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The dynamic functional anatomy of the craniofacial complex and its relation to the articulations of dentition

Introduction

Every bone that constitutes the modern human skull formed an essential framework for adapting the brain and sensory organs. Craniofacial mandibular structures, being a functioning system, are regarded as the most complicated system in the human body (Fig. 1). They consist of 28 bones: six ossicular bones (malleus, incus and stapes), eight vault bones (occipital, parietal, temporal, frontal and sphenoids) and fourteen facial bones (maxilla, nasal, lacrimal, ethmoid, concha, vomer, mandible, malar and zygoma).

The craniofacial bones are joined together at their junctions by so-called sutures or synchondroses. It is important to understand that, owing to these attachments, the bones are situated within a flexible or moving structure when pressure or tension is exerted on craniofacial mandibular structures. The sutures resist gross separation of the component bones, but also permit slight relative movement. However, in the past anatomists regarded cranial sutures as immovable joints, believing that each bone is rigidly positioned and that the bones are relatively fixed to each other, although the movement of skull bones is mainly due to brain growth, muscle contraction and functions of the masticatory
organ. Retzlaff and Frymann reported that cranial bones exhibited a state of motion. Frymann's study using fixed transducers with the head stabilized in a fixed position revealed that cranial motion is an independent one, affected by the individual's breathing cycles.

To understand the dynamics of the craniofacial complex, it is of utmost importance that we first discuss its functional anatomy. The cranium is composed of the upper and mid facial skeleton. The calvarium surrounds the superior and lateral portions of the brain and the bones of the cranial base lie beneath the brain. Sometimes all bones surrounding the brain are collectively referred to as the neurocranium, as they originated from the meninx primitiva that surrounds the rostral portion of the neural tube. The midfacial skeletal frame is a further part, known as the visceral cranium. However, the cranium and the facial bones are not separate functional units.

The size of the cranium at birth is approximately 60% to 65% of its final size and it grows rapidly. By the age of five years the cranium has developed to approximately 90% of its final size; this growth is achieved by sequential remodeling of the morphology of each region. External forces applied to these forming structures have the potential to distort shape and growth, with grave consequence for the final form and functions.

The floor of the brain case or cranial base was described as a foundation or scaffolding for the face. The facial complex may also be regarded as a superstructure.

The maxilla is a unique structure in its own way. Aside from one extension or process that directly braces the maxilla against the cranial bone, like the maxillo-frontal process, no other contact exists between the maxilla and the skull base. It is therefore braced against other bones as floating buttresses.

The facial bones also support various organs enclosed in its cavities such as the oral, nasal, orbital, nasopharyngeal sinuses, which include the organs of sight, breathing, smelling, eating, speaking and hearing.

Functions of the facial skeleton that involve dentition are mastication, deglutition, speech, respiration, facial expression, and posture as well as stress management. Functional movements of the mandible, chewing, swallowing, speaking and bruxing behavior, are now regarded as the most important of all the functional movements.
effective and important functions of the craniofacial structure. As homeostasis and the stability of occlusion involve other systems as well, the dentist is confronted with problems of equilibration of the teeth, whereby the problems might originate from factors quite remote from articulation.

Evolutionary Aspects of Craniofacial Bones

The base of the skull, the part that connects the skull vault and the facial skull, changed dramatically during human evolution. Comparison of a modern human skull with that of a modern ape reveals some striking differences (Fig. 2). The human neurocranium with its vertical forehead, bulbous occiput, rounded cranial vault, and centrally located foramen magnum appears to constitute the upright posture of the skull, although the viscerocranium in humans seems to be significantly smaller and wider than that in apes. The inferior projection of the mastoid process in human beings is related in part to the flexure of the cranial base. The geometry and mechanics of the cranial base flexure are determined by the sphenoo-occipital region of the cranial base.

The anteroposterior dimension of the human viscerocranium is strikingly small, especially if the relative size of the neurocranium is taken into account. When viewed in profile, one observes retrognathism of the mid and lower face to flat appearance with more vertically inclined long face than that in apes. When a monkey skull is viewed from below, the projection of the maxillary region is far forward, with a longer anteroposterior dimension of the sphenoo-occipital connection of the cranial base. A feature that determines the skull base in humans is the flexure of the cranial base, which is measured by ascertaining the flexion angle (cranial angle) (Fig. 3). In comparison to the skull of the quadruped, the skull base angle in humans is relatively small (Fig. 4). This is believed to be mainly due to upright posture, the increase in brain volume, and frontal positioning of the eyes - a consequence of stereoscopic vision. Postnatal changes in the proportion of the human cranium also result in a smaller basal flexion angle. Therefore, in the ontogenesis of the modern human being, the viscerocranium and especially the maxillary complex mainly grow in downward direction (Fig. 5).
Based on these considerations, the vertical growth of the viscerocranium in modern humans creates some difficulty in terms of proper fitting of the upper and lower dentition, because the descending spatial position of the maxillary occlusal plane easily creates anterior opening of the upper and lower jaws without continuous mandibular adaptation by rotation (Fig. 6). Therefore, functional adaptation of the mandible to maxillary occlusal surfaces that continuously descend in vertical position is fundamental in order to achieve proper functional occlusion. The anterior mimic muscles help to close the anterior opening of the jaws, which prevents the development of anterior open bite malocclusion (Table 1).

Craniofacial Bone Connection

The bones constituting the craniofacial complex are in a dynamic state of functional motion during life. Cranial bones mainly consist of two parts (Fig. 7 and 8):

1. Central connection of bones: ethmoid, sphenoid, occiput, vomer, maxillary bones
2. Bilateral connection of bones: temporal bones, mandible

Let us first consider the different parts or structures that interconnect with each other to form craniofacial structures.

Sphenoid Bone

The sphenoid bone comes from the word ispheni meaning wedge, as it forms a wedge between the face and the brain. The sphenoid bone plays a vital role in craniofacial morphology. It is joined by the occipital, ethmoid and frontal bone, and is considered to be an essential element of the mid-sagittal cranial base. The sphenoid bone is a principal central bone of the skull that is formed by cartilage. It provides early protection of capsular attachments for vital organs and also plays a role in the early development of the skull, both phylogenetically and ontogenetically.

It is also a major superstructure for the attachments of masticatory muscles, principally the temporalis on the greater wings, the superior belly of the external pterygoid in the horizontal portion of the greater wing (wherein both pterygoids arise from...
the lateral pterygoid plates) as well as the tensor palatal muscles originating in the scaphoid fossa and extending downward, crossing the hook of the hamulus. In addition, the sphenoid bone serves as a buttressed area for the temporal bone, as it is necessary to resist the pull of the external pterygoid muscles during function of the temporomandibular joint (Fig. 9).

Occipital Bone
The occipital bone is slightly funnel-shaped, with a large opening known as the foramen magnum. The basilar process is triangular in shape and is distinguished by an outer cortex and by inner cancellous bone. It is hollowed out in adults by the sphenoidal sinus. In youngsters, up to puberty, it is separated from the sphenoid body by a synchondrosis known as the spheno-occipital synchondrosis.

The synchondrosis between the basilar portion of the occipital bone and the sphenoid bone is considered to be the largest joint in the skull. It is made up of thick fibrous cartilage, which serves as a shock absorber, permitting growth, and simultaneously providing motional adjustment against external stress.

Vomer Bone
The vomer bone consists of two small flanges of bone that conform with the underside of the body of the sphenoid. It is important because of the nasal septum and its attachments to the palatine and maxillary bones. Aside from serving as a buttress for the upper jaw to receive shear forces, it is an important site of downward growth of the human face (Fig. 10).

In great apes, the cranial base is less flexed in the sagittal plane, and the base of the vomer is positioned further anteriorly. The vomer plays an important role as a transmitter of dynamic forces from the cranial base to the maxillary complex.

Temporal Bone
In the dynamic mechanism of the craniofacial skeleton, the temporal bone is the most important one because of its anatomical position. The temporal bones are located in the lateral-most aspect of the skull and fit in the space between the occipital, parietal and sphenoid bones (Fig. 11). The temporal bone's squamosal suture is fan-shaped and flaps...
over the parietal bone at its junction with the squama (Fig. 12).
The temporal bone is the keystone of the cranium because several muscles affect its movements. One of the key factors in dysfunction of the cranio-mandibular system is distortion and displacement of the temporal bone. The temporal bone consists of three main parts: the internal petrous portion, the external squama and the mastoid sections. Squama gives a zygomatic process, which extends forward and articulates with the malar bone and acts as the shock absorber for the TMJ. In the cranial scheme, the temporal bone articulates with the occiput, parietals, sphenoid, malar and mandibular condyles. Its primary motion is derived from the occiput, which gently moves the temporal bones into internal and external rotation during the respiratory phases of expiration and inspiration, respectively.

Two of the primary muscles of mastication, temporalis and masseter muscles, have a direct influence on the movement of the temporal bone. The large fan-shaped temporalis partly originates in the temporal squama and inserts in the mandible at the coronoid process and its anterior border. Contraction of this muscle exerts powerful downward and anterior force on the squama when the posterior teeth occlude. This force has the effect of causing external rotation, i.e. the superior border of the squama moves anteriorly and laterally while the mastoid tips move superiorly, posteriorly and medially. The mandibular condyles compensate by moving posteriorly and medially within the glenoid fossa.

Internal rotation of the temporal follows a movement that is the direct opposite of external rotation. The mastoid tips move inferiorly, anteriorly and laterally while the superior border of the squama moves posteriorly and medially. The condyle compensates in anterior and lateral position within the fossa.

Contraction of the sternocleidomastoid, splenius capitis, longis capitis and digastric muscles will induce internal temporal rotation. The stylohyoid and styloglossus muscles provide balancing movement of the temporal bone. The muscular attachments have their origin in the styloid processes. During contraction they inhibit and balance the movement of the temporal bone. The articulation between the temporal squama and the parietal bone is referred to as a shindylesis joint (joint with a long bevel). This architectural design provides a
Dental malocclusion with mandibular displacement will disrupt the temporomandibular joint function, which in turn causes temporal bone distortion.

The temporal bone affects the rotating movement of the sphenotemporal articulation, which is formed between the temporal and sphenoid bones; and temporal occipital articulation, which is formed between the temporal and occipital bones. The temporal bone itself rotates in the petrotemporal axis of the pyramidal portion. In recent orthodontics, during occlusion or in conjunction with a prosthetic construction bite, it was found that the facial bone is secondarily affected, once mandibular movement is transmitted to the temporal bone.

The midline bones of the cranium provide flexion and extension movements.

The clinical significance of flexion-extension, a side bending and torsion lesion is that they are usually self-correcting once the primary lesion is resolved.

Craniofacial Bone Dynamics

The sutural connections between bones permit articular mobility of the cranium. The midline bones of the cranium allow flexion and extension (Fig. 13). Continuous flexion of the midline bones results in a movement that reduces the anteroposterior dimensions of the cranial base and increases the lateral transverse dimension (Fig. 14), while the opposite is true in extension (Fig. 14). The sphenobasilar articulation is the most important joint for identifying the resultant motional dynamics of craniofacial function. However, the sphenoccipital synchondrosis acts as a joint that permits various kinds of motion in different planes such as flexion-extension, side bending, torsion, and strain. The motion of flexion-extension occurs in the vertical plane, similar to normal sphenobasilar joint motion. As a general rule, cranial distortions of flexion-extension are transient. Distortions are a compensatory reaction to primary lesions of forces secondary to occlusal function. The clinical significance of flexion-extension, a side bending and torsion lesion, is that they are usually self-correcting once the primary lesion has resolved. However, correction of these cranial faults does not have a stable effect; relapses are a common occurrence.

The normal flexion-extension motion responds around the transverse axis. Bilateral temporal bones respond to occlusal function through the temporomandibular joint in a manner referred to as external and internal rotation. As the bilateral bones go into
external rotation, the midline bones go into flexion. Tooth extraction, deflective contact of posterior teeth, deviation of the occlusal plane, hypertonicity of the cranio-mandibular-hyoid-cervical connection of muscles, clenching and bruxism, and many other factors may cause minor to major bone malalignment.

As midline bones go into flexion, the anterior portion of the sphenoid rotates downward. This causes the posterior portion of the ethmoid to rotate downward, with its anterior part rotating upward. When rotating upward, it moves postero-superiorly under the glabella. This, in conjunction with vomer flattening and vertical elongation of the maxilla with external rotation, causes lengthening and widening of the face.

As the sphenoid goes into flexion, it descends downward, carrying the vomer against the hard palate, causing the palate to flatten, and vertical elongation of the maxilla. This is responsible for poor anteroposterior dimensions of the maxillary bone and also hinders adequate growth of the posterior alveolar process for molar eruption, resulting in posterior discrepancy or posterior crowding. In this sense, posterior discrepancy, which creates several types of malocclusions, is not a genetic problem, but is closely related to the dynamic state of craniofacial structures.

In this sense, posterior discrepancy which acts in creating many malocclusions is not a genetic problem, but rather closely related with the dynamic state of craniofacial structure.

Occiput-Spheno-Maxillary Complex with the Vomer bone

The occiput-spheno-maxillary system consists of the occiput, sphenoid bone, maxillary bone and vomer bone (Fig. 7, 10 and 14). The body of the sphenoid forms an important joint or synchondrosis with the basilar process of the occipital bone. This joint fuses in late puberty, indicating that the dynamic motion of the joint continues until the terminal stage of functional growth, as a result of articulation of upper and lower dentitions.

Hanging down from the undersurface of the body of the sphenoid bone are two pairs of bony plates, the medial and the lateral pterygoid plate. The lateral pterygoid plate provides the origin of the pterygoid muscles, which are responsible for mandibular movement.

The maxillary bone articulates directly with 45% of cranial bones. Sutural attachments are shared with

The maxillary bone articulates directly with 45% of the cranial bones.
One of the primary etiologic factors in craniofacial dysfunction is the loss of vertical dimension. Lack of the vertical dimension as a result of inadequate normal eruption of natural dentition or loss of molar and bicuspid teeth or severe attrition of the occlusal biting surface and inadequate tooth contact reduces the amplitude of sphenobasilar symphyses into flexion and influencing cranial motion.

Maxillary Bone Growth According to the Dynamics of the Cranial Base

The process of bone displacement, translatory movement of the entire bone caused by the surrounding physical forces, is a primary and characteristic mechanism of skull growth. The entire bone is carried away from its articular interfaces, sutures, synchondroses, and the condyle with adjacent bones. Displacement of the maxillary complex is caused by the sum of pushing forces from sphenoidal motion via the vomer bone. It occurs parallel to bone growth, thus creating space around the contact surfaces into which the bone can enlarge. The rotating movement of the cranial base occurs at the sphenoid-occipital articulation. The rotating axes of the sphenoid and occipital bones are the anterior portion of the sella turcica and the posterior portion of the major occipital foramen, respectively. The rotating movement of the sphenoid bone is transmitted to the mandible through the vomer, which
results in anteroinferior pushing of the maxilla. The vomer has a direct effect on the rotation of the sphenoid, as the sphenoid and vomer are communicating with the rostrum of the inferior surface of the sphenoid and the wing of the vomer. In addition, the rotating movement of the sphenoid bone is indirectly transmitted to the maxilla because the inferior border of the vomer is connected to the maxillopalatine process and the nasal crest of the palatine horizontal plate. This is how the movement of cranial bones affects the maxilla, especially when the pushing direction of the maxilla changes in relation to the rotating direction of the cranial base; this would indicate growth of the maxilla. For example, rotation of the sphenoid bone is flexion. This would influence the rotating force of the wing of the vomer, which is posteroinferior, preventing anterior pushing of the maxilla. Instead, it would move inferiorly. On the other hand, when the rotation of the sphenoid bone is extension, rotation of the vomer will be anterior, and the maxilla will be strongly pushed anteriorly. The pushing movement of the maxilla affords adequate space in the posterior portion of the upper teeth, allowing growth of the posterior border of the maxillary tuberosity.

The direction of displacement of the maxilla is influenced by the dynamic states of the occiput-spheno-ethmoidal connection of the cranial base. There are three types of maxillary growth secondary to displacement of the maxillary complex: translation with the frontal bone, vertical elongation, and anterior rotation (Precious et al., 1987) (Fig. 15). Flexion motion of the cranial base causes vertical elongation of the maxillary complex. This is commonly seen in the development of a Class III skeletal frame. Extension of the cranial base causes anterior rotation of the maxillary complex. This is related to the development of a Class II skeletal frame.

Translation of the maxilla (anteroposterior) with the frontal bone to which it is attached below the frontal sinus shifts the maxilla in forward direction. The maxilla is passively displaced due to expansion of the middle cranial fossa, the anterior cranial base, and the forehead, without the growth process of maxilla itself being directly involved. Vertical elongation of maxillary complex and the formation of the alveolar process increase the height of the maxilla.

Bone deposition on the wall of the maxillary tuberosity is mainly important for creating space to allow the eruption of posterior teeth, resulting in

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posterior lengthening of the bony maxillary arch. This posterior elongation of the upper jaw is coupled with translation and anterior rotation of the maxillary complex, although the vertical elongation of maxillary bone does not provide posterior lengthening (Fig. 16).

The tooth buds of the upper molars have to be formed in the relatively small area of the maxillary tuberosity, indicating posterior discrepancy (Fig. 16). As the maxilla displaces by forward translation and anterior rotation, the formation of the alveolar process accompanies the downward movement of tooth buds. Thus, posterior crowding of the molars is eliminated.

The temporo-mandibular complex is one of the most important functioning systems of the cranium. Each temporal bone consists of the squamous, petrous and mastoid portions. The temporo-mandibular complex is one of the most important functioning systems of the cranium. In the functional cranial scheme, a U-shaped mandible, representing the most active functional movement in craniofacial structures, connects the two temporal bones at the lateral surface of the cranium. The temporo-mandibular system is composed of the articulation of the mandible with the cranium; this joint is referred to as the temporo-mandibular joint. The mandible and temporal bones affect their position and movement reciprocally (Fig. 17).

Each temporal bone consists of the squamous, petrous and mastoid portions. They also have other distinct parts such as the tympanic plate and the styloid process. The parietal notch of the temporal bone articulates with the mastoid angle of the parietal bone located above the mastoid process. A further unique characteristic of the temporal bone is that the squamous temporal considerably overlaps the parietal bone, rather than interdigitating, as many cranial bones do. The type of articulation that occurs between the temporal, occipital and parietal bones in the cranium may well reflect the large masticatory forces generated around the cranium. In addition to the overlapping articulation that occurs in all hominoid crania, the parietal bone overlaps with the mastoid portion of the temporal bone as well as with the occipital bone. Rak (1978) and Kimbel and Rak (1985) reported that this might be due to the resistance to extreme masticatory stresses in the vault bones of this region. The condition of overlapping vault bones
The Importance of the Function of Occlusion for Mandibular Growth

It has long been believed that the growing enlargement of condylar cartilage was the primary reason for mandibular displacement. According to this concept, the pressures exerted on the glenoid cavity by the growing condyle caused the mandible to be displaced out of articulator contact. Two simple questions may be raised in an attempt to explain clinical experience and the articulation of teeth. First, how do the upper and lower teeth fit together if the mandible is displaced by predetermined condylar growth? Second, is the maxillary bone, including upper dentition, adaptable to the continuously changing mandibular dentition?

Recent studies showed that mandibular displacement is the primary process and that condylar growth is secondary and adaptive. This reestablishes the relationship of the displaced mandible in the temporomandibular joint.

The mandible is greatly influenced by functional demands, especially the articulation. These are controlled by the central nerve-muscle system. According to Moss, a specific cranial component controls each function while the size, shape and spatial position of the individual components are relatively independent of each other.

The functional matrix includes the functioning space and the soft tissue components required for a specific function such as breathing or mastication. The function of the mandible is always executed in relation to the spatially positioned upper dentition (Fig. 18). Mandibular translation is caused by the functional shift of the mandible, which is induced by the functional articulation of teeth. The entire mandible is displaced downward and forward, away from its articular joints.

This translatory movement stimulates the enlargement and remodeling of the condyles and the rami, which take place parallel to displacement. Bone growth processes are directed upward and backward to an extent that equals the displacement of the mandible. From this standpoint of the masticatory system, the cranial determinant of mandibular growth is the spatial position of maxillary teeth.

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Craniofacial Growth and Development with Special Attention on the Occlusal Plane

Petrovic (1975) comprehensively studied factors affecting the growth of the maxillofacial skull. As a result, he described the cybernetic model of mandibular growth using Moss' concept as his foundation. The most significant point in the cybernetic model is that occlusal function is an important factor in mandibular growth. In anteroinferior displacement of the maxilla, the mandible is able to functionally adapt. This displacement directs adaptation of mandibular growth. In the cybernetic model, the functional factor that regulates mandibular growth is occlusal function.

The cybernetic model of Petrovic can be simplified in the manner shown in Fig. 19. The most important local factor in the control of mandibular growth is the spatial position of the maxillary occlusal surfaces and the maxillary dental arch. Functional movement of the mandible is dependent on the action of the central nervous system and masticatory muscles. Anteroinferior growth of the maxilla functionally shifts the mandible, making the TMJ adjust to the new mandibular position, which leads to mandibular remodeling or growth.

The most important point in this concept is that mandibular growth is not only controlled by the endocrine system and intrinsic capacity of the mandibular growth, but also the position of the occlusal surface (functional occlusal plane) of the maxillary teeth to which it is functioning with.

Moreover, adaptation to the new mandibular position is not always simply due to mandibular growth and internal remodeling of temporomandibular joint. The functional force from the mandible to the temporal bone through the joint, the masseter muscle, changes in traction force from the masticatory muscles to the temporal bone, and movement or rotation of the temporal bone, are liable to alter positional adaptation of the mandible.

In addition, the tension of the medial and lateral pterygoid process, which is related to the positional
change of the mandible, affects rotation of the sphenoid bone. Movement of the sphenoid bone changes maxillary movement and the vertical position through the vomer. The altered mandibular position due to occlusion controls the harmony of the entire maxillofacial skeleton.

Occlusal function and the maxillofacial skeleton are closely related, creating a unified dynamic mechanism. The balance of this dynamic mechanism has a great influence on the growth of the maxillofacial skeleton in active infants. Therefore, orthodontic occlusal treatment is not simply an alteration of occlusion but the consideration of a maxillofacial dynamic mechanism. This type of mandibular adaptation to occlusion causes a load on the mandibular condyle, where its growth will be regulated. However, when this load exceeds the adaptive capacity of the TMJ, it affects function in the temporal bone, articular disc, and masticatory muscles, causing TMJ arthrosis.

On the other hand, an increase in the vertical dimension that exceeds the growth of the mandibular condyle results in rotation of the mandible, presenting an open bite condition of the front teeth and creating a fulcrum in the molars, which in this case causes an abnormal load for the TMJ.

As mentioned earlier, the increase in the vertical dimension and mandibular growth are closely related. It is important to develop and maintain the harmony of both. Once the vertical dimension increases or decreases, the mandible adapts through functional displacement.

The occlusal plane is the most important component influencing the vertical dimensions of the lower face. For instance, the vertical position of posterior teeth in a Class III high angle and in open bite malocclusion is not stable during growth (Fig. 21). Continuous molar eruption occurs not only during growth, but also during post-puberty. In this sense, genetics may not be the sole reason for this type of malocclusion. Rather, the continued eruption of second and third molars in a limited space must be the major contributing factor. The development of such malocclusions must be regarded as an effect of posterior discrepancy or posterior crowding.
Cephalometric Evaluation of the Denture Frame (Denture Frame Analysis)

The skeleton, whose shape is directly related to occlusion and is the basic unit that supports the maxilla and mandible, is known as the denture frame. Since the denture frame is a basic skeleton that supports the upper and lower dentition, it must be in harmony, especially with the occlusal plane. The denture frame changes in response to occlusal changes because mandibular displacement affects it. The changes associated with its morphology and growth are closely related to occlusal function.

Occlusal construction is the most important measure for establishing the spatial position of the occlusal plane in the denture frame. In other words, orthodontic occlusal treatment restores the harmony of the denture frame and occlusion through attaining a correct occlusal plane. From this standpoint, denture frame analysis is done to determine the basic morphology of the denture frame. The palatal plane (PP), occlusal plane (OP), mandibular plane (MP) and AB plane (AB) of the morphology of the denture frame are closely related to occlusal function. Listed below are the reference points and planes used in denture frame analysis (Fig. 22).

1. FH plane (FH)
2. Palatal plane (PP)
3. Mandibular plane (MP)
4. AB plane (AB)
5. Occlusal plane (OP)
6. A’, 6’, A’-P 6’-P
7. Maxillary median incisal axis
8. Mandibular median incisal axis
9. 1st molar axis of the upper and lower mandible

Denture frame analysis is measured with the above mentioned items, which are also studied with regard to their respective functional background.
FH-MP
This determines the position of the denture frame in the craniofacial skeleton and is an important index to determine the functional adaptation capacity of the mandible to occlusion. When the FH-MP is high, the functional adaptation capacity due to anterior rotation of the mandible to the occlusion is low.

Usually, when the mandible shows excellent adaptation capacity due to its growth, it displays protrusive rotation. However, when the adaptation capacity is poor, it usually displays a retruded rotation. In case of protrusive rotation with bone remodeling of the inferior border of the mandible, there is a minimal change in the FH-MP angle while the AB plane and the MP angle decrease due to the protrusive position of the mandible (Fig. 21). In case of retruded rotation, the FH-MP angle increases, with minimal changes in the AB-MP angle. This presents the so-called high angle condition.

PP-MP
It is the angle formed between the palatal plane (PP) and the mandibular plane (MP). This shows the basic morphology of the denture frame. When this is increased, like the FH-MP, it does not induce protrusive rotation of the mandible as a functional response; rather it adapts to the occlusion through backward rotation. Although the PP-MP and the FH-MP are nearly the same, the significant difference lies in the descent of the palatal plane due to the protrusive rotation of the maxilla. This is usually observed in patients with mandibular distoclusion associated with deep overbite.

OP-MP
This is the angle of the occlusal plane (OP) and the mandibular plane (MP). Normally, the occlusal plane and the mandible have a functional relationship in order to maintain the OP-MP angle with neuromuscular function. In other words, when the occlusal plane changes to parallel or slightly horizontal during the growth process, the mandibular plane also moves in parallel to it. Even if the occlusal plane is changed to horizontal, the mandible reacts to maintain the OP-MP angle by rotating protrusively in response to the occlusal plane.
This phenomenon is also seen in individuals with normal occlusion, and slight changes of the occlusal plane are recovered through this type of mandibular adaptation. This does not result in a serious occlusal abnormality because it maintains the functional occlusion. However, when the occlusal plane is excessively displaced, it results in a backward rotation of the mandible, leading to an increase in the OP-MP angle.

Since the vertical support of the occlusion is insufficient, mandibular condyle growth is inhibited. The OP-MP angle does not adapt forward and remains decreased even during the growth process.

The angle of the OP-MP is not merely the angle formed between the occlusal plane and mandibular plane. It is the measurement of the relationship of the occlusal plane and the mandibular plane as a functional unit of the denture frame, which has a dynamic relationship with the functional adaptation capacity of the mandible.

**OP-MP/PP-MP**

This is the ratio of the OP-MP angle to the PP-MP angle. In effect, it shows the positional relationship of the denture frame and the occlusal plane. The value of a normal occlusal plane is 0.54; which is the basic morphology of the denture frame. If it exceeds 0.60 it is presumed that there is a deviation of the occlusal plane and that the mandible is not adapting to it. In an occlusal plane of less than 0.5, the posterior vertical dimension is insufficient, which leads to a retruded mandible brought about by the inhibition of the mandibular condylar growth due to a chronic compression load.

**AB-MP**

This is the angle formed between the AB plane, the point of A and B, and the mandibular plane (MP). It reveals the anterior border of the denture frame and the anteroposterior relationship of the lower and upper jaws. This usually shows the anterior displacement of the mandible due to its forward rotation. When there is over-eruption in the molar part, the mandible avoids the posterior interference through protrusive displacement. Persistent pushing of the molar in posterior discrepancy allows protrusive displacement to occur continuously, which somehow affects the mandibular condyle growth and alters the denture frame morphology.

There is a mutual relationship between the change of the occlusal plane and the change of the AB
plane, which results in an alteration of the occlusal plane to flat, associated with a reduction of the AB-MP angle. However, when the adaptation capacity of the mandible is low, there is no change in the AB-MP angle, and there is a tendency for the PP-MP to increase.

$A'-P'$

It is the distance between the $A'$ and $P'$. This represents the anteroposterior diameter of the maxillary basal bone. The $A'-P'$ in a 6-year-old child with a normal occlusion is 44.1 mm, and this gradually increases during growth. At the age of 13 years it becomes 50.0 mm, and is nearly consistent thereafter.

The increase of $A'-P'$ is brought about by the growth of the bone in the posterior border of the maxillary tuberosity. However, when the growth in this part is decreased, the $A'-P'$ angle is sustained, leading to an insufficient space in the posterior dentition, resulting in posterior discrepancy.

$A'6'$

It is the distance between the $A'$ and $6'$. This shows the protrusive length of the 1st molar in the maxillary basal bone. In an individual with a normal occlusion and without posterior discrepancy, the distance nearly does not change at all and the 1st molar position is extremely stable during the growth period.

However, in a patient with posterior discrepancy, $A'-6'$ decreases because of the eruption of the 2nd and 3rd molar associated with the mesial movement and the vertical pushing on the 1st molar. In effect, both the mesial movement and suprastructure are forms of posterior discrepancy. The degree of posterior discrepancy can be estimated with the $A'-6'$ parameter.

$A'6'/A'-P''$

This is the ratio of the values measured above. It shows the anteroposterior position of the 1st molar tooth in the maxillary basal bone.

0 Denture frame of the upper and lower frontal teeth and the measurement of the relationship of tipping and position of the molar.
1 – AB (°): the angle formed between the tooth axis of the maxillary central incisor and the AB plane.

1 – AB (mm): the distance from the incisal margin of the maxillary central incisor to the AB plane.

1 – AB (°): the angle formed between the tooth axis of the mandibular central incisor and the AB plane.

1 – AB (mm): the distance from the incisal margin of the mandibular central incisor to the AB plane.

Intermolar (°): the angle formed between the tooth axis of the upper and the lower 1st molar.

The angle and position of the frontal teeth are all evaluated through the relationship of the AB plane. Changes in the AB plane are due to maxillary rotation and adaptational change of mandibular position to the occlusal plane. Moreover, the AB plane and the occlusal plane are nearly at right angles to each other, and this reflects the adaptive capacity of the mandible to changes in the occlusal plane.

For example, the vertical dimension does not increase when there is a steep occlusal plane; the AB-MP angle increases because the mandible adapts to it. As a result, there is the relationship of the occlusal plane to the right angle. On the other hand, when the occlusal plane changes to flat, the mandible takes the protruded position and the AB-MP angle decreases, thus maintaining the relationship of the occlusal plane to the right angle.

The first molar axis has the most stable centric stops when the occlusal force is in vertical direction. However, in a patient with posterior discrepancy, mesial tipping is usually extensive and this has to be uprighted through an orthodontic occlusal reconstruction. Uprighting of the molars provides space for the dental arch, which offers the possibility to improve crowding and protrusion.

Implication for Dental Practice – Developmental Mechanism of Growth Abnormality

Research studies of maxillofacial skull growth occupy an important position in dental and orthodontics.
research studies. When continuing the occlusal management of an orthodontic patient, it is important to note that the important elements of the maxillofacial growth concept are certainly within the maxilla and the mandible. The growth of the mandible through time disregards the orthodontic approach and the efforts of both the surgeon and the patient are instantly wasted.

Various orthodontists are puzzled by the thought that the growth phenomenon is nothing but abnormality. What, then, is the mechanism of this type of growth abnormality? To ascertain this, it is by all means important to conduct a very accurate occlusal reconstruction.

As mentioned, environmental factors have a strong influence on the maxillofacial skull growth after birth and, more importantly, in the dynamic function of the stomatognathic system. Without doubt, the abnormalities of occlusal function could easily displace the mandible. In fact, various malocclusions show a displacement of the mandible from the center position. Moreover, this displacement in malocclusions increases with age (Fig. 22).

As understood in the cybernetic model of Petrovic, mandibular displacement, mediated by the neuromuscular system, induces secondary growth of the condyle. A persistent mandibular displacement consequently results in displacement of the skeletal morphology. According to Moss, the latent growth capacity of the cartilage is extremely low. Mandibular elongation is explained as a secondary or compensatory growth, which is achieved through the functional displacement of the mandible, related to the protrusive movement of the maxilla.

If this is true, it may be concluded that the abnormality in mandibular growth is actually an abnormal adaptation to occlusal function in the normal skeletal pattern. Moreover, the sudden increase in the abnormality of the TMJ, post puberty, creates an abnormal occlusal function which makes the mandibular condyle adapt by means of immense growth. This growth, however, diminishes the growth capacity of the mandibular condyle. Either way, the abnormal growth is assumed to be probably caused by the functional factor of the stomatognathic system in occlusal function.

In the field of orthodontics, it was long believed that growth-related development was the basic culprit. Orthodontists blame the growth factor to be the unknown cause of skeletal malocclusion. In case of no response to malocclusion treatment, or when
the anticipated growth does not match with skeletal changes, or if there is recurrence of malocclusion after surgical treatment, abnormal growth may be considered to be the underlying cause. All inconvenient circumstances for the orthodontist are due to growth. If growth-related development alone is, indeed, the cause of the development of malocclusion, it would be impossible to disregard such development and simply improve malocclusion. In the long run, we cannot help but disregard orthodontic treatment.

To assert that growth is the culprit of all, as mentioned a while ago, is incorrect. Rather, the abnormal growth pattern is the result of mandibular adaptation related to occlusal function abnormality. Therefore, early orthodontic management has a very important implication in the harmony of maxillofacial skeleton growth. This viewpoint is important in reconsidering the developmental process of skeletal malocclusion.

Management does not end with tooth replacement, especially in occlusal training and occlusal guidance. The harmony of the maxillofacial skeleton and the management of the entire growth are important. In order to achieve these, it is important to understand the relationship between occlusal development, the maxillofacial skeleton, and the development of specific skeletal growth abnormality. This theory is merely based on the dynamic mechanism of the maxillofacial skeleton and the developmental mechanism of skeletal malocclusion.
Sadao Sato

Figure 1a and 1b: Composition of the craniofacial complex. The skull consists of several different sophisticated bones that collectively form a hollow bony shell that houses the brain and sense organs, and provides a base for the teeth and the chewing muscles. In the stage of growth, the bones are in a flexible state and are dynamically interrelated. The components also have the ability to adapt to functions of the skull. The skull functions as a base and a structural framework for the first stage of the digestive system and masticatory organ. It also serves as an encasement for the brain and for the sense organs of sight, smell, and hearing. The functional balance of craniofacial bones is influenced by occlusal functions such as mastication, respiration, speech, clenching and bruxism.

Figure 2a and 2b: Composition of the skull of humans and primates. The connection of the Occipital-Sphenoid-Vomer-Maxillary bones in the primate skull (a) shows an expanded and longer anteroposterior dimension than that in humans; (b) the human skull indicates expansion of the neurocranium and reduction of facial prognathism. A shift in the position of the foramen magnum can be seen due to the uprighting effect of the skull and the increase in brain size. As a consequence of the great reduction in the anteroposterior dimensions of the viscerocranium, the human skull exhibited wider and more vertical growth than the primate one.
Figure 3a and 3b: Comparison of cephalogram tracings of human and primate skulls. In contrast to humans, primates have a large cranial base angle (N-S-Ba) with a posteriorly located foramen magnum and forward translation of the vomer and the maxillary bone. The modern human face tends to rotate backward and downward underneath the brain case, with the brain developing on the top of the facial skeleton. The human cranial base located between the face and the brain assumes a larger bend, thereby reducing the degree of flexure (N-S-Ba) compared to that in primates.

Figure 4: Superimposition of cephalogram tracings from modern humans and primates. This superimposition indicates how the flexure of the cranial base angle is related to changes in the craniofacial skeleton. Reduction of the cranial base angle greatly influences the facial profile and the direction of growth of the maxillary complex.

Figure 5: Verticalization of the viscerocranium during ontogenetic growth and development. As the viscerocranium increases in its vertical rather than anteroposterior dimensions, the facial complex of the modern human creates the necessity of functional mandibular adaptation in order to fit upper and lower dentitions.
Figure 6a and 6b: Adaptation of occlusion against verticalized growth of the facial skeleton. Vertical growth of the viscerocranium in the human skull creates an anterior open bite (a); the maxillary complex translates downward, resulting in posterior contact of the upper and lower teeth (wedge effect). Functions of the anterior mimetic muscles such as the orbicularis oris, mentalis, depressor and levator anguli oris, and buccinator muscles, include closing the mandible and helping to adapt the mandible by rotational movement, so that it fits with the upper and lower occlusal surfaces (b). Patients with weak mimetic muscle activity develop an anterior open bite malocclusion, as the mandible cannot adapt through rotation.

Figure 7: Craniofacial connection of the Occiput-Sphenoid-Vomer-Maxillary bones. The sphenoid bone is located in the center of the skull and joins with other mid-line bones such as the occiput, ethmoid, and vomer. It is directly connected to the maxillary bone via the vomer and palatine bones. The sphenoid bone is also connected to the occipital bone by a synchondrosis known as the sphenoid-occipital synchondrosis, which is in dynamic motion during the development of occlusion. The dynamic motion of the cranial base is transferred to the maxillary bone through the vomer bone.

Figure 8: Temporo-mandibular complex. The mandible is connected with the temporal bone through the temporomandibular joint. The complex is the most dynamic functional unit in the craniofacial skeleton. Dynamic movement of this complex influences the state of the Occiput-Sphenoid-Maxillary complex.
Figure 9: Connection of the sphenoid and temporal bones. The vertical and horizontal portion of the greater wing of the sphenoid and temporal bone are interconnected by a heavy butt joint (arrow). The dynamics of the temporal bone influence the spheno-occipital balance of the cranial base through this heavy joint. If the glenoid fossa were to receive compressive force from occlusion, especially when the upper and lower teeth grind strongly during bruxism, the forces would be transferred to the cranial base via the rotational movement of the temporal bone.

Figure 10: The dynamic connection of the Sphenoid-Vomer-Maxillary bones. The vomer bone plays an important role in transferring cranial motion to the maxillary bone. Therefore, the motion of the cranial base influences displacement of the maxillary bone.

Figure 11: Connection of mid-line bones and bilateral temporal bones. The mid-line bones of the cranium undergo a motion defined as flexion and extension. Two of the mid-line bones, the greater wings of sphenoid and occiput, articulate with the petrous portion of the temporal bone. This petrous extension acts as a rotational axis (petro-temporal axis) during motional activities.

Figure 12: Dynamics of the Temporo-Parietal suture. The long beveled suture of temporo-parietal bones possesses the ability of gliding movement. Reciprocating movements of the suture from external forces adjust themselves to balance cranial bones. The presence of malocclusion will disrupt the temporo-mandibular joint, resulting in mandibular displacement, which in turn causes distortion of the temporal bone.
Figure 13: Sagittal connection of the Occiput-Sphenoid-Vomer-Maxillary bones. The flexion-extension motion of the cranial base influences the direction of maxillary bone displacement, followed by sutural growth.

Figure 14a, 14b and 14c: Sagittal expression of the relationship between motion of the cranial base and displacement of the maxillary complex. Flexion of the cranial base causes vertical elongation of the maxilla while extension causes anterior rotation of the maxillary complex.

Figure 14b

Figure 14c
Figure 15a-15d: Different types of maxillary bone displacement. There are 3 types of maxillary displacement: translation (b), vertical elongation (c), and anterior rotation (d), according to the growth study done by Precious et al. (1987). It was suggested that the different types of maxillary displacement were closely related with cranial growth and cranial motion. Increase of the anterior cranial base causes translational displacement of the maxillary complex. The flexion motion of the cranial base induces vertical elongation of the maxilla while extension provides anterior rotation of the maxilla, as shown by an anterior-upward inclination of the palatal plane on the cephalogram.

Figure 15c and 15d
Figure 16: Growth of the upper jaw and eruption of posterior teeth. Most of the growth in the anteroposterior dimensions of the maxilla originates through bone apposition from the posterior aspect to the maxillary tuberosity. The initial appositional growth at the tuberosity arises with forward translation of the maxillary complex. Lack of maxillary translation makes it difficult to provide eruption space for the posterior molars; this creates posterior discrepancy.

Figure 17a and 17b: Frontal view of the craniofacial complex. Connection and posture of sphenoid, temporal bone, vomer, maxilla, and mandible are closely interrelated with the dynamic function of occlusion (a). Unilateral over-eruption of posterior teeth creates posterior interference and induces a mandibular lateral shift. Consequently the individual develops an asymmetrical balance of the craniofacial complex (b).
Figure 18a and 18b: Function of occlusion and mandibular growth. In the growing facial skeleton, adaptability is primarily located in the function of dentition and secondarily in the sutures and at the condyles. The growth of the lower face is guided by the function of occlusion, followed by secondary condylar growth. Thus, the three-dimensional change of the occlusal plane is an extremely important determinant of facial growth (a). Horizontalization of the maxillary occlusal plane provides rotational mandibular adaptation, with a simultaneous reduction in the mandibular plane angle (b).

Figure 19: Denture frame analysis of the lower face. Palatal plane (PP), mandibular plane (MP), maxillary occlusal plane (OP), and AB plane (AB) are used to assess the construction of the lower face. The Frankfort horizontal plane (FH) is used as a cranial reference line.

Figure 20: Longitudinal changes in the denture frame in a normally growing subject. The pattern of mandibular growth is closely related to changes in the spatial position and inclination of the upper occlusal plane.
Figure 21a and 21b: Longitudinal growth patterns of denture frame in cases developed skeletal Class III (a) and Class II open bite (b) malocclusions. Alteration of occlusal plane related not only with mandibular posture, but also with dynamic state of the cranial base.

Figure 22a and 22b: Shows two adults with skeletal Class III (a) and skeletal Class II (b) malocclusions. Differences in the length and angle of cranial base, position and inclination of the occlusal plane, position and posture of the maxilla and mandible, and dento-alveolar vertical height are seen.
References


