Part I

Abnormal Function of the Temporomandibular Joints and Related Musculature

Orthodontic Implications

John R. Thompson

A clinically-based review of the anatomy and function of the temporomandibular joint, both before conventional orthodontic therapy with its implications in treatment, and in later years when it may require correction by the orthodontist. Detailed procedures for clinical diagnosis and treatment of functional disorders are presented.

KEY WORDS: • FUNCTION • OCCLUSION • PAIN • • TEMPOROMANDIBULAR JOINT •

Normal condyle position in the glenoid fossa is with the anterosuperior surface of the condyle in close apposition to the posteroinferior surface of the articular eminence. The thin center of the articular disk is interposed in this area of closest apposition. The thickened posterior margin of the disk is *directly above* the superior margin of the condyle. This description of the normal condyle position is anatomical fact, not a created definition.

The space superior and posterior to the condyle in the fossa varies in size from one individual to another. It also varies with age. On the other hand, there is normally no variation in the relation of the condyle to the articular eminence, which is the functioning area of the joint. This conclusion is supported by the examination of over 500 skulls in the Department of Anatomy at the University of Illinois, many other skulls of all ages, and on the personal dissection by the Author of 25 temporomandibular joints.

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The temporomandibular joints are different from all other joints in the body. No other joint is subjected to such a precise discipline as that imposed by the intercuspation of teeth. Even the troublesome knees and elbows are free to function with no need to adapt to some remote anatomic relation or contralateral joint.

There are actually two temporomandibular joints that must function as one because they are connected by the solid bone of the mandible. This necessitates the division of each joint into upper and lower articulating mechanisms. These should not be referred to as compartments or cavities, because those words imply the presence of spaces between joint structures which actually lie in close apposition.

The condyle and disk, comprising the lower division of the joint, are normally held in firm contact by the short, tight medial and lateral fibers of the capsule. Only hinge movement, an equal rotation of the joints on both sides, is possible in the lower divisions.

The disk and articular eminence, which are part of the upper division, are held in firm contact by the superior head of the external (lateral) pterygoid muscle. The anatomist PRENTISS (1923) describes the superior head of the lateral pterygoid as the sphenomeniscus muscle, separate and distinct from the lower head. It is also so named in lower animals which do not have an inferior head of the external pterygoid. He states that the sphenomeniscus muscle acts on the capsule and the meniscus in a line of action that is in an almost vertical plane.

While the superior head of the external pterygoid attaches to the anterior margin of the disk, the posterior margin of the disk is attached to the posterior aspect of the condylar process by a thick band of fibrous tissue.

The fibrous capsule above the meniscus is looser than below, permitting translatory movement of disk. This gliding movement can occur bilaterally or on one side only, making oblique mandibular movement possible. In describing the articular capsule, GRAY'S ANATOMY (1977) states, "Above the articular disk the capsule forms a loose envelope, but below the disk it is taut."

The condyles are also different from other joints in their mode of growth. The mandibular condyles grow by appositional cartilage growth, independent of the influence of the dentition. SICHER (1949) says,

> "Since the condylar cartilage of the mandible is covered by a layer of dense connective tissue it cannot be compared with an articular cartilage of the tubular bones or to an epiphyseal plate, even though growth of the mandible does occur in the condyle by proliferation of the cartilage and its gradual replacement by bone just as in the cartilages of tubular bones. The covering of connective tissue enables the cartilage to increase in thickness not only by interstitial but also by appositional growth, whereas the cartilages of long bones, both articular and epiphyseal, thicken by interstitial growth only. The hyaline cartilage in the head of the mandible, therefore, holds a unique position and differs widely from that of other cartilaginous growth centers in its reaction to certain pathologic conditions."

The appositional cartilage growth of the condyle proceeds freely in an upward and backward direction, against soft tissue only. In the long bones, such as tibia and femur, the growth centers for interstitial cartilage growth butt one against the other. Growth cannot produce displacement of those joint structures as it can in the mandible.

In the mandible, the upward and backward growth of the condyles does not

position them farther upward and backward; rather, the entire mandible and its enveloping musculature are positioned downward and forward. The normal relation of close apposition of the anterosuperior surface of the condyle with the posteroinferior surface of the articular eminence is maintained.

Should the intercuspation of the teeth, with a tight incisal relation, become established before the cessation of growth of the condyle, the growth of the condyle will be expressed as a posterosuperior displacement.

This is the explanation for the late development of abnormal function of temporomandibular joints. If this should occur during the course of orthodontic treatment as maxillary incisors are retracted, that treatment procedure should be reversed to create sufficient overjet to free the mandible for normal functional positioning.

Two factors, (1) the constraints of intercuspation of the teeth, and (2) condylar growth independent from the dental occlusion, set the basis for the frequent occurrence of temporomandibular joint dysfunction. The first factor, the constraints of intercuspation of the teeth, is quite obvious. Not so obvious is the growth of the condyle independent from the dental occlusion.

The effects of condylar growth independent of the teeth and the opposite condyle requires further explanation. The growth of the facial skeleton (Brodie 1941) and the ontogenic development of occlusion (Broadbent 1931, 1941, 1975) are both components of the genetic growth pattern of the total being. Each is subject to modification from its norm by abnormal environmental influences. Traumatic and pathologic events can modify the normal growth of the mandibular condyle. Abnormal muscle forces can modify tooth alignment and alveolar processes. Orthodontic therapy is another environmental influence on the dentition. While corrective therapies can and do produce excellent intercuspation and alignment of the teeth (anatomical occlusion), and excellent facial esthetics, there is no way of precisely coordinating therapy with growth of the mandibular condyles or any other facial growth.

It is the Author's opinion, based on the radiographic cephalometric analysis of treated dental malocclusions for almost forty years, that there is no consistency in response demonstrating that orthodontic treatment either stimulates or retards mandibular condyle growth. To the contrary, excellent results are most frequently associated with favorable condylar growth at the time of active treatment.

This is a matter of fortuitous timing, rather than a response to mechanical therapy. The independence of dental occlusion and condylar growth is demonstrated in the following cases (Figs. 1-7).

Clinical Example 1

C. H., Figure 1

All permanent teeth are congenitally absent, with no tooth germs and no permanent alveolar processes. The growth potential of the deciduous alveolar processes was achieved early. With failure of the deciduous teeth to erupt, and no replacement by permanent teeth, the freeway space became progressively larger as normal condylar growth proceeded independently.

This case should not be classified as a Class III malocclusion; it is a functional Class I malocclusion with mandibular overclosure. No posterior condyle displacement accompanied the extreme overclosure in the absence of teeth, so there was no clicking of the temporomandibular joints. The closure was a hinge movement only.

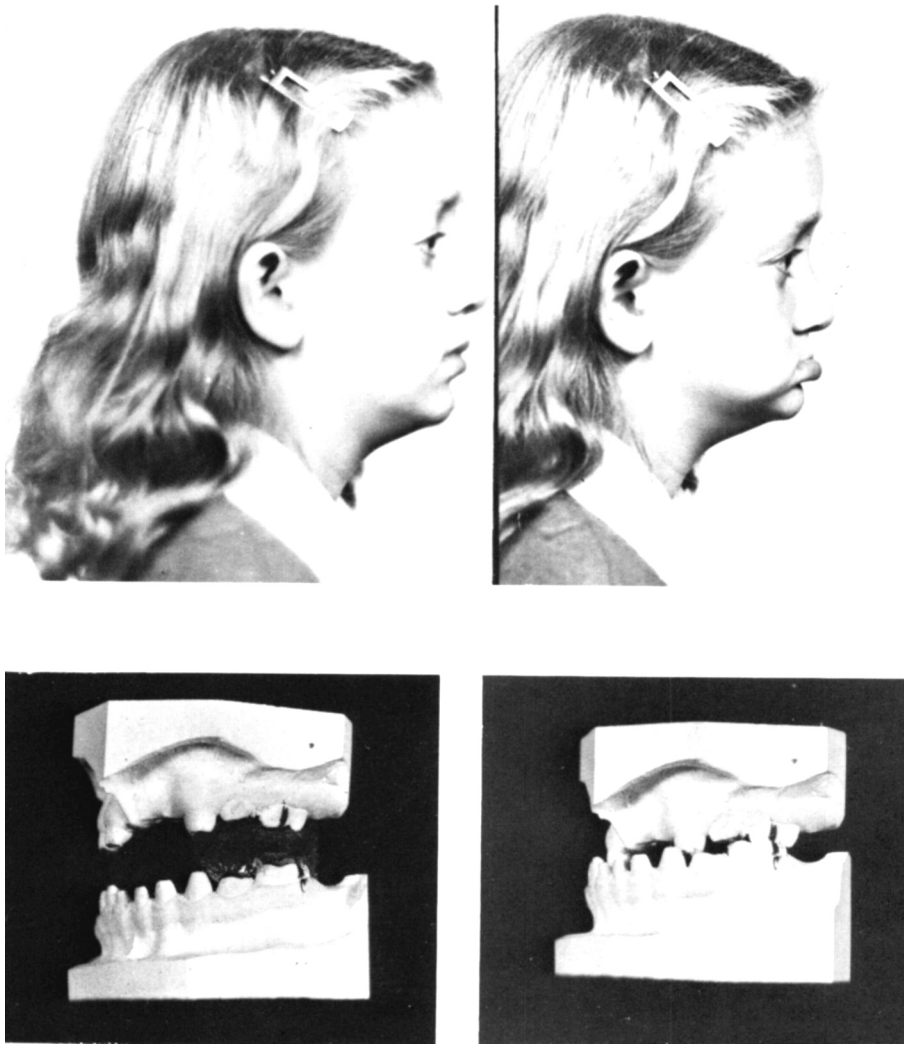
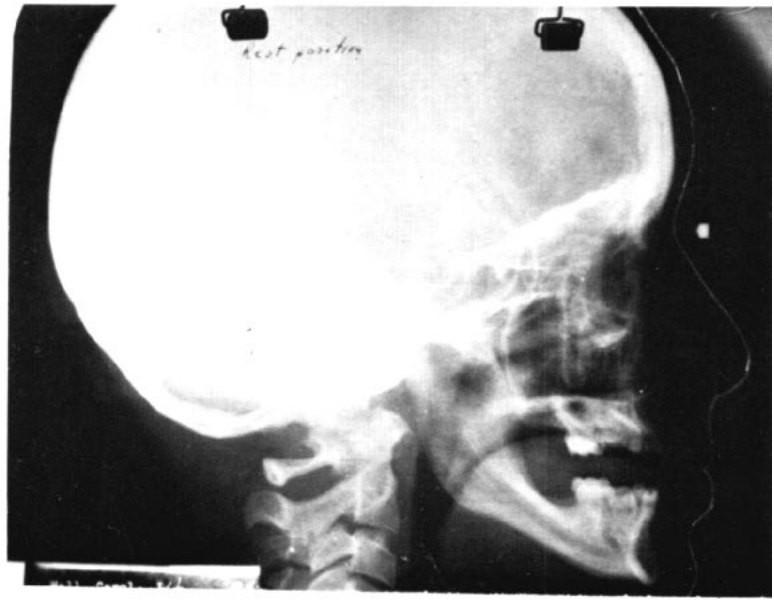


Fig. 1 Clinical Example 1

Partial anodontia, with deciduous ankylosis and all permanent teeth congenitally absent.

Above, **Facial and dental photos. Rest position is shown on the left, full closure on the right.**

Opposite page,
Lateral cephalometric views at rest *(top)* **and full closure** *(bottom).*


Rest position

Treatment was with a maxillary overdenture to reduce the 10mm freeway space to 3mm. This required replacement at intervals of about two years, until the condyle had achieved its inherent growth potential.

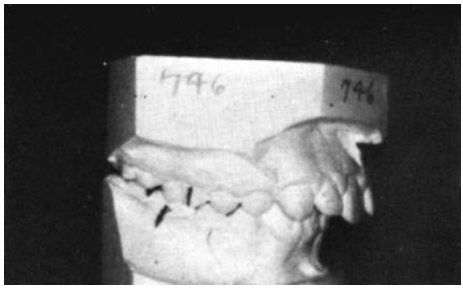
Clinical Example 2
D. M., Figures 2-5

This is a severe Class II, division 1 malocclusion in a poor skeletal pattern (Figs. 2 and 3). The A-N-B value is −7° before treatment. The four first bicuspids were extracted, but treatment was delayed for a year by a severe blow to the chin. Active appliance treatment was started at 13yr 3mo (b). After one year and six months of treatment (c), the patient and orthodontist were pleased, and retention was placed.

Despite the maxillary retaining appliance, relapse (Figs. 2 and 4) began immediately on removal of the treatment appliances. A composite showing the relapse and pretreatment tracings (Fig. 5) shows rotation of the mandible downward and backward as the maxilla was projected downward and forward by normal sutural growth. The −7° A-N-B value decreased further to −10°

To evaluate the net effect of condyle growth, superimpositions on the angle of the mandible are also shown in Fig. 5. The Broadbent-Bolton standards for 12yr and 16yr show an increase in ramus height (condyle growth) that balances growth in anterior face height and maintains the facial pattern.

While the D.M. composite shows good growth in mandibular corpus length, the critical vertical increment at the condyle is not there; condylar growth is zero. The orthodontic treatment had no influence on the condylar growth, but the absence of growth had a profound influence on the stability of the orthodontic result.



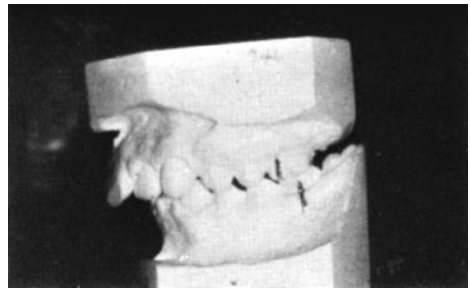
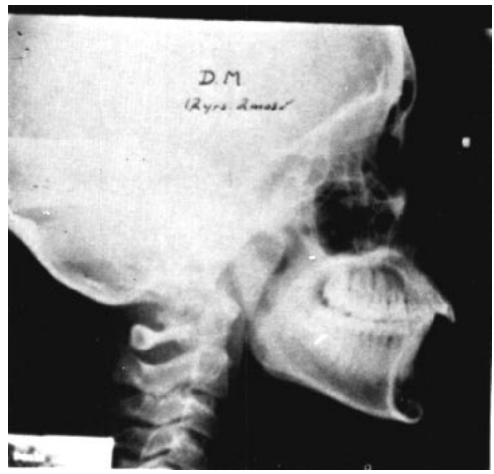


Fig. 2 Clinical Example 2
A severe Class II, division 1 malocclusion in a poor skeletal pattern



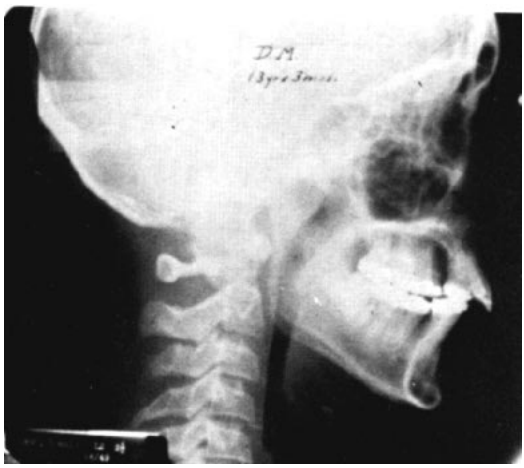
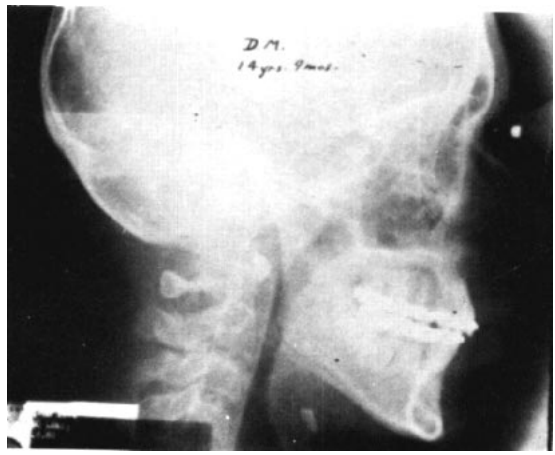


Fig. 3 Clinical Example 2
Top, Pretreatment, age 12yr 2mo.
Center, One year later, at start of active treatment, which was delayed by jaw injury.
Bottom, After 18mo active treatment.



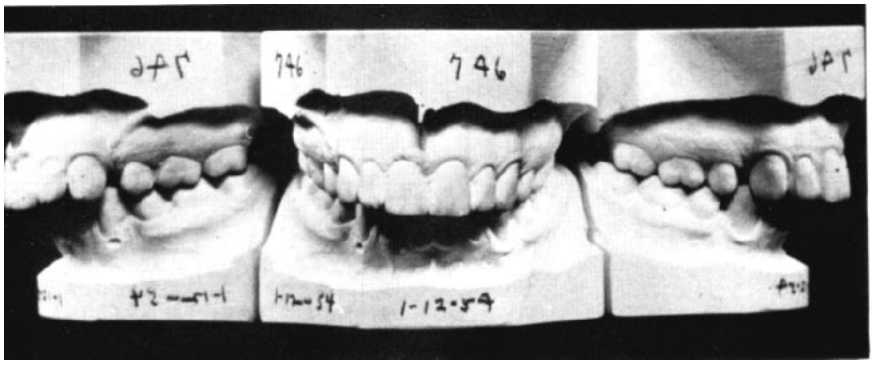


Fig. 4 Clinical Example 2
Age 17yr 11mo (compare to Fig. 2)

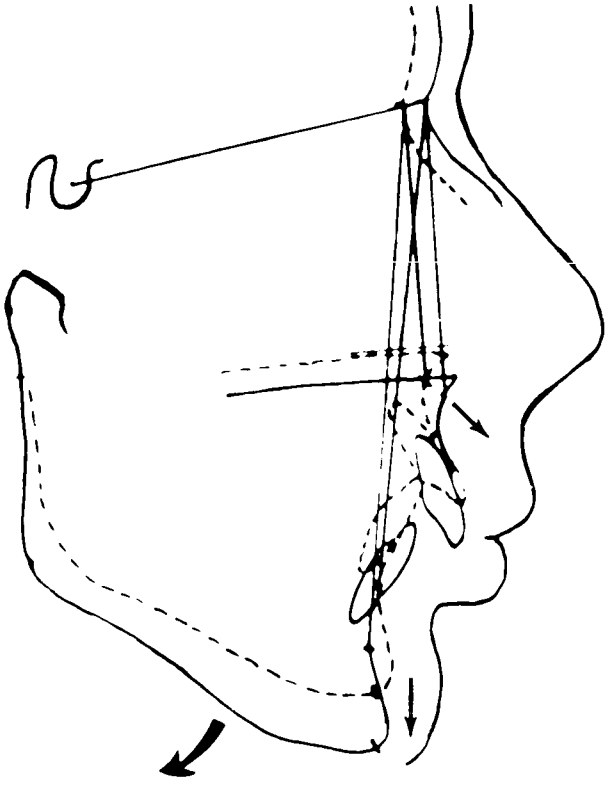


Fig. 5 Clinical Example 2
Left, Pretreatment, age 12yr 2mo, and age 16yr 4mo, showing effect of posttreatment condylar growth deficiency.

Center (opposite page), Broadbent-Bolton standards for 12yr and 16yr, superimposed on the posterior border and gonial angle. Note the increase in ramus height at the condyle.

Right, Same superimposition for Case 5; note comparable corpus growth and the absence of condyle growth.

Clinical Example 3
C. S., Figures 6 and 7

This 12yr-old presents a Class I dental malocclusion that grew into a severe Class III during the course of Class III appliance therapy with heavy Class III intermaxillary elastic traction. The treatment in no way inhibited the mandibular growth (Fig. 6). Superimposing on the mandibular angle (Fig. 7) shows the extreme amount of vertical growth at the condyle and horizontal corpus growth. The only treatment for such extreme growth discrepancies is reduction of the mandible by surgery after the cessation of growth, which was done in this case.

Clicking

A high percentage of the patients presenting for correction of dental malocclusion have clicking in one or both temporomandibular joints. The incidence over five years for the four orthodontists in the Author's practice was 50%, in another 35%. The exact figure is not important; the important point is that the incidence of this functional condition in untreated malocclusions before orthodontic treatment is high, and should be taken into account in the treatment planning.

The key is reshaping the maxillary arch, expanding buccal segments and/or advancing maxillary incisors so that the mandible can assume its normal non-clicking functional position. This will be demonstrated in the case histories that follow.

— Diagnosis —

The accepted methods of morphologic analysis of dental malocclusions using dental casts, cephalometric radiographs, dental radiographs and facial photographs must be supplemented by a functional analysis *done directly on the patient.* Only the patient is alive, dynamic and growing.

The following method of functional analysis has been outlined in prior publications (THOMPSON 1949, 1961, 1961, 1962 AND 1972).

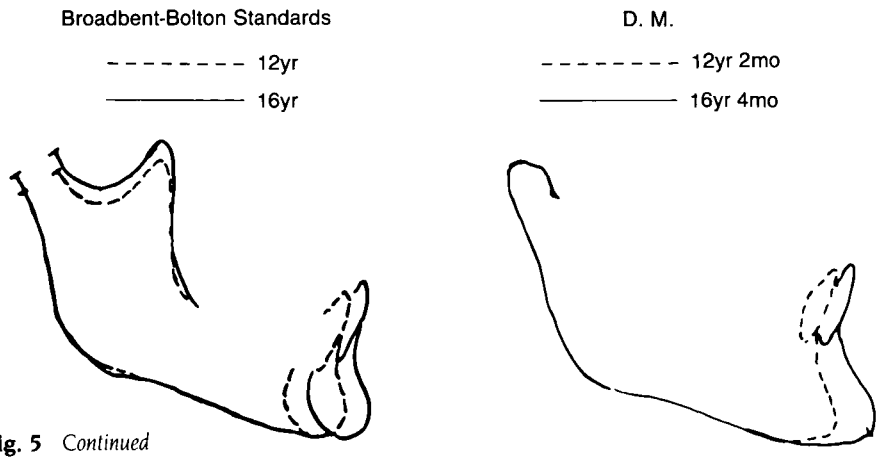


Fig. 5 *Continued*

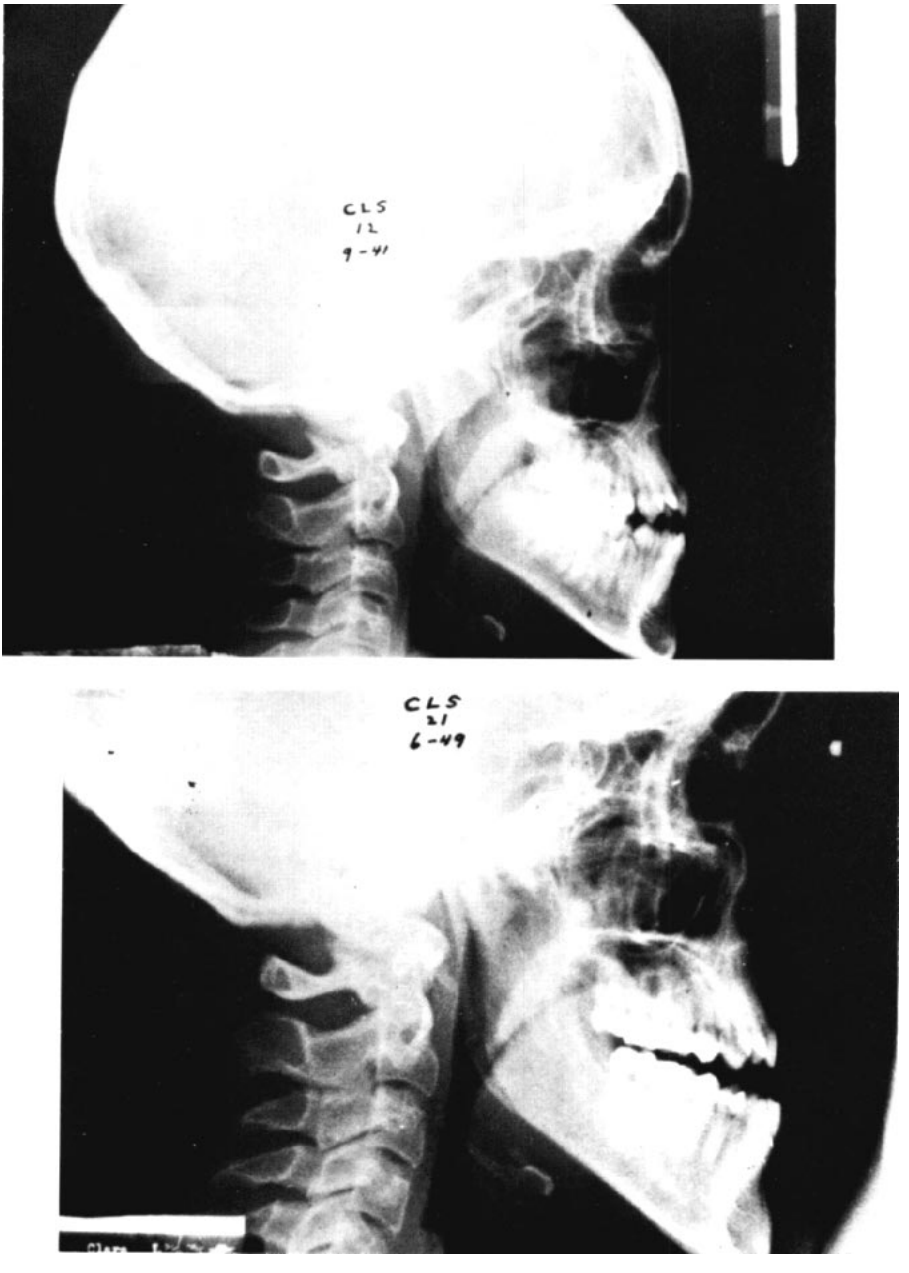


Fig. 6 Clinical example 3

Top, Age 12, before original orthodontic treatment.

Bottom, Age 21, showing effect of later mandibular growth. This condition was corrected surgically.

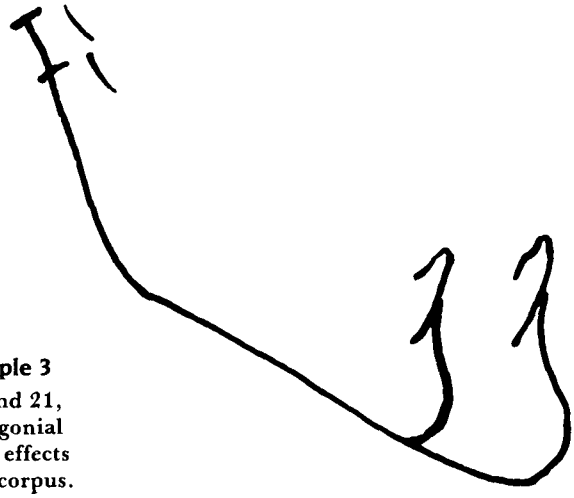


Fig. 7 Clinical example 3
Mandible at age 12 and 21, superimposed on the gonial angle to show growth effects on ramus height and corpus.

- The patient is seated upright in a comfortable position facing the operator, so that the mandibular movements in natural speech can be observed.
- If movement of one of the joints is restricted, the mandibular midline will deviate to that side in saying the C or other protrusive sounds.
- Opening and closing movements of the mandible are observed, and lateral deviations noted.
- Mandibular movements as the teeth come into contact are observed.
- Freedom in lateral function is observed; inability to move in one direction or the other may be due to tooth interferences interfering with the normal movements of the condyle or condyles on the articular eminences. These problems are anatomical, not mere habit.
- The fingers are then placed *lightly* — and I stress the word lightly — over the temporomandibular joint areas. A crinkling sensation or definite click may be felt as the teeth are separated and/or occluded. The clicking may be audible.

Clicking

An opening click may not occur at once, but at any degree of opening. The opening click means that the condyle and disk are slipping *into* normal relation, and the closing click means that they are being dislocated by the posterior displacement of the condyle.

It is also helpful to place the little fingers lightly in the ear canals. Crepitus and clicking can then be evaluated further as the mandible is moved. JAMIESON (1940) described the ear test that he used to determine the amount of condylar retrusion. *"The little fingers are placed in the ear holes with the thumbs on the forehead. In closed relation, the condylar heads can be readily felt during mandibular movements."*

It may be noted that the opening is primarily a hinge opening with the gliding movement restrained. One may observe hinge-only opening in one joint only, with deviation of the mandibular midline toward that side. The hinge and gliding movements may be clearly differ-

entiated is these cases, whereas normal function is a smooth combined movement.

Muscle Function

Clinical evaluation of muscle function is done by placing the fingers over the masseter and temporal muscles and asking the patient to occlude the teeth. The bulging of the muscles should be simultaneous. If not, the bulging will occur first on the side of first tooth contact. Such asymmetrical muscle response can be readily observed.

Occlusion

The clinical evaluation of the occlusion of the teeth is done by having the patient sit upright and tap the teeth together. As the operator listens, a single, solid tap of uniform contact should be heard.

A double or crunching tap signifies the abnormal functional condition of premature tooth contact. Teeth in premature contact have excessive mobility and facets of wear. Reference was made earlier to the inability of the mandible to perform certain tooth contact movements due to functional tooth interferences. A classification of abnormal function is shown in Chart 1.

The results of the functional analysis classify the malocclusion as functional or structural (Chart 2). This, in turn, dictates the age of treatment. The Author favors early treatment of functional malocclusion and later treatment of structural malocclusion.

Treatment of a functional problem requires a relatively short period of time and is most always restricted to the maxillary teeth. Structural treatment, related to the nature of the skeletal pattern and to the amount and timing of facial growth, requires more time. A structural malocclusion that is free of functional problems may be best treated at the time of the pubertal growth spurt. Very often more may be accomplished in one year at that age than in two or three years of earlier treatment.

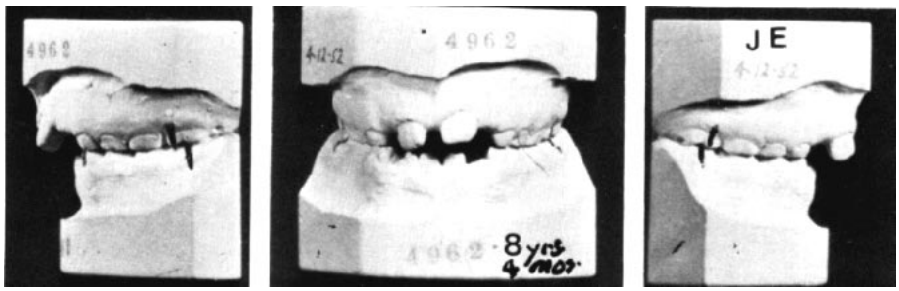
Another point favoring late structural treatment is that the termination of orthodontic treatment is occurring subsequent to the pubertal growth period, with the slowing of the growth process and stabilization of the various parts of the stomatognathic system. Treatment that is completed earlier may produce a dentition that is only temporarily harmonious with the joints and muscles, only to be disrupted by future disproportionate growth if the mandibular growth should exceed maxillary growth.

This is a matter of relative amounts of growth, which may introduce such abnormal functional conditions as premature contact of the incisor teeth or incisal interference causing posterior mandibular displacement (Thompson 1946).

Clinical Example 4
Figures 8-12

In retrospect, this case may have been treated too soon. Figure 8A shows the Class II[1] dental malocclusion at 8yr 4mo. Cervical traction was applied to the maxillary arch. Bands were placed on the central incisors for rotation and retraction with a light arch wire. Figure 8B shows the relation after one year and 3 months of treatment. There was no clicking of the temporomandibular joints.

At 11yr 1mo of age, clicking was present in both joints. The functional cephalometric series showing occlusion, incision and protrusion (Figs. 9 and 10) shows that the mandible is directed over the interfering maxillary incisors on a path requiring hinge opening and then hinge closing. The maxillary incisors could be felt to move more than is considered normal during this movement.



A, Pretreatment malocclusion

Fig. 8 Clinical Example 4

B, After treatment with cervical traction and archwire retraction of incisors.

Fig. 9 Clinical Example 4

Functional cephalometric series; full occlusion, incision, and maximum protrusion.

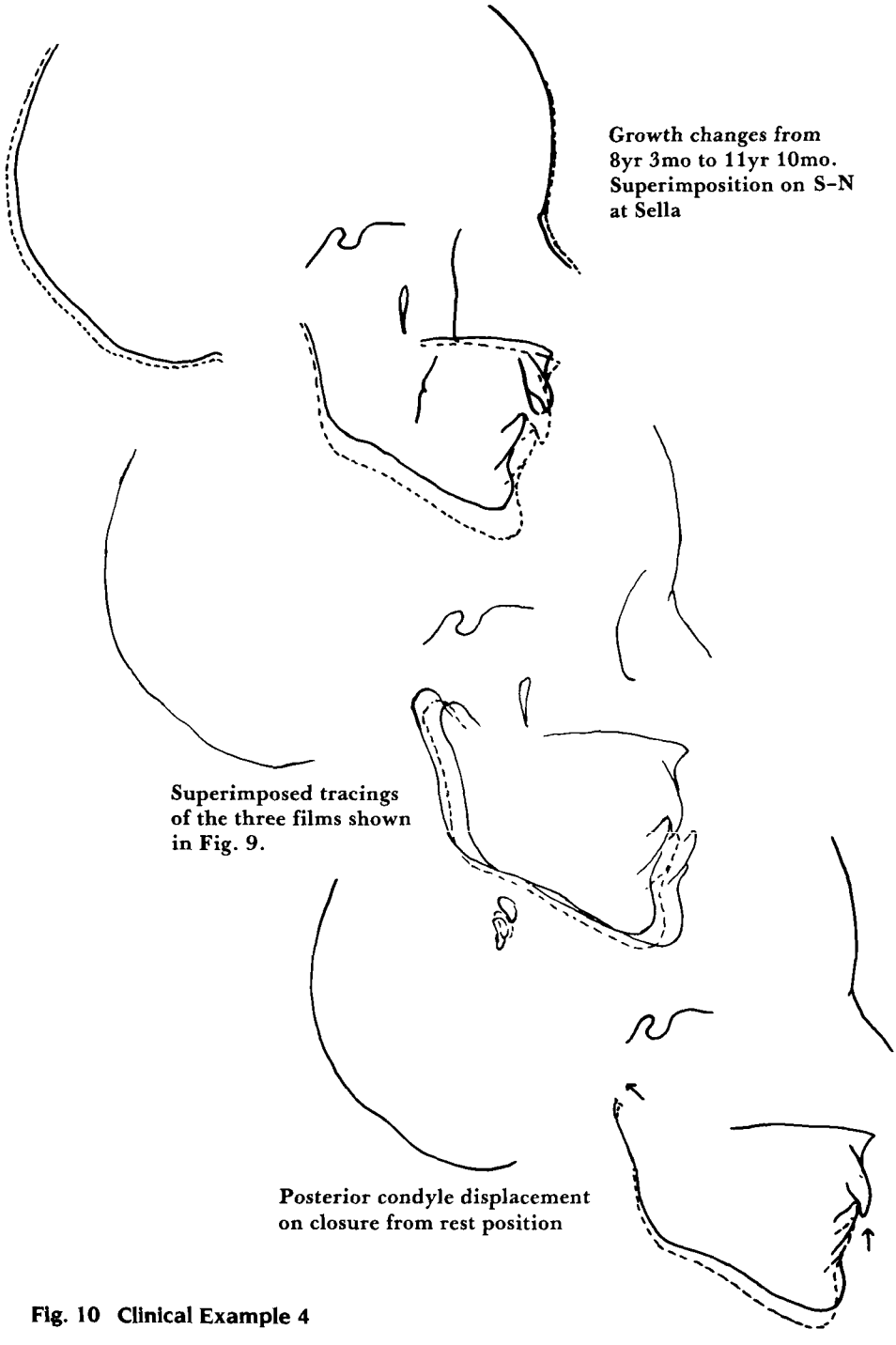


Fig. 10 Clinical Example 4

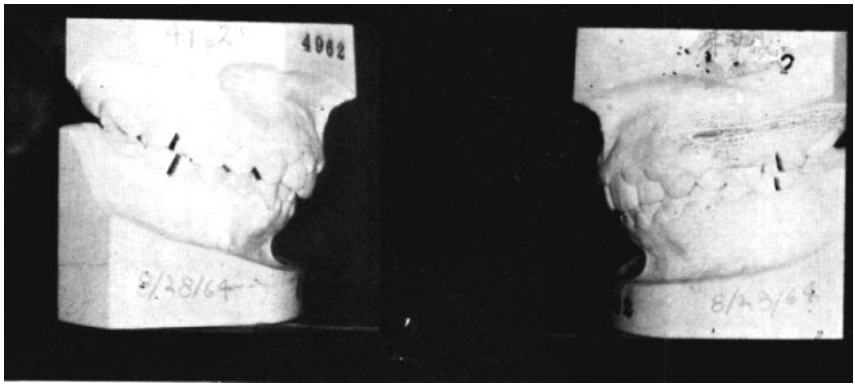


Fig. 11 Clinical Example 4
Occlusion after incisor advancement to relieve displacement and clicking.

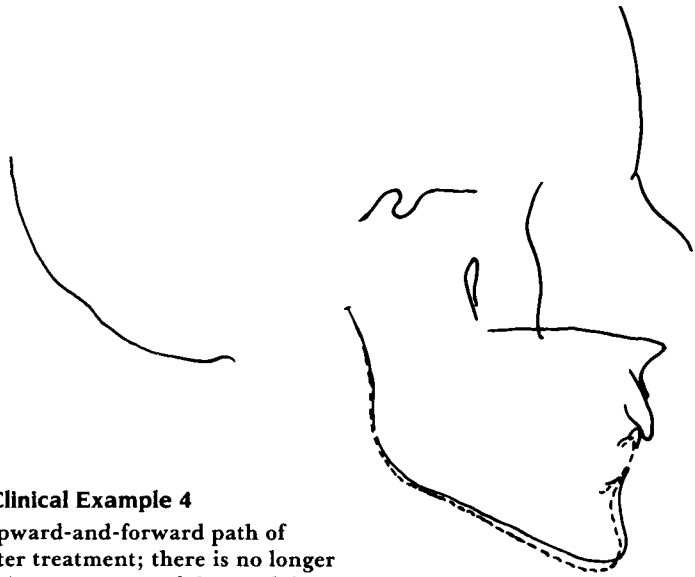


Fig. 12 Clinical Example 4
Normal upward-and-forward path of closure after treatment; there is no longer any posterior movement of the condyle.

The excellent amount of facial growth over the intervening period of 3½ years (Fig. 10, *top*) was independent of the orthodontic treatment. The path of closure from rest position to occlusion has become upward and backward, indicating posterior mandibular and condyle displacement that is a common cause of clicking of the temporomandibular joints.

There was joint clicking as the teeth occluded into the retruded position, and again as the teeth were separated. The second click, on separation, is the disk and condyle snapping back into normal relation with the eminence. There was no clicking during mandibular movements other than closure into full occlusion.

At this time, at 11yr 7mo, the maxillary incisors were moved labially. This was accomplished in a few months. Dental casts after retention (Fig. 11) shows the tooth intercuspation position which was achieved without clicking of the joints, indicating a dental occlusion harmonious with joint function. The normal path of closure from rest position to occlusal position is shown in Fig. 12. A few months of further treatment was advised to improve alignment of the maxillary incisors, but the patient declined.

Some cases corrected at about 12 years of age to an acceptable intercuspation of the teeth and normal function of the stomatognathic system (THOMPSON 1954 AND 1964) may be followed by a pubertal growth spurt causing abnormal function with no change in the same dental occlusion (THOMPSON 1972). This then requires further treatment, such as additional orthodontic treatment, occlusal equilibration, splinting, or restorative dentistry. This will be demonstrated in the case reports.

Early Crossbites

Oral Habits

Abnormal sucking habits can narrow the maxillary dental arch and introduce lateral mandibular displacement. These functional malocclusions must be treated early. The purpose of expanding such maxillary dental arches is not directed at influencing the succedaneous teeth, but at reshaping the maxillary arch to eliminate the tooth interference that is causing mandibular displacement.

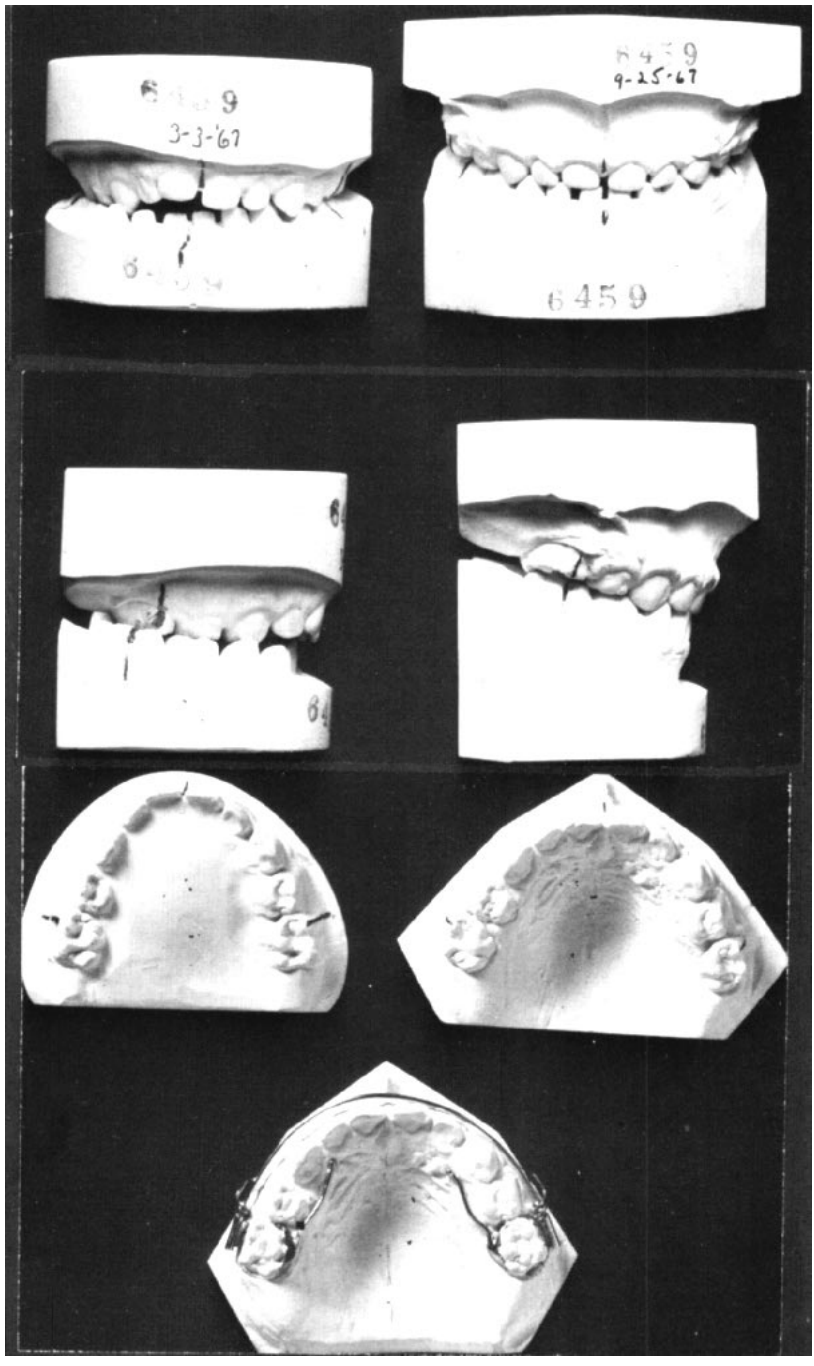
One such case is shown in Figure 13. There was clicking of the right temporomandibular joint before treatment. After expansion of the maxillary dental arch by an Oliver labial arch wire with lingual extensions, the mandible was centered to a non-clicking position by the postural musculature.

The dental malocclusion shown in Fig. 14 may have begun with a deciduous crossbite malocclusion such as that in Fig. 13 that went untreated. During the transitional period of dental development, the permanent teeth erupted and intercuspated at the position of mandibular displacement. The mandibular deviation and functional facial asymmetry was maintained as growth continued, and there was marked clicking and pain in the Class II side.

At this point, the simple functional malocclusion, so easy to correct early, has become a complex structural malocclu-

Fig. 13 *Next Page*

Crossbite in the deciduous dentition, causing a mandibular shift and clicking in the right joint. Expansion with a labial arch and lingual extensions allowed normal closure and eliminated the click.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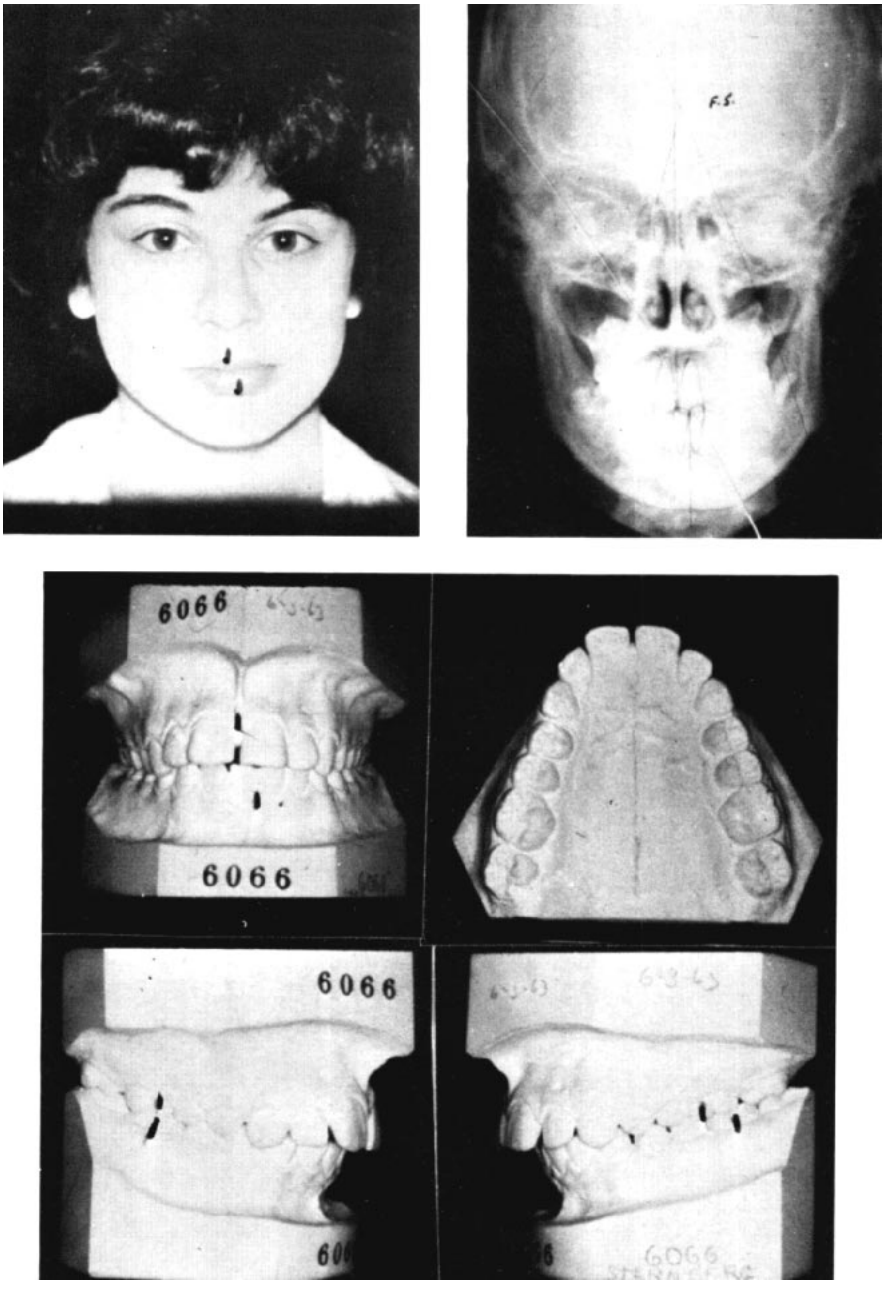

Fig. 14
Asymmetrical growth with unilateral class II malocclusion and clicking of the left joint.

sion. It is difficult, if not impossible, to fully correct the effects of these cumulative disruptions of function and growth.

A Class II dental relation, unilateral or bilateral, should not immediately signal a need for distal movement of maxillary teeth. If it is accompanied with clicking or crepitus of one or both temporomandibular joints, it may be functional and not structural in nature. The maxillary dental arch should be reshaped to permit a mandibular repositioning from the position of mandibular displacement to one of functional normality with normal unimpeded joint function.

STEINDLER (1935), in discussing the stability of joints, says —

> "The ligamentous structures sustain tension stresses only for limited periods, and they become relaxed when these stresses become excessive either in duration or in degree. By virtue of its tone and contractility, the muscle tissue alone is fit to sustain permanently and adequately the stresses of outside forces which threaten the integrity or continuity of the whole mechanical system."
>
> "It can be shown by innumerable instances that the first and principal safeguard of the integrity of the joint is the muscle, and that without it all joints would become eventually relaxed and even dislocated. In case of paralysis, for instance, in the shoulder, the force of gravity alone is amply sufficient to bring about such a relaxation of the unprotected joint that subluxation or even real dislocation results."

The breakdown in joint structures occurs in the lower division of the joint, where there is normally some degree of fibrous attachment of disk to condylar process. DOLWICK, LIPTON AND WARNER (1983) dissected twenty temporomandibular joints. they found fifteen to be normal and five to be abnormal. Of the five abnormal joints, the lower joint space extended relatively farther to the anterior than the amount of anterior displacement of the disk.

In 1940, PIPPIN wrote in regard to posterior condylar displacement that —

> ". . . The investigations made thus far indicate that the chief cause of disturbed temporomandibular articulation is due to anomalies of occlusion of the teeth and mutilated dentures. Mutilation may be caused by excessive wear of the occluding surfaces of the teeth or to their loss.
>
> "The disturbance to the temporomandibular relation will be determined by the character of the malocclusion or the positions of the teeth in the arches that have suffered mutilation. When the mutilation is unilateral, the condyle on the same side will show the chief malrelation. When the mutilation is bilateral, both condyles will be affected and the greatest disturbance will be found on the side where the mutilation is of the longest standing.
>
> "When a unilateral or bilateral posterior mutilation has occurred, the condyles will be disturbed unilaterally or bilaterally, showing a superioanterior displacement.
>
> "If the mutilation occurs to the anterior teeth and not to the posterior ones, there will develop a gradual posterior displacement. When there has been a general loss of interdental dimensions due to excessive wearing of the teeth, there will be found a variable degree of vertical superior displacement of both condyles.
>
> "With total mutilation, as is presented in the edentulous jaws, there will develop a posterior displacement with a tendency to an inferior rather than a superior position. The condylar displacements may be the result of a combination of the effects of mutilations, depending upon the order in which the mutilations have occurred and the time elapsed."

FARRAR (1968 AND 1971) discussed anterior displacement of the articular disk and presented methods of recapturing the disk. MCCARTY (1980), a coworker with Farrar, discusses the problem of anterior disk displacement and the surgical procedure of its recapture. On the nature of the breakdown of the fibrous structures he says — *"Left untreated or improperly treated, the end result is degenerative arthritis and the probability that the posterior attachment of the disk will become perforated."*

This Author (THOMPSON, 1946) believes that the faulty intercuspation of the teeth can cause posterior condyle displacement, producing progressive breakdown of the fibrous attachment of disk to condyle. The diagnosis and treatment of posterior mandibular displacement, first presented in the 1946 article, is also described further in subsequent publications.

The posterior attachment of the disk to the posterior surface of the condylar process (actually the posterior attachment of the superior head of the external pterygoid muscle) is first stretched, and then torn in more severe posterior displacement of the condyle. The ultimate effect is anterior displacement of the disk. The dental malocclusion causing the posterior condylar displacement is a key component in the initiation of this degenerative process.

—continued

Part II will appear in the July, 1986 issue

REFERENCES

Broadbent, B. H.

1931. New x-ray technic and its application to orthodontia, *Angle Orthod.* 1:45-66.

1941. Ontogenic development of occlusion, *Angle Orthod.* 11:223-241.

Broadbent, B. H., Broadbent, B. H. Jr., and Golden, H. 1975. *Bolton standards of dentofacial developmental growth* C. V. Mosby Company, St. Louis, Missouri.

Brodie, A. G. 1941. Growth pattern of the human head from third month to the eighth year of life, *Amer. J. Anat.* 68:209.

Dolwick, M. et al. 1983. Sagittal anatomy of the human temporomandibular joint spaces: normal and abnormal findings, *J. Oral Max. Surg.* 41:86-88.

Farrar, W. B.

1968. Diagnosis and treatment of painful temporomandibular joints, *J. Prosth. Dent.* 20:345-351.

1971. Diagnosis and treatment of anterior dislocation of the articular disc, *New York J. Dent.* 40:348-351.

Gray. 1977. *Anatomy*, A revised American edition, from the fifteenth English edition, Bounty Books, New York.

Jamieson, Charles H. 1940. Mandibular position and the partial denture, *J. A. D. A.* 27:3-10.

McCarty, William 1980. Diagnosis and treatment of internal derangements of the articular disc and mandibular condyle. Chapter VIII. Temporomandibular joint problems, Solberg, William K. and Clark, Glenn T. Quintessence Publishing Company, Inc., Chicago, Illinois.

Pippen, B. N. et al. 1940. Repositioning of the mandible, *Wash. U. Dent. J.* Vol. VI, No. 4.

Prentiss, H. J. 1923. Regional anatomy, emphasizing mandibular movements with specific reference to full denture construction, *J. A. D. A.* 10:1085-1099.

Sicher, Harry 1949. *Oral Anatomy* C. V. Mosby Co., St. Louis, Missouri, pg. 113.

Steindler, Arthur 1935. *Mechanics of normal and pathologic locomotion* C. C. Thomas, Springfield, Illinois.

Thompson, J. R.

1941. A Cephalometric study of the movements of the mandible, *J. A. D. A.* 28:750-761.

1946. The rest position of the mandible and its significance to dental science, *J. A. D. A.* 33:151-180.

1949. Oral and environmental factors as etiological factors in malocclusion of the teeth, *Am. J. Orthod.* 35:33.

1954. Concepts regarding function of the stomatognathic system, *J. A. D. A.* 48:626-637.

1961. Function and growth, *Angle Orthod.* 31:2 132-139.

1962. Abnormal function of the stomatognathic system and its orthodontic implications, *Am. J. Orthod.* 48:10 758-765.

1969. Dentofacial growth in the adolescent, *Dental Clinics of North America.*

1972. Differentiation of functional and structural dental malocclusion and its implication to treatment, *Angle Orthod.* 42:3 252-262.

1981. The free-way space and the passivity of the teeth, *Chic. Dent. Soc. Rev.* January pg 31.

Thompson, J. R. and Brodie, A. G. 1942. Factors in the position of the mandible, *J. A. D. A.* 29:924-941.

Thompson, J. R. and Craddock, F. W. 1949. Functional analysis of occlusion, *J. A. D. A.* 33:404-406.

Zimmerman, Arnold A. 1951. An evaluation of costen's Syndrome from an anatomic point of view. In Sarnat, Bernard G., Editor, The temporomandibular joint, first edition, Charles C. Thomas, Springfield, Illinois.