Orthopedic and orthodontic effects resulting from the use of a functional appliance with different amounts of protrusive activation

John P. DeVincenzo, DDS, and Michael W. Winn, MA
San Luis Obispo, Calif.

A functional appliance worn full-time was given to 50 consecutively treated girls aged 8½ to 14 years. These patients were divided into three groups: in 14 patients, protrusive activation was maintained at 1 mm; in another 14 patients, it was maintained at 3 mm; and in 22 patients, there was an initial, large single advancement averaging 5 to 6 mm. These amounts of protrusion were checked and maintained every 2 months. Analysis of the data, using control patients matched for age and sex, indicated that there was no difference in either orthopedic or orthodontic variables between the 3 mm continuous-advancement group and the single large-advancement group. The 1 mm continuous-advancement group showed a diminished but still statistically significant response. Assuming linearity, it was calculated that, had the 1 mm activation group been treated long enough to have obtained the mandibular orthopedic effects of the other two groups, the orthodontic changes also would have been comparable. (Am J Orthod Dentofac Orthop 1989;96:181-90.)

In the construction of functional appliances, both vertical and sagittal displacements can be achieved. Although several investigators have studied the effects in the oral-facial region of increasing amounts of vertical activation,1-7 little attention has been given to a systematic evaluation of the effects of varied amounts of protrusion. Rather, concerning the sagittal dimension, it appears that reports give only a rationale for delivering a desired amount of activation and frequently caution the reader, without the support of quantitative data, of the consequences of providing any other amount of mandibular advancement.

A number of investigators using a variety of functional appliances have used a single large sagittal advancement so that the incisors were at least in an edge-to-edge relationship.8-17 Generally these investigators believed that a major initial sagittal advancement could best stimulate those parts of the stomatologic system responsible for mandibular growth.

Other reports contained a more cautious attitude toward the magnitude of the construction bite, citing such concerns as the inability of the patients to wear the appliance in the desired jaw relationship while asleep,18 potential TMJ disturbances,19 and possibly more pronounced dentoalveolar changes brought about by these greater amounts of sagittal activation.20-23

In an effort to reduce dentoalveolar effects and to obtain more orthopedic change, some
clinicians have even advocated continuous small protrusive activations at short intervals of 6 weeks' to several months' duration. Malmgren and Ömblus\textsuperscript{24} activated the protrusive component 2 mm every 6 weeks and cited previously reported animal experiments to justify the smaller but more frequent activations. Recently Owen\textsuperscript{22} reduced the horizontal component of the construction bite, stating, "Current thought is that a construction bite of 3 mm will have a negligible retraction effect on the maxilla." However, Howe\textsuperscript{26} suggested that even 3 mm advancements were excessive and that 1 mm activations would be more beneficial.

Recently we described a functional appliance, similar in some respects to one used by Clark,\textsuperscript{27} which allowed for accurate and quantitated adjustment of sagittal activation.\textsuperscript{26} It is the purpose of this report to evaluate the orthopedic and orthodontic effects of different amounts of sagittal activation with this appliance.

**MATERIALS AND METHODS**

Fifty consecutively treated, growing female patients, aged 8½ to 14 years, with Class II malocclusions comprised the three treatment groups and were matched with controls for age, sex, and interval between cephalograms (Table I). None of the patients in the treatment group had any previous orthodontic therapy; and only the functional appliance was used during the treatment interval, with the unfortunate exception of two patients who had maxillary incisor banding with intrusion. For variables measuring changes in upper incisors, the values of these two cases were truncated. From the day of insertion, all treated patients wore the appliance full-time, even while eating. They were selected as described previously.\textsuperscript{26}

Forty female patients comprised the three control groups. Ten of these were used as controls in two different groups. Eleven controls had a mean molar relationship of Class I or ¼ Class II; 22 were ½ to ¾ Class II; and 7 were full Class II. In 13 of the controls, the maxillary incisors and first molars were banded, and only leveling and aligning in round wires ranging in size from 0.012 to 0.016 inches were accomplished during the control interval. In these controls no extraoral, intrusive, or torquing forces were applied, and only those forces generated by these leveling mechanics were acting on the dentition. The other 27 controls had no orthodontic treatment.

The functional appliance selected for this evaluation has been described previously\textsuperscript{26} and is shown in Fig. 1. All appliances were constructed alike, except for the amount of protrusive activation. Acrylic touched the lingual surfaces of the mandibular incisors. Hawley wires were placed on the mandibular and maxillary anterior teeth. At construction on the Hanau articulator, the incisal guide pin was always set at an opening of 3 mm unless a pronounced curve of Spee or overbite required additional opening to obtain the desired amount of protrusive activation.

The amounts of initial protrusive activation were 1 mm, 3 mm, or an amount sufficient to
obtain a Class I molar relationship. On initial construction, 1 and 3 mm activations were obtained by inserting shim material into the ball-and-socket arrangement on the Hanau articulator. The extent of activation in the single large-activation group depended on the extent of the initial Class II molar relationship and averaged 5 to 6 mm for this sample.

All patients were seen at 2-month intervals; at those appointments the appliances were adjusted. For the single initial-activation group, the vertical guide planes and occlusal indentations were redefined (sharpened) as needed by means of the procedure described previously. For the 1 and 3 mm groups, the procedure was to sharpen only if the level of activation to be maintained was still present. If changes had occurred such that there was less than 1 mm of activation remaining in the 1 mm group or less than 2 mm of activation remaining in the 3 mm group, then additional sagittal activation of 1 or 3 mm was delivered.

To determine the amount of activation remaining in the appliance after a 2-month interval, the mouth was opened sufficiently to allow the mandible to reposition into its most retruded position. While the mandible was maintained in the more retruded position, the distance between the vertical guide planes was measured with a millimeter rule.

The procedure for activation of the 1 and 3 mm groups was as follows. First, all the occlusal indentations on the biting pads were removed. Second, cold cure acrylic was added to the mandibular biting pads and, just before the new occlusal imprints were made on these pads by the opposing maxillary posterior teeth, a 1 or 3 mm wedge was placed between the vertical guide planes. Third, the mandibular biteplate was cured, trimmed, and inserted into the mouth. Fourth, cold-cure acrylic was applied to the occlusal surfaces of the maxillary biting pads and also into the bilateral anterior voids resulting from the mandibular advancement. This resulted in a new, more anteriorly positioned vertical guide plane for the maxillary portion of the functional appliance. Fifth, the patient was instructed to open slowly with a slight protrusive component so as not to remove any of the newly added vertical guide plane, and then the maxillary biteplate was cured, trimmed, and inserted. Sixth, the vertical guide planes were examined for sharpness, and the detail of the occlusal impressions made on the biting pads by the opposing teeth was noted. The entire occlusal surface of the opposing teeth had to contact the biting pads. Seventh, without adjusting the occlusal surface or the vertical guide planes of the mandibular biteplate, cold-cure acrylic was applied as needed to sharpen the vertical guide planes and occlusal surface; and just before insertion, a lubricant was applied to the vertical guide plane and occlusal surface of the maxillary biteplate. Eighth, the mandibular biteplate was again cured, trimmed, and then inserted. Ninth, the same procedure was followed for the maxillary biteplate. After the maxillary biteplate was cured and trimmed, it was inserted and again the vertical guide planes were examined for sharpness and exact perpendicularity to the occlusal plane. Occasionally additional sharpening was required on either the mandibular or maxillary portion. This entire activation procedure was time-consuming, requiring 50 to 60 minutes.
The vertical thickness of the biting pads generally increases 1 to 2 mm during treatment because of the sharpening (that is, redefining the vertical guide planes and the occlusal indentations) or advancement procedures.

All cephalograms were taken in centric relation; those from the treatment group were immediately compared with concurrently obtained models also trimmed in centric relation. If inconsistencies in sagittal mandibular-maxillary relationship were noted, either the models or cephalograms were immediately retaken. When discrepancies were noted, on patient examination, between centric relation and centric occlusion, a wax bite was prepared in centric relation and the patient or parent was instructed as to proper insertion just before the cephalogram was taken. All cephalograms were taken with an anode-to-midsurface distance of 152.4 cm (5 ft) and a midsurface-to-film distance of 14.5 cm. No adjustments were made for the 9.5% enlargement factor.

The treatment phase was terminated when (1) a Class I molar relationship was obtained, (2) no improvement in molar relationship or change in vertical guide plane measurements was observed for 3 months, or (3) treatment was progressing so slowly that a clinical judgment was made to stop the functional appliance therapy (Table II). Those in which insufficient progress was made were either switched later to a more pronounced activation or functional appliance therapy was discontinued with the placement of full-banded edgewise technique with Class II elastics and/or extraoral anchorage.

The cephalometric analysis has been described previously in detail26; the landmarks, reference lines, and planes are illustrated in Fig. 2.

Means, standard deviations, skewness, and kurtosis were calculated on initial values and differences for all variables for treated and control samples. The significance of the differences between treated samples and their controls was tested with the paired t test. The Lilliefors two-tailed test for normality was applied to both samples of differences for each treatment modality; in instances in which the assumption of normality could not be proved, the Wilcoxon signed ranks test was used to assess the significance of the differences for matched pairs. Since the sample size for two of the three groups was small (n = 14) and values for the same variable showed major differences between control groups at times, the values for differences for the treated cases were also compared with those of the total control sample. For this, the Mann-Whitney U test was used.

The Kruskal-Wallis one-way analysis of variance was used to test for significant differences in the values among the treated groups. Where indicated, pairs of treated groups were tested by a post hoc nonparametric procedure after the method of Conover.28 The multiple comparisons were not exhaustive but, following the Bonferroni procedure, were limited to a meaningful subset of two.

RESULTS
In Table III, changes in orthopedic variables are presented for the three treatment groups. A significant increase in mandibular length, measured from articulare, occurred in all three groups. The annual rate of mandibular length increase (Ar-Pog) during the treatment period was 3.6 mm for the 1 mm continuous-activation group; it increased to 5.1 mm in the 3 mm continuous-activation group. For the initial large single-activation group, the annual rate was 5.2 mm.

All three procedures demonstrated some horizontal movement of the mandible during the treatment phase (SNB, Y-B, Y-PM, Y-Pog). The 3 mm continuous-activation group generally yielded the most favorable results, although statistically there was little, if any, difference between this group and the initial large single-activation patients. The 1 mm group had less change, averaging 2.6 mm vs. 3.6 mm for Ar-Pog and Ar-PM for the other two groups. Likewise, the Y-ramus distance indicated that the mandible was positioned more anteriorly in the 3 mm and large single-activation groups.

The large single-activation group had a greater increase in anterior facial height (AFH, N-Gn) than in posterior facial height (PFH, S-Go), but the 1 mm and 3 mm continuous-activation groups had generally equivalent effects on anterior and posterior facial heights.

In Table IV, changes in orthodontic variables are presented. It is clear from this table that the 3 mm continuous group gave a response surprisingly similar to the initial large single-activation patients; in the 1 mm group, a lesser response, though of the same general type, can be seen.

In Table V, all the variables that showed significant differences between treatment groups are presented. No significant difference was found for mandibular length increase between the 3 mm and large single-activation groups. Despite a shorter treatment period, these two groups generally had a significantly greater mandibular length increase than that of the 1 mm advancement group. Only in the decrease of overbite was the large single-activation group significantly more effective than both the 3 mm and 1 mm groups.

Frequently, because of an unacceptable rate of progress in mandibular length increase, those patients in the 1 mm group were later switched to either 3 mm or large single-activation protocols (7), placed on extraoral traction (4), or fully banded with Class II elastics (2). Even in the 3 mm and large single-activation groups, not all patients obtained a complete Class I molar relationship. Six of 22 in the initial large single-activation group had at least a $\frac{1}{4}$ Class II molar relationship at termination of this functional appliance protocol, as did 5 of 14 in the 3 mm continuous-activation group.

**DISCUSSION**

The orthopedic and orthodontic effects of a single large protrusive activation and a smaller
3 mm continuous activation were similar, and even the 1 mm continuous activation often differed little from the other two. However, had the sample sizes of the 1 mm and 3 mm activation groups been larger, other statistically significant differences might have emerged.

For example, the actual mandibular length (Ar-Pog, Ar-PM) increased 3.6 mm in 8 months in both the 3 mm and large single-activation groups. However, the effective horizontal component (Y-B, Y-PM, Y-Pog), which would have indicated a more protrusive mandibular position relative to the craniofacial complex, might have been significantly different. The averages of these three horizontal measures of mandibular change in the 3 mm and large single-activation groups was 3.3 mm and 2.9 mm, respectively. Likewise, SNB increased 0.5° more in the 3 mm group than in the single large-activation group, and SN-GoGn increased 0.4° more in the large single-activation group than in the 3 mm group. These values, and X-PM and AFH as well, suggested that the 3 mm continuous activation had the better potential to limit the amount of anterior vertical development and thus might result clinically in a more protruding mandible.

Larger sample sizes could have been obtained by including male subjects in the study. But if some orthodontic and orthopedic measures have sexual dimorphism, then it would require that the proportion of male subjects to female subjects in each group be constant. To obtain this proportion, it would have been necessary to delete some treated male patients from the study, thus losing the power of a consecutively treated sample.

Unfortunately the matched control sample had weaknesses. Although it was predominantly a Class II sample, 27.5% of the control subjects had a Class I to 1/4 Class I mean molar relationship. Do the growth patterns differ between-Class I and Class II malocclusions? In support of a difference, the work of Harris and Downs would be representative, whereas Johnston used a combination of Class I and Class II malocclusions when studying the effects of Class II treatments, and McNamara found that the average yearly growth increments in untreated subjects with Class II malocclusions were similar to those expected for Class I occlusions.

Also, 32.5% of the control subjects had banding of the maxillary molars and incisors. However, the only forces applied were those generated by leveling and aligning as the arch wire sizes progressed from 0.012 inch to 0.016 inch. No rectangular wires nor extraoral forces were placed during the control interval. We are aware of no reports suggesting orthopedic effects from this minimal treatment.

The mean treatment times for the 3 mm and large single-activation groups were similar, but the 1 mm group was in treatment 1.7 months longer. How long would the 1 mm group have had to be treated, assuming that mandibular response to protrusive stimulation was linear, in order to obtain mandibular length changes comparable to those of the 3 mm and large single-activation groups? Determining the rate of mandibular length increase for four separate values (Ar-Pog, Ar-PM, Y-PM, Y-Pog), calculating a constant for each of these
values for the 3 mm and large single-activation groups (that is, the constant multiplied by the rate for the 1 mm group for a given variable would equal the rate for that variable for the 3 mm group, etc.), and obtaining the mean of these eight constants yielded an overall constant of 1.6. Thus to have obtained the mandibular length increase of the 3 mm and large single-activation groups, it would necessitate that the functional appliance be worn about 16 months (1.6 × 9.7 months).

Again, assuming that the dental response to protrusive force was linear, what effects would the 1 mm continuous activation have had on dental structures if applied for an additional 6 months? These data are presented in Table VI and suggest that orthodontic changes would have been comparable to those obtained with the 3 mm continuous and initial large single advancements. Thus it would not be unreasonable to conclude that for a given amount of mandibular length increase, there would be a similar amount of dental change regardless of the amount of protrusive activation. This would not be in agreement with those who contend that greater amounts of appliance activation would also result in greater dental changes.20-23

The Kruskal-Wallis test suggested that the maxillary incisor was affected less by the 1 mm activation (SN-SI, Y-SI, SI-APog, X-SI), but when adjusted by the 1.6 constant, these differences did not appear so impressive.

That the 1 mm activation resulted in statistically significant increases in mandibular length would suggest that either there is no threshold amount of activation required for mandibular length increases, as measured from articulare, or that the threshold amount was below 1 mm. Since it would be difficult clinically to deliver activations of less than 1 mm, the data in this report would not support the notion of a threshold activation in clinical practice.

Recent reports15,37 have indicated that the neuromuscular response to protrusive function, measuring the masseter muscle, is more pronounced with greater amounts of protrusive activation. The authors suggested that a large single activation would probably induce a greater morphologic change than a series of smaller ones. Likewise, others38-40 have indicated that greater amounts of protrusive activation should result in larger orthopedic effects. The data in this report do not support this position. Rather, it would appear that any amount of protrusive activation, if maintained long enough, would result in a similar increase in mandibular length.

Malmgren and Ömlrus24 have suggested that clinical experience indicates that a continuous forward repositioning of the mandible gives a better effect than a greater protrusion in one activation. The data in this report do not support that notion either. The orthopedic and orthodontic effects were quite similar in both the 3 mm continuous-activation group and the large single-activation group. Likewise, Owen's suggestion22 that a 3 mm activation will have negligible effects on the maxilla is not upheld by the data in this report.
Even the 1 mm activation proposed by Howe to have the least orthodontic effects was probably no different than a large single advancement.

Although the data of this investigation were in close agreement with that reported previously and supported the position that a significant amount of mandibular length increase, as measured from articulare, can be obtained from a functional appliance, it does not follow that this appliance should be readily prescribed for growing patients with Class II malocclusions and that it will necessarily be successful in all cases. There are several reasons for this. First, the effects of continuous, uninterrupted protrusive posture on the TMJ should be evaluated. Second, the exacting and time-consuming establishment of the vertical guide planes perpendicular to the occlusal plane must be appreciated, monitored, and maintained. The same applies to the detailed occlusal impressions in the biting pads. This is not an appliance that could be given to a patient and then 8 months later, with only minor adjustments, the malocclusion would be corrected. Third, the long-term results of this initial increase in mandibular length must be evaluated. Fourth, at the termination of this functional appliance phase of treatment, there was frequently a posterior dental open bite that corresponded to the initial curve of Spee and was often in excess of 3 mm. This occurred as a result of the mandibular incisors contacting the lingual surfaces of the maxillary incisors. In addition, as the maxillary incisors moved downward and backward as a part of the undesirable orthodontic effects of the functional appliance, this movement could have contributed to the posterior open bite. What effects would this posterior open bite have on TMJ function? How could this open bite be closed? What would happen to mandibular length while this posterior open bite was being corrected?

Although the data in this report suggest similar orthodontic and orthopedic responses regardless of the amount of mandibular advancement, it should not be assumed that the responses within the temporomandibular joint would be similar. Condylar elongation, glenoid fossa migration, and articular disk/connective tissue proliferation could vary with the amount and/or type of protrusive activation. Yet, with only articulare used as the mandibular reference point, none of these possible variations could be evaluated.

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