

# Three-Dimensional Diagnosis and Management of Class II Malocclusion in the Mixed Dentition

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**Class II malocclusion is a commonly observed problem, occurring in about one third of the United States population. The numerous treatment approaches that have been advocated to treat this malocclusion presumably produce differing treatment effects within the skeletal, dentoalveolar, and soft tissue components of the face. In the first section of this article, the three-dimensional components of Class II malocclusion are described, with transverse maxillary discrepancy, mandibular skeletal retrusion, and increased lower anterior facial height observed as common findings in a mixed dentition sample of Class II subjects. Second, the literature concerning two seemingly diverse treatment methods (extraoral traction and functional jaw orthopedics) is reviewed in detail. Last, cephalometric data are presented from a retrospective clinical study and is used to evaluate the treatment effects produced by cervical traction and the FR-2 appliance of Fränkel in comparison with an untreated sample of mixed dentition Class II patients. The results of this study indicated that although both skeletal and dentoalveolar components of Class II, Division 1 malocclusion were altered in the Class I direction by either a facebow or a Fränkel appliance, these two appliance systems accomplished the correction in dramatically differing ways. Cervical traction affected the skeletal and dentoalveolar components of the maxilla and mandible, whereas the FR-2 appliance had less of an effect on maxillary and dentoalveolar components and a greater effect on mandibular length. Thus, these two treatment modalities produce decidedly different treatment effects in patients with Class II malocclusions. (Semin Orthod 1996;2:114-137.) Copyright © 1996 by W.B. Saunders Company**

**C**lass II malocclusion is a commonly observed clinical problem, occurring in about one third of the United States population.<sup>1-4</sup> This classification of malocclusion seems to be more prevalent in individuals of Northern European ancestry (30% to 40%) than in other racial and

ethnic groups (eg, 14% to 18% in blacks), with about 8% to 10% of the overall population having overjets greater than 6 mm. Because Class II malocclusion is recognized easily by health professionals, as well as by patients and their families, especially in instances of excessive overjet, the correction of Class II problems may constitute nearly half of the treatment protocols in a typical North American orthodontic practice.

Over the years, numerous protocols have been advocated for the treatment of Class II malocclusion. These treatments include a variety of fixed appliances, extraction procedures, extraoral traction and arch expansion appliances, and functional jaw orthopedic appliances. Some practitioners select only a few of these modalities in

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the treatment of Class II malocclusion, depending on the experience, personal preference, and previous success rate of the clinician. Each treatment approach, however, differs in its effects on the skeletal and dentoalveolar structures of the craniofacial region, sometimes accelerating or limiting the growth or movement of the various structures involved, producing favorable, and occasionally unfavorable, growth changes.

In the first section of this article, the three-dimensional components of Class II malocclusion in the mixed dentition are described. Second, the literature concerning two seemingly diverse treatment methods (extraoral traction and functional jaw orthopedics) that currently are advocated for the treatment of Class II malocclusion is reviewed. In the last section of the article cephalometric data from a retrospective clinical study compares the treatment effects of both modalities to an untreated Class II population. Although both of these generic types of treatments have been used for nearly a century, and individually have been studied in detail, surprisingly few studies have directly compared the treatment effects produced by these methodologies.

### Components of Class II Malocclusion

The simplicity of the Angle classification of malocclusion<sup>5</sup> belies the fact that Class II malocclusion is not a single diagnostic entity. Angle based his classification system solely on the position of the permanent upper first molars. Underlying this occlusal condition can be numerous skeletal and dentoalveolar combinations, some intuitively obvious, some not. Ideally, a given treatment modality should directly (or sometimes indirectly) affect the particular skeletal and dentoalveolar components of the specific Class II patient.

Although there is substantial literature concerning the components of Class II malocclusion,<sup>6-15</sup> few studies have focused on how frequently the various factors that can contribute to a Class II occlusal relationship occur. Notable exceptions include the investigations of Henry,<sup>16</sup> Moyers et al<sup>17</sup> and McNamara.<sup>18</sup> Henry<sup>15</sup> proposed four categories into which most cases of Class II division 1 malocclusion can be classified: (1) maxillary dentoalveolar protrusion, (2) maxillary basal protrusion, (3) micromandible, and

(4) mandibular dentoalveolar retrusion. Moyers et al<sup>17</sup> presented an arborization that allows the identification of various groups of factors that can determine a clustering of Class II malocclusions with similar skeletal and dentoalveolar characteristics.

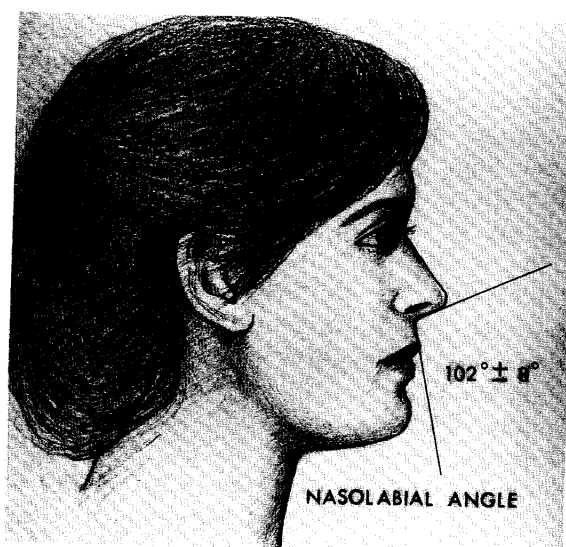
For the purpose of this article, the components of Class II malocclusion as defined by McNamara<sup>18</sup> are used to describe the anteroposterior and vertical elements of Class II malocclusion, as observed cephalometrically. The data from this study have been reanalyzed and are presented later. In this study, the frequency of Class II components in 277 patients of Northern European ancestry was examined. The age range (8 years 0 months to 10 years 11 months with an average age of 9 years 0 months) is representative of a typical mixed-dentition population of Class II patients. The criteria for inclusion of a subject in the study were the presence of at least an end-to-end molar and canine relationships as determined from the lateral headfilm. No skeletal criteria were used.

For ease of analysis, measures of craniofacial structure are divided into the following six components: four horizontal (maxillary skeletal, maxillary dentoalveolar, mandibular dentoalveolar, and mandibular skeletal) and two vertical components (mandibular plane angle and lower anterior facial height).

#### 1. Anteroposterior Components

The relationship of the upper and lower teeth can be affected by various sagittal components of Class II malocclusion, either alone or in combination. Most, but not all, of the variations in these components are intuitively obvious.

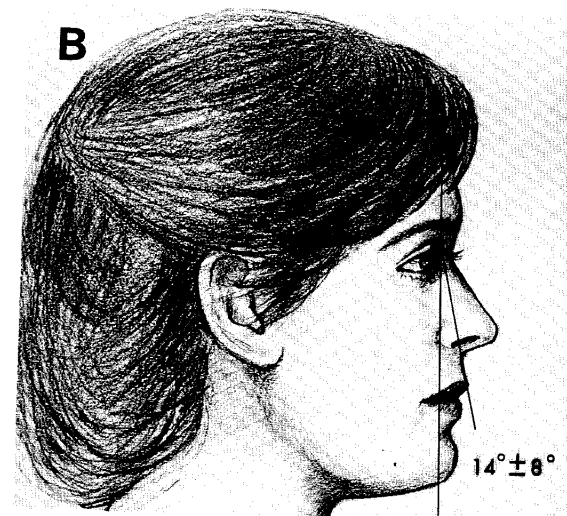
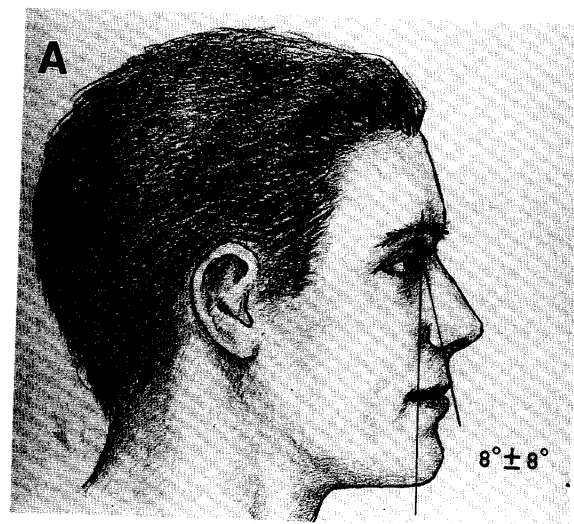
*a. Maxillary skeletal position.* Both hard and soft tissue factors must be assessed in evaluating the position of the maxilla relative to cranial base and cranial structures. Of critical importance is the soft tissue profile, particularly the nasolabial angle and the cant (slope) of the upper lip. Ideally, the nasolabial angle should be  $102^\circ \pm 8^\circ$  in both boys and girls of Northern European ancestry<sup>19</sup> (Fig 1), with more acute nasolabial angles observed in other racial and ethnic groups (eg, blacks,<sup>20</sup> Japanese<sup>21</sup>). In addition, the cant of the upper lip should be angled slightly in an anteroinferior direction ( $8^\circ \pm 8^\circ$  in white males;  $14^\circ \pm 8^\circ$  in white females relative to the nasion



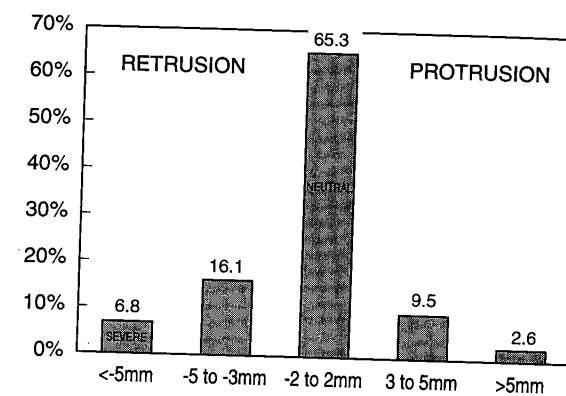
**Figure 1.** The naso-labial angle is formed by the intersection of tangents to the base of the nose and to the upper lip. The value for the naso-labial angle is similar for male and female patients. (Reprinted with permission from McNamara.<sup>19</sup>)

perpendicular<sup>19</sup> (Fig 2). Care should be taken to avoid overretraction of the upper lip, especially in instances of maxillary skeletal retrusion, a condition that occasionally occurs in Class II malocclusion.

Although the vertical position of the maxilla (relative to the upper lip) is best evaluated at the time of the clinical examination, the anteroposterior position of the bony maxilla is analyzed most

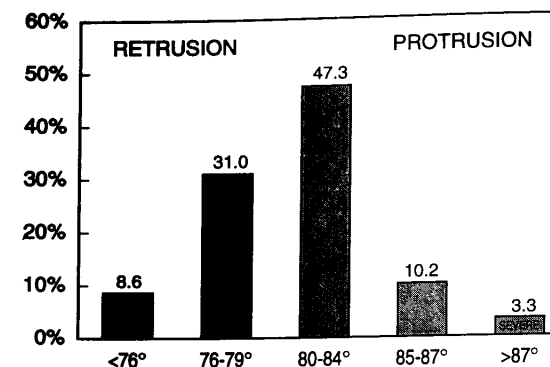


**Figure 2.** The cant of the upper lip. This angle is formed by the intersection of a tangent to the upper lip and the nasion perpendicular. (A) Male. (B) Female. The upper lip tends to be more protrusive in female than in male patients. Overretraction of the upper lip should be avoided. (Reprinted with permission from McNamara.<sup>19</sup>)



**Figure 3.** Graphic representation of the distribution of the measure from Point A to the nasion perpendicular. In this and subsequent graphs, the numbers at the top of each bar represent the percentage of subjects in the sample with values in the range indicated.

easily through cephalometric analysis. Two cephalometric measures of anteroposterior maxillary position are nasion perpendicular to Point A<sup>22</sup> (Fig 3) and the Sella-Nasion Point A (SNA) angle<sup>23,24</sup> (Fig 4). When these measures are applied to the mixed dentition sample,<sup>18</sup> both measures indicate that the position of the maxilla is normal in the majority of Class II individuals. In those patients in whom the position of the maxilla is abnormal, the maxilla tends to be retrusive more frequently than protrusive. Patients showing a long lower anterior facial height and a steep mandibular plane angle often have



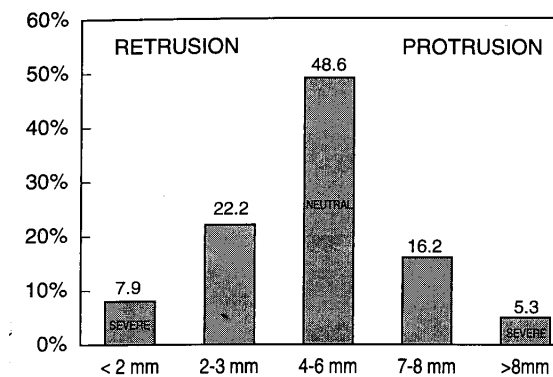
**Figure 4.** Graphic representation of the distribution of the SNA angle in the mixed dentition sample.

both a maxilla and mandible that are retruded relative to cranial base structures.

Thus, in evaluating the anteroposterior position of the maxilla, it is important to take both soft and hard tissue factors into consideration. When there appears to be a conflict between the findings of the clinical examination and the cephalometric appraisal of the hard tissue, the prudent practitioner usually will rely primarily on the findings of the clinical examination in choosing among a number of differing treatment options.

**b. Maxillary dentoalveolar position.** To eliminate the influence of maxillary and mandibular position relative to the cranial base when estimating the position of the upper incisor relative to the maxilla, the distance from the facial surface of the upper incisor to a vertical line drawn perpendicular to the Frankfort horizontal plane extended through Point A<sup>22</sup> is recommended. In a well-balanced face, this measurement should be 4 to 6 mm.<sup>22,25,26</sup> When this measure is applied to the mixed dentition Class II sample,<sup>18</sup> almost half have a normally positioned upper incisor (Fig 5), and about 20% have maxillary dentoalveolar protrusion. On the other hand, 30% have a retrusive position of the upper incisor (ie, less than 4 mm ahead of the Point A vertical).

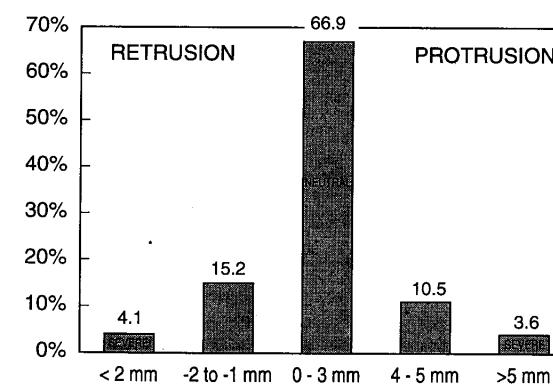
The implications of these observations are obvious. In any Class II treatment protocol that involves either the forward repositioning of the mandible (eg, functional appliance therapy, mandibular advancement surgery) or the retraction of the maxilla (eg, extraoral traction, Le Fort I osteotomy), an existing retruded incisor position should be corrected (eg, flared, intruded) before that phase of treatment to avoid incisal



**Figure 5.** The distribution of the distance from the facial surface of the upper incisor to a vertical line drawn perpendicular to the Frankfort horizontal through Point A.

interference. One of the more significant factors that can inhibit Class II correction, regardless of the nature of the orthodontic or orthopedic movement and regardless of whether teeth are removed to solve a tooth-size/arch-size discrepancy, is *unintentional incisal coupling*. Premature, unintentional contact between the upper and lower incisors can inhibit Class II correction significantly, regardless of the treatment protocol used.

**c. Mandibular dentoalveolar position.** The distance from the tip of the lower incisor to the A-Pogonion line<sup>26,27</sup> can be used to determine the anteroposterior position of the lower incisor in relation to basal structures. In the mixed-dentition Class II group, approximately two-thirds have a normally positioned lower incisor (Fig 6), with only 15% in a protrusive position and 20% in a retrusive position. The goal of



**Figure 6.** The distance from the facial surface of the lower incisor to a line drawn between Point A and pogonion.

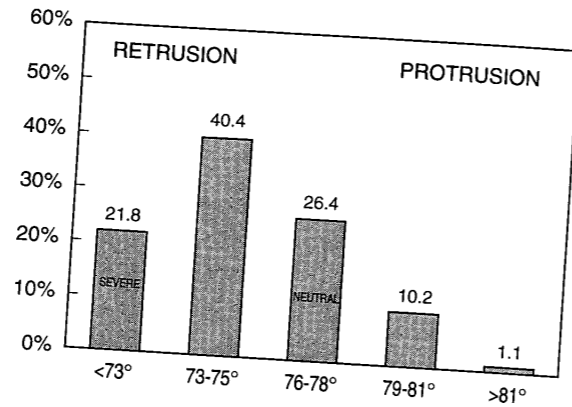
virtually all Class II therapies is to orient the lower incisors over basal bone in harmony with the surrounding soft tissue. Given the lack of potential osseous adaptation in the mandible (in comparison to the maxilla via rapid maxillary expansion), significant uprighting of the lower incisors may necessitate the removal of permanent teeth as part of the treatment protocol.

**d. Mandibular skeletal position.** Two measures are used to evaluate the position of the mandible relative to the cranial base and cranial structures: Pogonion to the nasion perpendicular<sup>22</sup> (Fig 7) and the Sella-Nasion-Basion (SNB) angle<sup>23,24</sup> (Fig 8). These measures indicate that a deficiency in the anteroposterior position of the mandible is a common finding in Class II malocclusion, with about 60% of the patients showing mandibular skeletal retrusion. Similar findings have been noted in an adult Class II sample.<sup>25</sup> Given the frequency of mandibular retrusion in the mixed dentition, protocols aimed at encouraging a positive mandibular growth response, either primarily or secondarily (to be discussed later), often are needed.

**2. Vertical Components**

Although Class II malocclusion usually is perceived as a sagittal problem, the vertical dimension of the patient also must be considered. As has been shown by Schudy,<sup>28,29</sup> variations in facial height may conceal or intensify the clinical appearance of the malocclusion.

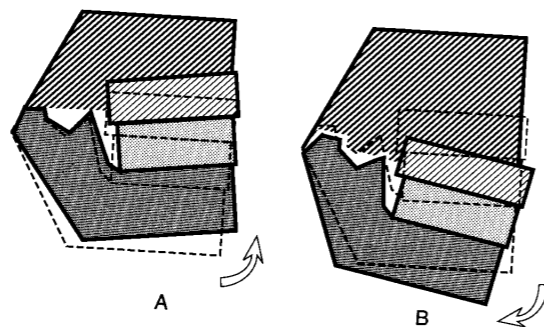
**a. Decreased vertical dimension.** As is well known in prosthodontics and surgical maxillary impaction, a decrease in vertical dimension



**Figure 8.** Graphic representation of the distribution of the SNB angle.

causes the mandible to rotate upward and forward (Fig 9A). This same phenomenon occurs in the Class II orthodontic patient, in that a short lower anterior facial height can camouflage a mandible that is structurally small relative to the midface. These patients typically have a low mandibular plane angle, a deep overbite with a strong chin point, and either retruded or flared upper incisors. Mandibular dentoalveolar retrusion also occurs.

**b. Increased vertical dimension.** A patient with an increased lower anterior facial height (Fig 9B) often is characterized by a retruded mandible (and occasionally the maxilla as well), a poorly defined chin point with a hyperactive mentalis muscle ("golf-ball" chin), and a tendency toward or an anterior open bite. A bump on the nasal contour ("dorsal hump") often is observed clinically in patients with both maxil-

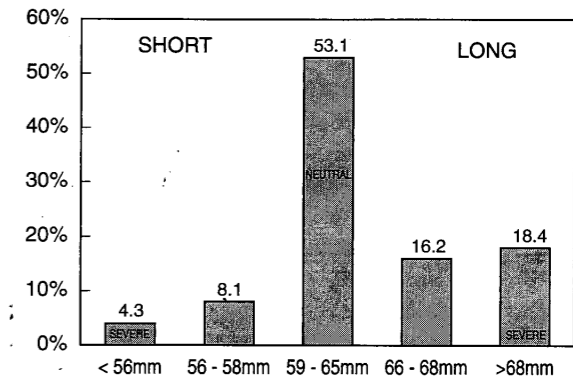


**Figure 9.** The relationship of the vertical dimension of the face to the anteroposterior position of the chin. (A) A decrease in lower anterior facial height results in a forward and upward rotation of the chin point. (B) An increase in lower anterior facial height results in a downward and backward rotation of pogonion.

lary and mandibular skeletal retrusion and a Class II malocclusion.

To evaluate the frequency of occurrence of these conditions in the Class II mixed dentition sample,<sup>18</sup> two measures of vertical dimension are examined. When the mandibular plane angle relative to the Frankfort horizontal is measured (Fig 10), approximately 40% of the sample has a neutral vertical dimension. A mandibular plane angle greater than 31.5° is observed in 17.5% of the sample, indicating excessive vertical development. Only 10% of the sample has a short lower anterior facial height, and this decrease in facial height often is associated with Class II division 2 malocclusion. An evaluation of lower anterior facial height (Fig 11), measured from anterior nasal spine to menton, indicates that more than half of the individuals have a normal face height measurement. Almost 35% of the sample have excessive lower anterior facial height.

The results of this evaluation indicate that, although Class II patients most frequently have a neutral vertical dimension, about one third have excessive vertical development. Decreased vertical development is less common, occurring only in about 10% of Class II subjects in the mixed dentition sample. As mentioned previously, increases in lower anterior facial height often are associated with a chin point that is positioned downward and backward, whereas decreases in lower anterior facial height are associated with a forward and upward position of pogonion. These changes are of critical importance when planning the treatment of a Class II patient, in that increasing the vertical dimension during Class II



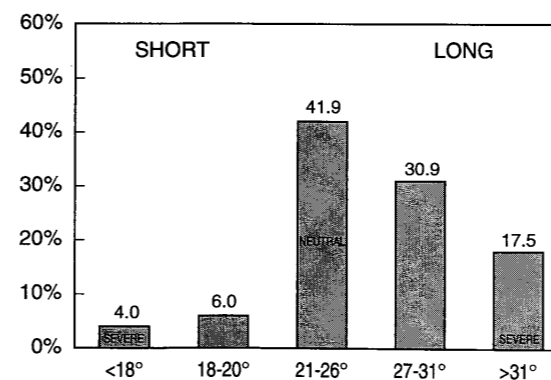
**Figure 11.** The distribution of the distance between anterior nasal spine and menton. Increased lower anterior facial height is a common finding.

treatment will tend to camouflage positive changes in mandibular length. Thus, if maximum advancement of the chin point is desired as a goal of treatment, increases in the vertical growth of the patient during treatment should be minimized.

**3. Transverse Components**

**a. Maxillomandibular discrepancies.** A dimension often overlooked in the evaluation of the Class II patient is the transverse relationship of the maxilla to the mandible. Most Class II patients appear to have a normal relationship of the buccal segments when the patient is in centric occlusion. Tollaro et al,<sup>30</sup> however, have shown that an underlying transverse discrepancy of 3 to 5 mm exists in dental arches with Class II malocclusion and seemingly normal buccal relationships. This underlying transverse discrepancy can be unmasked clinically by having the patient posture the mandible in an anterior position so that the canines are positioned in a Class I relationship. More significant transverse discrepancies are evidenced by unilateral or bilateral posterior crossbites in centric occlusion.

Baccetti et al<sup>31</sup> evaluated two groups of untreated subjects (a Class II group and a normal occlusion group) during the transition from the deciduous to the mixed dentition. They noted that the transverse discrepancy that existed in the Class II group in the deciduous dentition persisted into the mixed dentition. Baccetti et al<sup>31</sup> also noted that all Class II subjects maintained full Class II molar and canine relationships, and mean overjet increased when compared with mean overjet in the deciduous dentition. These



**Figure 10.** The distribution of the angle formed by the intersection of the mandibular plane and the Frankfort horizontal.

observations are similar to those of Arya et al<sup>32</sup> and Bishara et al,<sup>33</sup> both of which indicate that in the absence of therapeutic intervention or a change in the orofacial environment (eg, the elimination of a habit or an airway obstruction), Class II malocclusion generally is not self-correcting. Thus the Class II occlusal relationship tends to be self-perpetuating, and continue to be associated with a constricted transverse occlusal relationship.

McNamara<sup>26</sup> and Spillane<sup>34</sup> have recommended that in mild to moderate Class II patients with reasonably well-balanced faces, orthopedic expansion of the maxilla through rapid maxillary expansion during the early mixed dentition not only will create some additional arch space to allow for the eruption of the permanent incisors, but also may encourage the spontaneous correction of the occlusal relationship. Maintaining the maxilla in a widened position relative to the mandibular dentition during the postexpansion period encourages a transient forward mandibular posturing, in that the patient occludes more comfortably in a slightly anterior position. In this instance, the teeth themselves act as an "endogenous" functional appliance, producing a forward mandibular repositioning and ultimately a slight but clinically significant increase in mandibular length. If spontaneous Class II correction does not occur, definitive corrective therapies can be initiated, usually in the late mixed or early permanent dentition.

**b. Tooth-size/arch-size discrepancies.** Another issue that must be addressed in the treatment of Class II malocclusion is the relationship of tooth size to arch size. Howe et al<sup>35</sup> in a comparison of uncrowded and crowded adult dentitions, found a relationship between bony base dimensions (eg, as indicated by measuring maxillary intermolar width) and dental crowding, with much less of an association found between tooth size and dental crowding. They reported that the difference in transpalatal width between the two groups was about 6 mm, with the uncrowded group have the larger values ( $37.4 \pm 1.7$  mm in men,  $36.2 \pm 1.9$  mm in women).

A second study<sup>22,36</sup> indicated that about 2.5 to 3.0 mm of transpalatal width increase occurs in an untreated population from 7 to 15 years of age. The latter study also demonstrated that if a

child had a very narrow dental arch (eg, a transpalatal width of less than 31 mm) in the early mixed dentition, it is unlikely that the patient will attain adequate arch dimensions through normal growth processes alone. In many patients with mild to moderate arch length discrepancies observed in the mixed dentition, a Phase I treatment of early orthopedic expansion of the maxilla, with or without prior dental decompensation of the mandibular dental arch using a removable expansion appliance<sup>22,34,37</sup> is recommended before attempting definitive Class II correction.

**c. Summary.** The evaluation of the transverse dimension in Class II patients indicates that the goals of most Class II treatments should include the correction of obvious or camouflaged discrepancies between the maxilla and mandible. Although most clinicians recognize the need to eliminate unilateral or bilateral posterior crossbites as part of a treatment regimen, often the typical transverse discrepancy in the Class II patient with a seemingly normal buccal occlusal relationship is overlooked. Alteration of the transverse dimension by a variety of methods, including rapid maxillary expansion, expanding the inner bow of a facebow, or widening as part of functional appliance therapy, must be considered in addition to sagittal and vertical correction.

### Overview and Conclusions

The obvious overall conclusion that can be drawn from this three-dimensional component analysis is that the term "Class II malocclusion" is not a single diagnostic entity, but can result from numerous combinations of components. The cephalometric studies of Wylie,<sup>38</sup> Drelich,<sup>39</sup> Craig,<sup>40</sup> Blair,<sup>41</sup> Sassouni,<sup>42</sup> and Moyers,<sup>17</sup> among others, have reported wide variation in the size and shape of the various craniofacial components of Class II. All cephalometric studies by necessity, however, deal with only the sagittal and vertical elements of Class II malocclusion and that concomitant transverse deficiencies in the maxilla, mandible or both also must be taken into consideration when formulating an appropriate treatment plan for a specific patient.

## Class II Treatment Strategies

*My object all sublime*

*I shall achieve in time—*

*To make the punishment fit the crime.*

This quote from the second act of the Gilbert and Sullivan musical, *The Mikado*, written in 1885, in essence should summarize the overall goal of treatment for a specific Class II patient, in that the treatment regimen selected should address the underlying needs of the given patient. The management of Class II malocclusion has varied over the years, as a number of modalities have been developed and advocated for mixed dentition patients, including the expansion procedures mentioned previously. Perhaps the two major types of treatments most frequently used in mixed dentition patients are extraoral traction and functional jaw orthopedics, both of which address the skeletal and dentolaveolar elements of the Class II configuration. In some practices, one of these approaches is used as the major treatment approach to Class II correction, to the exclusion of the other. The treatment effects produced by two examples of these generic categories of treatment, cervical traction, and the function regulator (FR-2) of Fränkel, will be examined in detail.

### Extraoral Traction

Perhaps the most common adjunct used in the treatment for distocclusion is extraoral traction, a family of appliances typically used to restrict the normal downward and forward growth of the maxilla. The forces produced affect the normal craniofacial growth of the patient, allowing for the correction of the Class II occlusal condition.

Use of extraoral forces to modify the growth of the maxilla has a long history, dating back to the work of Kingsley in the 19th century.<sup>43</sup> Interest in extraoral traction was diminished in the first half of the 20th century, but was revived by Oppenheim<sup>44</sup> and later by Kloehn<sup>45-47</sup> who recommended the application of light forces for the mass distal movement of teeth. Kloehn's original design featured a facebow, the inner bow of which was attached to the maxillary first molars, with the outer bow connected by elastics to an occipital anchoring device. He later modified that design to include only a cervical neck strap. The method of attachment and the angula-

tion of the outer bow of the facebow could be altered to determine the direction of pull. Usually, the outer bow was adjusted to lie above the plane of occlusion to direct the force through the center of resistance and prevent distal tipping of the molars during treatment.

In reviewing the literature on extraoral traction, investigators have reached contradictory conclusions regarding the effects of such therapy. These differences can be explained, in part, by the specific treatment protocols used by the practitioner.

The type of extraoral traction device, as well as the magnitude of the force applied and the direction of pull, have been shown to be important considerations.<sup>48-51</sup> The cervical (low-pull or "Kloehn") facebow, the type of facebow seen most frequently in clinical practice today, typically is used in patients with decreased vertical facial dimensions. In contrast, a high-pull facebow generally is used in individuals in whom increases in vertical dimension are to be minimized or avoided. The facebow is attached to an occipital anchoring unit (headcap) to produce a more vertically directed force. As a growth guidance appliance, a high pull facebow can decrease the vertical development of the maxilla, thereby allowing for autorotation of the mandible and maximizing the horizontal expression of mandibular growth.<sup>52</sup> A facebow also can be anchored simultaneously to a cervical neckstrap and a headcap, a combination often termed a "combi" or "straight-pull" facebow.

### Treatment Effects Produced by Extraoral Traction

Extraoral traction has been shown to produce a variety of skeletal and dentoalveolar effects in Class II patients. Although there is some agreement among investigators as to the effects produced, the clinical management of the appliance, the direction of force applied and the amount of force used may explain some of the differences among investigations.

#### 1. Anteroposterior Dimension

**a. Maxillary skeletal position.** A primary treatment effect of extraoral traction is the restriction of maxillary skeletal growth. There is virtually universal agreement that, as a result of treat-



ment, Point A is repositioned posteriorly relative to the remainder of the face,<sup>47,53-60</sup> resulting in a reduction in maxillary prognathism.<sup>45,54,61-65</sup> Weislander<sup>66</sup> has shown that this technique also influences the cranial base by producing a counterclockwise tilting of the spheno-ethmoid plane during 3 to 4 years of treatment with a headgear.

**b. Maxillary dentoalveolar position.** Distal movement of the maxillary molars is a typical treatment effect produced by cervical headgear therapy.<sup>45,54,57,59,60,62,66-72</sup> In contrast, Hubbard et al<sup>73</sup> reported a mesial movement of the first molar. Extrusion of the maxillary molars also has been observed,<sup>54,56,63,74-78</sup> with two<sup>73</sup> to three<sup>75</sup> times as much extrusion reported as would be expected during normal growth. On the other hand, molar extrusion was not observed by Hubbard et al.<sup>73</sup>

Melsen,<sup>71</sup> using the implant method of Björk,<sup>79</sup> studied the effect of cervical-pull headgear on the craniofacial complex, in part to determine whether the specific angulation of the outer bow relative to the occlusal plane was clinically significant. In one group of children, the outer bow was tilted 20 degrees above the occlusal plane; and in the second group, the outer bow was angled 20 degrees below the occlusal plane. In the first group with the outer bow angled upward, only slight tooth movement was observed, but the entire maxillary complex moved posteriorly and inferiorly relative to the anterior cranial base. Melsen<sup>71</sup> stated that this method of facebow adjustment is appropriate for those patients with true maxillary skeletal protrusion. In the second group, more tooth movement was observed, particularly a distal tipping of the upper first molar. The extraoral traction had no appreciable influence on the maxillary complex. Melsen<sup>71</sup> stated that orienting the outer bow of the facebow below the occlusal plane may be appropriate in patients with mesially migrating or tipped upper first molars or both.

**c. Mandibular dentoalveolar position.** There is virtually no literature that addresses the effect of the cervical-pull facebow on the mandibular dentition other than the treatment effects that are produced in association with fixed appliance treatment.

**d. Mandibular skeletal position.** The anteroposterior relationship of the chin has been correlated to the amount of vertical opening produced during treatment. A downward and

backward rotation of the mandible and a similar movement of Point B and pogonion has been reported, as has an opening of the mandibular plane angle.<sup>51,74-76</sup> Kloehn<sup>45</sup> and Ringenberg<sup>57</sup> reported no change in the SNB angle, but other investigators noted either a posterior<sup>64,74-76</sup> or anterior<sup>56,60</sup> movement of Point B.

## 2. Vertical Dimension

There is no universal agreement as to the effect of cervical headgear treatment on the vertical dimension, as investigators have differed in describing the effect of this type of therapy on the various aspects of vertical facial measures.

**a. Mandibular plane angle and lower anterior facial height.** An opening of the mandibular plane angle as the mandible is hinged open has been reported by many investigators.<sup>58,66,74-76,78</sup> An opening of the bite and an increase in lower anterior facial height also has been a frequent finding.<sup>28,29,54,65,74,80-82</sup> Klein<sup>54</sup> and Ricketts<sup>27</sup> reported that extraoral force tends to open the Y axis angle and lengthen the face more than would occur with normal growth. A high-pull headgear has been recommended to reduce the extrusion of the upper first molar. In contrast, Ringenberg,<sup>57</sup> Baumrind<sup>81</sup> and Hubbard<sup>73</sup> reported a closure of the mandibular plane angle with treatment, whereas others reported no change.<sup>45,56,60,63,82-85</sup>

**b. Occlusal plane angle.** Investigators have differed as to the effect of extraoral traction on the orientation of the occlusal plane relative to the cranial base. The anatomic occlusal plane normally closes with age.<sup>86</sup> Klein,<sup>54</sup> King<sup>63</sup> and Hubbard<sup>73</sup> reported that the angle of the occlusal plane remains relatively unchanged during treatment, whereas Sandusky,<sup>56</sup> Merrifield,<sup>76</sup> and Cangialosi<sup>60</sup> reported an increase in the angle of the occlusal plane relative to the cranial base. Hubbard<sup>73</sup> noted a slight downward tipping of the anterior part of the palatal plane. The functional occlusal plane closed slightly with treatment as well.

**c. Palatal plane angle.** The palatal plane has been shown to tip anteriorly with an uneven descent, resulting in the anterior nasal spine tipping more inferiorly than the posterior nasal spine.<sup>54,56-58,60,69,73,76,78</sup> On the other hand, Kloehn<sup>45</sup> and Boecler<sup>85</sup> noted no change in the angulation of the palatal plane.

## 3. Transverse Dimension

Most clinical studies of extraoral traction have used cephalometrics as the primary analytical tool. Thus, consideration in the literature of changes in the transverse dimension with extraoral traction has been minimal. The only investigation to consider transverse changes is that of Ghafari,<sup>87</sup> who conducted a comparative study of the straight-pull headgear and FR-2 appliance of Fränkel. The inner bow of the facebow was adjusted at every appointment "to avoid any constriction or major expansion of the intermolar distance," resulting in a total expansion of the inner bow of 1.5 to 2.0 mm.<sup>87</sup> Ghafari<sup>87</sup> noted increases not only in intermolar distance, but in intercanine distance as well. These investigators hypothesized that the change in intercanine distance, a region not directly affected by the facebow, may have been a result of a shielding effect by the inner bow on the lip and cheek musculature, an indication of the influence of the buccal and labial musculature on tooth position.

### Functional Jaw Orthopedics

During the last 20 years, there has been an increase in the popularity of functional jaw orthopedic used to correct Class II malocclusion. All of the so-called "functional appliances" have one aspect in common: they induce a forward mandibular posturing as part of the treatment effect. Presumably, this alteration in the postural activity of the muscles of the craniofacial complex ultimately leads to changes in both skeletal and dentoalveolar relationships to the point that the underlying malocclusion is resolved. These appliances include the activator<sup>88-90</sup> and its derivatives: the bionator,<sup>91,92</sup> the Bimler appliance<sup>93</sup> the open activator of Klammt,<sup>94</sup> the kinator<sup>94</sup> and the twin block appliance.<sup>95</sup> These appliances are considered primarily tooth-borne in that they contact the teeth as part of anchoring the appliance in the mouth, and typically the lingual region of the oral cavity is used as the base of operation.

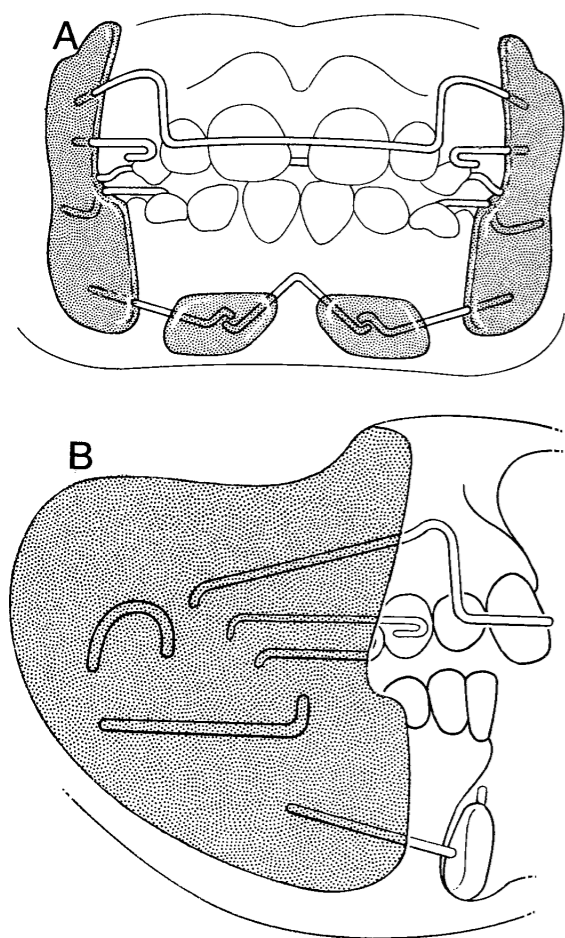
Another type of appliance, the Herbst appliance,<sup>96</sup> is attached directly to the teeth by a variety of anchoring units. The Herbst bite-jumping mechanism has been reintroduced using the original banded design by Pancherz,<sup>97-99</sup> although cast,<sup>100</sup> stainless steel crown,<sup>101</sup> and

acrylic splint<sup>102</sup> versions of Herbst appliances also are available. Treatment time tends to be reduced using the Herbst appliance when compared with the previously mentioned functional appliances, in that significant dentoalveolar, as well as skeletal adaptations, occur.<sup>98,103</sup>

When considering a comparison between extraoral traction and functional jaw orthopedics, there is a tendency to group all functional appliances into the same theoretical framework. There is a distinct difference between the activator/bionator family of functional appliances, devices that consist primarily of acrylic and wire that contact the soft tissue as well as the teeth, and the variety of currently available Herbst appliances that incorporate a rigid bite-jumping mechanism attached directly to the teeth, with minimal bony and soft tissue contact. A similar distinction among functional appliances concerns the function regulator (FR) of Fränkel, an appliance that has a different basis of operation and a different theoretical basis than most other functional appliances.

The function regulator (FR) group of appliances, including the FR-2 appliance (Fig 12) that is used routinely in the correction of Class II problems, was developed by Rolf Fränkel of the former German Democratic Republic.<sup>104-111</sup> In contrast to the Herbst appliance and to extraoral traction, the primary focus of treatment with the FR is the musculature of the craniofacial complex. Fränkel states that his appliances should be viewed first as an orthopedic exercise device, in that it aids in the maturation, training, and reprogramming of the orofacial neuromuscular system. This appliance system was developed according to the basic principles of Roux<sup>112</sup> concerning "functional orthopedics," principles that have been applied clinically in the field of general orthopedics for many years.

According to Fränkel, this orthopedic exercise device has been designed to overcome functional disorders and reestablish physiological conditions within the orofacial complex. Fränkel and Fränkel<sup>109</sup> stress that the FR family of appliances are not orthodontic appliances in the traditional sense, in that they are not meant for use in precise tooth positioning. In fact, they state that the FR appliance is inferior to other types of both fixed and removable appliances in that regard. Rather, treatment with this appliance is directed toward the correction of func-



**Figure 12.** The FR-2 appliance of Fränkel. (A) Front view. (B) Sagittal view. The vestibular shields of the appliance have a direct effect on the craniofacial musculature. (Reprinted with permission from McNamara.<sup>26</sup>)

tional disorders associated with skeletodental malformations.

As mentioned previously, one of the primary effects associated with most functional appliances is a change in the postural position of the mandible. In the treatment of mandibular skeletal retrusion, for example, the major aim of functional orthopedics is to overcome the poor postural performance of those muscles that determine the postural position of the mandible as well as mandibular movement. Fränkel<sup>111</sup> states that changes in mandibular postural position and ultimately in the size and shape of the mandible are not achieved by a mechanical advancement of the mandible, but rather by modifications in the postural activity of the associated musculature.

All Fränkel appliances are characterized not by large amounts of acrylic in the lingual and palatal areas (as are the activator- and bionator-type appliances), but rather by vestibular shields that lie in the buccal vestibule outside the dental arches. These appliances are constructed to prevent faulty muscular functions and to stimulate normal postural activity of all muscles that directly or indirectly help to establish a competent oral seal. According to Fränkel,<sup>108</sup> the achievement of a competent lip seal is an essential aim of this type of functional jaw orthopedics.

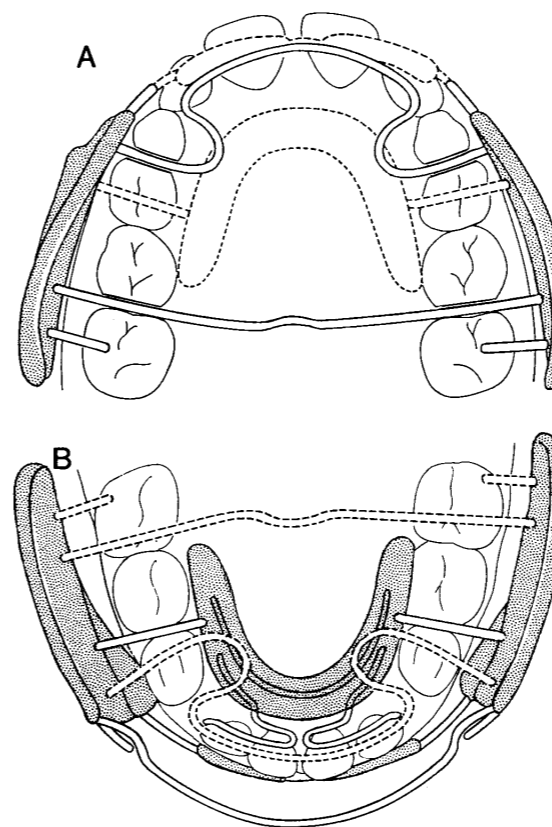
#### **Treatment Effects Produced by the Function Regulator**

The FR-2 has been studied by a number of investigators during the last 25 years. The findings of the clinical studies, however, often are contradictory and should be interpreted in light of many factors, not the least of which is the clinical management of the appliance. The treatment effects produced during function regulator therapy are very technique sensitive.

#### **1. Anteroposterior Dimension**

**a. Maxillary skeletal position.** The literature varies as to the effect of the FR-2 on the anteroposterior position of the maxilla. Most studies either show minor or no influence on the anteroposterior position of the maxilla.<sup>103,113-116</sup> In contrast, Creekmore<sup>117</sup> noted reduced forward growth of the maxilla in patients treated with the FR. This divergence in findings may be a result of differences in technique, as is discussed in the next section.

**b. Maxillary dentoalveolar position.** According to Harvold,<sup>118</sup> the correction of Class II occlusal relationships can result from inhibiting the downward and forward eruption of the maxillary buccal segments in growing individuals. As the crossover wires of the FR-2 appliance contact the maxillary posterior teeth (Fig 13), inhibition of posterior tooth eruption theoretically could occur during FR treatment. McNamara et al<sup>116</sup> have shown that although the horizontal movement of the upper first molars is slightly restricted compared with untreated Class II controls; the vertical movement of the maxillary first molars remains unaffected by FR treatment in comparison to control values.



**Figure 13.** The FR-2 appliance of Fränkel. (A) Maxillary view. (B) Mandibular view. (Reprinted with permission from McNamara.<sup>26</sup>)

The FR appliance has been shown to have a variable effect on the position of the upper incisor. Schulhof,<sup>119</sup> Creekmore,<sup>117</sup> Robertson<sup>114</sup> and Hamilton<sup>120</sup> noted pronounced retroclination of the upper incisors during Fränkel treatment, whereas McNamara<sup>116</sup> report only slight posterior tipping of the upper incisor. In some patients, posterior tipping of the upper incisor may be beneficial, in others not. Fränkel's treatment method requires notching of the maxillary posterior deciduous teeth. Robertson<sup>114</sup> and Creekmore<sup>117</sup> state, and Schulhof<sup>119</sup> implies, that that their samples had no such notching. Fränkel states that the lack of notching may lead to an unfavorable tipping of the upper incisors in a posterior direction and ultimately a restraint of maxillary growth.

**c. Mandibular dentoalveolar position.** The Harvold theory of dentoalveolar Class II correction through differential eruption of teeth<sup>118</sup> predicts increased eruption of the lower molar as a result of FR treatment. Creekmore,<sup>117</sup> Righellis<sup>113</sup> and

McNamara<sup>116</sup> noted additional vertical movement of the lower molars in the FR group. Schulhof<sup>119</sup> reported that Fränkel treatment produces additional mesial movement of the lower molar over that which is expected during normal growth, whereas most other studies do not.

Lower incisor proclination is a common finding in many of the clinical studies that have considered the treatment effects produced by the FR.<sup>117,119-121</sup> Sometimes lower incisor proclination occurs normally, as when lower incisors trapped behind the lower lip are freed as existing skeletal and muscular imbalances are corrected. In other instances, anterior lower incisor movement is not desired, but may result from improper technique, particularly concerning the management of the lower labial pads. Pad positioning that is too far superior to the depth of the vestibule or too far anterior to the mandibular alveolus (or both) can lead to lower incisor proclination because the pads can have a lip bumper effect on the orbicularis oris muscle, rather than the desired restrictive effect on mentalis activity.<sup>107,111</sup> If proper appliance management is maintained, labial tipping of the lower incisors is minimized.<sup>116</sup>

**d. Mandibular skeletal position.** The initial studies of FR treatment showed conflicting results concerning the effect on mandibular growth. For example, Schulhof,<sup>119</sup> Creekmore<sup>117</sup> and Robertson<sup>114</sup> were unable to detect any increase in mandibular length, whereas Fränkel<sup>122</sup> and Righellis<sup>113</sup> noted increases in mandibular length during treatment.

Falck<sup>123</sup> studied the long-term effect of FR treatment on the skeletal and dentoalveolar structures of the craniofacial complex. The material of this study consisted of standardized serial lateral cephalograms of 103 children with a Class II malocclusion associated with mandibular retrusion, 58 of whom were treated with either the FR-1 or FR-2 appliance. Forty-five untreated patients served as controls. A comparison of pretreatment morphology indicated that the two groups were almost identical at the beginning of the study period. The subjects were followed from 7 to 15 years of age. Falck<sup>123</sup> noted a forward movement of pogonion of 14 mm in the treated group and 7.3 mm in the untreated group, indicating a significant difference in mandibular growth increments between the two groups.

Fränkel<sup>111</sup> reanalyzed a portion of the patients in Falck's study. He reported an increase in mandibular length of 18.9 mm in the FR group as compared with 13.8 mm in the untreated group, a difference that was statistically significant. No statistically significant difference were noted in maxillary length or in lower anterior facial height between the two groups. Posterior facial height (ramus length), however, was greater in the FR group, and the facial axis angle closed in the FR group, indicating a more horizontal vector of facial growth.

McNamara et al<sup>116</sup> studied 100 patients treated with the Fränkel appliance. They divided the sample into a younger group (8.5 years at the beginning of treatment) and an older group (11.5 years at the beginning of treatment). These patients were compared with 41 untreated Class II controls, again divided by age. Greater increases in mandibular growth increments were noted in the older treated group than in the younger treated group, and both treatment groups had larger mandibular growth increments than their respective matched control groups. Both treated groups showed an increase in lower anterior facial height, but no change in the mandibular plane angle or in maxillary position, in comparison to controls.

A later study by McNamara et al<sup>103</sup> compared patients treated with the Fränkel appliance and with the acrylic splint Herbst appliance in comparison to untreated Class II controls. Greater dentoalveolar adaptation was produced by the Herbst appliance than by the Fränkel appliance.

## 2. Vertical Dimension

Most of the changes in vertical dimension have been incorporated into the discussion of sagittal correction described previously. Thus, only a summary of the vertical changes produced by FR treatment will be provided here. The 2-year clinical study by McNamara et al<sup>116</sup> indicated that mandibular length increased by 82% over control values in their older age group and 60% in the younger age group. However, such increases in mandibular length are not necessarily expressed by an advancement of the chin point to a comparable degree. Change in the horizontal position of the chin varies inversely with the amount of increased lower anterior facial height produced during treatment. Maximum anterior

repositioning of the chin is obtained by an increased in mandibular length without a concomitant increase in lower anterior facial height. Conversely, a significant increase in mandibular length can be camouflaged by a corresponding increase in lower facial height. Such increases have been shown to be a result of FR treatment.<sup>116</sup>

## 3. Transverse Dimension

There is virtually universal agreement that the vestibular shields of the FR lead to a spontaneous expansion of the dental arches.<sup>87,124-130</sup> Mosch (cited by Fränkel<sup>131</sup>) studied 400 patients treated only with the Fränkel appliance and observed that as a result of withholding cheek pressure through the use of the vestibular shields and the lower labial pads, a spontaneous widening of the dental arches occurred routinely. Mosch noted a mean increase in transpalatal width of over 4 mm in both the premolar and molar regions during a 2-year treatment time. No data regarding mandibular arch expansion were published.

McDougall et al<sup>124</sup> measured serial dental casts from 60 patients treated with the Fränkel appliance and compared them to serial dental casts from 47 untreated individuals. The results of this study indicated that expansion of the maxillary and mandibular dental arches occurred routinely with Fränkel appliance therapy. The expansion was not limited to a particular region of the dental arch, although in absolute terms the greatest amount of expansion occurred in the premolar and molar regions, whereas a lesser amount occurred in the canine region. The average amount of maxillary arch expansion was 4 to 5 mm, with 3 to 4 mm observed in the mandibular arch.

## Comparison of Treatment Strategies

In light of the previous literature review that indicates that cervical facebow therapy and function regulator treatment apparently produce differing treatment effects, a study was undertaken to compare these two modalities directly. This comparative approach has been used before to contrast extraoral traction to various types of functional appliances. For example, Meach,<sup>132</sup> Jakobsson,<sup>131</sup> Baumrind et al<sup>82</sup> and Derringer<sup>133,134</sup> have compared extraoral traction to the activator. Only a few studies have

compared the function regulator and extraoral traction directly.<sup>113,117,135-137</sup>

## Selection of Subjects

Serial cephalometric radiographs of three groups of Class II, division 1 patients were evaluated. Records from patients treated with the function regulator (FR-2) of Fränkel were compared with records of patients treated with a cervical-pull facebow combined with incisor bracketing and archwires, and also with longitudinal cephalograms of untreated children with Class II malocclusion. Records of the Fränkel patients and control subjects were part of samples previously described and evaluated by McNamara et al.<sup>116</sup>

**a. Exclusionary rules.** After each group of records was assembled, specific exclusionary rules were applied.<sup>116</sup> A patient or subject was eliminated from the study if one or more of the following conditions was found to apply (several of the rules were not relevant to the control sample).

1. Absence of Class II malocclusion. An end-to-end Class II molar and canine relationship (or worse) was necessary for inclusion in the study.
2. Retroclination of the upper incisors prior to treatment, as in Class II, division 2 malocclusion.
3. Inadequate timing of radiographs. To be included in the study, the pretreatment radiograph had to be taken 2.5 months or less before treatment, and the posttreatment radiograph had to be taken within 1 month following treatment.
4. Poor radiographic quality. Some anatomical landmarks were not identifiable.
5. Errors in mandibular position—obvious posturing of the mandible forward as indicated by the relative position of the posterior border of the ramus and the anterior border of the atlas in serial films.

Patients also were eliminated from initial consideration if the clinician judged that the patient's cooperation was poor. This judgment was based not on the success of treatment but, rather, on reports from parents and patients and from clinical signs of appliance wear (eg, hyperemia in specific areas of the oral soft tissue in FR patients).

## b. Sample groups.

1. *Fränkel (FR) Group.* Records of 151 patients who finished FR-2 treatment within a 2-year period were submitted by eight practitioners.<sup>116</sup> These patients were treated according to the protocol of Fränkel,<sup>111</sup> also as described by McNamara.<sup>26</sup> No other type of orthodontic intervention was provided during the study interval. The application of the exclusionary rules reduced the Fränkel sample to 100 patients (Table 1).
2. *Facebow Group.* The initial 75 patients in this group underwent a first phase of orthodontic treatment with a cervical traction headgear attached to the maxillary first molars. They also had bonds or bands placed on the upper central and lateral incisors that were connected by an archwire to the first permanent molars (the so-called 2 × 4 hook-up). Patients typically were told to wear the facebow 12 to 14 hours per day. After the exclusionary rules were applied, the facebow sample was reduced to 61 patients (Table 1).
3. *Control Group.* Changes over the course of treatment with the FR and cervical facebow were compared with changes recorded for a sample of untreated Class II children from the *University of Michigan Elementary and Secondary School Growth Study*.<sup>86,138</sup> The subjects in the control sample were subjected to the exclusionary rules applied to the treatment samples, except for parameters that were relevant only to treated patients. This plan resulted in the selection of records for 41 subjects of untreated Class II malocclusion.

After the exclusionary rules were applied to define the sample groups, one additional selection criterion was added, that being chronological age. The groups were defined further by

**Table 1.** Patient Selection

Group	Initial	After Exclusions	Final	Age at Start	Duration
Fränkel	151	100	26	9.1 yr	24 months
Headgear	75	61	34	9.0 yr	21 months
Control	41	41	20	9.2 yr	26 months

NOTE. Initial, number of records submitted for inclusion; after exclusions, number of subjects remaining after exclusionary rules applied (see text for description); final, final sample size; age at start, average age of the samples at the time of the initial lateral headfilm; duration, duration of the treatment/observation interval.



excluding patients and subjects who were younger than 7.5 years or older than 11 years of age at the beginning of the treatment/observation period. The application of this last criterion to the Fränkel sample reduced the size of the sample to 26 (17 girls and 9 boys). Similarly, the facebow group was composed of 34 patients (19 girls and 15 boys) and the control group was composed of 20 subjects (12 girls and 8 boys). At the end of the selection process, the groups were well matched according to chronological age, with an average age of about 9 years at the beginning of treatment for all groups (Table 1). The treatment/observation interval was approximately 2 years for each group (Table 1).

### Method of Analysis

Each cephalometric headfilm was traced by two investigators (JEP and JAM) to verify anatomic outlines and landmark placement. Landmark locations then were digitized using a customized digitizing program. For longitudinal analysis, serial lateral cephalograms were superimposed on the basion-nasion line with registration on the pterygomaxillary fissure.<sup>26,139</sup> Superimposition was checked against the posterior cranial outline as well.

The cephalometric analysis used was a modified and expanded version of the analysis used routinely by the senior author.<sup>22,26,116</sup> From the digitized lateral cephalograms, 28 measurements were derived for each patient at each time interval (Tables 2 and 3).

The FR and facebow groups had varying magnifications that ranged from 7% to 8%, whereas the control group subjects had a 12.92% magnification. All linear cephalometric measures were converted to an 8% enlargement to standardize the data.

### Statistical Methods

An analysis of variance initially was performed among all three groups. If a level of significance less than 0.05 was observed, Scheffe's method of multiple comparisons was used to determine differences among groups.

The error of the method has been previously calculated by McNamara<sup>103</sup> in a similar study. As the methods and equipment for the present study are part of a routinely used standardized

protocol, the error of the method is implied to be within acceptable limits for this study.

### Results

**a. Comparison of Starting Form.** As in our previous studies, we examined the equivalence of starting form by comparing pretreatment skeletal and dentoalveolar cephalometric values (Table 2).

**Skeletal measures.** Of the 18 skeletal measures, there were no statistically significant differences in starting form with respect to the Fränkel and control groups. There were differences, however, between these two groups and the facebow group. For example, maxillary skeletal position was slightly more retrusive in the control group than in the facebow group (Table 2). Similarly, the mandible was more retrusive in the control group than in the facebow group. In addition, lower anterior facial height was less in the facebow group than in the controls.

**Dentoalveolar measures.** Of the 10 measures used to evaluate dentoalveolar position, only the lower incisor to pogonion relationship differed when the FR group was compared with controls (Table 2). The upper incisor in the facebow group was located more anteriorly relative to the pterygomaxillary fissure than in either the FR or control groups.

**b. Analysis of treatment effects.** The analysis of the effects of treatment used the same 28 variables that were used to compare starting forms. Because the interval between the first and second headfilms varied slightly among groups, the data presented in Table 3 have been standardized to reflect a 24-month treatment/observation interval for all groups.

**Maxillary skeletal relationships.** The function regulator had little impact on the growth of the maxilla. In contrast, significant inhibition of the forward movement of the maxilla was noted in the facebow group. For example, Point A moved forward 0.4 mm in the control group relative to the nasion perpendicular (Table 3). In contrast, Point A was displaced posteriorly (-2.8 mm) in the facebow group. In addition, the SNA angle increased by 0.8° in the control group but decreased (-2.2°) in the facebow group. The increase in midfacial length also was less in the facebow group.

**Maxillary dentoalveolar relationships.** Changes in the horizontal positions of the upper upper

Table 2. Comparison of Starting Forms

	Headgear (n = 34)		Fränkel (n = 26)		Control (n = 20)		Significance		
	x	SD	x	SD	x	SD	H-F	H-C	F-C
Maxillary Skeletal									
Condylion-ANS (mm)	91.6	3.9	89.0	3.5	89.3	4.3	*	*	NS
Midfacial length (Co-Pt. A) (mm)	88.7	3.9	87.0	3.4	87.1	4.1	NS	NS	NS
SNA angle	81.5	3.4	80.4	2.0	79.5	2.5	NS	*	NS
Nasion perpendicular/point A (mm)	-0.1	2.2	-1.0	2.2	-2.0	2.9	NS	†	NS
Maxillary Dental									
Upper incisor horizontal (mm)	57.2	3.6	54.6	3.4	54.1	4.0	†	†	NS
Upper incisor/point A (mm)	5.7	1.6	4.9	2.0	4.2	1.9	NS	†	NS
Upper molar horizontal (mm)	24.3	2.5	22.7	2.6	23.2	2.7	*	NS	NS
Upper incisor vertical (mm)	47.0	3.6	47.1	4.3	49.2	4.3	NS	NS	NS
Upper molar vertical (mm)	40.0	2.5	40.4	3.0	41.4	2.4	NS	NS	NS
Mandibular Dental									
Lower incisor horizontal (mm)	7.3	2.6	8.6	3.4	7.9	3.5	NS	NS	NS
Lower incisor-APo	0.8	1.6	0.3	2.0	2.0	1.8	NS	*	‡
Lower molar horizontal (mm)	32.2	2.3	32.4	3.0	32.4	2.4	NS	NS	NS
Lower incisor vertical (mm)	39.0	3.0	39.3	2.8	40.5	2.9	NS	NS	NS
Lower molar vertical (mm)	29.3	2.6	29.1	2.0	30.3	2.3	NS	NS	NS
Mandibular Skeletal									
Mandibular length (Co-Gn) (mm)	106.9	4.2	105.3	4.6	106.6	4.1	NS	NS	NS
Pogonion/N perp (mm)	-7.9	4.1	-9.9	4.9	-12.4	4.7	NS	†	NS
Facial plane angle	85.5	2.3	84.4	2.6	83.2	2.5	NS	†	NS
SNB angle	76.0	3.3	74.9	2.3	74.1	2.1	NS	*	NS
ANB angle	5.5	1.3	5.5	1.6	5.4	1.8	NS	NS	NS
Articulare-gnathion	98.4	4.1	97.4	4.4	98.9	4.2	NS	NS	NS
Vertical									
Anterior facial ht (ANS-Me) (mm)	61.0	4.9	61.4	3.9	63.7	4.2	NS	*	NS
Posterior facial ht (Co-Go) (mm)	51.1	3.8	49.7	4.3	49.9	3.7	NS	NS	NS
Corpus length (Go-Po) (mm)	70.3	3.8	69.0	3.7	69.0	3.8	NS	NS	NS
SN plane	8.4	2.5	8.6	2.4	8.1	1.9	NS	NS	NS
Palatal plane	2.2	3.0	1.2	2.6	0.7	2.5	NS	*	NS
Occlusal plane	10.4	2.9	11.2	3.8	12.0	3.3	NS	NS	NS
Mandibular plane angle	23.2	3.7	25.5	5.6	27.1	4.2	NS	†	NS
Facial axis angle	-0.4	4.0	-2.4	3.7	-3.4	2.8	*	†	NS

Abbreviation: NS, not significant.

\* =  $P < .05$ .

† =  $P < .01$ .

‡ =  $P < .001$ .

molar and incisor were measured by dropping a perpendicular line from the most posterior point on the pterygomaxillary fissure to the Frankfort horizontal (Fig 14). Direct linear measurements were made to the mesial contact point of the upper first molar and to the tip of the upper incisor.<sup>116</sup> The upper incisor moved anteriorly

2.0 mm in the control group, but posteriorly in the facebow group (-4.2 mm). The position of the upper incisor in the FR group remained relatively unchanged. Slightly smaller differences in horizontal response were noted in the first molar region. No differences were noted among groups in the vertical movement of the

**Table 3.** Comparison of Treatment Effects

	Headgear (n = 34)		Fränkel (n = 26)		Control (n = 20)		Significance		
	x	SD	x	SD	x	SD	H-F	H-C	F-C
Maxillary Skeletal									
Condylion-ANS (mm)	1.2	1.4	2.4	1.8	1.4	1.2	†	NS	NS
Midfacial length (Co-Pt. A) (mm)	0.4	1.6	2.2	1.8	2.0	0.8	‡	‡	NS
SNA angle	-2.2	1.2	-0.4	1.4	0.8	1.2	‡	‡	†
Nasion perp/point A (mm)	-2.8	1.2	-0.4	1.4	0.4	1.0	‡	†	*
Maxillary Dental									
Upper incisor horizontal (mm)	-4.2	4.2	-0.2	2.6	2.0	0.8	‡	‡	*
Upper incisor/point A (mm)	-2.8	2.4	-1.2	1.8	0.4	1.0	†	‡	†
Upper molar horizontal (mm)	-1.8	2.4	1.8	1.6	2.0	1.0	‡	‡	NS
Upper incisor vertical (mm)	3.0	2.0	3.0	1.6	2.6	1.4	NS	NS	NS
Upper molar vertical (mm)	3.0	1.4	2.6	1.4	2.8	1.0	NS	NS	NS
Mandibular Dental									
Lower incisor horizontal (mm)	-1.8	1.6	1.2	1.6	-0.4	0.6	‡	‡	‡
Lower incisor-APo	0.4	1.2	2.8	1.6	0.2	0.8	‡	NS	‡
Lower molar horizontal (mm)	-0.6	1.4	0.2	1.0	0.6	1.0	*	‡	NS
Lower incisor vertical (mm)	0.2	1.6	1.0	1.4	1.6	1.0	*	‡	NS
Lower molar vertical (mm)	1.0	1.2	2.6	1.0	0.8	1.0	‡	NS	‡
Mandibular Skeletal									
Mandibular length (Co-Gn) (mm)	4.8	2.0	6.4	2.2	3.6	1.2	‡	*	‡
Pogonion/N perpendicular (mm)	-0.6	2.4	1.4	1.8	1.0	1.2	‡	†	NS
Facial plane angle	-0.1	1.2	1.0	1.0	0.8	0.6	‡	*	NS
SNB angle	0.4	1.2	1.2	1.0	0.8	0.8	†	NS	NS
ANB angle	-2.6	1.0	-1.6	1.2	-0.1	0.8	‡	‡	‡
Articulare-gnathion	4.6	1.6	6.0	1.1	3.4	1.2	†	*	‡
Vertical									
Anterior facial ht (ANS-Me) (mm)	2.0	1.0	3.2	1.6	1.0	1.0	†	*	‡
Posterior facial ht (Co-Go) (mm)	2.8	1.6	4.2	2.4	1.8	2.0	*	NS	‡
Corpus length (Go-Po) (mm)	2.4	1.4	3.4	1.6	3.0	1.4	*	NS	NS
SN plane	-0.6	0.6	0.0	0.6	-0.2	1.0	†	NS	NS
Palatal plane	-2.0	2.0	-0.8	1.6	-0.6	1.0	†	†	NS
Occlusal plane	-0.0	3.2	0.8	3.6	-0.2	2.6	NS	NS	NS
Mandibular plane angle	1.0	2.0	-0.2	1.8	-0.6	1.0	†	†	NS
Facial axis angle	-0.6	2.0	0.4	1.2	0.4	0.6	*	*	NS

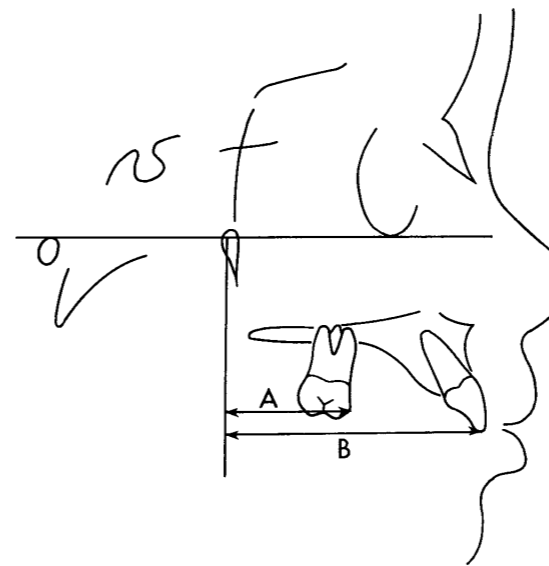
Abbreviation: NS, not significant.

\* =  $P < .05$ .† =  $P < .01$ .‡ =  $P < .001$ .

incisor or the first molar relative to the Frankfort horizontal (Table 3).

**Mandibular skeletal relationships.** As measured from condylion to gnathion, increases in mean mandibular length were greater in the FR group (6.4 mm) than in the untreated controls (3.6 mm). A statistically significant increase in man-

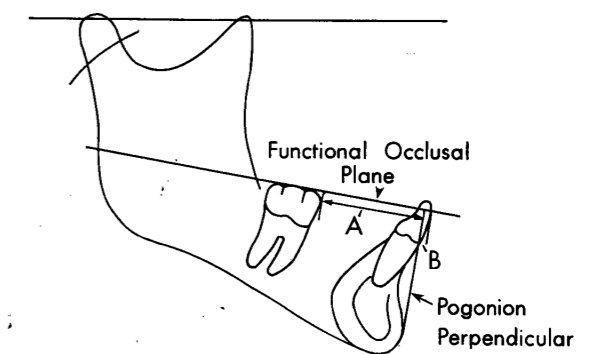
dibular length also was noted in the facebow group relative to control (4.8 mm). The chin point at pogonion relative to the nasion perpendicular moved backward slightly (-0.6 mm) in the facebow group, whereas a forward movement of pogonion occurred in the Fränkel (1.4 mm) and control (1.0 mm) groups (Table 3).



**Figure 14.** Determination of changes in the horizontal position of the upper first molar and upper incisor. (A) Distance from the mesial surface of the upper molar to a line drawn from the pterygomaxillary fissure perpendicular to the Frankfort horizontal (pterygoid vertical). (B) Distance from the tip of the upper incisor to the pterygoid vertical. (Reprinted with permission from McNamara.<sup>116</sup>)

**Mandibular dentoalveolar relationships.** The average horizontal movement of the lower molar and lower incisor was measured by establishing the functional occlusal plane (FOP) and then drawing a line from the FOP through pogonion, establishing the pogonion perpendicular (Fig 15). Measurements were made from the mesial contact point of the lower molar and the tip of the lower incisor to the pogonion perpendicular.<sup>116</sup> Forward movements of the lower molar and lower incisor were reported as a positive values. Forward incisor movement was noted in the Fränkel group (1.2 mm), whereas slight distal movement of the tip of the lower incisor was noted in the controls (-0.4 mm) and in the facebow group (-1.8 mm). Less differences were noted in the molar region (Table 3).

Vertical movements of the mandibular incisor and molar were determined by constructing a vertical line through the incisal tip and the mesial cusp of the molar, respectively, perpendicular to the functional occlusal plane to the point of intersection with the mandibular plane. Increased eruption of the molar was observed in the FR group in comparison with controls and the facebow group (Table 3). Less vertical move-



**Figure 15.** Horizontal movement of the lower incisor and lower molar. After establishing the functional occlusal plane (FOP), the pogonion perpendicular is constructed from the chin point perpendicular to the FOP. (A) Distance from the mesial contact point of the lower molar to the pogonion perpendicular. (B) Distance from the tip of the lower incisor to the pogonion perpendicular. (Reprinted with permission from McNamara.<sup>116</sup>)

ment of the incisor was observed in the FR and facebow groups than in the untreated Class II sample.

**Vertical relationships.** Lower anterior facial height, as measured from anterior nasal spine to menton, increased in both treatment groups, with the greatest increase observed in the FR group. Similar increases in posterior facial height were noted as well. The mandibular plane angle decreased slightly in the FR and control groups and increased slightly in the facebow group. Comparable changes in the facial axis angle also were observed.

### Discussion

The results of this retrospective study indicate that the FR-2 appliance of Fränkel, and the cervical-pull facebow combined with anterior brackets and archwire, produce significant treatment effects on the craniofacial structures of Class II mixed dentition patients. These treatment approaches, however, affect the skeletal and dentoalveolar structures in differing ways.

**a. Pretreatment comparisons.** This study evaluated three groups of individuals with Class II malocclusion. From the initial sample of 267 sets of records (Table 1), specific exclusionary rules were applied to refine the sample. In addition, specific age parameters at the start of treatment were defined to match the sample according to chronological age. An evaluation of starting

form (Table 2) showed that the Fränkel and control groups were well-matched according to the 28 variables used in this study. Despite these efforts to match the groups some significant differences existed between the facebow group and the other sample groups. Specifically, both the maxilla and the mandible were slightly more retruded in the control sample, and lower anterior facial height was less in the facebow group than in the control. In addition, both the upper incisors and molars were more anterior in the facebow group before treatment than in the control.

These differences in pretreatment form between the facebow group and the other two groups is a reflection of "susceptibility bias,"<sup>140</sup> in that patients were selected by the clinician as being susceptible to a given treatment, ie, facebow therapy or FR treatment. Historically, the type of headgear used in this study (cervical facebow) has been recommended for use in patients with short lower anterior facial heights and protrusive maxillary dentitions (see previous discussion of this issue in this article). In contrast, Fränkel therapy has been recommended for treatment of patients with mandibular skeletal retrusion and associated neuromuscular problems. The pretreatment descriptive statistics of the three samples seem to reflect some susceptibility bias, which confounds the analysis of posttreatment changes, especially with regard to the facebow group in comparison with the other groups.

**b. Posttreatment comparisons.** The analysis of the treatment effects produced by the two therapies reveals that these two modalities have very different effects on the skeletal and dentoalveolar structures of the craniofacial complex. For example, there was a 3 mm difference between the change in position of Point A between the facebow group and control during the treatment period. Similar changes were observed in the SNA angle and the increments of midfacial length increase, as measured from condylion to Point A. In contrast The Fränkel appliance has minimal effect on midfacial development.

One of the most striking differences between the two treatments was with regard to the antero-posterior position of the maxillary incisors and molars. The FR appliance tipped the upper incisor posteriorly and did not affect the position of the upper molar in comparison to control. In

contrast, the facebow, combined with partial anterior appliances, produced a significant posterior relocation of the upper incisor, a 6 mm difference in comparison to control values. Similarly, the upper molar was relocated almost 4 mm posteriorly in comparison to the untreated group. Thus, the facebow and fixed appliance combination had a profound effect on the position of the maxillary dentition in comparison to controls.

One explanation for the difference in upper incisor movement is that often in Class II division 1 patients, the upper incisors are spaced and flared before treatment. One of the objectives of so-called "2 × 4 treatment" is to close the spaces and to reduce the flaring of the upper incisors through the application of lingual crown torque. Such movement is appropriate in these types of patients.

The two appliances had opposite effects on the movement of the lower dentition, but to a much less extent than in the maxilla. Modest lower incisor proclination was observed following FR treatment, whereas modest incisor retroclination was noted in the facebow group. In addition, increased molar eruption was noted in the FR group compared with the other groups.

As has been shown in this sample,<sup>103,116</sup> as well as in other such samples,<sup>111,113,123</sup> increased increments of mandibular length were noted following FR treatment. These findings are in contrast to those of Schulhof,<sup>119</sup> Creekmore<sup>117</sup> and Robertson,<sup>114</sup> who noted no increased mandibular growth, but whose studies differed significantly from the present study with regard to the technical management of the appliance.

A statistically significant increase in mandibular length was measured in the facebow sample in comparison with the untreated Class II sample. This increase in mandibular length lends support to the concept of a mandibular response during therapy with extraoral traction. Although this concept has been part of the conventional wisdom of many orthodontic practitioners and has been mentioned in articles dealing with the Tweed philosophy,<sup>141,142</sup> little data has been presented previously to support or refute this concept. The data from the present study indicate increased mandibular growth in the facebow sample in comparison with control values. Presumably the disruption of the occlusion during facebow use may have the effect of altering the anteroposterior position of the mandible during

treatment, perhaps in a manner similar to that produced by rapid maxillary expansion,<sup>26</sup> particularly in that the inner bow of the facebow typically is widened during treatment. Alteration of intercuspation during the correction of the molar relationship with the facebow may lead to a slight transient posturing forward of the mandible, which may result in a modest increase in mandibular length.

### Summary and Conclusions

This article has examined the diagnosis and treatment of Class II malocclusion from several perspectives. Initially, the frequency of occurrence of various components of Class II problems was examined by reanalyzing the cephalometric data from a large number (N = 277) of individuals in the mixed dentition. Mandibular skeletal retrusion and increased vertical dimension were the most frequent problems observed, although there was wide variation in the distribution of the components within the sample population. Transverse maxillary constriction also was shown to be a frequent component, also indicating that Class II malocclusion cannot be treated as a single diagnostic entity.

The second part of the article examined the literature concerning two of the most commonly used generic treatments for Class II malocclusion, extraoral traction and functional jaw orthopedics. Variations among the particular appliances (eg, high-pull *v* cervical-pull facebow, Herbst appliance *v* FR-2 appliance of Fränkel) and treatment effects were evaluated in an effort to review what is known about these two types of orthodontic and orthopedic interventions.

The third part of the article presented the results of a retrospective clinical study that compared directly the treatment effects produced by the cervical-pull facebow (in combination with partial fixed appliances) and the function regulator (FR-2) appliance of Fränkel to an untreated sample of subjects with Class II malocclusion. Patients treated with the FR appliance showed increased increments of mandibular length and lower anterior facial height in comparison with untreated controls. The chin point moved slightly forward in the FR group in comparison with controls. Little effect was noted in maxillary skeletal and dentoalveolar structures.

Facebow/fixed appliance treatment produced

different effects. The most profound changes were evident in maxillary structures (eg, restriction of the forward movement of the maxilla, distal movement of the maxillary molars and incisors) in comparison with controls. A modest increase in mandibular length also was noted in the facebow group, although the chin point moved slightly backward in the facebow group relative to controls.

The results of this retrospective study indicate that the effects produced by these two treatment protocols indeed are different. Therefore, the conscientious clinician should undertake a thorough evaluation of the Class II patient in all three dimensions and subsequently tailor the orthodontic and orthopedic protocols to address the needs of the given patient.

As with all short-term (eg, 2-year) clinical studies, and especially those that are retrospective in nature, no global conclusions can be reached regarding the ultimate effects of the two treatments considered in this study on the growth of the craniofacial complex. For example, although this study indicated that maxillary growth is inhibited significantly with cervical facebow treatment, the present study was in the mixed dentition of children. In essence, the study was of a moving target, in that the craniofacial complex of these children still was growing. Other studies have shown that mandibular growth is increased above normal after treatment in the mixed dentition. Thus, long-term studies of treatment effects produced by various orthodontic and orthopedic appliances are indicated.

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