.04	.97
	Twin Block	−0.92		−1.19	−4.28	<.0001**	−0.26		0.38	1.37	.17	−0.55		−0.11	−0.38	.71
	MARA	−1.32		−0.80	−2.86	.005*	0.22		−0.10	−0.35	.73	−0.43		−0.23	−0.81	.42
Overjet	Bionator	−1.80	−2.46	−0.66	−2.52	.01*	−0.15	0.07	0.22	0.84	.40	−0.70	−0.80	−0.10	0.40	.69
	Twin Block	−1.54		−0.92	−3.50	.001**	−0.31		0.38	1.46	.14	−0.92		0.12	0.44	.66
	MARA	−1.76		−0.70	−2.67	.01*	−0.06		0.13	0.50	.62	−0.78		−0.02	−0.07	.94
Wits	Bionator	−1.28	−2.71	−1.43	4.59	<.0001**	−0.08	0.03	0.11	0.36	.72	−0.58	−0.97	−0.39	−1.26	.21
	Twin Block	−1.38		−1.33	−4.27	<.0001**	−0.09		0.12	0.40	.69	−0.70		−0.27	−0.88	.38
	MARA	−0.98		−1.73	−5.57	<.0001**	0.10		−0.07	−0.23	.82	−0.36		−0.61	−1.96	.05*
Go-Me:SN	MARA	−0.72	1.85	0.26	3.30	.001**	1.87	0.85	−1.03	−1.32	.19	0.77	1.21	0.45	0.58	.56
ULP, mm	Bionator	−0.29	−0.98	−0.69	−2.34	.02*	−0.37	−0.32	0.05	0.16	.87	−0.30	−0.48	−0.18	−0.60	.55
	MARA	−0.27		−0.71	−2.42	.02*	−0.31		−0.01	−0.02	.98	−0.29		−0.18	−0.63	.53
Twin Block (T) vs other treatment (OT) groups																
Co-A	Herbst	0.13	1.50	−1.37	−2.18	.03*	0.74	0.33	0.41	0.65	.52	0.49	0.94	−0.45	−0.72	.47
Overbite	Herbst	−2.12	−0.92	−1.19	−4.28	<.0001**	0.13	−0.26	0.38	1.37	.17	−0.66	−0.55	−0.11	−0.38	.71
Overjet	Herbst	−2.46	−1.54	−0.92	−3.50	.001**	0.07	−0.31	0.38	1.46	.14	−0.80	−0.92	0.12	0.44	.66
Wits	Herbst	−2.71	−1.38	−1.33	−4.27	<.0001**	0.03	−0.09	0.12	0.40	.69	−0.97	−0.70	−0.27	−0.88	.38
Go-Me:SN	MARA	−0.72	2.10	−2.82	−3.63	.0004**	1.87	0.56	1.31	1.69	.09	0.77	1.11	−0.34	−0.44	.66
MARA (T) vs other treatment (OT) groups																
Co-A	Herbst	0.13	1.75	−1.62	−2.57	.01*	0.74	0.97	−0.23	−0.37	.71	0.49	1.30	−0.82	−1.29	.20
Overbite	Herbst	−2.12	−1.32	−0.80	−2.86	.005*	0.13	0.22	−0.10	−0.35	.73	−0.66	−0.43	−0.23	−0.81	.42
Overjet	Herbst	−2.46	−1.76	−0.70	−2.67	.01*	0.07	−0.06	0.13	0.50	.62	−0.80	−0.78	−0.02	−0.07	.94
Wits	Herbst	−2.71	−0.98	−1.73	−5.57	<.0001**	0.03	0.10	−0.07	−0.23	.82	−0.97	−0.36	−0.61	−1.96	.05*
Go-Me:SN	Bionator	1.00	−0.72	1.71	2.21	.03*	0.67	1.87	−1.20	−1.55	.12	0.82	0.77	0.05	0.07	.95
	Herbst	1.85		0.26	3.30	.001**	0.85		−1.03	−1.32	.19	1.21		0.45	0.58	.56
	Twin Block	2.10		2.82	3.63	.0004**	0.56		−1.31	−1.69	.09	1.11		0.34	0.44	.66
ULP, mm	Herbst	−0.98	−0.27	−0.71	−2.42	.02*	−0.32	−0.31	−0.01	−0.02	.98	−0.48	−0.29	−0.18	−0.63	.53

[a] OT indicates other treatment group; T, treatment group; and Diff of Δ, difference of delta.
* $P \leq .05$; ** $P \leq .002$.

over time. The flaring of the maxillary and mandibular incisors was only temporary after phase I therapy and was resolved at the end of edgewise treatment. The decrease in SNA could be due to the distal remodeling at A-point caused by the initial flaring of the upper incisors; therefore, it could not be solely attributed to restriction of maxillary growth. Co-Apt did not decrease over time. This finding contrasts with that of Pangrazio-Kulbersh et al[34] who reported significant restriction of maxillary growth with MARA treatment. Remodeling at A-point, resulting in a decrease in SNA, has been reported by Mills and McCulloch[13] and Illing et al.[32] The changes in Co-Apt did not correlate with the decrease in SNA. Posterior condylar growth expressed during MARA treatment could have influenced the total maxillary length masking the true effect of the appliance on maxillary growth. The decrease in SNB is most likely due to the increase in the vertical dimension, which was significant when compared with the controls. This vertical increase is most likely related to growth and changes in the occlusal plane.

Overall, there were no significant soft tissue changes in any of the groups studied. This contrasts the findings of Berger et al[22] who reported significant improvement of the facial contour after functional appliance treatment. The difference in findings is most likely attributed to tracing error. The soft tissue of the control sample was not always clear due to the aged cephalograms. Pancherz and Anehus-Pancherz[30] reported that the profile changes exhibited by patients who were treated with Herbst therapy were variable and unpredictable.

CONCLUSIONS

- No significant long-term dento-skeletal differences were observed between the various treatment groups and matched controls.
- When comparing the treatment groups among themselves, the Herbst and MARA appliances significantly restricted maxillary growth and produced a steeper occlusal plane.
- The Twin Block was most effective in controlling the mandibular plane angle and had the greatest effect long term on labial version of the mandibular incisors.

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