

bunden mit einem verstärkten alveolären Wachstum bei den unteren Molaren. Die Achsenneigung der unteren Schneidezähne blieb praktisch innerhalb der Norm. Die Behandlungsergebnisse des Distalbisses weisen auf die Wirksamkeit der funktionellen Behandlungsmethode nach Fränkel hin, und wir möchten diese Methode unter Berücksichtigung des Alters für eine breite kieferorthopädische Praxis empfehlen.

#### РЕЗЮМЕ

Строение лицевого скелета при дистальном прикусе и его изменения после лечения активаторами

На боковых телерентгенограммах анализировано строение лицевого скелета у 179 пациентов с дистальным прикусом по сравнению с контрольной группой II класса по Энглю. У 59 человек проводилось лечение с помощью активаторов. При этом была значительно уменьшена начальная имевшаяся ретрогнатия.

#### SUMMARY

The architecture of the facial skeleton in distocclusion and its changes after treatment with the functional regulator.

Lateral telerradiographs served to compare the architecture of the facial skeleton in 173 patients presenting with distocclusion with that of patients in class I of Angle's classification. 59 patients were treated with functional regulators by means of which the initial mandibular retrognathism was widely corrected.

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### Functional considerations in orthodontic treatment

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#### ZUSAMMENFASSUNG

Funktionelle Betrachtungen zur kieferorthopädischen Behandlung

Verschiedene experimentelle Untersuchungen an wachsenden Rhesusaffen zeigten, daß eine geeignete apparative Vorverlagerung des Unterkiefers zu einer erhöhten Aktivität des M. pterygoideus lateralis führt. Diese hatte ein verstärktes Wachstum im Kondylenknorpel zur Folge. Eine Stimulierbarkeit der Unterkieferlänge unter Benutzung des Aktivators bei Kindern ist fraglich. Funktionsregler nach Fränkel scheinen den experimentellen Bedingungen, die zu einer veränderten Muskelaktivität führten, am meisten zu entsprechen. Der Einfluß dieses Gerätes auf das maxilläre und mandibuläre Wachstum wurde bei 57 Patienten der Angle-Klasse II mit Hilfe von Fernröntgenaufnahmen untersucht. 37 Fälle der Angle-Klasse II dienten als Kontrollgruppe. Die Längenzunahme des Unterkiefers (Condylare-Gnathion) war in der Behandlungsgruppe signifikant größer. Dagegen war die Zunahme der effektiven Oberkieferlänge (Condylare-A-Punkt) in der Kontrollgruppe gering, aber statistisch signifikant größer. Um den Einfluß des Alters auf den Behandlungseffekt zu prüfen, erfolgte eine Unterteilung der Probanden in je eine Gruppe mit Behandlungsbeginn vor und nach dem Alter von 10,5 Jahren. Bei den Kontrollfällen unterschied sich die Zunahme der Unterkieferlänge nicht signifikant in den beiden Untergruppen. Bei den Funktionsreglerfällen war die Zunahme der Unterkieferlänge in der älteren Untergruppe größer

Zahn Bogens mit der Norm ist ersichtlich, daß nur der erste Prämolare zur „Streß-Achse“ die Norm um 0,82 nicht erreichte (Parameter 59).

Der untere gnathische Abschnitt wird durch folgende 29 Parameter charakterisiert: 8, 9, 10, 11, 12, 13, 17, 19, 22, 30, 34, 36, 37, 38, 39, 40, 41, 45, 48, 49, 50, 51, 56, 57, 58, 63, 66, 67.

Vor der Behandlung wurde beim Distalbiß im Vergleich zum Neutralbiß ein Unterschied in 20 von 29 Parametern festgestellt (Tab. 2). Die wichtigste morphologische Abweichung bestand bei Distalbiß in einer Mikrognathie (Retrognathie) des Unterkiefers. Davon zeugen die Verminderung des Kieferwinkels um  $1,9^\circ$  (Parameter 26) und die Verkürzung des Unterkieferkörpers ( $MT_1$ ) um 3,07 mm (Parameter 36), was die Verkürzung der Gesamtlänge des Unterkiefers (Gn-Co) um 4,36 zur Folge hatte. Das führte zu einer posterioren Lage der unteren Zahnreihe (Oc'-6), des Pogonions (Oc'-Pg) und der Apikalbasis (Oc'-B). Die Winkel MM, AB, SeNB, SeNPg, ANPg, NSeGn und GnCoH waren bei den Patienten mit Distalbiß anfangs vergrößert, was eine Vergrößerung des T-Winkels zur Folge hatte. Damit im Zusammenhang stand wahrscheinlich der stärkere Überbiß der Schneidezähne und die sagittale Schneidezahnstufe. Außerdem wurde eine hintere Inkliniation (Flexion nach Bimler) des Unterkiefers zur Frankfurter Horizontalen (GnCoH-Winkel) festgestellt, die sich auch in der Neigung des Okklusionsplanums (OcP-Pn) widerspiegelte.

Im Resultat der Behandlung des Distalbisses wurden die festgestellten morphologischen Abweichungen teilweise oder völlig beseitigt (Parameter 6, 9, 10, 11, 12, 13, 17, 19, 22, 30, 36, 37, 38, 39, 49, 50, 56, 57, 58, 63, 66). Der Funktionsregler nach Fränkel stimulierte das Wachstum des Unterkiefers nach vorn und unten. Hinweise darauf lieferten die Vergrößerung der Körperlänge des Unterkiefers ( $MT_1$ ) um 2,14 mm (das fehlte in der Norm), die Verlängerung der Strecke Gnathion-Condylare um 4,65 mm und der „Y“-Achse um 5 mm, die bedeutend größer als in der Norm waren. Besonders starken Zuwachs zeigte der Unterkieferamus, der sich um 3,26 mm verlängerte.

Die ersten Molaren des Unterkiefers (6-MP) verlängerten sich um 4,42 mm, ihr Abstand zum Okzipitalpunkt (Oc'-6) vergrößerte sich um 3,21 mm, was bei den Probanden der Angle-Klasse I nicht der Fall war. Diese Veränderungen können als Resultat einer Vergrößerung der Strecke Okzipitalpunkt — Pogonion um 3,92 mm angesehen werden. Die sagittale Schneidezahnstufe verminderte sich um durchschnittlich 2,04 mm. Alle oben genannten Veränderungen verbesserten die Verhältnisse zwischen den Apikalbasen. Es vergrößerten sich die Winkel NAB um  $4,3^\circ$ , MM um  $4,2^\circ$ , AB um  $4,47^\circ$ , SeNB um  $2,52^\circ$ , SeNPg um  $2,77^\circ$  und NAPg um  $3,76^\circ$ . Solche Winkelveränderungen traten bei den neutralen Gebissen nicht auf oder kamen wesentlich schwächer zum Ausdruck. Im Ergebnis der Behandlung des Distalbisses kam es zu einer anterioren Rotation des Unterkiefers (Verminderung des Winkels NSeGn um  $1,92^\circ$ ; Vergrößerung der Winkel MP-Pn um  $3,26^\circ$  und H um  $1,17^\circ$  und Normalisierung des Winkels Gn CoH). Das Zuwachstempo und die Zuwachsgröße des Unterkiefers waren intensiver, was von der Wirksamkeit der Fränkel-Methode bei der Behandlung des Distalbisses zeugt. Ästhetische Verbesserungen des Gesichtsprofils zeigten sich in einer Verminderung des T-Winkels um  $4,77^\circ$ , der sich während des Wachstums bei den neutralen Gebissen nicht änderte.

Beim Vergleich der Parameter nach der Behandlung des Distalbisses mit den neutralen Gebissen konnten wir eine fast völlige Normalisierung feststellen, Unterschiede gab es nur bei den Parametern 6, 9, 10, 18, 22, 26, 30, 31, 49, 50, 51, 63. Der Gonionwinkel blieb während der Behandlung unverändert. Die Winkel SeNB, NAB, MM, AB sowie Schneidezahnstufe und Überbiß erreichten ihre Normgröße nicht. Es gelang also nicht immer, die morphologischen Abweichungen völlig zu beseitigen. In den meisten Fällen wurde von uns die untere Normgrenze, d. h. ein morphologisches, funktionelles und ästhetisches Optimum erreicht.

Die Untersuchungen weisen darauf hin, daß die gnathometrischen Verbesserungen besonders durch eine Verlängerung des Ramus mandibulae mit gleichzeitiger Rotation des Unterkiefers nach oben und vorn (Winkel MP-PN) vor sich ging. Dieser Prozeß war ver-

ns in der jüngeren. Bei der jüngeren Altersgruppe vergrößerte sich die effektive Oberkieferlänge bei den Kontrollfällen mehr als bei den Behandlungsfällen. Dagegen bestand beim Vergleich der älteren Probanden kein Unterschied der Zunahme der effektiven Oberkieferlänge zwischen Behandlungs- und Kontrollgruppe. Obwohl die Zunahme der unteren vorderen Gesichtshöhe bei den Behandlungsfällen größer war als bei den Kontrollfällen (auch hier zeigten sich größere Werte in der älteren Gruppe), kam es bei den Behandlungsfällen zu einer durchschnittlich gleichwertigen Verringerung des Mandibularplanumwinkels. Die bessere Stimulierbarkeit der Unterkieferlänge in der älteren Gruppe bedeutet keine Empfehlung, mit der Funktionsreglertherapie die zirkumpubertale Wachstumsperiode abzuwarten. Das kondyläre Wachstum ist nur ein Aspekt dieser Behandlung.

Im zweiten Teil der Arbeit wurden der Aufbau und die Adaptationsfähigkeit des Kiefergelenks an erwachsenen Rhesusaffen untersucht. Gegenüber jungen Affen war die Anzahl der Chondrozyten im Kondylenknorpel deutlich geringer, eine hypertrophe Zone selten. Ein weiteres Merkmal war der Abschluß des Knorpels von den Markräumen durch Zusammenschluß der Trabekel zu einer kompakten Knochenhaube. Die relative Dicke der Knorpelschicht war bei den einzelnen Tieren unterschiedlich. Bei neun erwachsenen Affen erfolgte eine apparative Vorverlagerung des Unterkiefers, von denen drei fast keine morphologische Antwort im Gelenk zeigten. Sechs Affen wiesen eine beträchtliche Hyperplasie des Kondylenknorpels auf. Das Ausmaß der Veränderungen war aber geringer als bei den jungen Tieren. Auch der temporale Teil des Kiefergelenks wies Umbauvorgänge auf.

Bei einer funktionellen Behandlung von erwachsenen Patienten zwischen 19 und 32 Jahren war die Zunahme der Unterkieferlänge gering. Die verbliebene Adaptationsfähigkeit des Kiefergelenks reichte für eine Beseitigung größerer skelettaler Diskrepanzen nicht mehr aus.

A recent study of the components of Class II malocclusion in children (McNamara, 1981a) indicates that this type of dentofacial abnormality is not a single clinical entity but can result from numerous combinations of skeletal and dental components. Maxillary skeletal protrusion, which is most efficiently treated by headgear therapy, occurs relatively infrequently. In a sample of 277 children with Class II dental relationship, only about 15–20% of the subjects had what cephalometrically could be classified as a true maxillary skeletal protrusion. This percentage is even lower if the soft tissue profile and the nasolabial angle are considered (McNamara, unpublished data). Thus, the routine use of extraoral traction in the treatment of Class II malocclusion does not seem to be indicated, since in most instances the skeletal portion of the maxilla does not contribute to the problem.

The same study indicates that retrusion of the mandible is the most common contributing factor in a Class II malocclusion. All four cephalometric measures used to determine mandibular position indicated that mandibular retrusion occurred 50% to 70% of the time. Thus, in the majority of Class II cases, deficient mandibular growth contributes to the overall dentofacial deformity. Yet historically, the question of whether mandibular growth can be altered therapeutically or experimentally has been quite controversial, particularly with regard to the use of functional appliances.

#### *Clinical studies in growing patients*

The majority of clinical studies of functional jaw orthopedics involve the use of activator type appliances in growing patients. The appliances usually have been some variation of the original design of Andresen and Häupl (Andresen and Häupl, 1936; Andresen, 1936, 1943; Häupl, 1938). Whether this type of functional appliance can induce an increase in mandibular length is not clear from the reports in the literature. For example, Björk (1951), Jacobsson (1967) and Harvold and Vargervik (1971) all state that in the patients that they studied, functional therapy using activators did not produce alterations in mandibular growth that were different from that which would have occurred without treatment. In contrast, Browne (1959) and Marschner and Harris (1966), in two of the few clinical studies that considered total mandibular length increments in addition to mandibular positioning, noted a significantly higher rate of mandibular growth in a group of patients treated with functional appliances than that in an untreated group. Browne (1959) states that the

mandibular growth increments were statistically higher in the treated group, and that the growth increment of each treated patient was above the average of the controls. Other investigators have found significant increases in mandibular growth after treatment, as is described below.

Those investigators who have reported increases in mandibular growth have proposed two general reasons why an increase in mandibular growth may occur. The more obvious theory is simply that the growth of the mandible has been stimulated above normal levels. Freunthaller (1967) has stated that functional therapy has a "stimulating effect on growth centers and sites". Korkhaus (1960) and Tiegelkamp (1960) likewise have maintained that increased growth of the condyle is the most important factor. Other authors do not directly refer to "stimulation of bone growth", but rather talk in more guarded terms about "tissue transformation" (Gresham, 1953; Häupl, 1958; Weise, 1962; Moss, 1962; Madsen, 1962; Hausser, 1968). The concept of tissue transformation is apparently similar to the concept of growth rate stimulation as described above.

The second explanation for the increase in growth of the mandible is that functional therapy does not directly stimulate growth itself, but rather affects the underlying conditions which regulate the growth process. Grossman and Moss (1964) state that although mandibular growth cannot be induced beyond a genetically limited size, alteration of the environment (eg., muscle function) can result in a pattern of growth that could not otherwise be attained. When inhibiting factors are removed, there is an increase in growth that would not have occurred otherwise, and normalization of the growth process will ensue (Moss, 1962; Meach, 1966).

As can be surmised from the review of the literature provided above, much confusion exists regarding not only the possibility of therapeutically increasing mandibular growth, but also the possible mechanism or mechanisms through which it can occur. Because of the confusion and contradictions present in the clinical literature, animal experiments have proven useful in clarifying the question of mandibular growth regulation.

#### *Experimental studies in growing animals*

The effect of altered function on the growing craniofacial complex has been studied extensively in a series of animal experiments. Various appliances have been constructed that prompt the lower jaw into a protrusive position, thereby altering the function of the muscles associated with the mandible. The resulting craniofacial adaptations associated with the use of these appliances have been studied cephalometrically or histologically by a number of investigators. Breitner (1930, 1933, 1940), Häupl and Psansky (1939), Hoffer and Colico (1958), Baume and Derichsweiler (1961) and Stöckli and Willert (1971) demonstrated that the condylar cartilage exhibits compensatory tissue response to experimental alteration of the mandibular postural position. Joho (1968) in a similar study noted an opening of the gonial angle and an increase in mandibular length. Vogel and Pignanelli (1958) in histochemical studies found that experimental protrusion of the mandible in rhesus monkeys also resulted in an increase in chondrogenic activity at the head of the mandibular condyle.

Petrovic, Stutzmann and associates (Charlier, 1967; Charlier et al., 1968, 1969; Lemoine et al., 1968; Petrovic, 1970, 1972; Petrovic et al., 1973, 1975, 1979, 1981; Stutzmann and Petrovic, 1974; 1975a; 1975b; Stutzmann, 1976) reported that anterior displacement of the mandibular condyle in rats resulted in increased growth of the condylar cartilage. In one study (Petrovic et al., 1981) a group of rats wore protrusive appliances during their entire growth period. The average final length of the mandible in the treated group was significantly longer than the average length in the control group. This study provides the first evidence, either clinical or experimental, that the final length of the mandible can be increased over a presumed genetically limited size.

Since 1968, our laboratory has also considered the question of the form/function relationship, with particular emphasis on the alterability of mandibular growth. We have used many experimental designs in our studies, the most frequently used being the experiments

functional protrusion (Elgoyhen et al., 1972; McNamara, 1972, 1973, 1975a, 1976, 1980; McNamara and Carlson, 1979; McNamara et al., 1975, 1982).

The basic design of all functional protrusion experiments carried out in our laboratory and elsewhere seems to simulate one goal of functional orthopedic appliance treatment, that is to effect an alteration in mandibular postural position. In the case of the experimental animal, an altered postural position of the mandible is produced by cementing cast gold or ticonium onlays on the upper and lower dental arches. These castings usually produce a 4 to 5 mm anterior and a 2 to 3 mm inferior displacement of the mandible during closure and results in the displacement of the mandibular condyle away from the structures in the glenoid fossa (Fig. 1).

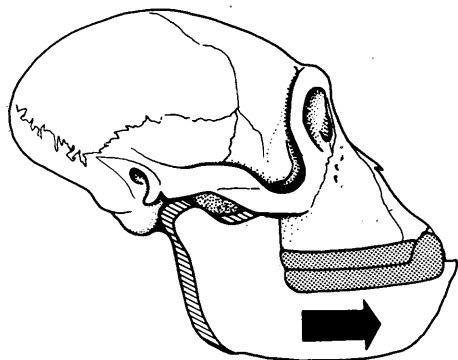


Fig. 1  
Forward positioning of the mandible produced by maxillary and mandibular castings (from McNamara, 1976).

#### *Electromyographic Findings*

The neuromuscular reaction seen in the experimental monkey studies closely parallels that which is often observed in patients wearing functional appliances on a full-time basis. I call this reaction, which begins during the first few months after appliance placement, the "pterygoid response". The first indication of the pterygoid response can be observed quite easily in experimental animals (Fig. 2), that is the increased tonic activity seen not

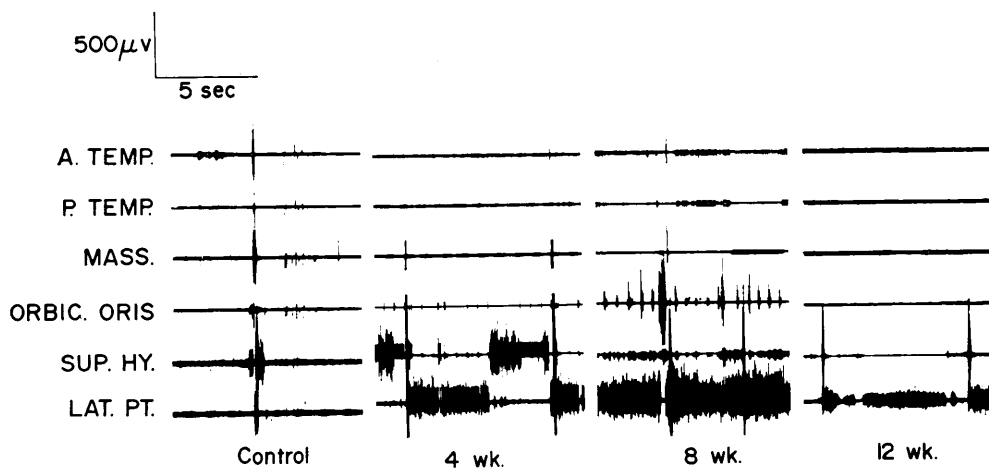


Fig. 2. Typical alterations occurring in muscle activity during the experimental period. In the control records, the superior head of the lateral pterygoid muscle fired during such movements as chewing, clenching and swallowing, but not independently during the maintenance of the mandibular postural position. After appliance cementation the activity of the lateral pterygoid muscle gradually increased during both functional movements and postural maintenance. This activity has been termed the "pterygoid response" (from McNamara, 1975).

only during functional movements but also during the maintenance of the postural position of the mandible.

Initial placement of protrusion appliances in the experimental animals resulted in an increase in the overall activity of the muscles of mastication as the animals sought to find a new occlusal position (McNamara, 1972, 1973, 1975, 1980). However, during the first few hours immediately after appliance placement, there was no demonstrable change in the pattern of muscle activity, as indicated by the fact that electromyographic recordings taken during this time could not be distinguished from those taken before appliance placement. A distinct change in muscle activity did occur during the first few weeks after appliance placement. This change was characterized by a decrease in the activity of the posterior temporalis muscle, an increase in activity of the masseter muscle and most significantly an increase in the function of the lateral pterygoid muscle. This increase in lateral pterygoid activity (which I assume is similar to the pterygoid response observed clinically in functional appliance patients) was different from lateral pterygoid activity seen in control records in that the superior head of the muscle fired independently from, as well as simultaneously with, the jaw closing muscles. This new functional pattern first appeared in association with such phasic activities as swallowing and then during such tonic functions as the maintenance of the mandibular postural position. As the experiments progressed, a gradual return toward the pre-appliance levels and patterns of muscle activities occurred (Fig. 2).

#### *Cephalometric Findings*

In order to monitor skeletal changes cephalometrically, metallic implants were placed in the animals before the beginning of the experimental period in various regions of the craniofacial complex, including the mandible (McNamara and Graber, 1975), the maxilla, the frontal bone and the cranial base region (McNamara et al., 1976).

The presence of a Class III malocclusion at the end of the experimental period (Fig. 3) could not be explained by adaptations in any single craniofacial structure or region; rather it was a result of both pronounced and subtle adaptations that occurred throughout the structures of the craniofacial complex (McNamara, 1972, 1973, 1980). Thus, changes were found in both the maxilla and the mandible, as well as in the dentition. Of specific interest to this paper are the mandibular changes. Significant adaptations occurred in the mandibles of those animals that wore functional protrusion appliances.



Fig. 3. Intraoral view of the occlusion following appliance removal. Note the Class III relationship of the canines and posterior teeth (from McNamara, 1980).

A

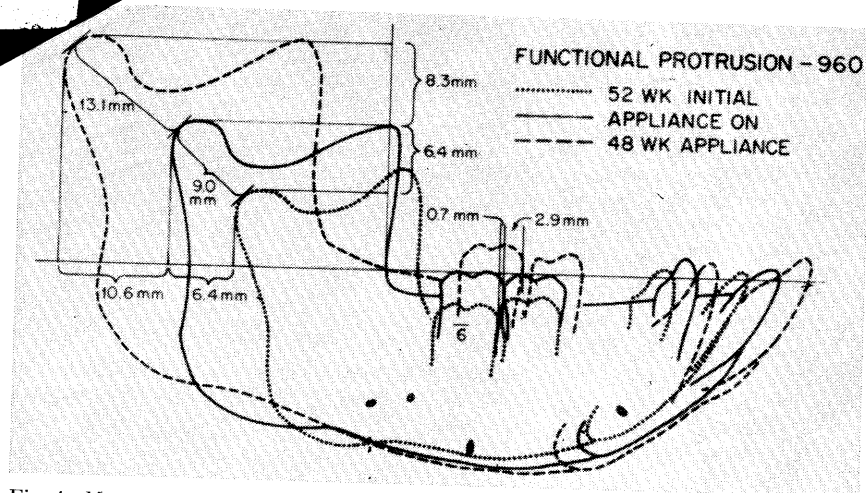


Fig. 4. Mandibular tracings of a juvenile experimental animal which, after a control period of 52 weeks, wore a series of protrusive appliances for a 48-week period. The growth increments monitored during the control period were similar to the average value of the control group. Note the increase in posterior and posterosuperior growth during the experimental period (from McNamara, 1980).

One such animal (Fig. 4) which, after a control period of 52 weeks, wore a series of protrusive appliances for 48 weeks, demonstrates an alteration in both the amount and direction of mandibular condylar growth that is typical of the 11 experimental animals and 24 control animals in the study (McNamara, 1980). The amount of growth that occurred during the control period was very similar to that observed for the control animals. During the subsequent 48-week experimental period this animal demonstrated a 45% increase over control values in the amount of posterosuperior growth of the condyle and more than a 50% increase in the amount of posterior condylar growth. The amount of growth of the mandibular condyle superiorly was only slightly more than that of the control animals. There was also an increased amount of forward movement of the lower dentition (2.9 mm as compared to 1.0 mm in the controls.) This animal represents the type of condylar response which we have routinely observed cephalometrically in our studies. I assume that similar types of response would be observed in patients wearing a functional appliance that produces a protrusive postural change in mandibular position.

#### *Histological Findings*

A short-term series of functional protrusive experiments in juvenile animals was carried out so that the histological adaptations of the temporomandibular joint could be studied (McNamara et al., 1975; McNamara and Carlson, 1979; McNamara, 1980). A total of 14 experimental and 14 control animals were used in this study. One to three experimental animals were sacrificed at 2, 4, 6, 8, 10, 12, and 24 weeks after appliance placement. In comparison to controls (Fig. 5A, B) specific adaptations could be seen in the temporomandibular joint region of the experimental animals, the nature of which could be related to the time that had elapsed after appliance placement. Significant adaptations could be seen along the posterior and posterosuperior region of the temporomandibular joint in the animals sacrificed after only two weeks of appliance wear (Fig. 5C, D). Increased deposition of new bone was also evident along the posterior border of the ramus and the anterior border of the posteroglenoid spine. Similar adaptations were observed in the animal sacrificed at four weeks. The largest response was observed in one of the animals sacrificed at four weeks. The largest response was observed in one of the animals sacrificed at 6 weeks

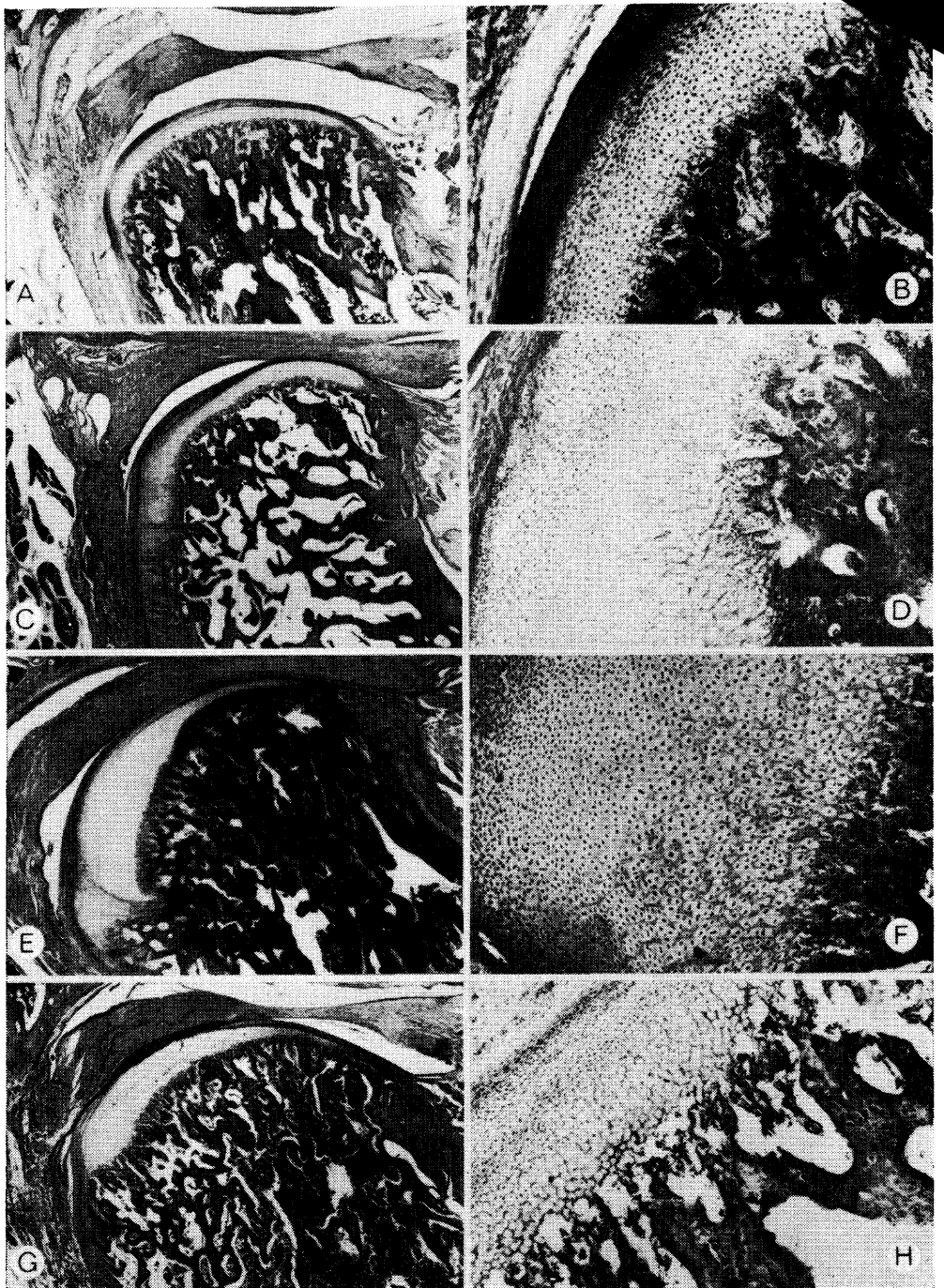


Fig. 5. A. Overview of the temporomandibular joint region of a typical juvenile control animal. B. Higher power view of the condylar cartilage in a typical juvenile control animal. C. Temporomandibular joint region of a two-week juvenile experimental animal. Note the proliferation of tissue, particularly in the posterior portion of the condylar cartilage and along the posterior border of the ramus. D. Proliferation of cartilage along the posterior border of the condyle in a two-week experimental animal. Note the increase in both size and number of condrocytes. E. The



F). The animal exhibited a fourfold increase in the posterior thickness of the condylar cartilage. Rapidly forming new bone was also observed in this area. As the elapsed time after appliance placement increased, the response of the cartilage in the mandibular condyle decreased (Fig. 5G, H) so that by the end of the 24-week period, it was difficult to distinguish the condyles of the experimental animals from those of the controls. However, increased mytotic activity in the prechondroblastic layer of the condylar cartilage could still be observed autoradiographically at 24 weeks (NMcamara et al., unpublished data).

#### Overview

The two diagrams seen in Figure 6 summarize the adaptive responses observed in our functional protrusion experiments. The placement of the appliance results in an immediate change of the stimuli to the receptors in the orofacial region, particularly those in the tongue, gingiva, palate, dentition, muscles and temporomandibular joint region (Fig. 6A). (Presumably this same response occurs in human patients after the placement of a functional appliance.) This alteration in stimuli is transmitted to the central nervous system which mediates changes in muscle activity such as an increase in the function of the lateral pterygoid muscle ("pterygoid response"). This alteration in muscle function leads to a forward positioning of the jaw. These muscle changes are very rapid and can be measured in terms of minutes, hours and days.

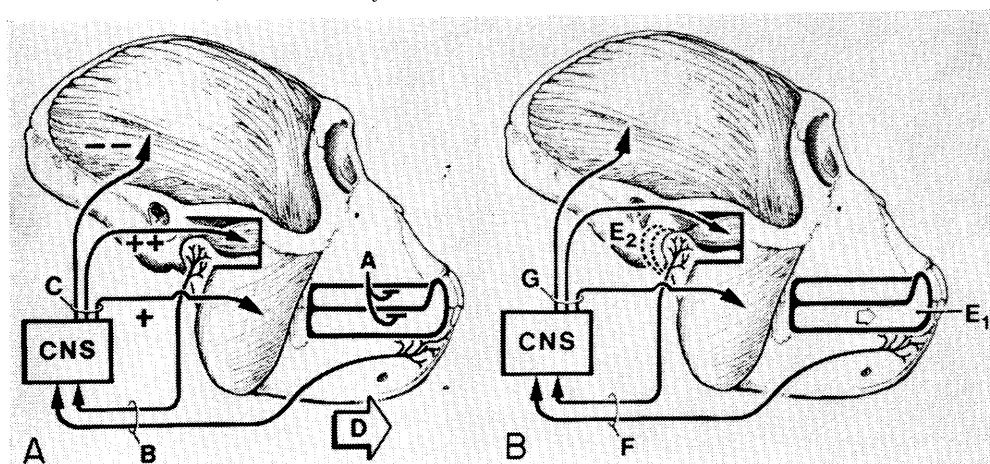


Fig. 6. Overview of the neuromuscular and skeletal adaptations that occurred during the functional protrusion experiments. Insertion of the appliance (A) results in a change in the sensory stimuli to various orofacial receptors. This information is relayed (B) to the central nervous system (CNS) which mediate changes in the level of activity (C) of various craniofacial muscles. This change in activity leads to the forward displacement of the mandible (D) in both phasic and tonic activities. The above neuromuscular responses are rapid in nature. Skeletal adaptations are more gradual. Structural harmony can be reestablished by a combination of mechanisms, including dentoalveolar movement (E<sup>1</sup>) or increased condylar growth (E<sup>2</sup>) or increased condylar growth (E<sup>2</sup>). The exact nature of the skeletal adaptations depend upon the of the animal. Such adaptations again alter the sensory stimuli, which is transmitted (F) to the CNS. The need for neuromuscular adaptations is reduced (G) so that the normal structural and functional balance is once again attained.

temporomandibular joint region of a six-week experimental juvenile animal. Note the increase in the thickness of the condylar cartilage, particularly along the posterior aspect of the condyle. F. Higher power view of the posterior portion of the condylar cartilage in a six-week animal. G. Temporomandibular joint region of a twelve-week juvenile experimental animal. Some continuing cartilage proliferation is observed. H. Higher power view of the temporomandibular joint region of a 24-week animal (adapted from McNamara, 1980).

Structural adaptations in the craniofacial region are more gradual in nature and occur throughout the craniofacial region, as indicated in Figure 6B by a forward movement of the dentition and an increase in growth at the temporomandibular joint region. As structural balance is restored during the weeks after appliance placement, the need for altered muscle activity is lessened and there is a gradual return to the pattern of muscle activity that existed before the onset of treatment. It must be remembered, however, that in the experimental animals the pattern of muscle activity before appliance placement was essentially normal. In a clinical situation this return to the pretreatment level of muscle activity may not occur and, in fact, may be an unwanted sequela of treatment. In any event, this model of functional protrusion in the rhesus monkey provides a clear illustration of the relationship between form and function in the growing individual.

*The relationship of experimental studies to clinical treatment in growing individuals*

The obvious question that is often raised is, "What is the relationship between the experiments in rats and monkeys and clinical treatment in man, particularly regarding the use of functional appliances in a growing patient?" One point that must be emphasized is that not all functional appliances are the same. First, I will consider the relationship of our experiments to activator treatment. Andresen and Häupl (1936), Grude (1938, 1951) and Eschler (1954) postulate that the activator increases the frequency of muscle activity by reflex contractions due to proprioceptive stretch reflexes. Schwartz (1952) and Ahlgren (1960) suggest that the orthopedic force produced by the activator is due, at least in part, to isometric contractions against the bulk of the appliance. Harvold (1946), Ballard (1955) and Herren (1953, 1956, 1965) state that the increased muscle activity produced when an activator-type appliance is worn results from increased tonus in the stretches postural muscles so that the frequency of draw movement is less significant. Ahlgren (1970) postulates that activators give rise to both continuous and intermittent muscle forces. Therefore, the rise in muscle activity is due to an increased passive and tonic muscle force. The vector of force generated is directed toward the correction of the skeletal imbalance. Tension is generated in the skeletal and selected dental elements due to the tendency of the mandible to return to its original position (Ahlgren, 1960).

When my initial functional protrusion experiments were conducted in the late 60's and early 70's, part of the motivation was the fact that the use of activator and its many variations was controversial at the time. After the initial phase of these studies was completed (circa 1972), it became apparent that these functional protrusion experiments would not prove or disprove that the use of an activator-type of appliance could increase mandibular growth.

There were many obvious differences between the experiments described above and the clinical use of the activator-type appliance. Activators are usually worn 10–14 hours per day, but the monkeys wore the appliances 24 hours per day since the castings were cemented in place. Secondly, in the functional protrusion experiments the effect of the castings was to splint the teeth together as one unit in each arch, thus minimizing the possibility of tooth movement. In a clinical situation, the individual teeth are often in direct contact with the activator. In addition, since most functional appliances are not usually considered to be very efficient in moving individual teeth, the ideal functional appliance, for the most part, should be tissue borne so that a minimum of tooth movement and a maximum of muscular and skeletal adaptation can occur during appliance treatment.

Our functional protrusion experimental studies seem most directly applicable clinically to the use of the functional regulator of Fränkel (1967, 1969, 1971, 1974, 1977, 1980; McNamara and Huges, 1981). The Fränkel appliance (Fig. 7) is worn on a full-time basis and produces a forward positioning of the mandible similar to that produced by the occlusal splints of the primate experiments; it is used during the mixed and early permanent dentition stages to effect changes in anteroposterior, transverse and vertical jaw relationships; and it is primarily tissue borne rather than tooth borne.

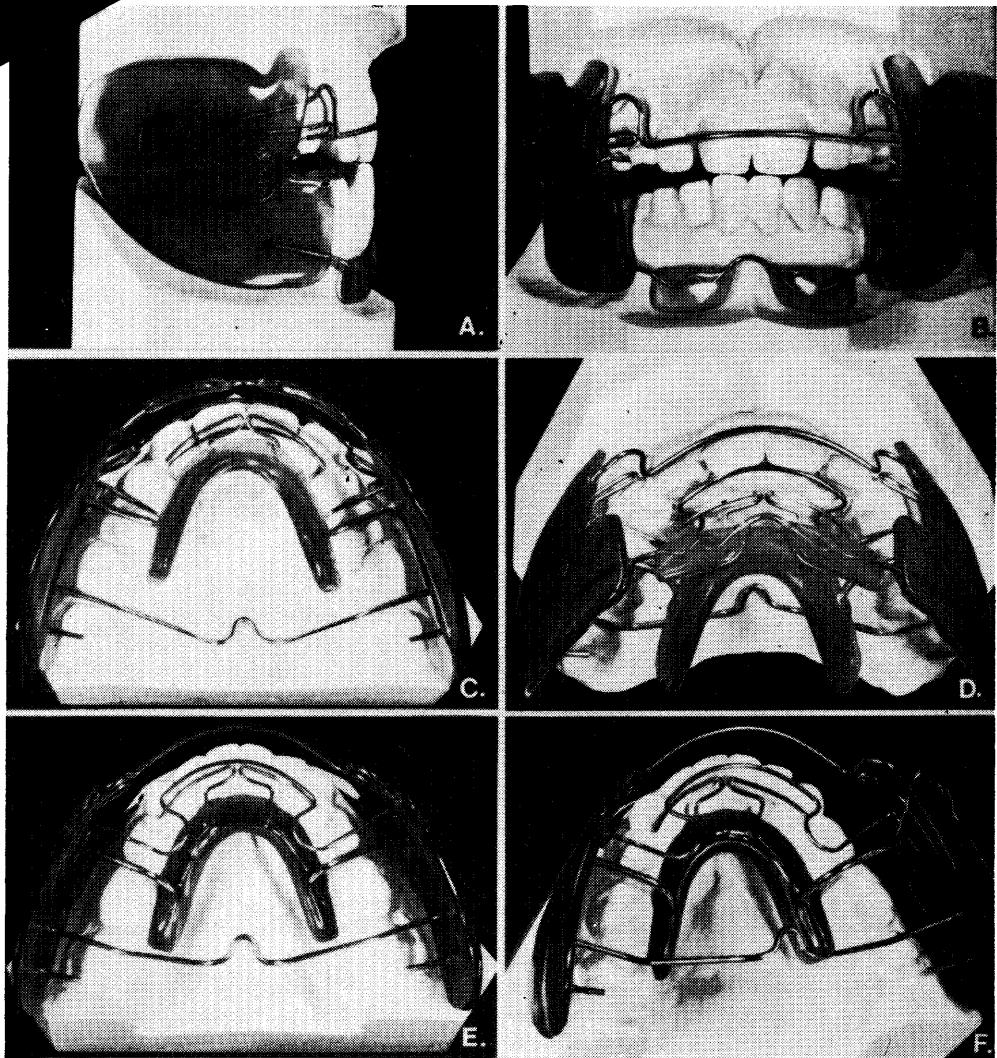


Fig. 7. Functional regulator (FR-2) of Fränkel. A. Lateral view. B. Frontal view. C. Maxillary occlusal view. D. Maxillary oblique view (from McNamara and Hüge, 1981).

The Fränkel appliance has two main treatment effects. First, it serves as a template against which the craniofacial muscles function. The framework of the appliance provides an artificial balancing of the environment that promotes a more normal pattern of muscle activity. The second effect of the Fränkel appliance is its influence on dental and skeletal development. The Fränkel appliance removes muscle forces in the labial and buccal areas that restrict skeletal growth, thereby providing an environment which maximizes skeletal growth and minimizes tooth movement.

#### *Effect of Fränkel Treatment on Craniofacial Growth*

In order to evaluate whether or not Fränkel treatment has any effect on maxillary and mandibular growth, a study of patients treated with the Fränkel appliance has been initiated. This ongoing study currently includes 57 patients from five different orthodontic practices. The treatment results are compared to the growth records of untreated individ-

uals who were selected from the files of the University of Michigan Elementary and Secondary School Growth Study (Riolo et al., 1974; Moyers et al., 1976).

For the purpose of this paper, measures sensitive to anteroposterior and vertical skeletal relationships will be used. These measures are derived from a method of cephalometric analysis (McNamara, 1982a), which is routinely used by us in the analysis of treated cases. An ideal subject (Fig. 8) is used to illustrate this method of analysis. The ideal subject has a Class I molar relationship and a balanced facial profile. The effective length (not the actual anatomic length) of the maxilla can be determined at any given age by measuring the distance from point A to condyion (the most posterior superior point on the mandibular condyle). Effective mandibular length (in this case, an approximation of the actual anatomical length) can be determined by measuring the distance from condyion to gnathion (the most anteroinferior point on the mandibular symphysis). If the effective maxillary length is subtracted from the effective mandibular length, the maxillomandibular

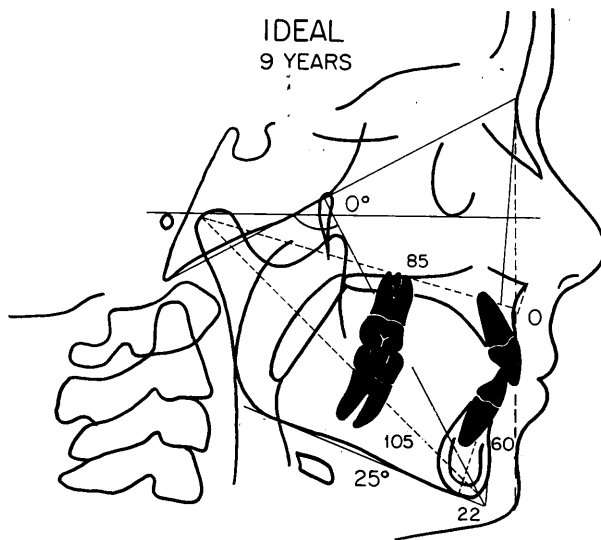


Fig. 8  
Idealized tracing of a growing  
patient.  
Fig. 8a  
Nine years of age.

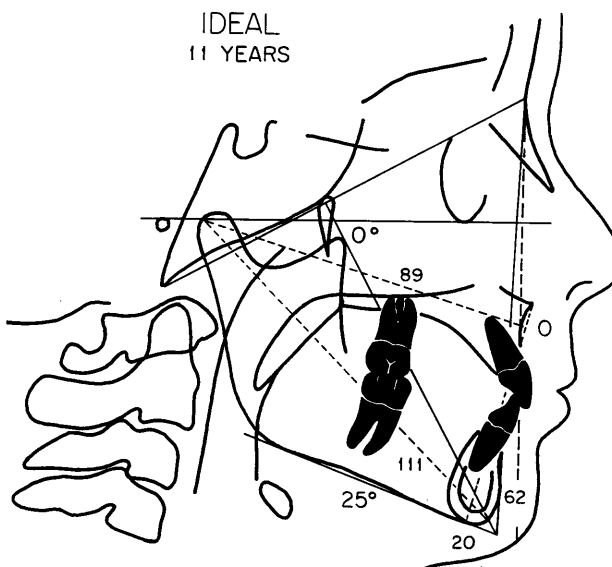


Fig. 8b  
Eleven years of age.

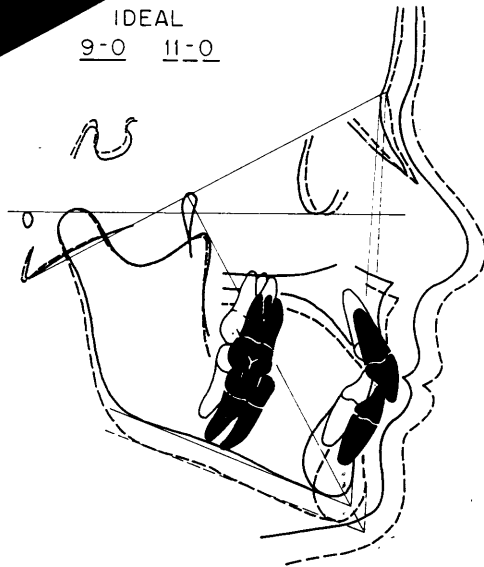


Fig. 8c  
Superimposition of tracings along the basion-nasion plane at the pterygomaxillary fissure.

differential is obtained. In the example shown in Figure 8a, the effective maxillary length (adapted from Harvold, 1974) is 85 mm, the effective mandibular length is 105 mm and the maxillomandibular differential is 20 mm at nine years of age. Our studies have shown that there is a constant ratio between effective maxillary length, effective mandibular length, and lower anterior facial height, regardless of the craniofacial dimensions of the patient (Fig. 9; McNamara, 1982a; Behrents and McNamara, unpublished data).

If this ideal patient is radiographed two years later (Fig. 8b), a comparison of the growth increments can easily be derived. During a two-year growth period from the age of 9 to 11 years, the effective maxillary length increases by 2 mm per year from 85 mm to 89 mm and effective mandibular length increases 6 mm from 105 mm to 111 mm. The maxillo-mandibular differential in this example increases by 1 mm per year.

In fact, the growth increments described for the ideal patient (Fig. 8) are slightly higher than the values derived from the 32 children (16 male and 16 female) which comprise the Bolton Standards (Broadbent et al., 1975; Behrents and McNamara, unpublished data) who have been classified as patients with balanced faces. There was some variation in the rate of increase in the length of the maxilla and mandible which is related to the age of the patient. Sexual dimorphism was also clearly present. Minimal amounts of growth occurred in females past the age of 14 and larger increments of growth were observed in males

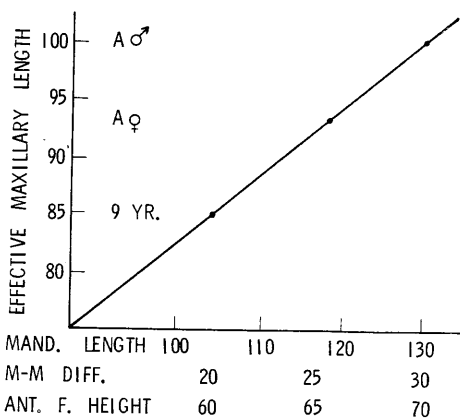


Fig. 9  
Graphic representation of the relationship of effective maxillary length to effective mandibular length and lower anterior facial height (from McNamara, 1982a).

Fig 10. Typical response of a growing patient to FR-2 therapy.

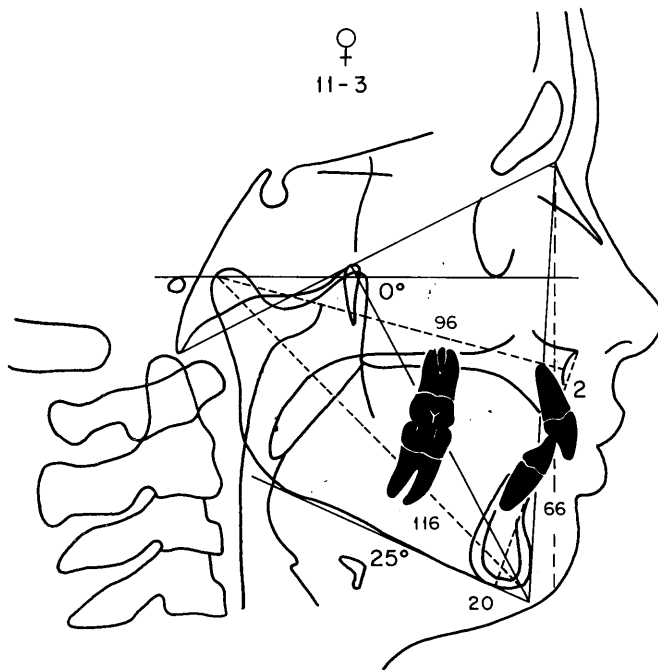


Fig. 10a. Initial tracing of headfilm taken at 11 years and 3 months of age.

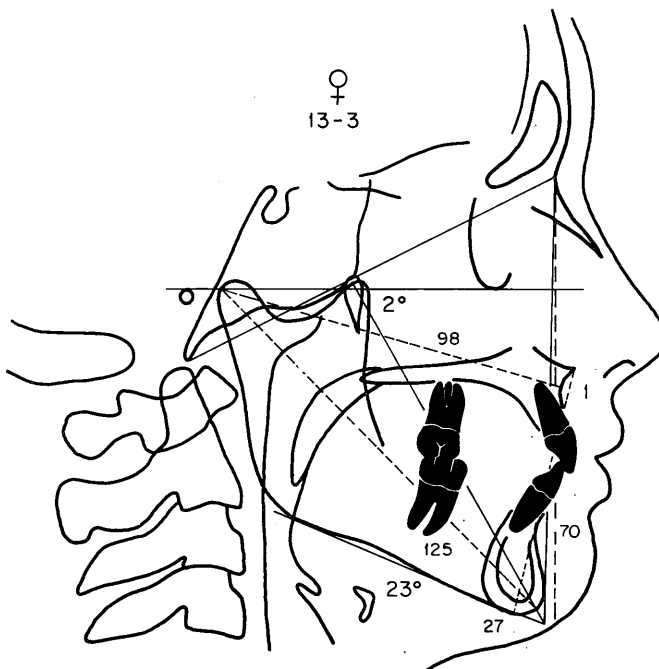


Fig. 10b. Tracing of headfilm taken at the end of the functional appliance phase (13 years, 3 months).

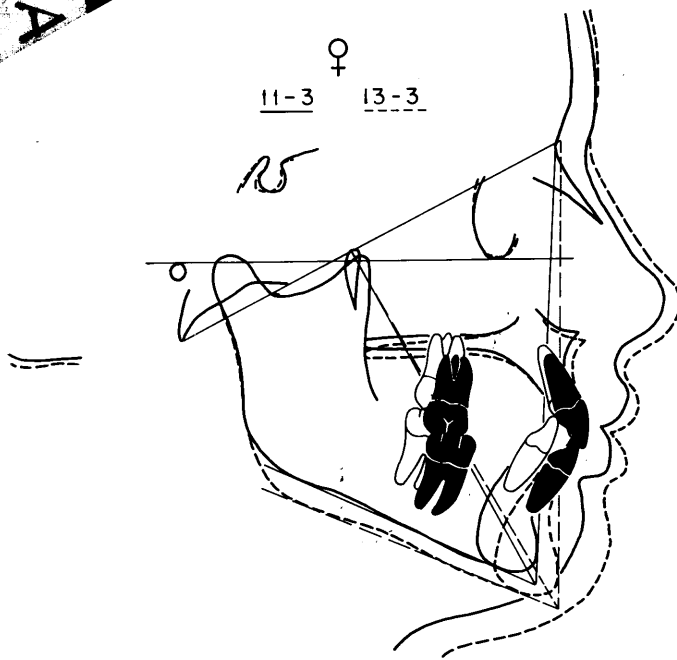


Fig. 10c. Superimposition of the first two tracings along the basion nasion plane at the pterygo-maxillary fissure.

until age 18. The amount of maxillary growth per year in females was highest in the period from 6 to 12 years of age (approximately 1.6 mm per year), at which point it decreased substantially (0.3 mm per year from 14 to 16 years of age). The increase in maxillary length for males ranged from 1.5–2.0 mm per year. Similar differences in mandibular length increases also were observed. The average amount of mandibular growth per year in females ranged from 2.1 mm to 3.1 mm from age 6 to 14 years, with a dramatic drop-off at that time; in males it ranged from 2.2 mm per year between 9 and 12 years of age to 3.1 mm per year between 14 and 16 years of age.

Figure 10 demonstrates typical treatment results in a Class II patient treated with the FR-2 of Fränkel. The patient presented with a normal maxillary position relative to cranial base structures and an effective maxillary length of 96 mm (Fig. 10a). The corresponding effective mandibular length for a patient with an effective maxillary length of 96 mm should be approximately 125 mm (Fig. 9), which means that the patient has a skeletal mandibular deficiency of approximately 9 mm. Lower anterior facial height is 66 mm which is within normal limits (Fig. 9).

Two years of full-time wear with the Fränkel appliance (FR-2) resulted in a 2 mm increase in effective maxillary length and a 9 mm increase in effective mandibular length (Fig. 10a and 10b). Lower anterior facial height increased by 4 mm. A composite of the two tracings (Fig. 10c) demonstrates the overall soft and hard tissue changes observed during treatment.

The effects of Fränkel therapy on anteroposterior and vertical dimensions of the cranio-facial complex were studied in 57 treated patients and were compared to 37 untreated Class II individuals. Because there was annual cephalometric data available on a number of the 37 patients for the period of 8 to 13 years of age, 17 of these patients were used as controls for each of two different aspects of the study — that in which the effects of treatment began before the age of 10.5 years were studied and that in which the effects of treatment began after 10.5 years were studied. Thus, 17 individuals were studied during

Table Pretreatment Comparisons

	Control (N = 54)		Fränkel (N = 57)		SIG.
	$\bar{X}$	S. D.	$\bar{X}$	S. D.	
Mandibular Length	108.0	4.7	107.3	5.1	NS
Maxillary Length	88.0	3.9	88.9	4.4	NS
M-M Differential	20.0	2.8	18.4	3.1	**
Lower Facial Height	64.3	4.5	62.7	4.5	*
Mandibular Plane Angle	26.2°	4.1°	26.2°	5.0°	NS
Growth Axis	-2.7°	3.0°	-2.2°	4.0°	NS
Maxillary Skeletal (A to N. Perp.)	-0.8	3.0	-0.9	2.2	NS
Maxillary Dental (I to Point A)	3.9	4.1	4.2	3.1	NS
Mandibular Dental (I to A-Po)	-2.2	2.0	-0.4	2.0	****
Mandibular Skeletal (Pogonion to N. Perp.)	-10.6	4.9	-10.6	4.6	NS

NS = not significant

$\bar{X}$  = <.05

\*\* = <.01

\*\*\*\* = <.0001

two intervals and 20 individuals were studied during one or the other interval, producing a total number of 54 observations for the control group (Table 1).

In order to determine whether there were any significant differences between the control and treated samples at the beginning of the study, the cumulative pretreatment values of the two groups were compared (Table). No significant differences were found between the two samples except in three measurements. The difference in the maxillo-mandibular differential indicated that the Fränkel cases had a slightly greater discrepancy (1.6 mm) between the lengths of the upper and lower jaws, and anterior facial height tended to be slightly shorter (1.6 mm) in the Fränkel group than in the control group. No significant differences could be seen between the two groups in the anteroposterior position of the maxilla or mandible relative to the cranial base or in the anteroposterior position of the maxillary dentition. However, the control group exhibited moderate dentoalveolar retrusion in the mandible when compared to the pretreatment values for the treated sample.

As mentioned earlier, Figure 10 represents a typical response of the growing Class II patients treated with the Fränkel appliance. Although there was significant individual variation, generally there was increased mandibular growth in the treated group when compared to the controls.

Effective mandibular length increased 2.3 mm per year in the control group and 3.5 mm per year in the treated group, a difference which was highly significant (Fig. 11). This presumably indicates that the Fränkel appliance did, in fact, increase the rate of mandibular growth. In contrast, the average yearly increase in effective maxillary length was greater in the control group than in the treated group by a slight, but statistically significant amount (Fig. 12). The increase in mandibular growth and the slight decrease in maxillary growth in the treated group led to an average yearly change in the maxillomandibular differential of 2.5 mm, again a value which was highly significant when compared to the average yearly change in differential of the control sample.

*Treatment Effects According to Age.* In order to determine whether there were any effects of treatment that were related to age, the control and treated samples were divided into two groups, those individuals who began treatment at 10.5 years of age or less and those individuals who began treatment after the age of 10.5 years. There was no difference in the mandibular growth increments between the two control subgroups. However, in the



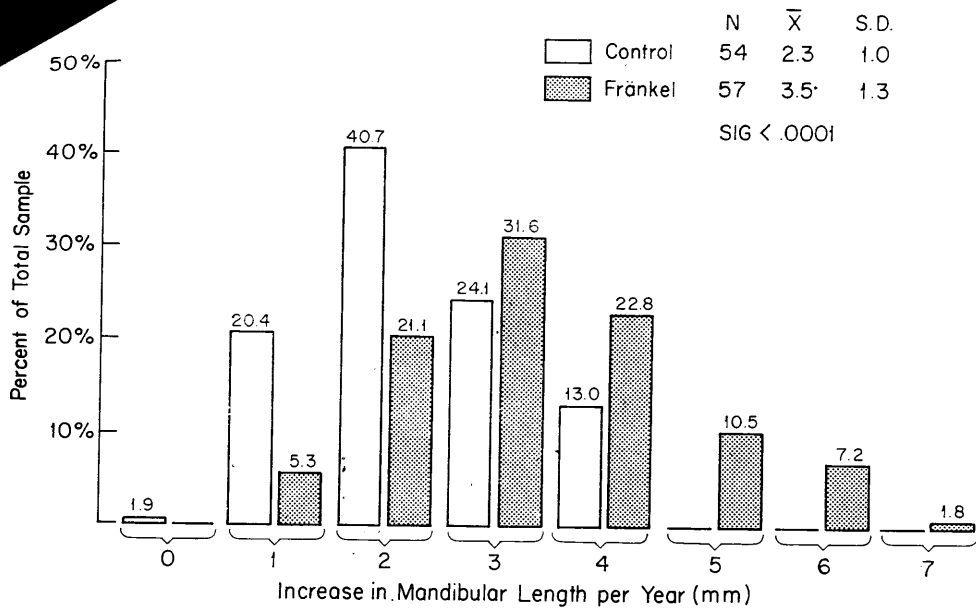


Fig. 11. Comparison of increases in mandibular length per year between the control subjects and the patients treated with the Fränkel appliance.

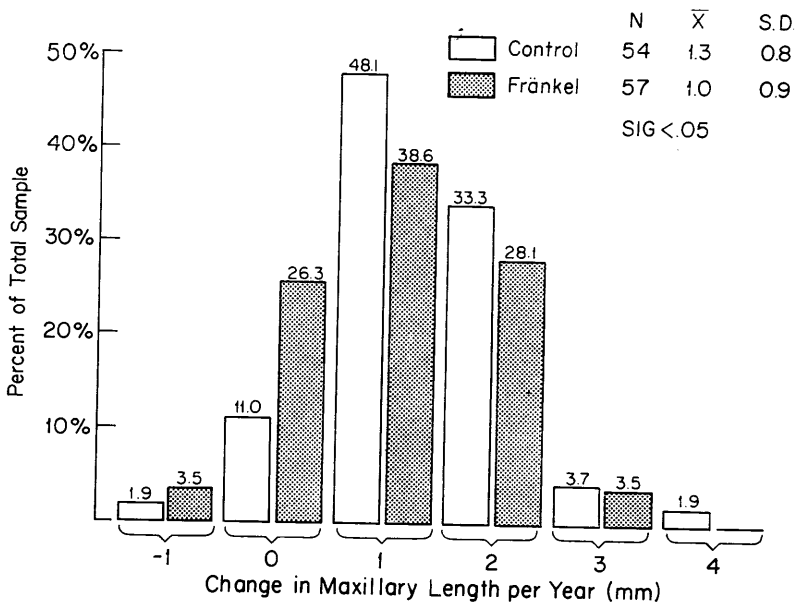


Fig. 12. Comparison of changes in maxillary length per year between the control subjects and patients treated with the Fränkel appliance.

Fränkel sample, effective mandibular length increased by an average of 3.0 mm per year in the younger age group (Fig. 13) and 4.1 mm per year in the older age group (Fig. 14). In both instances these values were highly significant when compared to controls. One interesting finding, which will have to be substantiated as the number of cases study is increased in this is the effect of the Fränkel treatment on maxillary length increases.

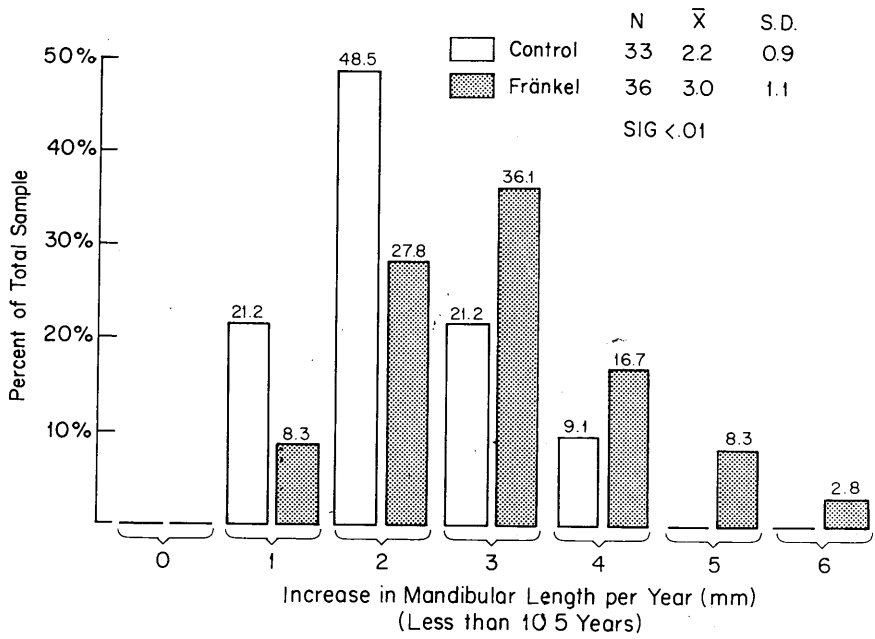


Fig. 13. Comparison of increases in mandibular length per year between the treated and untreated subjects whose first observation occurred at or before 10.5 years of age.

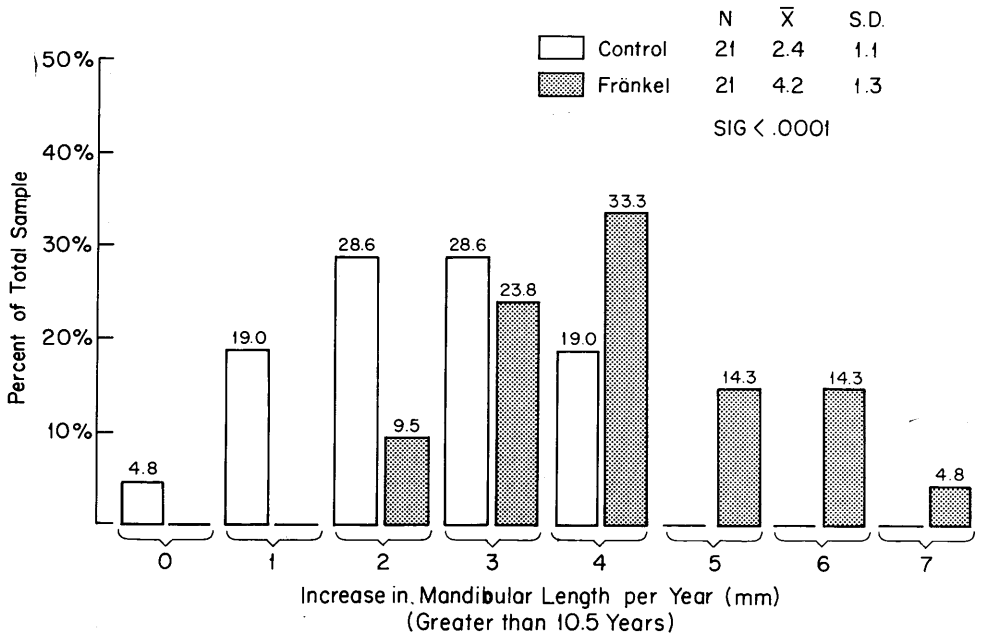


Fig. 14. Comparison of increases in mandibular length per year between the treated and untreated subjects whose first observation occurred after 10.5 years of age.

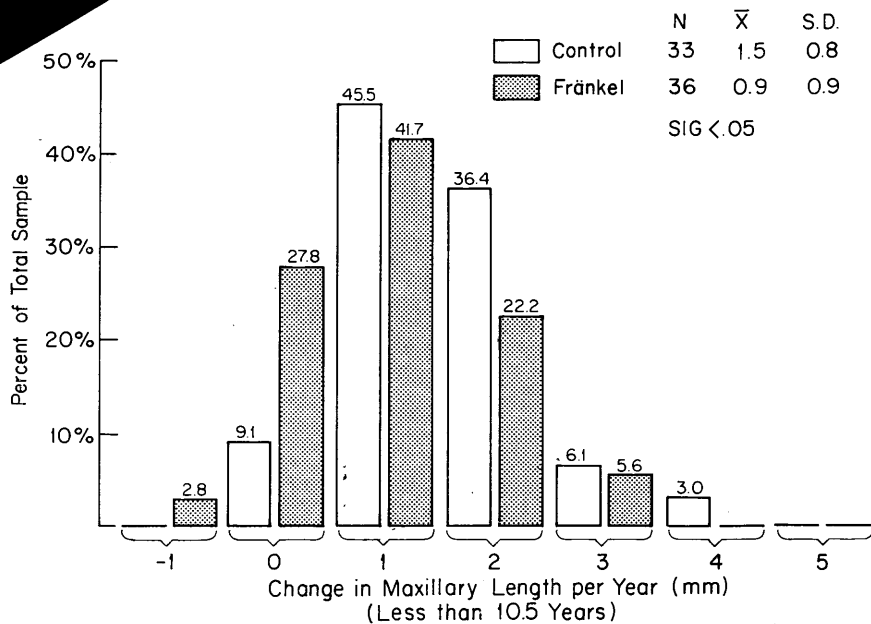


Fig. 15. A comparison of the changes in maxillary length per year in the treated and untreated subjects whose first observation occurred at or before 10.5 years of age.

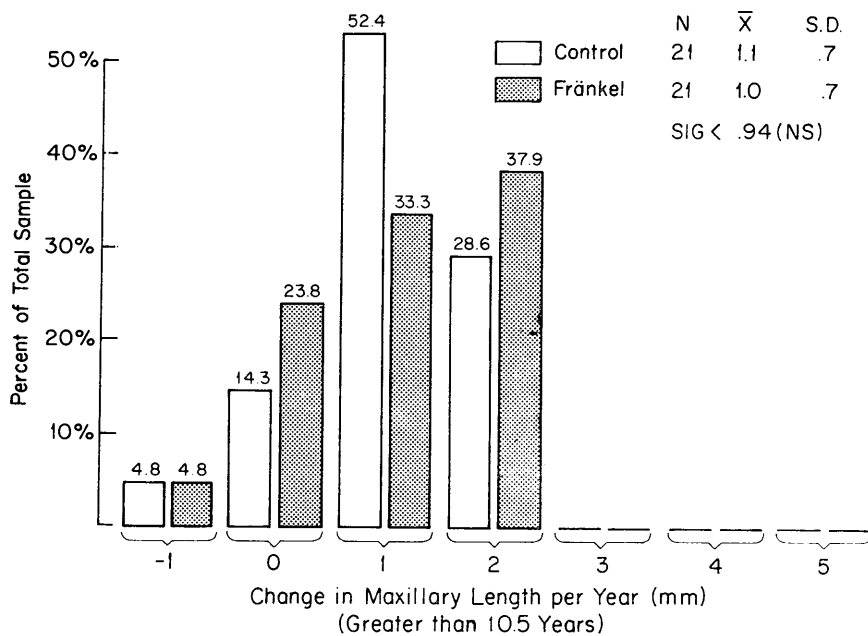


Fig. 16. Comparison of changes in maxillary length per year in treated and untreated subjects whose first observation occurred after 10.5 years of age.

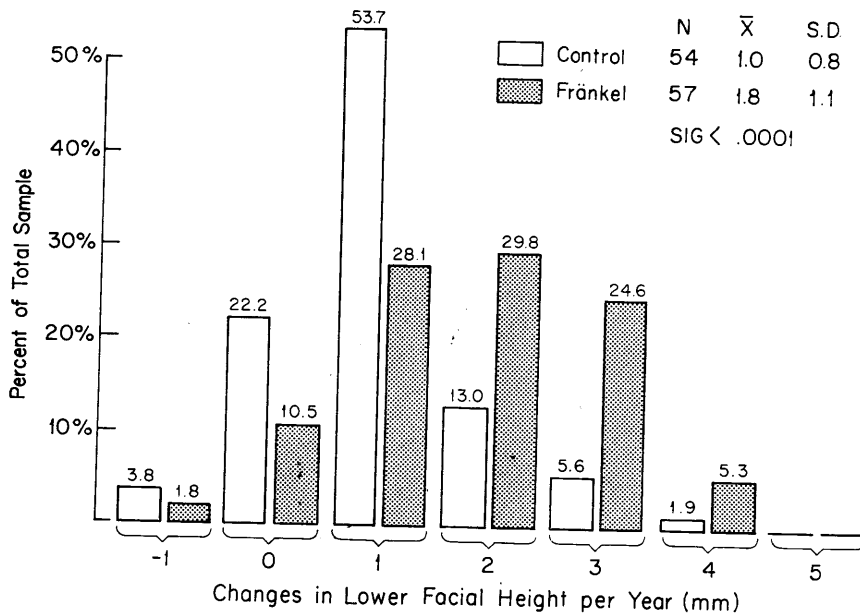


Fig. 17. Comparison of changes in lower anterior facial height, measured from anterior nasal spline to menton, between the control subjects and the patients treated with the Fränkel appliance.

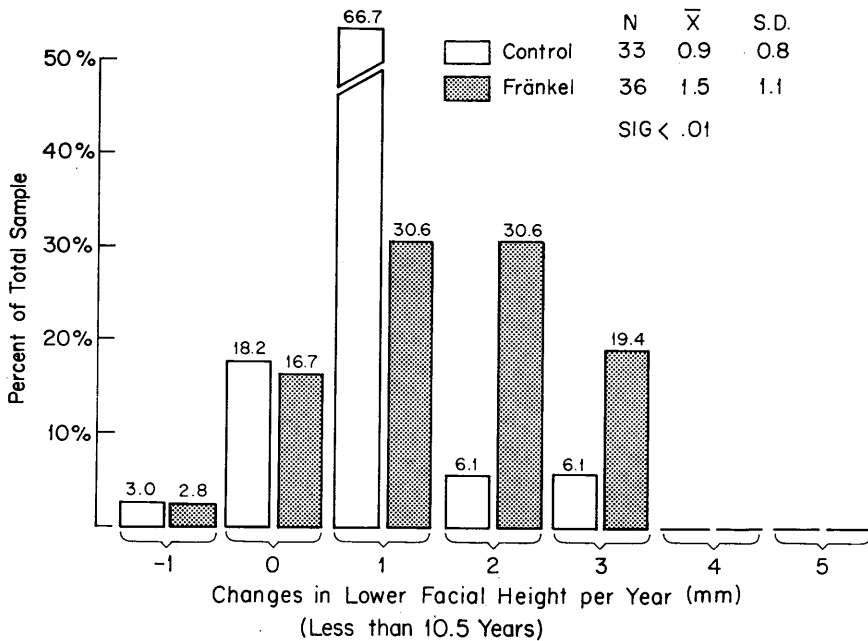


Fig. 18. A comparison of changes in anterior facial height in treated and untreated individuals whose first observation occurred at or before 10.5 years of age.

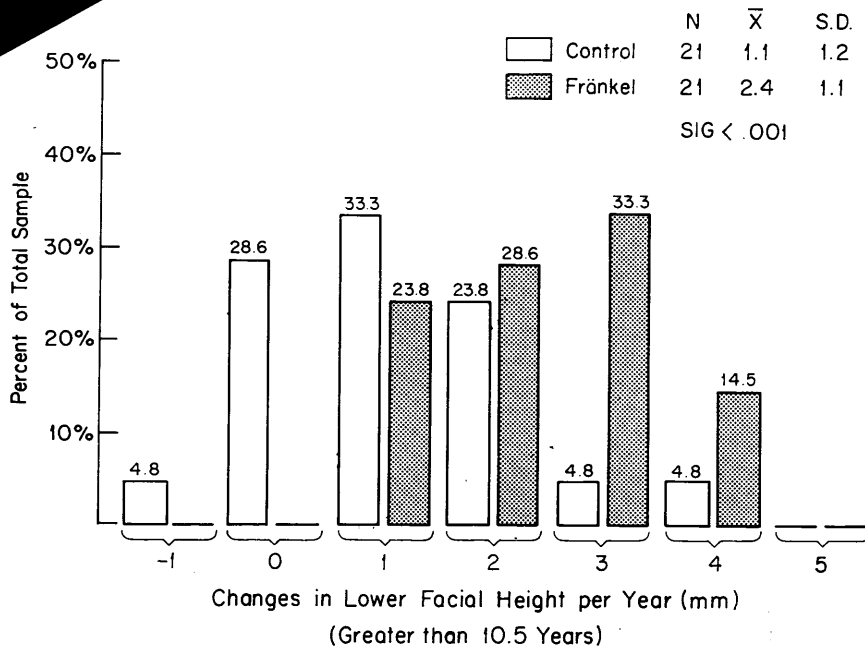


Fig. 19. A comparison of increases in lower anterior facial height in treated and untreated subjects whose first observation occurred after 10.5 years of age.

In the younger group, effective maxillary length increased 1.5 mm per year in the control and only 0.9 mm per year in the treated group (Fig. 15), indicating that the appliance therapy had some restricting effect on maxillary growth. In contrast, there was no significant difference in effective maxillary length increments when the older control and treated groups were compared (Fig. 16). In both the younger and older age groups, the differences in maxillomandibular differential were highly significant.

*Vertical Changes.* Dimensional changes in the vertical aspect of the lower portion of the face also were monitored. The first measurement, from anterior nasal spine to menton, was a direct assessment of lower facial height. This measurement is a variation of the approach presented by Harvold (1974) and Linder-Aronson and Woodside (1979). For example, in a nine-year-old child with a well-balanced face (Fig. 8), this value is approximately 60 mm and should be expected to increase approximately 1 mm per year until adult facial height is reached (Behrents and McNamara, unpublished data).

The mandibular plane angle or the angle formed between the anatomic Frankfurt plane and a line constructed along the lower border of the mandible through gonion and menton was the second measurement taken (Fig. 8a). The last measurement was of the growth (facial) axis angle (Fig. 8a). This measurement, invented by Ricketts (1960, 1981), is determined by constructing a line from basion to nasion and by intersecting that line with a line drawn through the posterosuperior aspect of the pterygomaxillary fissure and gnathion. According to Ricketts, if the face is balanced, the two lines will be perpendicular ( $0^\circ$  deviation). Deficient vertical development is indicated by positive values and excessive vertical development by negative values. Ricketts maintains that this value usually does not change with age. The average increase in lower facial height in the control group was 1.0 mm per year, the expected annual increase in lower facial height according to the Bolton Standards (Fig. 17). Lower facial height in the treated group increased by an average of 1.8 mm per year. The differences between two values was statistically significant. This increase in lower facial height did not seem to indicate what might be expected, i. e., a posterior rotation of the mandible during treatment. In fact, there were no significant

differences between the treated and control groups, with the mandibular plane actually decreasing in value.

Lower facial height increased less in the younger treated children (1.5 mm per year; Fig. 18) than in the older treated children (2.4 mm per year; Fig. 19). This finding is similar to the anteroposterior dimensional changes described earlier.

*Overview.* It appears that the average yearly growth increments in the untreated Class II sample are similar to that expected for individuals with so-called "balanced faces", such as the Bolton Standards. It also is apparent that the anteroposterior and vertical facial development is affected by Fränkel appliance therapy. Significant increases in effective mandibular length increments were observed for the whole treated group, as well as for each of the two different age groups. The effect of Fränkel therapy on the maxilla is less clear. While there was a slight decrease in effective maxillary length increments for the whole sample, only in the younger treated subgroup was there a decrease in effective maxillary length. Increases in lower facial height were a common finding in the treated group. However, it should be remembered that the initial values of anterior facial height were shorter in the treated sample than in the control sample (Table).

It is interesting to note that the greatest effect of the Fränkel appliance was seen in the older group of growing children. Perhaps this is not surprising in light of the experiments of Petrovic and associates (Petrovic et al., 1973, 1975; Stutzmann et al., 1975) on the interaction of orthopedic therapy and growth hormone. These investigators report that in young rats both orthopedic therapy with the postural hyperpropulsor device and the administration of somatotrophic hormone individually result in a significant increase in the rate of growth of the condylar cartilage. However, some of the effects produced when the postural hyperpropulsion and growth hormone were applied together were greater than the sum calculated when either was applied separately. Petrovic and co-workers (1975) state that there is a positive interaction between these two treatments, the effect of one having been amplified by the other, and they hypothesize that an orthopedic treatment intended to stimulate condylar cartilage growth should be more effective during periods characterized by high levels of somatotrophic hormone, such as the circumpubertal growth period. It appears that the preliminary results of this study of Fränkel patients seem to support this hypothesis; that is that the mandibular growth increments may be greater during the circumpubertal growth period than at an earlier age. This does not imply that functional orthopedic treatment, particularly with the functional regulator of Fränkel, should be delayed until just before the onset of puberty, because condylar growth is only one aspect of this type of treatment. Other skeletal, as well as muscular and dental factors, must be taken into consideration in selecting the time of treatment initiation.

#### *Adaptations in the adult temporomandibular joint*

As the interest and enthusiasm surrounding functional appliances has increased during the last few years, a number of clinicians have advocated the use of functional jaw orthopedic appliances in adult patients. The use of functional therapy in adults seems to go against the traditional theory of the immutability of the temporomandibular joint. Ramfjord and Ash (1971) have advocated adapting the occlusion to the temporomandibular joint rather than the joint to the occlusion in adults. Previous experimental studies of temporomandibular joint adaptation (Hiniker and Ramfjord, 1966; Ramfjord et al., 1971; McNamara, 1972; Ramfjord and Blankenship, 1981) have demonstrated little evidence of temporomandibular joint adaptation.

Our laboratory has recently completed a study of temporomandibular joint adaptations in 19 young adult female rhesus monkeys (*Macaca mulatta*; McNamara et al., 1982). There were 12 animals in the experimental group and 7 in the control group. The animals involved in the study had been at The University of Michigan for at least 3 years as breeder animals in the reproductive endocrinology program. All were physiologically nature, with third molars in occlusion.

of the nature of the dentition, it was only necessary to construct a mandibular appliance that produced an anterior displacement of 5 mm and an inferior displacement of 2-3 mm when the animal was in occlusion. The experimental animals were studied for 2, 4, 6, 8, 12 and 24 week periods.

#### *Control Sample*

In all instances, there were clear morphological differences between the temporomandibular joints of the 7 adult control animals used in this study and the 14 control juvenile animals reported in our previous experiments (McNamara, 1972; McNamara et al., 1975; McNamara and Carlson, 1979). There was a marked reduction in the number of chondrocytes in the condylar cartilage of the adult animals (Fig. 20 A, B) compared to the juvenile animals (Fig. 5 A, B), and the presence of hypertrophic chondrocytes was rare in the adult animals. A second major feature common to all of the adult control animals was the closing off of the cartilage layer from the underlying medullary spaces by a coalescence of bony tra-

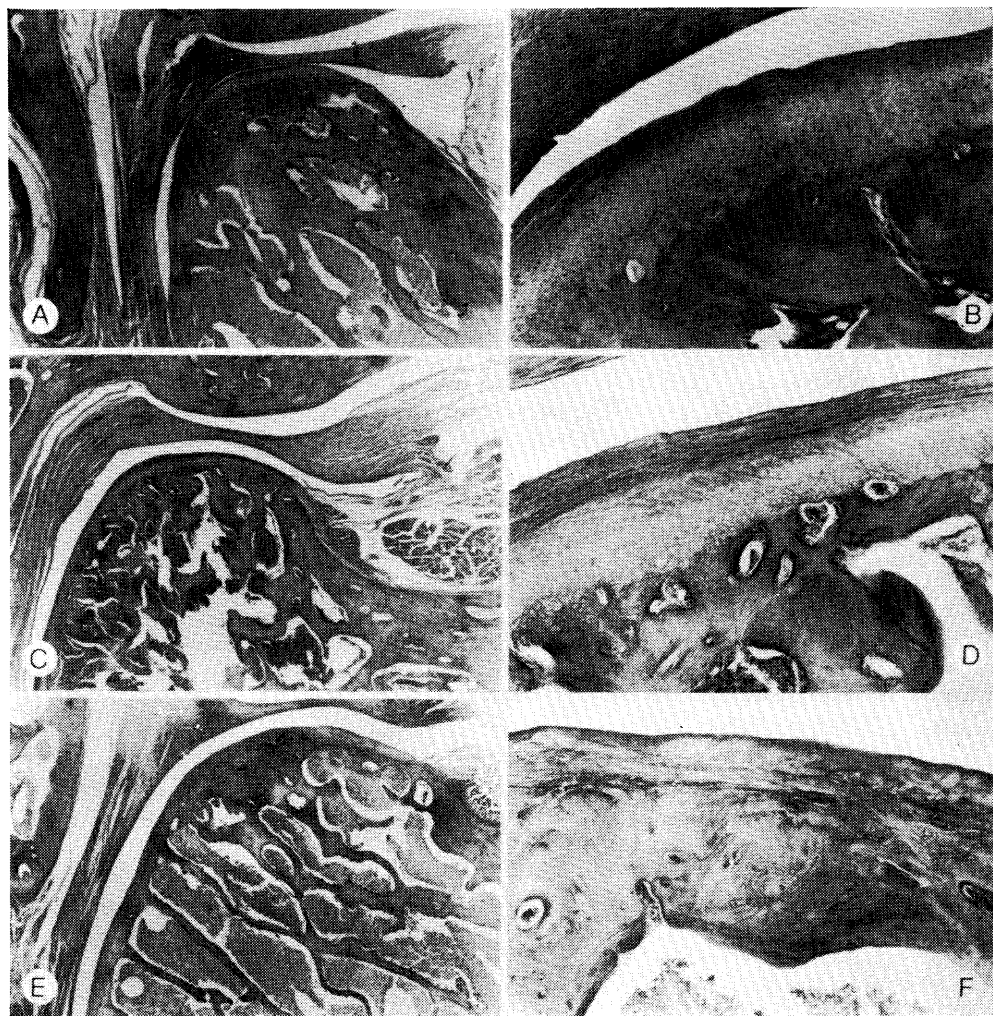


Fig. 20. Variation in condylar morphology in the adult control animals. A and B. Maximum cartilage proliferation. C and D. Moderate cartilage proliferation. E and F. Minimal cartilage proliferation (from McNamara et al., 1982).

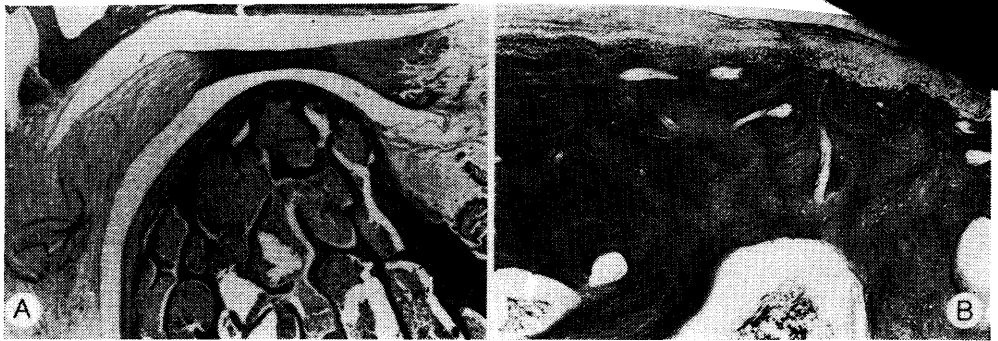


Fig. 21. A. Temporomandibular joint region in a 12-week adult experimental animal. Note lack of condylar cartilage hypotrophy. B. The appearance of the condylar cartilage in the same animal. Note the thickness of the bony cap and the limited number of cells present (from McNamara et al., 1982).

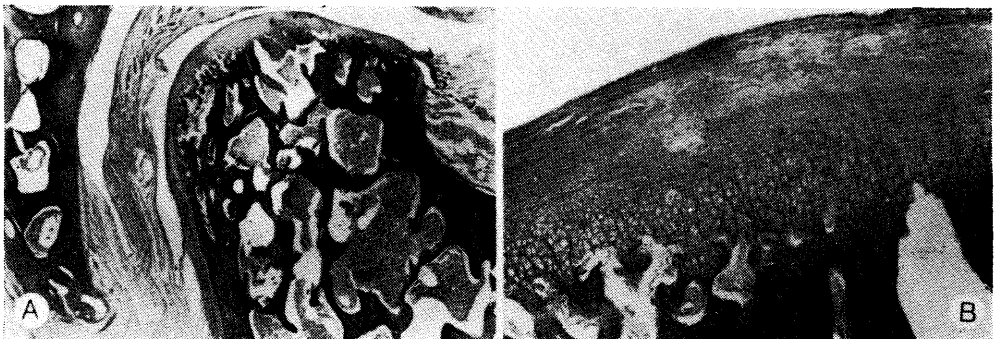


Fig. 22. A. Temporomandibular joint region of a two-week adult experimental animal. B. Appearance of condylar cartilage along the superior surface of the condyle (from McNamara et al., 1982).

beculae and, in a number of cases, by a layer of compact bone. (Fig. 20A, B). One of the most common characteristics of the adult condyle was the formation of this so-called "bony cap" which provides a clear separation of the cartilage from the underlying medullary spaces. A bony cap was not present in the condyles of the juvenile controls. Even though there were many similarities among the adult condyles, there were some striking differences (Fig. 20). The relative amount of condylar cartilage was greater in some animals (Fig. 20A, B) than in others (Fig. 20E, F). If the potential for adaptation in this region is related to the relative amount of cartilage present, then there were obvious differences among the temporomandibular joints of the adult control animals.

#### *Experimental Sample*

Response in the temporomandibular joint region of the experimental animals was varied due, in part, to the development of cross bites in three animals. Of the remaining nine animals, three exhibited almost no perceivable response to the appliance, except for some indications of slight chondrocytic proliferation (Fig. 21). The temporomandibular joint morphology resembled that of the controls in the three nonresponsive animals. Considerable hyperplasia of the cartilage layer occurred in the other six experimental animals (Figs. 22 and 23), particularly in the superior and posterosuperior regions. There were sites of active growth in the adult experimental animals which were similar in nature (but not in extent) to those in the juvenile experimental animals. A trilaminar configuration was noted in some of the adult experimental animals, including a prechondroblastic zone, a chondroblastic zone and a layer of hypertrophying chondrocytes.



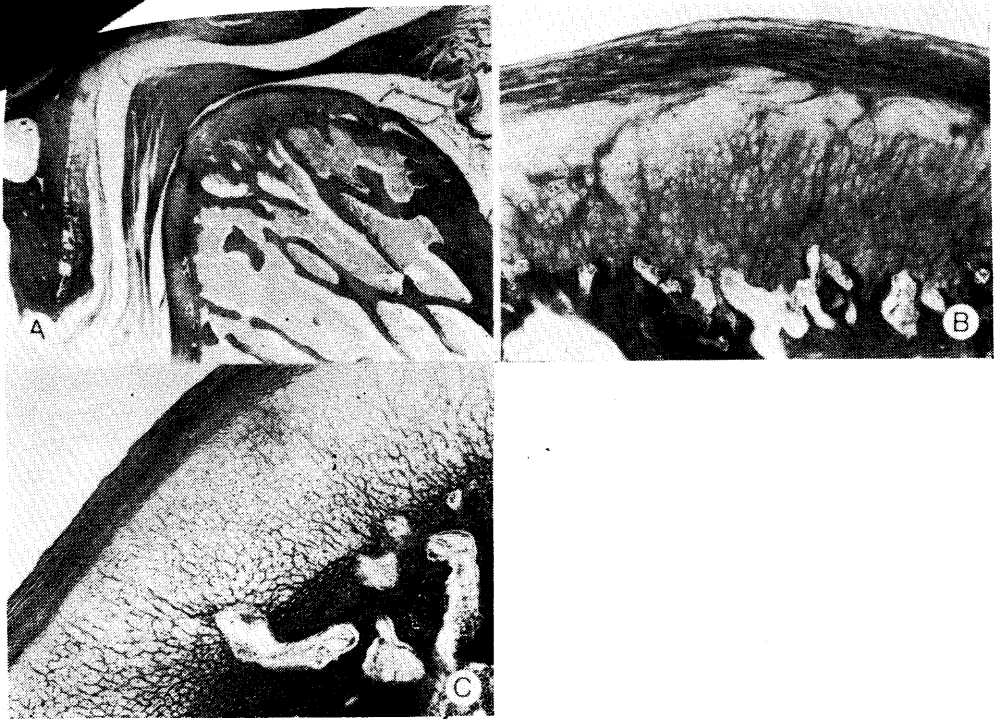


Fig. 23. A. The temporomandibular joint region of an 8-week adult experimental animal. Note the increased thickness of the condylar cartilage along the superior and posterior aspects of the condyle. Note also the bony deposition along the anterior border of the post-glenoid spine. B. Proliferation of the cartilage along the superior border of the condyle. C. Proliferation of cartilage along the posterior border of the condyle (from McNamara et al., 1982).

The bony cap which was typical of adult control animals became invaginated in many of the adult experimental animals by chondrocytic proliferation. This was accompanied by the incorporation of calcified cartilage into newly formed bony spicules.

In contrast to the juvenile experimental animals (Fig. 5A, B), the area of adaptation in the adult experimental animals was located in the superior or posterior region of the condyle and only occasionally along the posterior aspect (Figs. 22 and 23). Evidence of

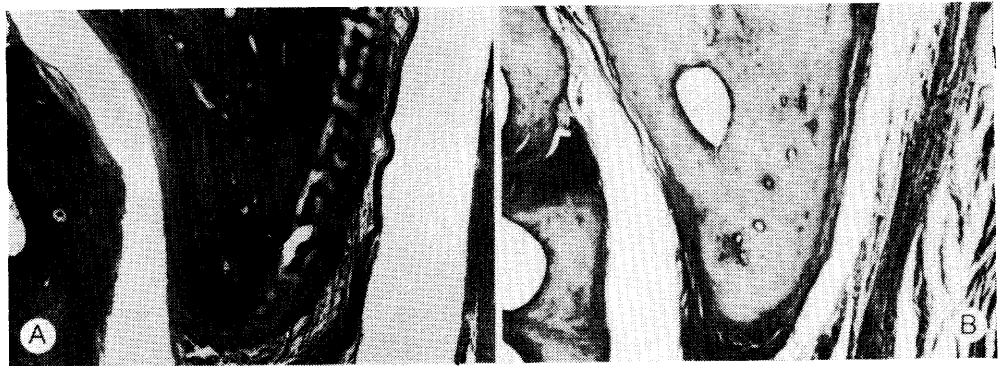


Fig. 24. A. Proliferation of new bone along the anterior surface of the post-glenoid spine in an 8-week adult experimental animal. B. Post-glenoid spine in a control animal (from McNamara et al., 1982).

bone deposition along the anterior surface of the postglenoid spine (a structure observed in monkeys but not in man) and the posterior surface of the mandibular fossa was observed in both 8-week animals, one of the 12-week animals and both 24-week animals (Fig. 24). Thus, remodeling of the temporal component of the temporomandibular joint was also observed.

The results of this study seem to indicate that in many instances the temporomandibular joints of young adult animals are capable of some functional adaptation. This in itself is not surprising, even in light of previous studies which have reported contrary findings. The usefulness of this adaptive capability of the adult temporomandibular joint perhaps is best observed in patients who have undergone various orthognathic surgical procedures of the mandible (e. g. Ware and Taylor, 1968; Hollender and Ridell, 1974). In many of these cases, the mandibular condyle is repositioned or rotated to a moderate extent, yet reports of temporomandibular joint pathology in these cases are rare. Since pathology is lacking and because there has been radiographic evidence of remodeling documented in such cases, the indication seems to be that adaptive responses in the temporomandibular joint are elicited to accommodate the new structural relationships in that region after surgery.

#### *Functional treatment in adults*

What is the relationship of the experiment in adult animals to functional jaw orthopedic therapy in adult patients? One case (McNamara, 1982b) will be presented which illustrates my clinical observations to date.

A 20-year-old male presented in my private practice with excessive overjet and a small mandible. A treatment plan was suggested that incorporated comprehensive edgewise orthodontics combined with a sagittal split osteotomy to advance the mandible and a Le Fort I osteotomy to advance the maxilla. During the consultation the patient expressed an aversion to surgery and asked if a functional jaw orthopedic appliance could be used instead. The patient was told that this would be possible under certain conditions. First, treatment would be discontinued if any temporomandibular joint symptoms occurred, and secondly, the appliance had to be worn at least 20 hours a day.

#### *Initial Cephalometric Analysis*

The analysis of the initial headfilm indicated that the patient had a significant skeleton retrusion. Since the effective length of the maxilla was 100 mm (Fig. 25a), the effective length of the mandible should be 130 mm (Fig. 9). In fact, his effective mandibular length was 120 mm, indicating a 10 mm anteroposterior jaw discrepancy. In addition, the maxilla was also posteriorly placed relative to the cranial base, as indicated by a 3 mm measurement from the nasion perpendicular to Point A (McNamara, 1982a). Anterior facial height was normal, although the mandibular plane angle was 32 degrees, indicating a deficiency in posterior facial height.

#### *Post-treatment Adaptations*

The patient wore an FR-2 for two years on a full-time basis without any apparent temporomandibular joint dysfunction. At the end of two years, another lateral headfilm was taken and the changes that occurred during the two year interval analyzed (Fig. 25b). The mandible increased in length from condyion to gnathion by 3 mm during the two-year period. Effective maxillary length increased by 1 mm, which may indicate that normal craniofacial growth in this patient had not ceased. Even though the patient demonstrated a 3 mm increase in mandibular growth, lower face height also increased from 69 to 72 mm during the two-year period. The net effect of the vertical increase combined with the anteroposterior increase was virtually no change in the anteroposterior position of the chin (Fig. 25C). Dentoalveolar adaptations were also evident.

The case report cited above is representative of the experience I have had to date in using functional appliances on adults. While my sample is admittedly small (six individuals

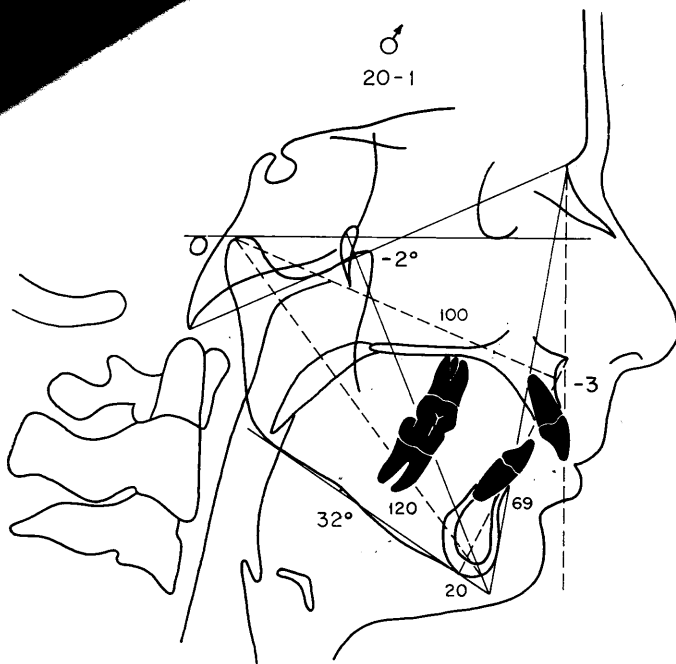


Fig. 25a. Initial cephalometric tracing taken at 20 years and 2 months of age.

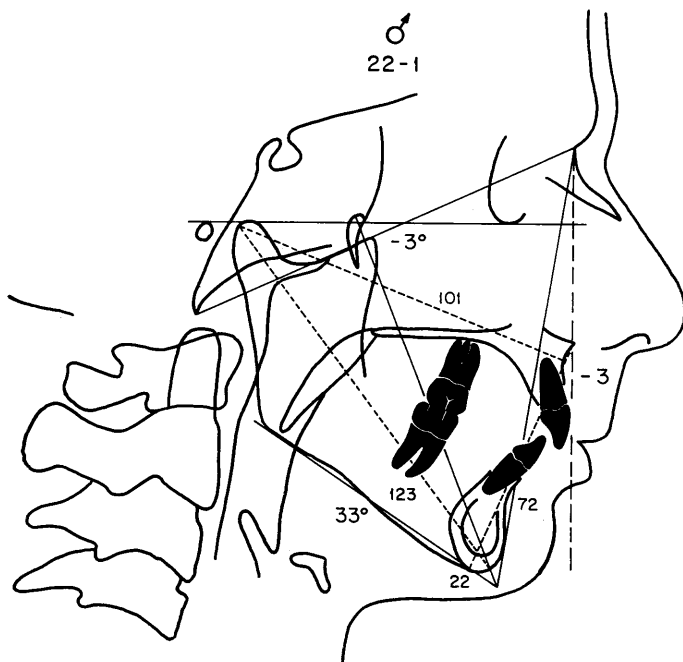


Fig. 25b. Cephalometric tracing taken at 22 years and 2 months of age after functional regulator therapy.

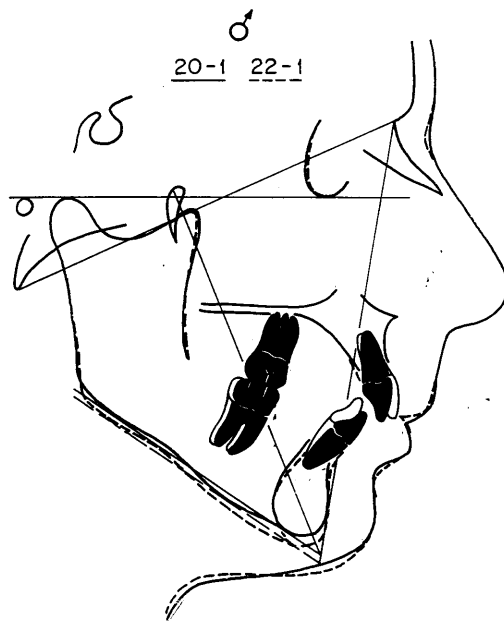


Fig. 25c. Superimposition of the first two tracings along the basion-nasion plane at the pterygo-maxillary fissure (adapted from McNamara, 1982b).

ranging from 19 to 32-years of age), all of the case have yielded similar results. In no instance was a large increase in mandibular length noted. In one patient, temporomandibular joint symptoms appeared which necessitated the discontinuance of the appliance after 6 weeks.

The results of our experimental studies, as well as those of my limited clinical experience, seem to indicate that it might be possible to obtain a few millimeters of increased mandibular growth in some adult patients by using functional therapy functional appliances, but it does not seem possible to use to correct a significant mandibular skeletal deficiency. This still requires orthognathic surgery. There are two reasons for this. First, while in the majority of instances the qualitative response of the condyle in our adult experimental monkeys was similar in many respects to that observed in juvenile experimental monkeys, the magnitude of the response was greatly reduced. The amount of cartilage proliferation in the adult animals was not nearly as great as that observed in the young monkeys. Thus it must be kept in mind that the *biologically* significant changes documented in our experimental studies may or may not be *clinically* significant. Secondly, it must be noted that in our previous experiments using juvenile animals, condylar responses were observed in every animal studied (McNamara and Carlson, 1979). In contrast the morphology of the condyles in three of the nine experimental animals (excluding the three additional crossbite animals) could not be distinguished from that of the controls. These nonresponding animals (Fig. 21) had a reduced cartilage thickness overlying the solid bony cortex which was similar to those control animals which had a limited cartilage thickness (Figs. 20E and 20F). Since the exakt age of the animals used was not known, it is not possible to evaluate whether the lack of response was primarily attributable to a more advanced age or to variation in responsiveness among individual animals. It may be that as individuals age the condyle gradually loses the ability to respond functionally as the cartilage cells are lost. The problem then facing the clinician is how to predict which patients have sufficient capability to adapt to functional orthopedic treatment.

### Summary and Conclusions

It has been the purpose of this paper to review and present pertinent experimental and clinical findings dealing with induced adaptations in the growth of the various components of the craniofacial region of both growing and adult individuals. The experimental and clinical studies cited seem to give ample evidence that the growing craniofacial complex can be altered either by clinical or therapeutic means. However, as an individual gets older, this adaptive response lessens so that adults have significantly less adaptive capability than children. It seems clear that functional jaw orthopedic appliances in general, and the Fränkel appliance in particular, combined with fixed appliance therapy, can achieve results in patients that would not be possible using either method alone.

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### РЕЗЮМЕ

#### Функциональные условия ортодонтического лечения

Различные экспериментальные исследования на взрослых резус-обезьянах показали, что соответствующие аппаратное выдвижение нижней челюсти вперёд ведёт к усилению активности боковой крыловидной мышцы. Следствием этого является усиление роста хряща суставного отростка. Возможность стимуляции длины нижней челюсти у детей при использовании активаторов является спорным. Функциональные аппараты френкеля, ведущие к изменению активности мышц оказались в условиях эксперимента наиболее оптимальными. Влияние этого аппарата на рост нижней и верхней челюстей исследовано с помощью телерентгенограмм у 57 больных II класса по Энглю. 37 пробандов II класса по Энглю служили контрольной группой. Увеличение длины нижней челюсти (точки Condylare-Gnathion) было выражено в исследуемой группе статистически достоверно сильнее. Напротив, увеличение эффективной длины верхней челюсти (точки A-Condylare) контрольной группе незначительно, но достоверно сильнее. С целью определения влияния возраста на эффект лечения проведено разделение контингенте исследуемых по группам по началу лечения до и после 10,5 лет. В контрольной группе различия в увеличении длины нижней челюсти не носили статистически достоверного характера. При применении активаторов степень увеличения длины нижней челюсти была более выражена в старшей группе, чем в младшей. В младшей группе эффективная длина верхней челюсти увеличивалась в контроле интенсивнее, чем в лечённой группе. У старших пациентов, напротив, не установлено различий при сравнении эффективной длины верхней челюсти между лечённой и контрольной группой. Несмотря на то, что увеличение нижней передней высоты лица в лечённой группе было сильнее выражено, чем в контрольной (и здесь данные в старшей группе имели наибольшую величину) наблюдалось у лечённых больных в среднем одинаковое уменьшение угла нижней челюсти. Оптимальная возможность стимуляции длины нижней челюсти в старшей группе не означает тактики ожидания пубертальной фазы роста для применения активаторов. Кондиллярный рост является только одним из аспектов этого лечения. Во второй части работы исследованы строение и адаптационная способность верхнечелюстного сустава у взрослых резус-обезьян. По сравнению с молодыми особями количество хондроцитов в суставном хряще было значительно меньше, а наличие гипертрофических зон редким. Характерной чертой является ограничение хряща от мозговых полостей путём слияния трабекул в сплошную костную капсулу. Относительная толщина хрящевого слоя у единичных животных была различной. У 9 взрослых обезьян проведено аппаратное выдвижение нижней челюсти вперёд, причём у 3 из них отсутствовали морфологические реакции в суставе. У 6 особей обнаружена значительная гиперплазия суставного хряща. Размеры изменений носили не такой выраженный характер, как у молодых животных. В височном отделе сустава также отмечались признаки перестройки.

При функциональном лечении взрослых в возрасте от 19 до 32 лет степень увеличения длины нижней челюсти была невелика. Оставшаяся способность верхнечелюстного сустава к адаптации являлась недостаточной для устранения значительных скелетных дисгармоний.

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