Original Article

Cephalometric Determinants of Successful Functional Appliance Therapy

H. P. Patel, BDS, MSc, FDSRCS, M(Orth)RCS[a]; H. C. Moseley, BChD, MSc, FDS(Orth)RCS, M(Orth)RCS[b]; J. H. Noar, BDS, FDSRCS, MSc, M(Orth)RCS ILTM[c]

Abstract: This retrospective study was undertaken to determine the presence of any features on a pretreatment lateral cephalogram that may be used to predict the success of improvement in the sagittal dental base relationship during functional appliance therapy in patients with a Class II skeletal pattern. Seventy-two patients judged to have been successfully treated with a functional appliance were selected for the study. Pre- and posttreatment radiographs were analyzed and the change in the ANB angle was used to determine the skeletal response to treatment. Within the total sample size of 72 patients, two groups were selected. One group of 13 patients who demonstrated a reduction in ANB angle of 3.0° or more were identified as the skeletal group. A second group of 15 patients who demonstrated a change in ANB angle equal to or less than 0.5° were identified as the nonskeletal group. Statistical analysis of these two groups revealed the presence of skeletal and dentoalveolar differences on the pretreatment lateral cephalogram. In the skeletal group, which responded with a favorable skeletal change, the mandible was smaller both in length ($P < .01$) and ramus height ($P < .05$) and the anterior and posterior lower face heights were smaller ($P < .05$). The cranial base was also smaller when compared with the respective lengths in the nonskeletal group. (*Angle Orthod* 2002;72:410–417.)

Key Words: Functional appliance; Cephalometry; Class II treatment

INTRODUCTION

The term functional appliance refers to a variety of orthodontic appliances designed to induce a change in activity of the various muscle groups that influence the function and position of the mandible in order to transmit forces to the dentition and the basal bone. Altering the sagittal and vertical mandibular position generates these changes in muscular forces and results in orthopedic and orthodontic changes.[1]

The possibility of affecting the growth of the jaws, particularly in skeletal Class II malocclusions, by functional jaw orthopedics is widely discussed in the orthodontic literature. The findings from animal studies[2–4] have been accepted by some as evidence that functional appliances can stimulate condylar growth. However, with regard to clinical evidence, there remains considerable controversy regarding the nature of the changes. Several studies have claimed that they are able to make changes in the underlying skeletal pattern of the patient, and such appliances may stimulate the growth of the mandible. In support were McNamara et al,[5] Hotz,[6] Marschner and Harris,[7] Meach,[8] and others.[9,10] By contrast, Björk,[11] Wieslander and Lagerstrom,[12] and others[13–16] have reported changes that were thought to be purely dentoalveolar with no effect on mandibular growth. Mills and McCulloch[17] carried out a cephalometric investigation into the treatment effects of the Twin Block appliance and found that the achieved results fell between the opposing views. Approximately 50% of the molar correction was accomplished by skeletal improvement in the lower jaw and 50% by dentoalveolar change. Birkebaek et al[18] concluded that the clinically observed results should be considered as a combination of factors, and the following have been suggested:[19]

- inhibition of mesial migration of maxillary teeth
- mesial movement of mandibular teeth
- inhibition of maxillary alveolar height increase and extrusion of mandibular molars

[a] Specialist Registrar in Orthodontics, Mount Vernon Hospital, Watford General Hospital and Eastman Dental Institute, London, UK.
[b] Consultant Orthodontist and Honorary Senior Lecturer, Watford General Hospital and Eastman Dental Institute, London, UK.
[c] Consultant Orthodontist and Honorary Senior Lecturer, Mount Vernon Hospital and Eastman Dental Institute, London, UK.
Corresponding author: J. H. Noar, Department of Orthodontics, Watford General Hospital, Vicarage Road, Watford, Hertfordshire WD1 8HB, UK
(e-mail: J. Noar@eastman.ucl.ac.uk).

Accepted: December 2001. Submitted: June 2001.

- inhibition of forward growth of the maxilla
- increased growth of the mandible
- changes in condylar growth direction and amount
- anterior relocation and remodeling of the glenoid fossa.

Selecting cases that will ensure a successful response to functional appliance therapy remains a problem because the treatment results are often variable and unpredictable. A wide individual variation in the response to treatment is evident even if broadly similar malocclusions are treated.[19]

Differing responses to treatment may be due to the design of the appliances. The possibility exists that different functional appliance designs act in dissimilar ways and are not directly comparable. Variations in appliance action such as the amount of mandibular advancement, types of construction bite, and prescribed time of wear are so marked that practically no two investigators use similar appliance design and construction bite.[20] The use of functional appliances to coincide with the pubertal growth spurt has been emphasized.[1,11,21] Björk[11] found that the effectiveness of functional appliances is reduced as patients get older. Cohen[21] suggested that treatment should start before the patient achieves peak growth rate in order to take advantage of periods of fast growth, which both precede and follow the peak growth rate itself. At present, it is difficult to predict the precise timing of the peak rate of facial growth before it takes place, but studies have shown a strong correlation between the peak of facial growth and peak height velocity.[22,23] Tanner et al[24] found that the peak height velocity occurred, on average, at 12 years in girls and at 14 years in boys.

It has been suggested that the success of a functional appliance is totally dependent on cooperation.[1] The minimum amount of wear that results in successful treatment is not known. In view of this, instructing patients to wear an appliance full time would maximize the opportunity for success, especially if one can only expect the patient to wear the appliance for 50% of the instructed time.[25]

Individual differences in sensory and neuromuscular response to functional appliance therapy could also be responsible for variations in treatment outcome. It has been shown that successful functional therapy is accompanied by specific transient changes in the reflex activity of the masseter.[26]

Assuming that a patient is compliant and is wearing the appliance as instructed, it may be that pretreatment skeletal morphologic factors are responsible for a poor treatment outcome. Parkhouse[27] demonstrated that those patients who responded successfully to therapy had a larger pretreatment ANB angle. Ahlgren and Laurin[28] concluded that the pretreatment ANB value was the only morphologic difference between successfully and unsuccessfully treated cases. A more recent study[29] found that, the smaller the SNB angle prior to treatment, the more successful was the reduction in overjet. The authors suggested that individuals with a small SNB angle would posture the mandible further forward, resulting in an increased muscle stretch, which may enhance the effectiveness of the appliance.

Authors have attempted to relate pretreatment vertical relationships to treatment outcome. Tulley[13] found that cases with an open bite prior to treatment were unsuccessful. Rather than a reduction of the overjet, the open bite was accentuated due to an unfavorable growth pattern. Pancherz[30] noted that a combination of an increased maxillary-mandibular plane angle (MMPA) and open bite resulted in a deterioration of the sagittal relationship following activator therapy. However, the magnitude of pretreatment MMPA alone had no influence on treatment outcome. It seems that successful treatment depends on the absence of an open bite rather than on a high or low MMPA. Indeed, the degree of overbite has been identified as a feature associated with a good prognosis for treatment outcome in other studies.[29] These findings relating to vertical relationships may be a reflection of an upward and forward growth pattern, which would be favorable for the correction of a skeletal Class II discrepancy. In subjects with an open bite or lack of overbite, the reverse may be true and could be indicative of an inherent adverse growth rotation.

Categorizing cases according to the orthopedic response to treatment provides an opportunity for comparing characteristics and identifying differences between those that responded with a skeletal change and those that did not. The aim of this study was to determine whether there are any skeletal morphologic features evident on a pretreatment lateral cephalogram that may be used to predict a successful improvement in the sagittal dental base relationship during functional appliance therapy in patients with a Class II skeletal pattern.

MATERIALS AND METHODS

This retrospective study utilized the standardized cephalometric radiographs of 72 (37 males, 35 females) consecutively treated patients demonstrating Class II Division 1 malocclusions as defined by the British Standards number 2048. All of the cephalometric radiographs were exposed with the teeth in occlusion and all subjects were treated with functional appliances. The criteria for inclusion in the study were

- no adjunctive orthodontic treatment either prior to or during the period of functional treatment
- availability of a high-quality pretreatment radiograph (T1) taken less than six months prior to the start of treatment and a posttreatment (T2) radiograph taken within a month of completion of functional treatment
- case notes recording the start and completion date of functional treatment.

Different clinicians performed the treatment; however, all were under the guidance and supervision of one senior cli-

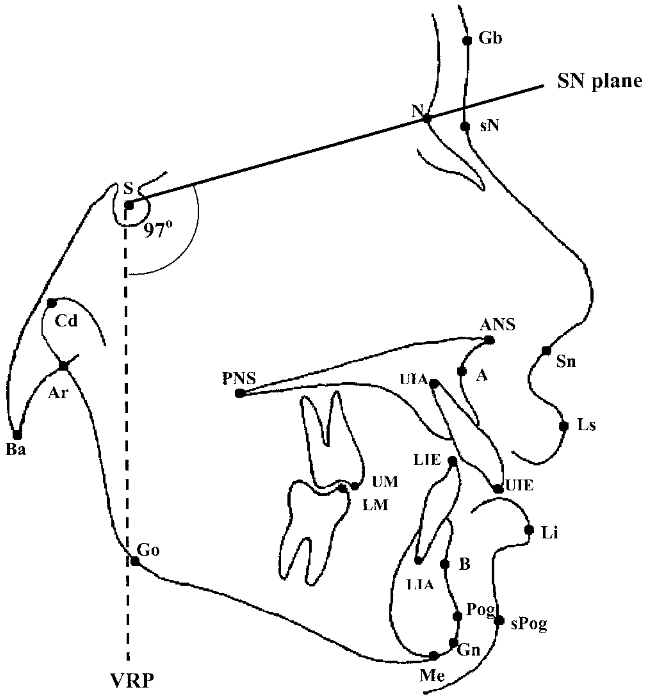

FIGURE 1. Cephalometric landmarks plus the vertical reference plane.

nician. Three types of appliances were used in this study: Medium Opening Activator,[31] Clark Twin block,[32] and Function Regulator II.[33]

The radiographs were directly digitized and analyzed using a customized computer programme (Gela software). Each landmark was digitized in a predetermined sequence, first on the pretreatment radiograph and then on the posttreatment radiograph. Both films from each patient were placed side by side on the viewer to try and minimize errors in locating cephalometric landmarks. The identification of these landmarks were based on the definitions by Riolo et al.[34] A vertical reference plane (VRP) through the sella at 97° to the sella–nasion plane[35] was constructed (Figure 1). The computer program was used to calculate 43 angular, linear, and proportional measurements (Table 1). Comparative statistical analysis of the data was made using analysis of variance (ANOVA).

Following digitization of pre- and posttreatment radiographs for the 72 subjects, the T1 to T2 change in the ANB angle was identified and plotted as a bar chart (Figure 2). This angular change was then used to subdivide the sample.

The group labeled skeletal represents 13 patients who each demonstrated a reduction in the ANB angle of 3.0° or more. This group showed a favorable change in the sagittal dental base relationship. The group labeled nonskeletal represents 15 patients that demonstrated a reduction in ANB angle of 0.5° or less. This group showed a less favorable change in the sagittal dental base relationship in response to treatment with functional appliance therapy. Groups at either end of the spectrum were used to allow any differences in the pretreatment cephalometric variables to be more readily identified.

Method error evaluation

The error study involved analysis of 25 radiographs picked at random from the study group and redigitized after a period of six weeks. For the error assessment, systematic and random error were calculated separately as described by Houston.[36] Variables showing statistical significance amounted to 0.4 mm for linear measurement between sella and nasion and 0.8° for upper incisor inclination.

RESULTS

The results are presented in tabular form. The mean ages and length of treatment for both groups were similar (Table 2). Table 1 presents comparative data for the pretreatment cephalometric measurements at the start of treatment (T1) for the two groups. Table 3 presents comparative data for the changes that occurred during treatment (T1 to T2) for the two groups. The cephalometric variables were then grouped in the following subgroups for ease of interpretation:

- cranial base variables
- face height variables
- antero-posterior variables
- horizontal planes
- mandibular variables
- dento-alveolar variables
- soft-tissue variables
- cranial base variables.

The cranial base lengths at the start of treatment, although not statistically significant, showed a tendency to be smaller in the skeletal group. The cranial base angle (N-S-Ar) was larger by 3.2° in the skeletal group. At the end of treatment, the skeletal group showed a statistically significant increase ($P < .05$) in lateral cranial base length (S-Ar) and total cranial base length (Ba-N). This group also demonstrated a decrease in the cranial base angle in contrast to the increase the cranial base angle seen in the nonskeletal group.

Face height variables

Both upper and lower anterior face heights and lower posterior face height were smaller ($P < .05$) before treatment in the skeletal group. During treatment, these measurements showed a greater increase in the skeletal group, with the increase in lower posterior face height being significant ($P < .05$).

Antero-posterior variables

There was a significant difference in the ANB angle at the start of treatment, which was mainly due to a smaller

TABLE 1. Pretreatment Cephalometric Variables (T1)

	Nonskeletal Group		Skeletal Group			
	Mean	SD	Mean	SD	*P* Value	Significance[a]
Cranial base variables						
S-Ar (mm)	37.1	4.0	34.0	3.7	.051	NS
S-N (mm)	75.9	3.4	73.9	2.3	.075	NS
Ba-N (mm)	113.6	5.6	109.8	4.1	.055	NS
N-S-Ar (degrees)	124.0	6.3	127.2	4.8	.138	NS
Face height variables						
UAFH (mm)	54.9	4.3	51.7	2.7	.027	*
LAFH (mm)	65.7	6.1	60.6	5.1	.025	*
UPFH (mm)	45.0	4.2	42.9	2.7	.141	NS
LPFH (mm)	33.2	5.3	28.7	5.1	.029	*
%LAFH	54.4	2.4	53.8	2.3	.539	NS
%LPFH	42.4	4.1	39.8	4.1	.114	NS
S-Ar-Go (degrees)	140.9	5.4	137.7	5.5	.135	NS
Antero-posterior variables						
SNA (degrees)	82.4	3.4	82.1	3.7	.835	NS
SNB (degrees)	76.3	3.7	74.3	3.6	.149	NS
ANB (degrees)	6.2	2.6	7.8	1.3	.047	*
VRP-Cd (mm)	15.7	4.3	15.1	2.7	.639	NS
VRP-ANS (mm)	79.6	4.9	76.9	4.1	.125	NS
VRP-A (mm)	74.7	5.0	72.4	3.4	.171	NS
VRP-B (mm)	63.5	7.7	59.0	5.3	.087	NS
VRP-Pog (mm)	75.5	9.4	71.5	6.5	.209	NS
S-N-Pog (degrees)	77.3	4.1	75.8	3.8	.314	NS
Horizontal plane variables						
SN-MxP (degrees)	7.6	3.7	6.8	2.4	.496	NS
SN-MnP (degrees)	34.5	5.9	34.5	5.0	.973	NS
MxP-MnP (degrees)	27.0	5.8	27.7	4.8	.763	NS
Mandibular dimensions						
Cd-Go (mm)	58.4	6.0	53.2	6.0	.030	*
Cd-Gn (mm)	118.3	6.7	110.6	6.4	.005	**
Go-Gn (mm)	76.1	5.5	72.7	5.7	.13	NS
Ar-Gn (mm)	110.0	7.3	104.4	6.4	.041	*
Ar-Go-Me (degrees)	129.7	6.8	129.5	5.4	.946	NS
Dento-alveolar variables						
OB (mm)	6.3	2.1	6.0	3.1	.734	NS
OJ (mm)	8.9	2.6	11.6	3.7	.032	*
UI-MxP (degrees)	114.8	7.3	114.5	12.4	.923	NS
LI-MnP (degrees)	90.2	14.8	91.3	7.0	.808	NS
II (degrees)	128.0	15.8	126.6	15.3	.812	NS
UM-MxP (mm)	22.4	3.7	20.4	3.1	.131	NS
LM-MnP (mm)	31.1	3.6	28.0	2.5	.016	*
VRP-UM (mm)	42.4	5.3	40.0	3.6	.194	NS
VRP-LM (mm)	41.1	4.9	36.3	4.2	.010	*
Soft-tissue variables						
VRP-Gb (mm)	85.0	3.9	83.0	3.1	.149	NS
VRP-sN (mm)	80.9	3.6	78.8	2.5	.093	NS
VRP-Sn (mm)	90.6	5.6	87.3	3.8	.093	NS
VRP-Ls (mm)	92.4	6.3	88.7	6.2	.136	NS
VRP-Li (mm)	84.2	7.6	80.0	7.2	.143	NS
VRP-sPog (mm)	63.9	9.2	59.7	6.1	.170	NS

[a] NS, not significant; *, $P \leq .05$; **, $P \leq .01$.

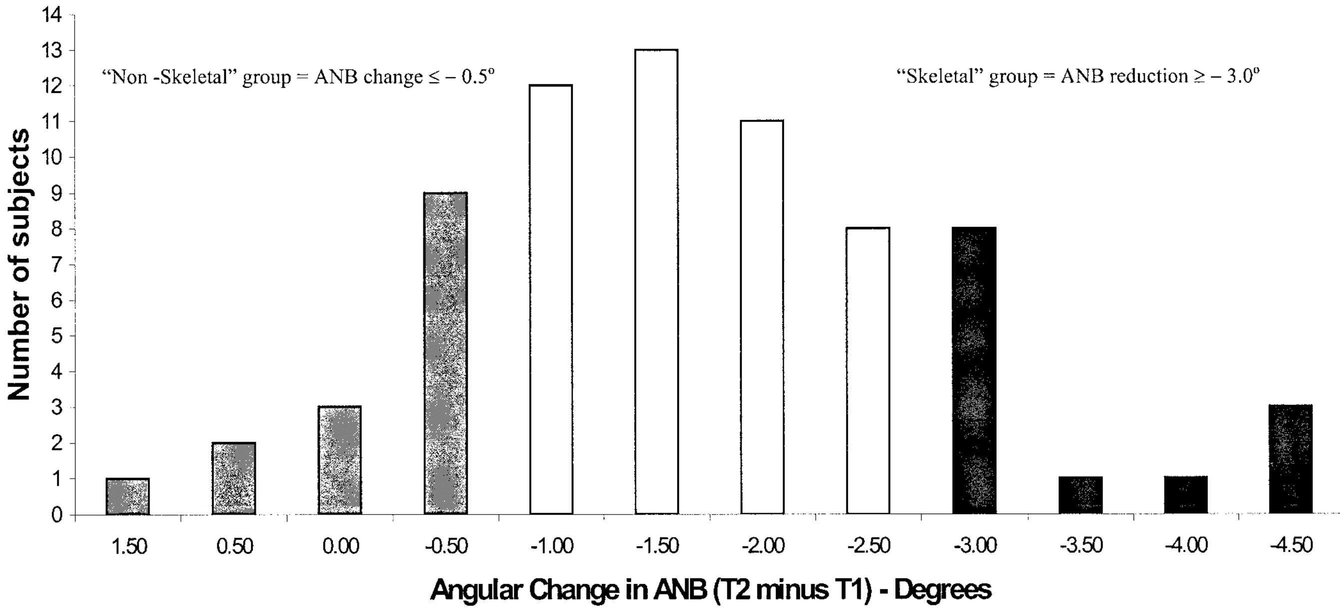

FIGURE 2. Difference in ANB before and after treatment.

SNB angle in the skeletal group. After treatment, the reduction in ANB angle was, as defined by the groups, significantly different between the two groups. This was due to a forward movement of the mandible in the skeletal group, demonstrated by the significant differences in SNB ($P < .001$), VRP-B ($P < .001$), VRP-Pog ($P < .01$), and S-N-Pog ($P < .01$) (Table 3).

Horizontal planes

At the start of treatment, all of the horizontal planes were comparable between the two groups. However, at the end of treatment, there was a statistically significant change in the angles, MxP-MnP ($P < .01$) and SN-MxP ($P < .05$) between the two groups. The skeletal group showed a reduction in these angles, in contrast with a slight increase demonstrated in the nonskeletal group.

Mandibular variables

At the start of treatment, the overall dimensions of the mandible were smaller in the skeletal group. The diagonal unit length, as measured from condylion to gnathion, was 7.7 mm smaller ($P < .01$), and this was highly statistically significant. Measuring this length using the alternative landmarks, articulare to gonion, also gave a smaller value of 5.6 mm ($P < .05$). Ramus height and mandibular corpus length were also 5.2 mm ($P < .05$) and 3.4 mm smaller, respectively; however, the angle of the ramus to the body (Ar-Go-Me) showed no difference. Although both groups exhibited an increase in the overall dimensions of the mandible at the end of treatment, a much greater increase occurred in the skeletal group. The difference between the two groups was statistically significant for all mandibular lengths, but the angle of the ramus to the body did not significantly change.

Dento-alveolar variables

A significant difference in the starting mean overjet was found between the two groups. Overjet in the skeletal group was 11.9 mm and in the nonskeletal group was 8.9 mm. The incisor inclinations were, however, similar in both groups, implying that the difference lies in the skeletal discrepancy between the two groups. Both mandibular dento-alveolar height (LM-MnP) and the linear measurement from the vertical reference plane (VRP-LM) to the lower molar were smaller ($P < .05$), implying a lack of development in this area in the skeletal group. At the end of treatment, VRP-LM increased significantly, by 6.4 mm ($P < .001$), possibly reflecting a greater forward movement of the mandible in the skeletal group.

TABLE 2. Mean Ages and Length of Treatment

	Nonskeletal Group		Skeletal Group			
	Mean	SD	Mean	SD	*P* Value	Significance
Age (years)	12.8	2.2	12.2	1.5	.410	NS
Length of treatment (months)	11.2	5.9	13.6	5.9	.294	NS

TABLE 3. Changes in Cephalometric Variables from T1 to T2

	Nonskeletal group		Skeletal Group			
	Mean	SD	Mean	SD	*P* Value	Significance[a]
Cranial base variables						
S-Ar (mm)	0.5	1.2	1.7	1.8	.050	*
S-N (mm)	0.9	1.2	1.8	1.7	.120	NS
Ba-N (mm)	1.1	1.9	3.1	2.1	.014	*
N-S-Ar (degrees)	0.4	3.2	−0.8	2.7	.293	NS
Face height variables						
UAFH (mm)	1.3	1.8	2.5	1.8	.094	NS
LAFH (mm)	4.5	2.3	4.9	1.7	.595	NS
UPFH (mm)	0.6	1.3	1.5	1.8	.139	NS
LPFH (mm)	2.4	2.3	4.5	2.2	.020	*
%LAFH	1.1	1.3	0.8	0.8	.480	NS
%LPFH	1.4	2.2	2.9	2.1	.071	NS
S-Ar-Go (degrees)	0.9	3.7	0.0	4.0	.563	NS
Antero-posterior variables						
SNA (degrees)	0.1	1.5	−0.9	1.0	.059	NS
SNB (degrees)	0.0	1.7	2.5	1.3	.000	***
ANB (degrees)	−0.1	0.6	−3.5	0.7	.000	***
VRP-Cd (mm)	−0.5	2.4	0.5	1.4	.202	NS
VRP-ANS (mm)	1.3	1.8	2.2	2.6	.282	NS
VRP-A (mm)	1.0	1.4	0.8	1.5	.782	NS
VRP-B (mm)	0.6	2.9	5.2	2.1	.000	***
VRP-Pog (mm)	1.7	4.2	6.8	3.8	.003	**
S-N-Pog (degrees)	0.0	1.7	2.1	1.2	.001	**
Horizontal plane variables						
SN-MxP (degrees)	0.6	1.6	0.7	1.6	.836	NS
SN-MnP (degrees)	1.6	2.1	−0.5	2.0	.010	*
MxPMnP (degrees)	1.0	1.7	−1.3	2.0	.004	**
Mandibular dimensions						
Cd-Go (mm)	2.2	3.2	4.6	2.5	.041	*
Cd-Gn (mm)	3.7	3.7	7.8	2.3	.002	**
Go-Gn (mm)	2.1	1.5	4.2	2.4	.009	**
Ar-Gn (mm)	4.2	2.1	7.9	2.3	.000	***
Ar-Go-Me (degrees)	−1.6	7.0	0.3	3.5	.392	NS
Dento-alveolar variables						
OB (mm)	−3.3	2.8	−2.3	3.9	.462	NS
OJ (mm)	−4.5	2.9	−7.5	4.6	.043	*
UI-MxP (degrees)	−6.8	7.7	−6.0	10.4	.818	NS
LI-MnP (degrees)	5.1	10.4	4.6	5.1	.862	NS
II (degrees)	0.6	9.1	2.7	10.1	.561	NS
UM-MxP (mm)	1.3	1.7	1.4	2.1	.905	NS
LM-MnP (mm)	1.4	1.5	2.1	1.9	.245	NS
VRP-UM (mm)	−0.6	2.3	0.0	2.6	.570	NS
VRP-LM (mm)	2.5	2.6	6.4	2.2	.000	***
Soft-tissue variables						
VRP-Gb (mm)	1.3	1.4	1.8	2.3	.542	NS
VRP-sN (mm)	0.9	2.0	1.9	2.1	.186	NS
VRP-Sn (mm)	1.2	2.2	2.8	3.0	.125	NS
VRP-Ls (mm)	0.3	2.7	1.8	3.6	.226	NS
VRP-Li (mm)	2.4	5.1	6.1	4.7	.060	NS
VRP-sPog (mm)	0.4	3.4	5.3	2.4	.000	***

[a] NS, not significant; *, $P \leq .05$; **, $P \leq .01$; ***, $P \leq .001$.

Soft-tissue variables

Perpendicular linear measurements from the vertical reference plane to soft-tissue landmarks were similar, with no statistically significant differences between the two groups prior to treatment. At the end of treatment, the only variable showing statistical significance ($P < .001$) between the two groups was the linear measurement from vertical reference plane to soft-tissue pogonion (VRP-sPog). This again demonstrates the forward movement of the mandible itself in the skeletal group.

DISCUSSION

All 72 patients selected for this study had undergone functional appliance therapy for correction of a Class II Division I incisor relationship. The correction of this incisor relationship, however, was achieved differently for the two patient groups. In one group, there was significant skeletal change, and in the other, a more dento-alveolar change leading to the reduction in the overjet. The pretreatment skeletal morphology of the two groups was compared to identify any significant differences.

The differences between the two groups are most obvious in the lower jaw. For those where skeletal movement is high, there is a much greater movement of B point and pogonion forward and specifically an increase in the size of the mandible itself.

In addition, at the start of treatment, the mandible was smaller in the group that responded skeletally to treatment than in the group that responded with dento-alveolar change. It can be suggested that those patients who showed a greater skeletal change perhaps had a lower jaw that had more room for development and could be described as more immature at the start of treatment. This is not related to age, as the two groups were similar in age at the start of treatment. No attempt was made in this study to categorize the appliances used into groups based on the possibility that different functional appliance designs act in dissimilar ways. It is our view, however, that the Class II effects of functional appliances are essentially similar and individual design is not relevant.

The study also revealed significant differences in the growth of the cranial base. Patients who responded skeletally to treatment demonstrated an increase in the length of the cranial base and a reduction in the cranial base angle. Lewis et al[37] reported that growth spurts in the cranial base and the mandible are correlated. This would indicate that craniofacial growth in general is a factor related to treatment outcome rather than the local effects of functional appliance therapy. Further, it can be seen that, although not significant, the cranial base measurements of the group that responded skeletally to functional appliance therapy were smaller than the group that did not. This again supports the conclusion that the skeletal group had more development of their craniofacial form to complete as compared with the nonskeletal group, which may well be more mature in their facial development.

The significance of these results will only have a clinical use if patients with high growth potential can be identified at the start of treatment. Further work on a greater number of patients would be required to attempt to relate cranial base variables and mandibular variables to Class I individuals, eventually allowing the production of an index of cranial base and mandibular length for various age groups. If this were completed, individual patients could be analyzed and compared with developmental norms and an assessment of the growth potential in the mandible made available. This would give the most accurate prediction perhaps of whether or not growth modification with functional appliances would be possible in any individual case.

CONCLUSIONS

In this study, cephalometrically determined skeletal differences were evident between those patients that responded skeletally to functional appliance therapy and those that responded less favorably. In the patients that responded favorably to treatment, the pretreatment differences were found to be a smaller and more retrusive mandible and smaller anterior and posterior face heights. Cranial base dimensions, although not statistically significant, were also found to be smaller. This overall lack of development was not necessarily related to age.

During the treatment period, patients that showed a favorable response to appliance therapy demonstrated a greater increase in dimensions within the mandible and cranial base, suggesting that there was more growth potential available in this group at the start of treatment.

REFERENCES

1. Bishara SE, Ziaja RR. Functional appliances: a review. *Am J Orthod Dentofacial Orthop.* 1989;95:250–258.
2. Elgoyhen JC, Moyers RE, McNamara JA Jr, Riolo ML. Craniofacial adaptation of protrusive function in young rhesus monkeys. *Am J Orthod.* 1972;62:469–480.
3. Petrovic AG. Mechanisms and regulation of mandibular condylar growth. *Acta Morphol Neerl Scand.* 1972;10:25–34.
4. Charlier JP, Petrovic A, Herrmann-Stutzmann J. Effects of mandibular hyperpropulsion on the prechondroblastic zone of young rat condyle. *Am J Orthod.* 1969;55:71–74.
5. McNamara JA Jr, Hinton RJ, Hoffman DL. Histologic analysis of temporomandibular joint adaptation to protrusive function in young adult rhesus monkeys (*Macaca mulatta*). *Am J Orthod.* 1982;82:288–298.
6. Hotz RP. Application and appliance manipulation of functional forces. *Am J Orthod.* 1970;58:459–478.
7. Marschner JF, Harris JE. Mandibular growth and Class II treatment. *Angle Orthod.* 1966;36:89–93.
8. Meach CL. A cephalometric comparison of bony profile changes in Class II, Division 1 patients treated with extraoral force and functional jaw orthopedics. *Am J Orthod.* 1966;52:353–370.
9. Freunthaller P. Cephalometric observation in Class II, Division I malocclusions treated with the activator. *Angle Orthod.* 1967;37:18–25.

10. Pancherz HA. Cephalometric analysis of skeletal and dental changes contributing to Class II correction in activator treatment. *Am J Orthod.* 1984;85:125–134.
11. Björk A. The principle of the Andresen method of orthodontic treatment, a discussion based on the cephalometric x-ray analysis of treated cases. *Am J Orthod.* 1951;37:437–458.
12. Wieslander L, Lagerstrom L. The effect of activator treatment on Class II malocclusions. *Am J Orthod.* 1979;75:20–26.
13. Tulley WJ. The scope and limitations of treatment with the activator. *Am J Orthod.* 1972;61:562–577.
14. Hirzel HC, Grewe JM. Activators: a practical approach. *Am J Orthod.* 1974;66:557–570.
15. Stockli PW, Dietrich UC. Sensation and morphogenesis experimental and clinical findings following functional forward displacement of the mandible. *Trans Eur Orthod Soc.* 1973:435–442.
16. Nelson C, Harkness M, Herbison P. Mandibular changes during functional appliance treatment [see comments]. *Am J Orthod Dentofacial Orthop.* 1993;104:153–161.
17. Mills CM, McCulloch KJ. Treatment effects of the twin block appliance: a cephalometric study [see comments]. *Am J Orthod Dentofacial Orthop.* 1998;114:15–24.
18. Birkebaek L, Melsen B, Terp S. A laminagraphic study of the alterations in the temporo-mandibular joint following activator treatment. *Eur J Orthod.* 1984;6:257–266.
19. Vargervik K, Harvold EP. Response to activator treatment in Class II malocclusions. *Am J Orthod.* 1985;88:242–251.
20. Woodside DG. Do functional appliances have an orthopedic effect? [editorial]. *Am J Orthod Dentofacial Orthop.* 1998;113:11–14.
21. Cohen AM. The timing of orthodontic treatment in relation to growth. *Br J Orthod.* 1980;7:69–74.
22. Hunter CJ. The correlation of facial growth with body height and skeletal maturation at adolescence. *Angle Orthod.* 1966;36:44–54.
23. Bjork A. Timing of interceptive orthodontic measures based on stages of maturation. *Trans Eur Orthod Soc.* 1972:61–74.
24. Tanner JM, Whitehouse RH, Marubini E, Resele LF. The adolescent growth spurt of boys and girls of the Harpenden growth study. *Ann Hum Biol.* 1976;3:109–126.
25. Barton S, Cook PA. Predicting functional appliance treatment outcome in Class II malocclusions—a review [see comments]. *Am J Orthod Dentofacial Orthop.* 1997;112:282–286.
26. Carels C, van Steenberghe D. Changes in neuromuscular reflexes in the masseter muscles during functional jaw orthopedic treatment in children. *Am J Orthod Dentofacial Orthop.* 1986;90:410–419.
27. Parkhouse RC. A cephalometric appraisal of cases of Angle's Class II, Division I malocclusion treated by the Andresen appliance. *Dent Pract Dent Rec.* 1969;19:425–433.
28. Ahlgren J, Laurin C. Late results of activator-treatment: a cephalometric study. *Br J Orthod.* 1976;3:181–187.
29. Caldwell S, Cook P. Predicting the outcome of twin block functional appliance treatment: a prospective study. *Eur J Orthod.* 1999;21:533–539.
30. Pancherz H. Activity of the temporal and masseter muscles in class II, Division 1 malocclusions. An electromyographic investigation. *Am J Orthod.* 1980;77:679–688.
31. Orton HS. *Functional Appliances in Orthodontic Treatment.* London: Quintessence; 1990.
32. Clark WJ. The twin block traction technique *Eur J Orthod.* 1982;4:129–138.
33. Frankel R. The treatment of Class II, Division 1 malocclusion with functional correctors. *Am J Orthod.* 1969;55:265–275.
34. Riolo ML, Moyers RE, McNamara JA, Hunter WS. *An Atlas of Craniofacial Growth.* Monograph 2, Craniofacial Growth Series. University of Michigan Ann Arbor, Mich; 1974.
35. Burstone CJ, James RB, Legan H, Murphy GA, Norton LA. Cephalometrics for orthognathic surgery. *J Oral Surg.* 1978;36:269–277.
36. Houston WJ. The analysis of errors in orthodontic measurements. *Am J Orthod.* 1983;83:382–390.
37. Lewis AB, Roche AF, Wagner B. Pubertal spurts in cranial base and mandible. Comparisons within individuals. *Angle Orthod.* 1985;55:17–30.