Changes in mandibular length before, during, and after successful orthopedic correction of Class II malocclusions, using a functional appliance

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Forty-seven girls were successfully treated with a functional appliance (FA). To be included in this study, the rate of increase in mandibular length during treatment had to be greater than twice the mean rate for a subgroup of 20 of these patients evaluated during a pre-FA observation period. The mean mandibular growth rate was 6 mm per year while the FA was activated. In the ensuing months, cephalograms were taken at intervals coinciding with five post-FA phases, including complete edgewise treatment and retention. During the post-FA phase of initial edgewise treatment, the mandibular growth rate was dramatically reduced when compared with 47 controls matched for age, sex, and initial SN:GoGn angle. Selected individual cases are presented to illustrate the great variability in growth responses that were obtained. This study found highly significant increases in mandibular length still present 2 years after treatment, diminished but still significant gains after 3 years, and no significant difference after 4 years. (Am J Orthod Dentofacial Orthop 1991;99:241-257.)

Can a functional appliance (FA) stimulate mandibular growth? Animal studies, with some exceptions, have found significant increases in length. In human beings conflicting results have been reported with use of the Herbst® and the Fränkel appliances and the activator. In an attempt to resolve this disparity between the results in animals and human beings, DeVincenzo et al. developed a new FA that closely resembled the appliances used in monkeys and obtained comparable increases in mandibular length (ML). However, will this increased ML, which occurred in a 6- to 12-month activation interval, be sustained throughout the remainder of the long circumpubertal growth period?

When using this FA, it was a clinical impression that in the subsequent fixed multibanded phase of treatment, Class II elastics and extraoral force were frequently required. Could this mean that there was a decrease in the rate of mandibular growth immediately after FA therapy? What were the rates during the multibanded and retention phases? This report will address these questions.

METHODS AND MATERIALS

During 1982, 1983, and 1984, 77 girls were treated with the new FA, and 47 of these girls were selected for inclusion in this study. The remaining 30 girls were excluded because of a missing or inadequate cephalogram in the series (16), insufficient orthopedic effect (10), or less than full-time wear (4). Each patient had a Class II malocclusion with no prior orthodontic treatment and, during the FA phase, had obtained at least double the mean rate of ML increase observed during a pre-FA period. While in the FA phase, all activations were either advanced edge to edge or moved forward in 3 mm increments at 2-month intervals.

Cephalograms were taken at intervals corresponding to the treatment phases of this study (Table I). During the FA phase, 23 patients had a palatal intrusion appliance with 42 gm of intrusive force, while 8 had a 28 gm intrusion force to the mandibular incisors. No intraoral or extraoral force to correct the Class II condition was used except for the force derived from the FA alone. All patients wore the FA full time, even while eating. This phase was deemed completed when a Class I molar relationship was attained. During the holding
Table I. Summary of the clinical protocol used to determine the timing of cephalograms, the phases of treatment, and related data

<table>
<thead>
<tr>
<th>Cephalogram no.</th>
<th>Timing</th>
<th>n</th>
<th>Phase</th>
<th>n</th>
<th>Duration</th>
<th>Mean</th>
<th>(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial</td>
<td>20</td>
<td>Prefunctional appliance</td>
<td>20</td>
<td>7.0</td>
<td>(4.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Pre-FA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Beginning of FA activation</td>
<td>47</td>
<td>Functional appliance (FA)</td>
<td>47</td>
<td>10.3</td>
<td>(5.2)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>End of FA activation</td>
<td>47</td>
<td>Holding (H)</td>
<td>28</td>
<td>7.3</td>
<td>(2.7)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>End of wearing nonactivated FA</td>
<td>29</td>
<td>Synthetic (S)</td>
<td>32</td>
<td>9.5</td>
<td>(4.4)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Beginning of edgewise Rx</td>
<td>47</td>
<td>Pause (P)</td>
<td>13</td>
<td>8.9</td>
<td>(4.1)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>After 9 months of edgewise Rx</td>
<td>43</td>
<td>Early edgewise (EE)</td>
<td>43</td>
<td>8.6</td>
<td>(3.2)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>After 20 months of edgewise Rx</td>
<td>42</td>
<td>Late edgewise (LE)</td>
<td>38</td>
<td>11.0</td>
<td>(3.5)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1 year later</td>
<td>38</td>
<td>Retention (R)</td>
<td>34</td>
<td>13.7</td>
<td>(6.2)</td>
<td></td>
</tr>
</tbody>
</table>

NOTES:
A. Interim cephalograms taken during the FA phases were labeled No. 3. These were excluded from the report.
B. The holding device for 24 patients was the nonactivated FA, and for 5 patients it was a single-arch occlusally indexed biteplate.
C. Twelve patients began edgewise treatment immediately after FA therapy (cephalogram No. 4 = cephalogram No. 6 for these patients); 21 patients began edgewise treatment after a holding phase (cephalogram No. 5 = cephalogram No. 6 for these patients); and 14 patients began edgewise treatment after a pause phase.
D. Four patients had their first cephalogram after banding taken about 20 months later, these cephalograms were denoted No. 8.
E. Four patients had their second cephalogram after banding taken about 2 years after their first, these cephalograms were denoted No. 9. One patient resumed FA therapy after cephalogram No. 7 and was thereafter excluded from this report.
F. In nine patients, edgewise treatment was completed before the end of this phase.
G. Seven patients were still undergoing edgewise treatment at the end of this phase.
H. One case had an interval of less than 3 months and was truncated here.
I. Twelve patients began edgewise treatment immediately after FA therapy and thus were deleted here. Two patients had a very short interval and another had a very long interval. These were also deleted here.
J. The pause phase comprised 14 patients, of whom 8 paused after cephalogram No. 5 and No. 6 paused after cephalogram No. 4. One case paused over 24 months and was truncated here.
K. Four cases with a cephalogram No. 8 had no cephalogram No. 7.
L. Four cases with a cephalogram No. 9 had no cephalogram No. 8.

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Table II. Age and mandibular length at various cephalograms for the entire group compared with mixed Class I- Class II control sample

<table>
<thead>
<tr>
<th>Cephalogram No.</th>
<th>Duration (months)</th>
<th>Matched controls</th>
<th>FA treatment Ar-Pog (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>2</td>
<td>138.5 (12.8)</td>
<td>101.5 (5.5)</td>
<td>100.5 (4.6)</td>
</tr>
<tr>
<td>4</td>
<td>148.7 (13.9)</td>
<td>103.6 (5.8)</td>
<td>105.1 (5.1)</td>
</tr>
<tr>
<td>5</td>
<td>151.9 (12.5)</td>
<td>104.5 (5.7)</td>
<td>106.1 (5.6)</td>
</tr>
<tr>
<td>6</td>
<td>156.1 (13.5)</td>
<td>105.0 (5.6)</td>
<td>105.8 (5.2)</td>
</tr>
<tr>
<td>7</td>
<td>164.7 (13.8)</td>
<td>106.7 (5.4)</td>
<td>106.3 (3.3)</td>
</tr>
<tr>
<td>8</td>
<td>175.8 (14.8)</td>
<td>107.6 (5.4)</td>
<td>107.1 (5.5)</td>
</tr>
<tr>
<td>9</td>
<td>188.2 (13.4)</td>
<td>108.5 (5.9)</td>
<td>107.7 (6.0)</td>
</tr>
</tbody>
</table>

nOTE: The values reflect both meaningful changes and the influence of a varying sample size.

The next radiograph was obtained either at the termination of edgewise treatment (16 patients), or at some interval deemed necessary and always more than 5½ months from the last one. After a postedgewise retention period (31 patients) or on termination of edgewise treatment (7 patients), a final radiograph was taken.

All cephalograms were obtained in centric relation (CR) and not in centric occlusion (CO), from the same machine, using an anode-to-midsubject distance of 152.4 cm (5 ft) and a midsubject-to-film distance of 14.5 cm. No adjustments were made for the 9.5% enlargement factor.

If there was a discrepancy between CR and CO, a wax bite was prepared in CR, and the patient/parent was instructed on the proper insertion just before the radiograph was taken. Also, before each radiograph a study model was obtained in CR and on receipt of every radiograph, a comparison was made with the cephalogram; if there was a possible CR discrepancy, another radiograph was taken. The radiograph technicians were trained to record in CR, and the importance of this was constantly reinforced.

To avoid investigator bias, a blind protocol was used to determine the distance from articulare to pogonion. First, the dentition and patient information were covered, and a combination of letters and numerals was substituted (letters for patients and random numbers for each radiograph). Next, all cephalograms from a patient were examined, and the one that showed the least asymmetry and greatest clarity was selected for the construction of a template that outlined the cranial base structures and articulare. This template was then superimposed on each of the other coded radiographs for that patient and overlaid with another sheet of acetate onto which was constructed articulare and the structures of the mandibular symphysis. Next, the template was placed over its cephalogram again, the symphysis was outlined, and pogonion was identified. Finally, to minimize random error, this pogonion was transferred by means of symphysis superimposition to all the other tracings of that particular patient. To reduce systematic error, all tracings of a particular patient were completed at one sitting. Articulare-pogonion distance was recorded to the nearest 0.5 mm.

The control group was selected from 100 girls from the Burlington Growth Centre (Table II). Many of the girls had received some form of orthodontic treatment before becoming a part of the control group: 45% had space maintainers; 26% had bite planes; 23% had cervical neck gear; 21% had monoblock treatment. While serving as controls for this study, four had extraoral force, and two had used a monoblock part time. No patient with a Class III malocclusion was used. This group was considered clinically to be 55% Class I and 45% Class II. The groups were matched for sex, age, and SN:GoGn angle. The mean absolute difference between matched pairs for age was 2.8 months (SD 1.7), and for SN:GoGn it was 0.3° (SD 0.3). The mean SN:GoGn angle was 35.4° (SD 5.5) for both samples, with seven matched pairs less than 30° and 12 pairs 39° or greater. The raw values for ML in the controls were adjusted to match the 9.5% magnification. A smaller Class II control group (85% considered dental Class II) was selected from the same 100 patients and additionally matched for original ML with the 20 treatment
Fig. 1. Mandibular growth rates for entire group compared with mixed Class I–Class II control sample. ◯ = Treatment; + = controls. (See Table I for explanation of letters.)

Table III. Age and mandibular length at various cephalograms, with only those patients who had a pretreatment interval and compared with a predominantly Class II control sample

<table>
<thead>
<tr>
<th>Cephalogram No.</th>
<th>Age (months)</th>
<th>Matched controls</th>
<th>FA treated Ar-Pog (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>1</td>
<td>129.6 (14.7)</td>
<td>97.8 (3.4)</td>
<td>97.8 (3.8)</td>
</tr>
<tr>
<td>2</td>
<td>136.6 (14.5)</td>
<td>99.1 (3.5)</td>
<td>98.8 (4.2)</td>
</tr>
<tr>
<td>4</td>
<td>145.4 (15.9)</td>
<td>101.0 (4.1)</td>
<td>102.7 (4.7)</td>
</tr>
<tr>
<td>5/6</td>
<td>152.9 (14.6)</td>
<td>102.4 (4.1)</td>
<td>103.8 (4.8)</td>
</tr>
<tr>
<td>7</td>
<td>161.4 (14.6)</td>
<td>103.8 (4.2)</td>
<td>104.3 (4.7)</td>
</tr>
<tr>
<td>8</td>
<td>173.3 (15.5)</td>
<td>105.1 (4.5)</td>
<td>105.1 (4.8)</td>
</tr>
<tr>
<td>9</td>
<td>182.8 (15.2)</td>
<td>105.7 (4.4)</td>
<td>106.2 (6.0)</td>
</tr>
</tbody>
</table>

These longitudinal controls had cephalograms taken about 1 year apart from ages 8 to 18 years, except that none were obtained during the fifteenth year. Since the radiograph intervals of the FA-treated patients were not uniform but were dictated by their clinical progress, the data for each control were derived by interpolation, i.e., matching its treated counterpart for age exactly at each stage and then calculating the control's mandibular length proportionally from the immediately adjacent radiographs.

The treatment of the data included the calculation of standard descriptive parameters. The exploratory data analysis included scaled box-and-whisker plots, marked with hinges and standard deviations, indicating visually the scale of the samples, especially their outliers and length of tails. Stem-and-leaf diagrams were plotted showing contour features of the samples, and the Lilliefors' test for normality was applied to all samples. Values for differences and rates were deleted for those intervals of duration less than 3 months or more than 24 months, to curtail systematic errors. The statistical experiment was designed to include at least 30 patients for whom pre-FA cephalograms were available (Table III).
Fig. 2. Mandibular length for entire group, starting with FA therapy and continuing for 4 years compared with mixed Class I-Class II control sample. □ = Treatment; + = controls. (See Table I for explanation of letters and numbers.)

Fig. 3. Increases in mandibular length for entire group during various phases of this study and compared with mixed Class I-Class II control sample. (See Table I for explanation of letters.)
cases. In all but one paired test, the requirement of normality for both of the paired samples failed; thus the Wilcoxon signed ranks test was used throughout to assess the significance of the differences for matched pairs.

RESULTS

The results are presented in Tables II and IV and Figs. 1 to 4. It is clear that an initial pronounced increase in ML occurs during the FA phase. This is followed by a significant reduction of the subsequent mandibular growth rate during the following 18 months (Phases S and EE in Table IV). The overall increase in ML from the insertion of the FA (cephalogram No. 2) through the retention phase is startlingly similar to that of the controls (Figs. 3 and 4). Note in Table IV the decrease in the level of significance as the observation interval increases. The results for the 20 patients with a pre-FA cephalogram and their more Class II control group are presented in Tables III and V and Figs. 5 to 6 and are similar to those found for the larger sample except that a decrease in growth rate for the treatment group occurs only in the early edgewise phase.

In Table VI a more detailed analysis of the holding and pause phases is presented. Although the growth rates during these phases were similarly depressed, the rates were even lower in the early edgewise phase.

Fig. 7 presents six selected patients and their matched controls. Note the wide variability in the response to FA treatment, the marked variation in the growth rate for some of the controls, and the peak growth rates in some controls that are comparable to those seen with an FA.

The growth rates in the post-FA phases were examined for all individual patients, and 47% of those treated experienced a reduction in ML of at least 0.5 mm during one phase or more. Only one control had a similar reduction. This relapse was rather evenly distributed among all the post-FA phases: retaining 21%, synthetic 21%, early edgewise 16%, late edgewise 21%, and retention 22%. In addition, 26% of the treated patients experienced either zero growth or actual decrease in ML of at least 0.5 mm in two or more of the post-FA phases. This did not occur in any control.

The treated sample was subjected to cluster analysis for initial posterior face height (Ar-Go), mandibular plane angle (SNGoGn), SNA, SNB, and ANB, and meaningful high and low clusters identified for these variables. Each proved to be poorly correlated with ML response to FA treatment and in all post-FA phases.

DISCUSSION

Articulare, a highly reproducible and reliable point, was chosen over condylion because in the cephalograms the condyles often were not clearly discernible. Others have made similar observations. **22,23**
Baughan et al. reported the coefficient of reliability for articulare at 0.95 and found it to be similar to that for sella, while it was considerably less for condylion. They concluded that the anatomically desired condylion had to be replaced by articulare. Many investigators have used articulare. There were two disadvantages in using articulare. First, the condyles might not have been seated in their respective fossae. Although not a part of this report, in pretreatment and posttreatment tomograms of these patients, the condyles generally appeared to be located in the same relative positions within the fossae. In addition, leaf-gauge treatment indicated the radiographs were taken in CR. Second, if clinically significant contouring of the glenoid fossae does occur in FA therapy, then measurements from condylion would be of theoretical interest even though of little clinical relevance. That is, a forward thrust of pogonion is the clinical goal; whether it comes from increased ML or anterior migration of the fossae is academic.

Only females were selected because most of their mandibular growth has occurred by 15 years of age. Inclusion of males would have required the protocol to extend an extra 3 years. Also, in an all-male or predominantly male sample, relapse or a diminished growth rate after FA therapy might be easily masked by the normally late and pronounced mandibular growth characteristic of that group. In addition, if there was a sexual dimorphic component to FA therapy, post-FA response, or circumpubertal facial growth, it could have affected the interpretation of the data if males had been included. Finally, the greatest orthopedic response may occur coincident with general skeletal development. In boys the age of greatest compliance would be considerably before that time. To prescribe this appliance early might result, for boys, in more orthodontic correction of the Class II condition and less orthopedic response.

Since there is controversy regarding the effects of an FA on ML, it is surprising that a blind protocol for obtaining the data has never been used before. Articulare can be located reliably, but I seriously question whether condylion can be located as accurately. Since landmark location is the major source of error in cephalometrics and location errors on the order of 1 to 2 mm are common, perhaps all investigations of FA effects should be done with a blind protocol.

The matched control groups contain several weaknesses. The patients were not from the same geographic region, their radiographs were obtained with different equipment and technicians, and some early orthodontic
intervention had been performed on many of them. The larger control group was a mixture of Class I and Class II malocclusion; even the smaller group was not a pure Class II sample as it contained three Class I malocclusions.

Recently Buschang et al. indicated that mandibular growth rates differed between Class I and Class II occlusions, and that by the age of 15 years, the cumulative ML may be 2 mm shorter in girls with Class II malocclusions. This had been suggested earlier. However, many reports have found no difference. The mandibular growth rates during the late edgewise and retention phases were close to that of the Class II control group.

Since mandibular growth is clearly sex and age dependent, a control sample should match for these variables. Since the response to FA therapy might also be related to the mandibular plane angle, the controls were also matched for SN:GoGn. As a separate group, the 20 patients of the smaller treatment group were also matched for initial ML by selecting 20 of the 100 potential controls. This more Class II control population closely approximated the treatment group and might show differences if mandibles in Class I patients normally grow at a faster rate than those in Class II patients. The importance of control samples that accurately reflect sex, age, and relevant skeletal mix of the treatment sample cannot be overemphasized and has sometimes been overlooked.

Initial ML for the treatment group was less than that for the controls and has been reported for Class II populations. The lower pre-FA mandibular growth rate for the subgroup of 20 patients was not statistically significant.

The increase in ML during the FA phase was pronounced, and the rate of increase dramatic. These responses were similar to those previously reported. But during the post-FA phases the growth rate never reached that of the control group (Figs. 1 and 3), and in the final analysis, there was no long-term additional mandibular length over controls (Figs. 2, 3, and 4).

The length of the observation interval may be critical to an understanding of the long-term benefits of an FA (Table IV). If the study interval had been 2 years from the time of FA insertion (cephalographs Nos. 2 to 7), a highly significant increase in ML would have been reported. In a 3-year study (cephalographs Nos. 2 to 8) a lesser but still significant increase would have been found, but after 4 years (cephalographs Nos. 2 to 9)
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There was no difference. Impressive results immediately after FA treatment had evaporated by the end of 4 years.

The 20 patients with a pre-FA phase and matched against a predominately Class II control group were evaluated separately (Figs. 5 and 6; Tables III and V). As with the entire sample, it was clear that this FA treatment had no long-term impact on mandibular length (Fig. 5, Table V).

According to some, stability after FA treatment has a high correlation with good intercuspatation and occlusal contacts. In this study, no effort was made to eliminate the frequent posterior open bite present at

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**Table V.** Duration, differences in mandibular length, and rate of mandibular growth during selected phases, with only those patients who had a pretreatment interval and compared with a predominantly Class II control sample

<table>
<thead>
<tr>
<th>Cephalogram no.</th>
<th>Phase</th>
<th>Duration (months)</th>
<th>Matched controls</th>
<th>FA treatment</th>
<th>Matched controls</th>
<th>FA treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Ar-Pog (mm)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>1-2</td>
<td>Pre-FA</td>
<td>7.0 (4.3)</td>
<td>1.2 (0.8)</td>
<td>1.0 (1.4)</td>
<td>2.1 (0.7)</td>
<td>1.5 (1.5)</td>
</tr>
<tr>
<td>2-4</td>
<td>FA</td>
<td>8.7 (5.4)</td>
<td>1.7 (1.5)</td>
<td>3.9 (1.5)**</td>
<td>2.3 (0.9)</td>
<td>6.2 (2.2)**</td>
</tr>
<tr>
<td>4-6</td>
<td>S</td>
<td>7.5 (6.1)</td>
<td>2.1 (1.7)</td>
<td>1.4 (1.4)</td>
<td>2.3 (1.1)</td>
<td>2.1 (1.5)</td>
</tr>
<tr>
<td>6-7</td>
<td>EE</td>
<td>8.5 (3.3)</td>
<td>1.5 (0.7)</td>
<td>0.5 (0.9)**</td>
<td>2.1 (1.0)</td>
<td>0.6 (1.3)**</td>
</tr>
<tr>
<td>7-8</td>
<td>LE</td>
<td>11.3 (4.1)</td>
<td>1.2 (1.0)</td>
<td>1.0 (1.7)</td>
<td>1.3 (0.9)</td>
<td>1.2 (2.1)</td>
</tr>
<tr>
<td>8-9</td>
<td>R</td>
<td>11.6 (4.4)</td>
<td>0.7 (0.7)</td>
<td>1.0 (1.5)</td>
<td>0.7 (0.8)</td>
<td>0.7 (1.5)</td>
</tr>
<tr>
<td>2-7</td>
<td></td>
<td>24.8 (9.0)</td>
<td>4.8 (2.5)</td>
<td>5.5 (2.4)</td>
<td>2.3 (0.8)</td>
<td>2.8 (1.1)</td>
</tr>
<tr>
<td>2-8</td>
<td></td>
<td>36.1 (10.1)</td>
<td>6.0 (2.9)</td>
<td>6.4 (3.0)</td>
<td>2.0 (0.8)</td>
<td>2.3 (1.2)</td>
</tr>
<tr>
<td>2-9</td>
<td></td>
<td>47.6 (11.1)</td>
<td>6.7 (2.9)</td>
<td>7.4 (3.6)</td>
<td>1.7 (0.8)</td>
<td>2.1 (0.9)</td>
</tr>
</tbody>
</table>

*p < 0.05.

**p < 0.01.

***p < 0.001.
PATIENT 7

Fig. 7. Individual patients and their matched control selected to illustrate diversity of response in growth rates and variation in timing of the cephalograms during the phases of this study. □ = Treatment; + = matched control. Ordinate is articolare-pogonion in month and year, and abscissa is age in months. (See Table I for cephalogram number and phase descriptions. Patients 7, 8, and 14 had no pre-FA cephalograms, and the pre-FA rate shown is the mean for the 20 patients [Table V].) A, Patient 7. Note decreased rate during holding; slight rebound during early edgewise; dramatic absolute relapse of 2.5 mm during late edgewise and retention.

Table VI. The effect of the holding and pause phases on mandibular length and growth rate

<table>
<thead>
<tr>
<th>Cephalogram no.</th>
<th>Phase</th>
<th>Duration (mo)</th>
<th>Matched controls</th>
<th>FA treatment</th>
<th>Matched controls</th>
<th>FA treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ar-Pog (mm) Mean (SD)</td>
<td>Ar-Pog (mm) Mean (SD)</td>
<td>Ar-Pog (mm/yr) Mean (SD)</td>
<td>Ar-Pog (mm/yr) Mean (SD)</td>
</tr>
<tr>
<td>2-4</td>
<td>FA</td>
<td>9.4 (4.8)</td>
<td>2.1 (1.4)</td>
<td>4.7 (1.8)**</td>
<td>2.6 (1.0)</td>
<td>6.5 (1.9)***</td>
</tr>
<tr>
<td>4-5</td>
<td>H</td>
<td>7.3 (2.7)</td>
<td>1.5 (0.9)</td>
<td>0.8 (1.1)**</td>
<td>2.6 (1.4)</td>
<td>1.5 (2.0)**</td>
</tr>
<tr>
<td>6-7</td>
<td>EE</td>
<td>9.0 (3.2)</td>
<td>1.3 (0.8)</td>
<td>0.6 (0.9)**</td>
<td>1.9 (1.1)</td>
<td>0.8 (1.3)**</td>
</tr>
<tr>
<td>2-4</td>
<td>FA</td>
<td>9.8 (5.9)</td>
<td>2.0 (1.2)</td>
<td>4.6 (1.9)**</td>
<td>2.6 (1.5)</td>
<td>6.4 (2.0)***</td>
</tr>
<tr>
<td>4-5</td>
<td>P</td>
<td>8.9 (4.1)</td>
<td>1.4 (0.9)</td>
<td>0.8 (1.2)</td>
<td>2.0 (0.9)</td>
<td>1.1 (1.7)</td>
</tr>
<tr>
<td>6-7</td>
<td>EE</td>
<td>8.1 (3.4)</td>
<td>1.0 (0.6)</td>
<td>0.5 (1.3)</td>
<td>1.5 (0.8)</td>
<td>0.6 (1.8)</td>
</tr>
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**p < 0.01.
***p < 0.001.

the end of the FA phase. Could this open bite have contributed to the decreased rates?

During the holding phase, the FA continued to be worn full time, and therefore there was no functional posterior open bite. Yet the growth rate was about half that of the controls and was similar to that seen during the pause phase in which the FA was not worn and thus there were no plastic occlusal contacts for any posterior open bites (Table VI). Of the 20 patients in the pre-FA subgroup, the rate was comparable to that of controls...
Changes in mandibular length with a functional appliance

PATIENT 8

Fig. 7 (Cont'd). B, Patient 8. Note massive response, in excess of 9 mm/yr, resulting in an actual increase of 5.5 mm during FA; and the unusually low growth rate during the remainder of growth period.

Mean values (Figs. 1 to 6) do not show the variety of individual responses. Imagine the difficulty in treating patient No. 7 during the late edgewise phase (Fig. 7, A). Note the absolute decrease in mandibular length of 2.5 mm, commencing after solid posterior intercuspation had been obtained. The responses observed in patients No. 8 and No. 34 would gratify FA advocates, and be expressed as a continued increase in ML but at a considerably reduced rate.

If the mandible is carried forward passively with the growth of the maxilla, then a restraint on maxillary growth should suppress mandibular growth as well. If a FA increases ML while not proportionately stimulating maxillary growth or altering the cranial base, then possibly in later months or years the mandibular growth rates would be reduced to such an extent as to bring the maxilla/cranial base and mandible back to the pretreatment proportion. If so, new clinical approaches would be needed to assure long-term stability.

Regardless of the cause, it is clear that the major loss of ML increase induced by FA treatment comes during the synthetic and early edgewise phases of treatment. Investigations directed at these intervals or new treatment modalities during these phases might prove beneficial.
PATIENT 14

Fig. 7 (Cont’d). C, Patient 14. Note relatively modest growth rate of 4.9 mm/yr but overall increase in mandibular length of 7.5 mm during FA; good and stable growth rates during the first two post-FA phases (holding and early edgewise); sharp decrease to zero rate during late edgewise; and subsequent shortening during retention.

PATIENT 22

Fig. 7 (Cont’d). D; Patient 22. Note increase of 10.5 mm during the 19 months of FA and holding; zero growth during the 22 months of pause and early edgewise; subsequent increases in late edgewise and retention.
whereas the matched control for patient No. 14 grew at the same rate, sustained that growth over a longer time interval, and still had some active growth during the retention phase (Fig. 7, B, C, E). The increase in ML during the 6 years spanning these observations was 8.5 mm in the FA-treated patient, while in the control it was 15.3 mm (Fig. 7, C).

The surprising magnitude of the growth rates in the matched controls for patients No. 14 and No. 34 should serve as a graphic reminder that one can find individual responses to support any hypothesis. Would not the response to an FA have been dramatic, even if worn only 30 minutes a day, if it had been given to control No. 14 at 140 months and worn for 2 years?

To study facial growth accelerations, Krieg suggested cephalograms at frequent intervals. Synchronizing these radiographs with the phases of treatment contributed to a better understanding of the variety of responses observed. For example, a considerably different picture of mandibular changes after the FA phase would have emerged had only the holding and retention phases been recorded in patients No. 22 and No. 41 (Fig. 7, D, F).

What would have been the results had a bionator, activator, Fränkel, Bass, or twin block appliance been substituted for the FA used in this report? The brilliant work of Lyle Johnston indicates that all FAs have a similar mode of action, i.e., unloading the joint. Comparing ML changes, he found the same results with the activator and bionator and also suggested similar results with the Fränkel appliance. Vig showed that all FAs have surprising similarities when reduced to their component parts. However, with the rat, Petrovic found different responses depending on the type of FA used. (He also found a 14% increase in ML with the use of Class II elastics.)

Pronounced orthopedic growth rates of a magnitude comparable to those obtained with this FA have not been reported with the bionator, activator, Fränkel, or Bass appliance except in isolated cases. Therefore one would not expect to see, with these devices, prolonged and pronounced decreases in the growth after FA therapy. Small orthopedic increases during FA treatment should result in small decreases in the ensuing months. Taber suggested this, with the activator. Others found no increased ML over controls during activator treatment, and also no relapse.

Large growth rates have been reported with the Herbst appliance and a significant decrease in rate of growth occurred in the post-FA intervals.
Although Wieslander\textsuperscript{57} found normal post-FA growth at condylion, when not using a blind protocol, his point B companion measurement did show a dramatic reduction.

Pancherz and Hansen\textsuperscript{35} evaluated 40 patients for stability 6 and 12 months after FA therapy. They concluded that although relapse did occur, it was primarily dentoalveolar and only minor amounts could be attributed to poor mandibular growth. However, all lateral cephalograms were obtained in centric occlusion; since measurements of ML were from a perpendicular through the occlusal plane, any amount of anterior posturing would have been recorded as increased ML. Also, the sample was 77\% male and included only 40 of 70 subjects.

Although no group data have been presented with the Twin Block appliance,\textsuperscript{36,38} it most closely resembles the FA used here, and thus it would not be unreasonable to assume similar results.

The few post-FA evaluations on animals have suggested that relapse or diminished growth rates occurred,\textsuperscript{3,30,65} but extensive and detailed investigations unfortunately are lacking.

In summary, it is proposed that when an FA is used and little orthopedic response is observed, then the post-FA evaluations will show little or no orthopedic relapse. Conversely, the greater the orthopedic result, the greater the likelihood of a post-FA orthopedic relapse will occur.

From this report there arise some specific questions that should be answered: What factors contribute to the decrease in ML following FA therapy? Will the mandibular growth rate continue to be less than that for the matched controls in subsequent years? Could alterations in the protocol during the pre-FA, FA, or post-FA phases enhance the stability or increase the growth rates in the holding, edgewise, and retention phases?

Change in the shape or location of the glenoid fossae,\textsuperscript{35,33,33,47} decreased thickness in the posterior part of the articular disk,\textsuperscript{33} reduction in the gonial angle,\textsuperscript{27,63,67} cessation of anterior posturing of the mandible,\textsuperscript{32,32,32} and condylar resorption/remodeling could influence ML. The extent to which each of these contributed to the post-FA response of this study would be of interest.

That ML can be increased significantly with this FA is well established. Future problems lie in identifying and developing post-FA modalities of treatment and, in addition, modifying these so that they would be compatible with multibanded techniques. Then perhaps orthodontic goals could be achieved without undermining previous orthopedic gains.
The many talents of Michael Winn in assembling and organizing the data and in providing critical and provocative comments were invaluable. The outstanding technical skills of Robert Gill in both statistics and computer software and the counsel of Robert K. Smidt, PhD, of the California Polytechnic State University at San Luis Obispo in statistical procedures are recognized. The consistent technical assistance of Dorothy Simeral, who constructed all of the appliances, is valued. Continued stimulating discussions with Robert Huffer, DDS, and Frank Daniel, DMD, are appreciated. The willing cooperation of Dr. Michael Riolo of the Center for Human Growth and Development, The University of Michigan, and of Dr. Frank Popovich of the Burlington Growth Centre to supply raw data from the Michigan and Burlington population samples, which allowed us to compare their control samples with our treated group, is gladly acknowledged. Without the cooperation and dedication of a wonderful group of patients and their parents over an extended period, this work could not have been accomplished.

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