A Review of the Clinical Significance of the Occlusal Plane: Its Variation and Effect on Head Posture

"Optimizing the Neuromuscular Trajectory - A Key to Stabilizing the Occlusal-Cervical Posture."

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Abstract
Head posture is a resultant response of environmental influences on the growth and development of the cranio-mandibular complex. A review of the literature substantiates the importance of a proper occlusal plane orientation and how it plays a major role in postural stability. Failure to recognize and treat cranio-mandibular dysfunctions without an understanding of the importance of head posture and proper occlusal plane orientation during the diagnostic and laboratory phase can often result in relapse of the "rehabilitated" cranio-mandibular dysfunction (CMD) patient. The importance of optimal head positioning is significant relative to many areas of dentistry such as bite registration, occlusal plane determination and occlusal management for fixed reconstruction, full denture, and orthodontic diagnosis and treatment. A physiologic level head position with an accompanying average 6-10 degree anterior sloping occlusal plane has been confirmed in literature. This paper discusses how these neuromuscular principles have effected the orientation of the occlusal plane as it relates to head positioning, the cervical neck alignment, and how the neuromuscular trajectory can affect head posture. Computerized mandibular scanning (CMS) and electromyography (EMG) objectively substantiates these findings. Boney and soft tissue reference planes are discussed to help give the clinician a practical way to mount the maxillary cast using the Fox occlusal plane analyzer in a modified manner. Recent research data comparing two methods using a modified Fox occlusal plane method and the classic HIP (hamular notch and incisive papilla) reference method to mount the maxillary cast is presented and compared. Discussion as to these findings and clinical relevance are also presented showing the importance of a proper occlusal plane reference which impacts the diagnosis and treatment of phase II therapy of the comprehensive restorative/orthodontic case. Head posture and the clinical significance of the occlusal plane orientation must be considered if the clinician desires to bring stability and health to the stomatognathic cervical system.

INTRODUCTION

The dental complex is composed of many structures that are involved in such functions as respiration, speech, balance and posture. The relationship of these structures to one another is orthopedic in nature. Many muscles of this complex assist in chewing and swallowing with the help of the temporomandibular joints, the atlas, the cervical and thoracic vertebrae. In addition, the shoulder, the sternum and clavicle, are all part of this dynamic moving system during swallowing and mastication. All these structures are a part of the neuromuscular system. These structures must be coordinated and synchronized with a correctly aligned masticatory organ if these body functions are to smoothly function without stress or strain and in balanced form with one another. The study of these structural relationships affirms that cranio-mandibular orthopedics is a logical and natural forward progression of study based on physiology, physics and bio-mechanics which are all part of traditional dentistry.

Many have recognized the most significant of structural relationships within the neuromuscular system is the relationship of the mandible to the cranio-maxillary base.[1,2] It has been recognized that mandibular posture as it relates to the cranio-maxillary complex (skull) is influenced both by proprioceptive intra and extra oral forces and lower postural changes distant from the head and neck. Accommodative postural influences may occur within the stomatognathic neuromusculature in pathologic dysfunctional conditions, such as malocclusion. Pathologic engrams, habitual muscle patterns, and iatrogenic environmental influences develop into altered states of teeth, temporomandibular joint conditions, and the central nervous system's health.[3,4] In physiologic normal states, habitual engrammed muscular patterns develop as a result of balanced occlusion.[5-7] Malocclusion occurs when physiologic states are altered and persistent muscle tension is sustained altering the mandibular opening and closure patterns, the feedback and control mechanisms, as well as the craniomandibular cervical postural system.[8-12] These observed musculoskeletal occlusal dysfunctions explain the prevalent muscle dysfunctions, pain and temporomandibular joint derangement pathologies commonly observed in clinical practice.[13-15] It should not be assumed that a habitual centric occlusal position and temporomandibular joint position are always compatible with the neuromuscular system, but rather resulting structural alterations, breakdown, and adaptive changes due to these pathologic accommodations occur within the musculoskeletal occlusal system, leading to further dysfunction.

Patients experiencing craniomandibular dysfunction (CMD) are a result of developmental pathologies that stem from early childhood chronic mouth breathing, chronic allergies and aberrant tongue posture.[1] Patients who present with craniomandibular disorders or TMD typically have a forward head posture involving the neck, shoulder, and mandible.[8,16] The dominance of the teeth and their inherent proprioceptive mechanisms has been noted as a prominent factor in the accommodation of the skeletal bones, the muscles and the central nervous system.

Scientific Literature Review

There is a substantial body of literature that confirms the connection of head posture to the lower musculoskeletal system and its impact on craniomandibular disorders. The scientific neuromuscular arena has clearly established a physiologic relationship between the craniomaxillary complex with the mandibular occlusal joint complex in multi-dimensions starting from a homeostatic rest position.[1,17] Literature both in the orthodontic as well as the restorative and prosthodontic arena substantiates the maxillary to cranial base orientation as it relates to earths horizontal level.[18-21] The orthodontic and orthopedic literature acknowledges a need to properly align the head position and cranial base for cephalometric evaluation and diagnosis. The orthodontic and prosthetic literature have also consistently confirmed through scientific studies and techniques that the maxillary occlusal plane does produce a downward angulating average slant of 6-10 degrees as referenced from a level head position.[23-24] (Figure 1) Although very little has been written to discuss the correlation of the neuromuscular myo-trajectory in the antero-posterior and frontal domain and its impact on head position and the cervical neck relationship,[25] it must be recognized that form follows function. A pathologic mandibular and cervical posture will contribute to a compromised forward head position enhancing the mal-alignment of the maxilla and influence the neuromuscular trajectory. An aberrant occlusal plane orientation, abnormal occlusal chewing patterns and jaw closure patterns posterior to the neuromuscular trajectory or myo-trajectory are functional outcomes of a pathologic form. Pathology will only support pathology. Physiologic health will support healthy form and optimal function.

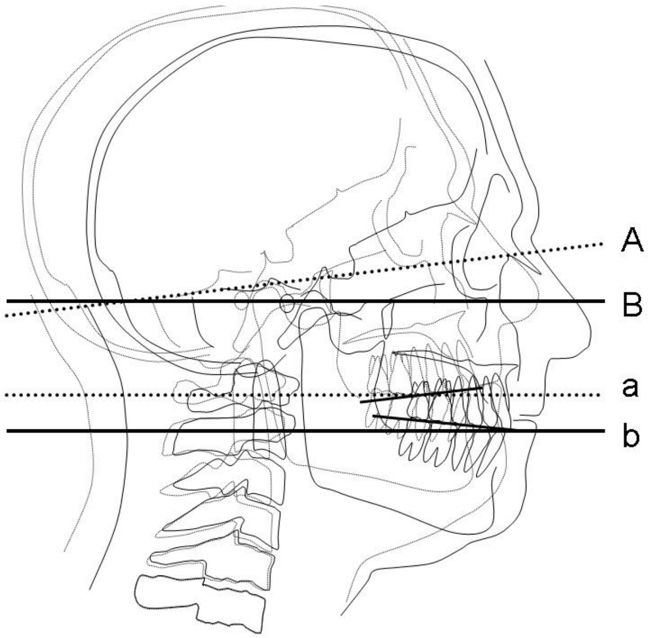


Figure 1: Head posture is a resultant response of environmental influences on the growth and development of the cranio-mandibular complex. The occlusal plane plays a major role in postural stability. Upward head posture with an accompanying upward sloping occlusal plane (A and a). Physiologic head position with a 6-10 degree anterior sloping occlusal plane (B and b).

Yamada, Ogawa and Koyano (1999) investigated the effects of head posture on mandibular habitual closing movements. As the head bent forward, the closing path approached the maximum intercuspal position from the anterior region, and as the head bent backward, the closing path approached the maximum intercuspal position from the posterior region. A correlation between head posture and stability of the closing movement was reported. It was reported that forward bending of the head decreased the stability of the closing path, and conversely, the backward bending increased the stability of the closing path. Clinicians have confirmed that head posture affects the direction and stability of the mandibular closing movements due to masticatory muscle activity, tension and resistance of inframandibular soft tissue varying with changes of head posture.[26]

The musculoskeletal system must be more fully understood both in its static as well as kinetic functional state before abnormalities, dysfunctions and pain mechanisms can be recognized. Pathologic changes of the craniomandibular cervical complex can be prevented by understanding these systems and applying principles and techniques to reverse the abnormal and disabling causes of these musculoskeletal dysfunctions. Through optimization of the neuromuscular trajectory up from the physiologic rest position, numerous clinicians have confirmed through scientific methodologies that improvement has occurred both to the craniomandibular and postural complex of the treated patient population.[17, 27] (Figure 2) It is through these significant findings that positive neuromuscular responses have occurred in the treatment of the compromised musculoskeletal dysfunctional case involving the head and neck region.

OPTIMIZING THE NEUROMUSCULAR TRAJECTORY
Using the Chan Protocol

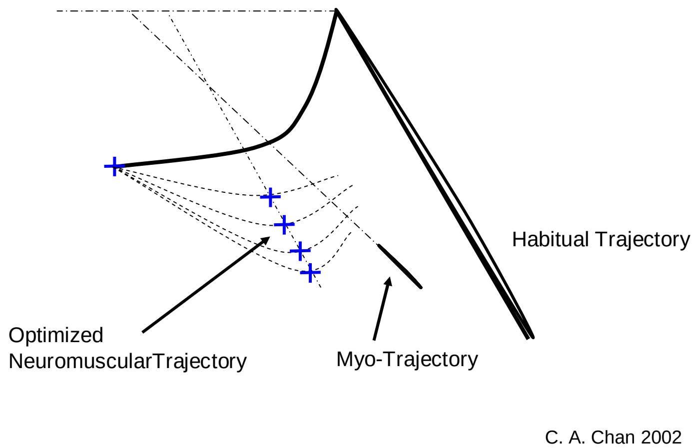


Figure 2: CAREFULLY OBSERVE THE REPEATING CURSOR POSITION! "The patient is asked to protrude and *slowly* relax the mandible multiple times, observing a consistent repeatable position of the mandible in the antero-posterior domain". Optimizing the neuromuscular trajectory and mandibular vertical relationship, requires a need to overcome proprioceptive pathologic occlusal engrams and neuromuscular influences. (Myotronics K7 Kineseograph, Scan 5 [*]).

Development of Head Posture

Huggare and Raustia (1992) described the correlation of head posture and the close interrelationship between the masticatory muscle system and the muscles supporting the head as they relate to treating craniomandibular disorders. [28] Head posture represents an enter play between the cellular metabolic process of respiration and the balance between intra and extra oral forces of muscle tension, teeth, jaw joints and the central nervous system. Garry and Gray were strong proponents of a patent upper airway and indicated that there is a constant need for oxygen during resting states and body functioning modes of work, that optimally is satisfied via patent upper airways of the nose.[29, 30] Common sense dictates that when upper airway obstruction occurs there is a concomitant lowering of the mandible increasing the mandibular plane angle.[31] If one cannot get enough air through the nose, he or she opens the mouth, resulting in: mouth breathing, increased facial height, increased mandibular plane angle, increased angulation of the mandible to sella nasion line, forward head posture, retrognathic mandible, short sagittal depth of the nasopharynx, a long and narrow face, rolled shoulders and a non-physiologic low tongue position at rest.[29, 31, 32] (Figure 2 and 3) A forward head posture will always influence the physiologic resting state of the mandible and will always contribute to "abnormal jaw closure patterns" (Wolford), posterior to an optimal myo-trajectory.[33] Abnormal jaw closures that are posterior to an optimized neuromuscular trajectory can have devastating results, especially in restored full mouth reconstruction cases that did not acknowledge these significant signs and symptoms that led to the need for intra oral rehabilitation. Rehabilitation of worn and debilitated dentition does not start with the rehabilitation of the teeth, but with a diagnosis and awareness of these underlying problems. A thorough treatment plan should acknowledge the complete craniomandibular, cervical, postural, and breathing system for long term occlusal stability and success.

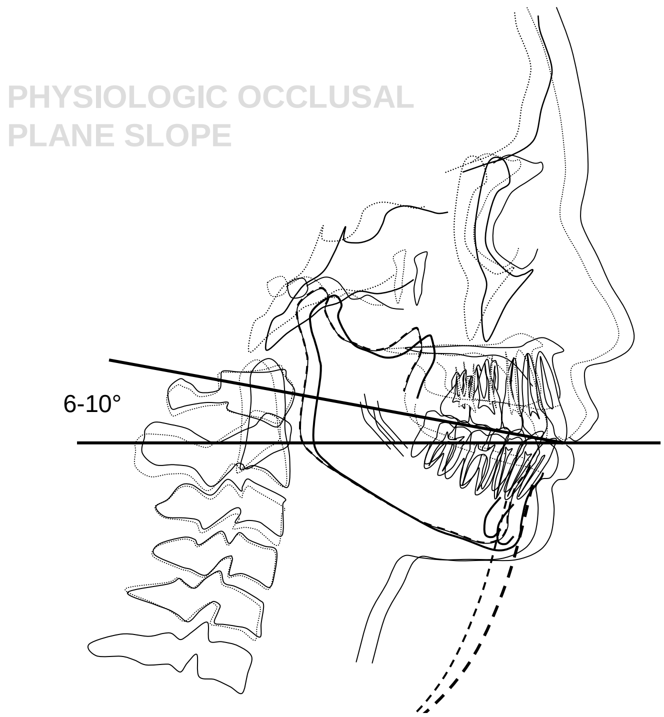


Figure 3: As the mandible relaxes from the habitual trajectory anterior to the neuromuscular trajectory, the head position also changes from an upward position to a relative horizontal level changing the orientation of the occlusal plane angulation and associated structures.

The Effects of Upper Airway Restriction

Abnormal open mouth breathing and abnormal tongue posturing can be devastating to the otherwise normal development of the craniomandibular cervical neck complex, leading to numerous musculoskeletal-occlusal signs and symptoms of TMD/TMJ. Some of these signs can be clinically exhibited as crowding of the anterior teeth, bicuspid drop off, deep curve of Spee, deep bites, cross bites, lingually inclined teeth, high vaulted palates, and narrow arches. These are often accompanied by clicking/popping joints, ear congestion feelings, temporal headaches, neck aches, and shoulder pain.[34-38]

Wolford (2003) indicated that these dysfunctions of the craniomandibular cervical complex are a result of “abnormal jaw closure patterns” (posterior to myo-trajectory).[18, 33] Abnormal jaw closure patterns contribute to kyphosis of the neck, upward head tilt and realignment of the eye gaze that can mislead the clinicians in determining an optimal head position. It is folly to believe that a narrow compromised airway breathing passage either through the nose or oro-pharyngeal area will produce stable cervical neck posture and stable occlusion. (Figure 4-7) Consider the compensating forward head posture on the musculature of the cervical area and posteriorizing occlusal forces that contribute to mal-occlusion. This is due to imbalanced muscular forces that often posteriorize the mandible contributing to an abnormal forward and lateral tongue posture. Restricted volume of oral pharyngeal space due to a retrognathic jaw will produce abnormal occlusal forces and strains on teeth retention.

"Poiseuille's Law" indicates that if you take a tube of one centimeter in diameter and remove one millimeter of its circumference, the increased resistance to flow will be a phenomenal 28%.[39] The same can be considered with slight restriction in nose diameter resulting in an increased resistance in the turbinate's or decrease in the oral pharyngeal region due to hypertrophied tonsillar tissue increasing the actual caloric work load (output) 80,000 times normal a year, this leads to forward posture without a person being conscious of it.[40]

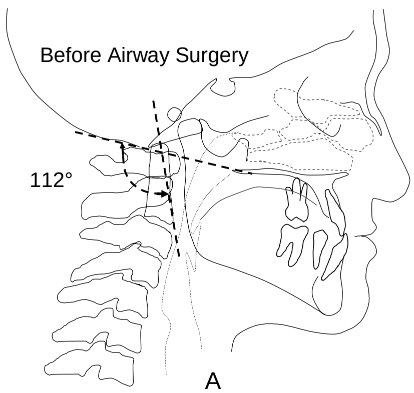


Figure 4: 17 year old male with obstructed upper airway and forward head posture (basi-occiput to odontoid angle 112°) – Class III molar relationship (A). After airway obstruction surgery (septoplasty and turbinectomy) patency and improved head posture was noted (basi-occiput to odontoid angle 105°) with improved mandibular posture – Class I molar relationship (B).

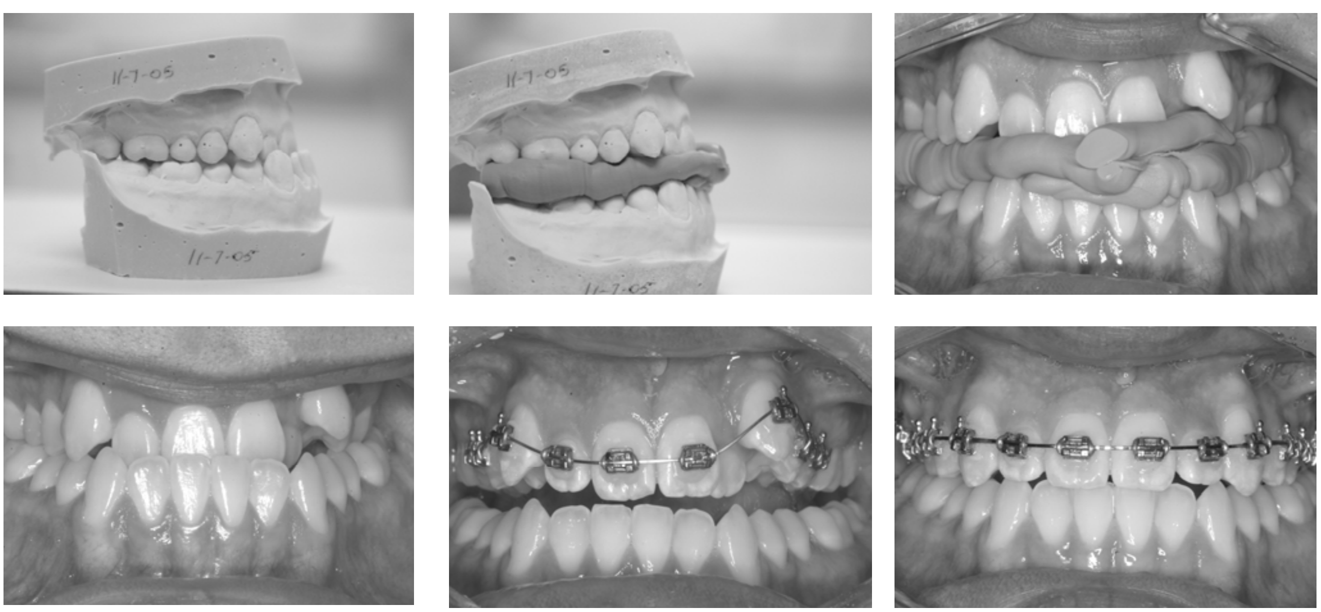


Figure 5: An initial .016x.016 Thermal Kinetic arch wire (Ortho Organizers, Carlsbad, CA) was used to begin leveling and aligning of this 17 year old male. Round .016 NiTi segment wire with open coil

spring (not shown) to further develop arch space with maxillary Nitanium Palatal Expander (NPE2) followed by a .018x.025 NiTi arch wire. β

Figure 6: 7 months wear of NPE2 (Nitanium Palatal Expander 2 – Ortho Organizers, Carlsbad, CA) to assist in orthopedic arch development and spacing for upper left canine.

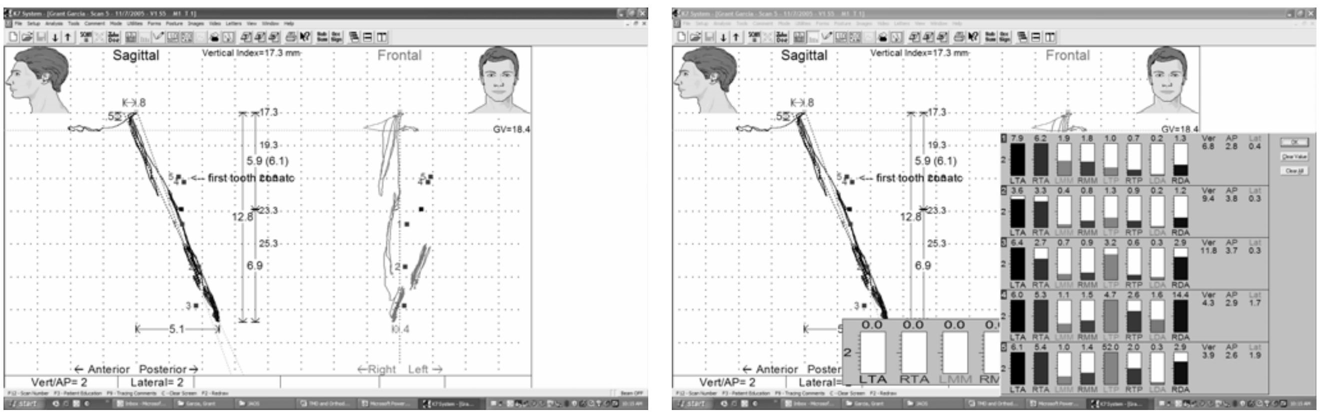


Figure 7: The diagnostic importance of validating vertical dimension increase and its accompanying horizontal change in mandibular positioning confirms the need for quantitative data of existing muscle tension and skeletal mal-relation in evaluating the indications for surgical correction of prognathism. Since the mandible moves posteriorly an average of 1 mm for every 2 mm of increased vertical opening (1:2 A/V ratio), the mere act of vertically repositioning the mandible 5 mm to a more open, relaxed position concomitantly moves the mandible 2.5 mm posteriorly, altering the Angle classification and eliminating the need for mandibular realignment surgery.

Garry emphasized the need for *upper* (nose) airway evaluation. He stated "The most significant principle to understand is that teeth seek a neutral position within a system of forces acting on them. The force system changes constantly during growth and development. Teeth move in response to stimuli in their environment, so does head position change on the cervical neck structures. Clinical observation can, with experience, enable a dentist to assess the force system in a child or adult and determine whether the position of the teeth may improve or deteriorate when balance between the dentition and force system has been established." [40]

GROWTH AND DEVELOPMENT OF THE OCCLUSAL PLANE

The predominant features of the developing newborn's face are composed of a large basi-cranium, orbits of the eyes, a nasal cavity, and a primitive U-shaped mandible with a bulbous alveolar process.[41, 42] The brain within this large cranium is a highly innervated developing neurological command center designed to face the new worlds challenges as it begins to take its first breath of air and initiate the swallowing movement. The mandible of the newborn is suspended in its muscular sling and functions uninhibitedly in all directions. The voluntary functional movement is a forward-backward movement to secure and swallow milk.[21] At birth the tongue lies over the developing alveolar ridges. During infant feeding the tongue expels its food forward. There is no proprioception for its lateral borders due to lack of teeth, but over time this unlearned tongue reflex disappears as it matures. As the child develops, the mandible throughout its growth phase becomes increasingly constrained often in its forward direction during closing as the deciduous central incisors erupt into position. Later a vertical stop evolves when the deciduous first molars attain occlusal contact setting the stage for facial and intra oral vertical dimensions.

Once all the deciduous teeth erupt, a highly coordinated opening and closing path of the mandible is developed to reach an occlusion with precise interdigitation through cusp and fossa contacts of molars and the pointed cusps of the canines. As a result, the occlusion of the deciduous dentition actually serves as the key that controls the engrammed muscular patterns for further growth and development of the mandible and maxilla throughout life. As long as there is no retention of noxious habits, no chronic upper respiratory allergies, no chronic obstructing tonsils or adenoids, and no genetic orofacial deformities that would displace the tongue, lips, and cheeks, creating abnormal force vectors against the palate and erupting dentition, a normalized growth and development of the dentition, orofacial morphology and cervical head posture will occur.[31]

Developmental Effects of the Swallowing Muscles on Jaw Posture

Moyers (1940) classical study using electromyography to plot normal and abnormal facial muscle function during the suckle swallow and relative nonuse of facial muscles in the mature swallow[43] was confirmed by Graber's study on comparative muscle pressures during normal swallow. Only the lateral pterygoid, anterior and middle temporal, and posterior muscle fibers showed moderate activity. The remaining muscles, including the facial group, showed only slight activity, whereas in an abnormal swallow there was a larger component of facial muscle activity and an altered pattern in the muscles of mastication.[44] Abnormal jaw opening and closure patterns will result when the infantile swallow is retained due to a generalized weakening of the intra and extra oral masticatory muscles leading to mal-aligned teeth and dental arch formation. Muscles of mastication become more active as the child progresses from an infantile swallow to a more mature swallow.

Moorees (1995) wrote, "Figuratively speaking, the mandible is a marionette moved by physiologic strings. But it is well endowed by nature to respond to changing needs through remodeling of its body (particularly the entire inner and outward surfaces of the ramus), as well as condylar growth to maintain the joint function. Even the change from distoclusion to neutroclusion during orthodontic treatment is well within the capability for adaptive growth processes in the human being."[21]

Compensatory Development of the Cranio-Mandibular Postural System

Enlow proposed the question and simply asked: "If a given increment is added to a specific bone, or soft tissue part, *where* must an equivalent increment to be added to *other* bones or parts if the same form and balance are to be retained?"

The process of compensation is a developmental process that provides latitude of imbalance in certain areas of the body in order to offset the effects of disproportions in other areas and regions. The growth and development is not randomly orchestrated by nature, but is a systematic planned growth process. (Figure 8) The "Counterpart Principle" of craniofacial growth also applies to all neuromuscular systems of the craniomandibular cervical complex. It states that the growth of any given facial or cranial part relates specifically to other structural and geometric "counterparts" in the face and cranium. The maxillary arch is a counterpart to the mandibular arch. The upper cervical alignment is counter to the lower body alignment, so is the head posture counter to the mandibular posture.[45]

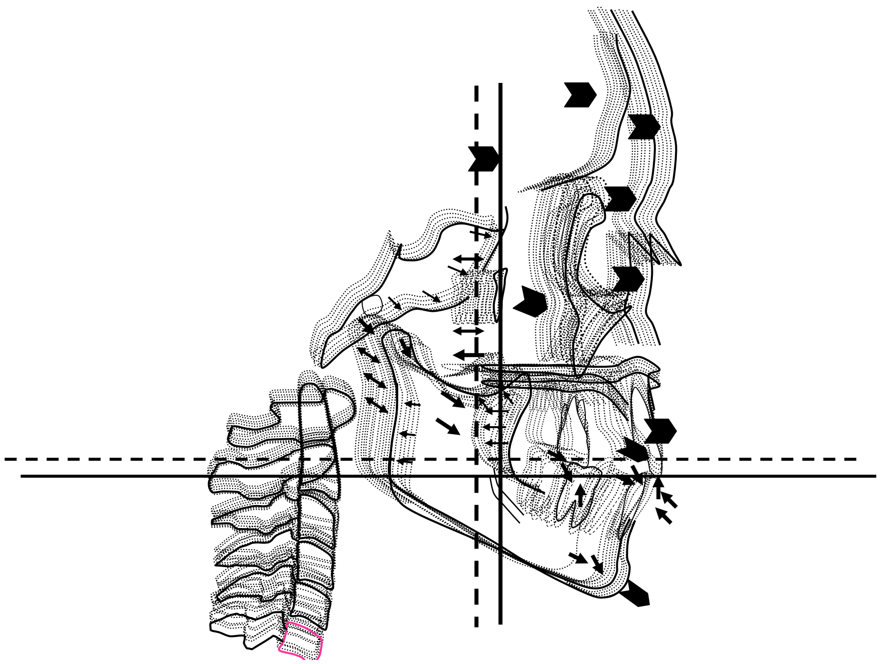


Figure 8: Growth and development of the cranio-mandibular complex are composed of multiple remodeling and displacement movements of the facial, cranial, and mandibular regions. Influencing forces on any part of this complex can alter the growth and development of the occlusal plane affecting form and function. A perfectly balanced mode of growth in all the parts of the face and cranium **never** occurs in real life (Enlow).

Remodeling of the Maxillo-mandibular Complex

As the maxilla develops and elongates in the posterior region of the maxillary tuberosity, the anterior cranial fossa, the palate, and the body of the mandible also has to follow and lengthen. The mandible does this by remodeling the anterior part of the ramus posteriorly, still leaving an offset relationship between the upper and lower arches with the maxilla more protrusive than the mandible (Class II type relationship). To keep pace with the anterior directed maxillary growth, the posterior portion of the ramus remodels. Anterior portion of the ramus resorbs and the posterior portion remodels, maintaining the same width of the ramus and at the same time relocating it more posteriorly to allow for lengthening of the body of the mandible and allows for perfect positioning of the mandible with the maxilla returning to a Class I position of the teeth. The upward and backward remodeling of the ramus occurs to lengthen the vertical dimension and provides horizontal enlargement of the mandible with a further descent of the mandibular arch and occlusal separation.

As growth and development occurs, the cranial floor also changes due to dimensional growth changes in the temporal lobes of the cerebrum and the middle cranial fossae. Resorption on the endocranial side and deposition of bone on the ectocranial side occurs at the spheno-occipital region of synchondrosis (a major cartilaginous growth site of the cranial floor). All structures anterior to the middle cranial fossa grow in a forward direction. The forehead, anterior cranial fossa, cheekbone, palate, and maxillary arch all undergo protrusive displacement in an anterior direction.

The ramus is the specific structural counterpart of the middle cranial fossa. Both are counterparts of the pharyngeal space. The skeletal structure of the ramus bridges both the pharyngeal space and middle cranial floor in order to place the mandibular arch in proper anatomic position with the maxilla. This makes the antero-posterior position of the ramus a critical component for balanced alignment of the craniofacial structures. The former protrusion of the maxilla has now been matched by the mandibular protrusion. The molars once again returned to a Class I position, and the upper incisors no longer have an over-jet.

Remodeling of the Nasomaxillary Complex

Enlow has noted extensive remodeling of the nasomaxillary complex during development in an anterior and inferior growth direction and lengthens posteriorly. The displacement and remodeling growth centers in the posterior and anterior regions of the maxilla is a response to clockwise or counter-clockwise rotating displacements caused by the down and forward growth of the middle cranial fossa. In compensation, the nasomaxillary complex remodels itself in a rotational manner in order to maintain its position relative to the vertical axis and orbital axis of the head.[45]

The nasal bones grow forward due to the expanding anterior cranial floor due to the enlarging brain as well as the surrounding sutures that connect each frontal, parietal, occipital and temporal bone. The upper part of the face, the ethmomaxillary nasal region, also undergoes incremental growth further developing the nose and face.

The vertical lengthening of the nasomaxillary complex is due to the internal resorption of the superior nasal side of the palate and deposition on the inferior oral side, thus producing a downward remodeling movement of the palatal form. This allows for increased enlargement of the nasal region to keep pace with the developing lungs of the body. This sets the stage for a variety of compensatory changes and orientation of the developing maxillary arch. This relocates the maxillary arch in an inferior direction that allows for enlargement of the overlying nasal cavity.[45]

Remodeling of the Maxillary Complex

The anterior portion of the maxilla is comprised of periosteal bone that is resorptive. This area grows straight downward. The labial or external side of the premaxillary region faces mostly upward and away from the downward direction of growth and is resorptive in nature. The lingual side faces downward and is depository in nature. This growth pattern provides for the remodeling of the alveolar bone as it adapts to the changing positions of the incisors. The maxillary midline undergoes sutural deposition of bone due to physical growth forces underlying the soft tissue. Similarly the movement of the teeth is also by downward displacement of the whole maxilla, carrying the entire dentition passively with it. Each tooth moves or drifts on its own in a downward direction with the addition and resorption of each tooth socket. The vertical drift is a significant concept overlooked in most teaching curricula and literature. Vertical drift is not eruption as it is often confused, but rather it is an addition to eruption due to the additive and resorptive processes of bone remodeling and deposition. This is significant in understanding orthodontic/orthopedic movements.[45]

The whole palate and maxillary arch is able to remodel and is prone to displacing movements either clockwise or counterclockwise in a rotational manner. The selective remodeling process occurs either in the anterior or posterior portions of the nasomaxillary complex undergoing counter rotational changes caused by growth and developmental influences in the middle and anterior cranial fossa.[45] Anterior or posterior nasal obstruction can contribute to clockwise and counter clockwise rotational influences of the maxillary arch.

The rotations, tipping, and inferior drift of the individual maxillary teeth, in combination with the characteristic external bony resorptive surface of the whole forward part of the maxilla occur during palatal growth and remodeling. Over time a near complete exchange of old for new hard and soft tissue occurs from childhood to older age. At each successive descending level of growth, the palate literally becomes a different palate due to the dynamics of connective tissue, epithelia, blood vessels, nerve extensions, etc. In actuality when one visualizes the palate of a newborn and a young child, the clinician should realize that the palate in that same person at an older age is not the same palate.[45]

Dentists are able to control these movements by substituting nature's controls with clinical treatment influences when natures own intrinsic biologic controls have been influenced. If alteration to the composite balance has occurred during childhood growth and development, intervening treatment methods can be implemented to direct and control the influencing forces toward stability to overcome the disrupted system. Teeth have little capacity to remodel, but can only be displaced and moved either individually within the socket or as an arch unit.

The maxillary arch is able to grow downward and the mandibular teeth and alveolar bone drift upward to attain full occlusion. This downward and upward tooth movement process occurs due to superior drift of each mandibular tooth and remodeling of the alveolar process. The extent of downward drift of the upper teeth can exceed the upward drift of the lower teeth if there are significant imbalances within the system resulting in mal-alignment of the teeth and cervical head posture.

Natural increases in palatal width are the result of vertical drift of the posterior teeth with expansion laterally occurring according to Enlow's V principles of growth. This is different than the therapeutic induced expansion of the mid-palatal sutures which is entirely a different process. Increase in arch width results mainly from remodeling of the alveolar process laterally and inferiorly. Expansion and remodeling from non sutural expansion is subject to the same rules of biologic balance as when applying expansion mechanics to mid sutures during orthodontic treatment.

Natures Tendency Toward Downward and Forward

During growth and development there is a natural tendency toward downward and forward growth of the face relative to the cranial base.[18, 42] The mandible remodels in a predominately posterior superior manner as it simultaneously becomes developed in an anterior inferior direction. It is sufficient to realize that as the mandible develops in a down and forward fashion over time that, if harnessed or entrapped during orthodontic therapy or comprehensive restorative treatment, the mandibulo-occlusal entrapment will have significant bearing on the stability and long term prognosis of the patient's health. (Table 1)

The difficulties experienced in treatment can be attributed directly to the extent of the excessive disharmony of the breathing mechanism as well as disharmony in the craniomandibular cervical postural patterns. It is better to recognize these disharmonies early in treatment and inform the patient than later to be embarrassed by the challenges that may arise once treatment begins.

A Forward Head, Hunched Shoulders, and a Abnormal Jaw Closure Pattern Produce the Following Bodily Adaptations

- Decreased neck rotation and upward rotation.
- Decrease breathing depth (less efficient).
- Increased upper back and back of shoulder muscles fatigue.
- Makes upper back muscles and spine more injury prone.
- Increases risk for temporomandibular (jaw) joint problems.
- Increases load on cervical spine, which, when combined with excessive forward curvature of the cervical spine, increases the probability of ruptured discs, and pinched nerves.
- Lower spine curvature changes - Can cause chronic lower back pain and may alter pelvic position.
- Reduce overall biomechanical efficiency and hinder proper function of most organs, which reduces overall physical performance.
- May increase injury risk because of decreased load-bearing abilities.
- Can contribute to height loss of more than 2 inches.
- Makes one look stooped, saggy, and "old", which hurts self-perception and confidence, and does not convey to others confidence, competence, vigor, energy, or athleticism.

Table 1

INFLUENCING FACTORS ON THE UPPER AND LOWER POSTURAL SYSTEM

Evidence has accumulated over recent years that support the view that environmental and neuromuscular influences may alter dentofacial and craniomandibular cervical structures. The morphologic changes have shown some recovery following neuromuscular treatment once the deleterious impacts have been removed. Harvold et al from his non human primate studies reported any factor lowering the postural position of the mandible will promote additional tooth eruption and increased lower anterior facial height. One such factor is the obstructed nasopharyngeal airway. [46, 47]

Linder-Aronson and Woodside (2000) listed a number of factors that were contributory toward malocclusions and altered skeletal relationships. Investigative studies confirmed the following list were contributory factors: Genetic predisposition, enlaraged adenoids, enlarged tonsils, allergic rhinitis, sleep apnea, deviated nasal septum, choanal atresia, altered mandibular posture, altered tongue posture, extended head posture, incorrect orthodontic treatment, e.g., creation of dual bites, amelogenesis imperfecta, weakness in the muscles of mastication, and thumb sucking. [46]

Lundstrom and Woodside studied mandibular growth directions of 260 participants at the Burlington Growth Centre study. During a 5 year period following adenoidectomy and established mouth-closed breathing they reported mandibular autorotation and horizontal mandibular growth direction occurred following changed mode of breathing. The results showed reduced lower facial heights, less steep mandibular plane angles, and more prognathic jaw movements (a reversal from retrognathism). [47]

In all these cases one or more conditions were found to contribute to: 1) altered mandibular posture – the mandible rotates down and back, 2) altered tongue posture – the tongue moves superiorly and anteriorly, and 3) extended head posture – *the mandible is held in position while the cranium and maxilla rotates upward.*

Obstructed Airway Effects on Cervical Posture
Nasal mucosal swelling has been noted to significantly contribute to mandibular incisor crowding. Solow and Sonnesen have shown a close association between incisor crowding and craniocervical posture.[48] Subjects with incisor crowding in both arches had craniocervical angles that were on average 3-5 degrees larger than subjects without crowding. It has been noted that a more vertically inclined to a more labially inclined incisor after a return from mouth to nose breathing occurred partly due to changes in tongue and orbicularis oris pressures. Lowe found a highly significant correlation between the activity in the genioglossal muscle and overbite and suggested that the tongues' postural activity exerts a definite influence on incisor positioning.[49]

Many investigators have shown that extended head posture relates to compromised oral respiration.[50-52] As the head postures forward, the posterior cranio-cervical muscles shorten and the anterior prevertebral, infrahyoid, and suprahyoid muscles are stretched. These stretched infrahyoid and suprahyoid muscles pull the mandible posteriorly and inferior resulting in musculoskeletal dysfunction of the head and neck. When the suboccipital and or sternocleidomastoid muscles are foreshortened the occiput is extended and the spinous process of C-1 will approximate the occiput which can create compression pathology in the high cervical region. This can result in suboccipital cervical pain radiating down the back and up as high as the vertex of the cranium. Keep in mind that an obstructed breathing passage (upper airway) will cause a forward head posture which will foreshorten the suboccipital musculature and elongate the prevertebral musculature, resulting in muscle engrammed posterior trajectory closure patterns with accompanying intra oral occlusal signs and symptoms.

Head Position and Respiration
Hellsing determined and confirmed the interrelationship between induced oral respiration, changed head posture, and the EMG activity of the suprahyoid muscles. [53] Hellsing and L'Estrange also found that the upper lip pressure decreased when the patient changed from nose to mouth breathing, but increased during 5 degree extension. There was a clear correlation between lip pressure and cranial posture. Thus, the long term effects of altered head position, compensatory muscle function associated with the extension and flexion of the head may be one of the determinants of craniomandibular cervical morphogenesis in the changing human. [54]

EVALUATING THE HEAD FOR BALANCE AND LEVEL

The head's center of gravity lies near the sella turcia which is anterior to the atlas and axis. When the head is positioned forward of this center of gravity the posterior cervical neck muscles relative to the flexor muscles of the neck will be hyperactive producing neck and shoulder pain. It is the extensor muscles that counter gravities force of the head whereas the flexors muscles are assisted by gravity. Constant muscle tonus of the posterior neck musculature prevents the head from tilting forward.

Cervically, both extensor and flexor muscles are also in balanced tonus with one another to support a neutral level head position.

Head posture and the eye gaze within the orbits is an accommodative response based on mandibular positioning within the cranial base. A mandible that exhibits an opening and closing pattern posterior to a myo-trajectory will have an accompanying forward head posture (kyphotic cervical spine) with an upward head tilt. A mandible that exhibits an opening and closing path along the myo-trajectory anterior to the habitual closing path will have a more normalized head position with the head at level (downward tilt from the accommodated position). (Figure 9)

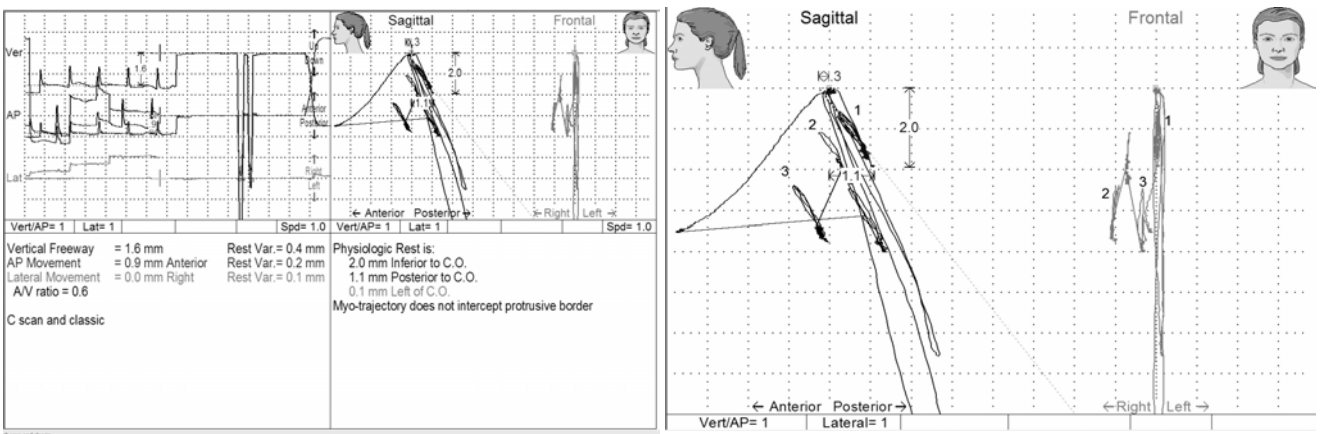


Figure 9: Computerized mandibular scanning (CMS Scan 4/5 Myotronics K7 jaw track of sagittal and frontal displaying various trajectories of intra-extra oral, cervical muscle relaxation and head posture . (1) Indicates an engrammed posterior trajectory coincident with a voluntary habitual trajectory. (2) A physiologic shift occurs from a voluntary habitual trajectory anteriorly to a myo-trajectory as musculature and head seeks homeostasis. (3) Overcoming further the proprioceptive occlusal influences an optimized and repeatable neuromuscular trajectory can be identified (Chan protocol) improving mandibular, cervical and head posture.

Nature's leveling bubbles, the eyes, are centered within the orbits with the superior rectus, lateral rectus, inferior rectus and medial rectus and, with the superior and inferior oblique musculature, also balance intra orbitally to assist a balanced and level head position. The internal as well as external muscular systems physiologically help to support an anatomical balanced relationship of reference planes and musculature while either standing or sitting.

An evaluation of forward head posture is essential when treating craniomandibular dysfunction of the head and neck. A simple visual evaluation of the head posture relating it to various planes of head orientation can assist the dentist in recognizing postural dysfunctions that can involve posture of the head on the atlas with concomitant muscle accommodation. Standing posture is preferred rather than a sitting position, this allows the patient to take on as natural a habitual body posture as possible. A level head position is one where all muscle activity of the cervical and cranio-mandibular complex is in balanced tonus with one another. The eyes should be centered of the orbits when the patient's eyes are gazing at the horizon. The inter-pupillary level frontally should not be used as a stand alone reference, but rather used as one of many supportive references when visually assessing head balance, facial symmetry and anterior smile line harmony. Cranial distortions and skews of the surround orbital bones (frontal, sphenoid, ethomoid, superior maxillary, malar, lachrymal and palatal) can cause the inter pupil eye reference to slope slightly downward to the left or right when assessing this level reference frontally.

Evaluating the Cervical Spine and Head

The cervical vertebral column in a balanced state is concave posteriorly (cervical lordosis). Any changes in cervical concavity are a result of neuromuscular responses of accommodation to maintain head balance and level. The weight of the human head is about 15 lbs. with its center of gravity at the sella turcica. The head's center of gravity in normal healthy states is anterior to the occipito-atlantal (OA) joint placing more weight anterior to the OA joint. An 8 degree forward head posture requires 35-40 pounds of pull from the fulcruming spine in the posterior musculature to the occiput to maintain an optimal head position.[30, 55] This explains the consistent occipital pain, shoulder and neck tension and headaches that occur when imbalances exist in abnormal head posture. A dysfunctional change in head posture can have devastating effects to the neuromuscular system.

The antero-posterior (AP) posture of the head in relation to the cervical spine can be determined by a vertical plumb line from head down to the dorsal portion of the thoracic spine. Garry has reported measuring the neck curvature using a plumb line to the deepest curvature of the posterior of the cervical neck region to determine the distance and degree of forward head posture.[30]   Optimal distance according to Racabado is 6 cm.[8, 56] Racabado further defined normal cervical lordosis and normal craniovertebral relationships based on cephalometric measurements. A line that connects the posterior nasal spine to the basi-occiput is called the McGregor's plane. The odontoid plane (OP) is a line that extends from apex to the anterior inferior angle of the odontoid process. (Figure 10) A normal measurement of the posterior-inferior angle at the intersection of McGregor's plane and OP is 101 degrees +/- 5 degrees (96-106 degrees). A distance between the basi-occiput to the posterior arch of the atlas is 4-9 mm (less than 4 mm indicates cranio-vertebral compression).[8, 57]

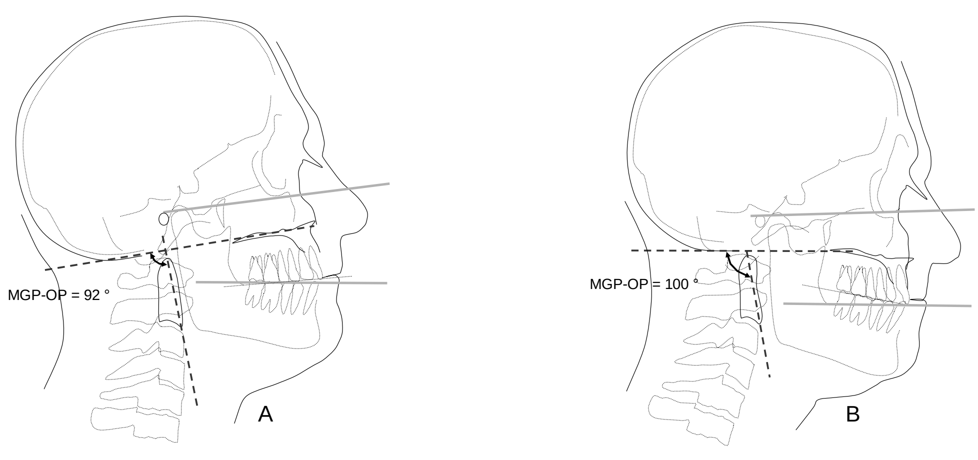


Figure 10: The cranio base-odontoid angle is measured to relate the cranium to cervical spine. (A) Abnormal craniocervical relationship with kyphosis. (B) Normal craniocervical relationship with normal lordosis (A).

Accommodation of the head and cervical spine posture should not be considered as insignificant when finalizing restorative and or orthodontic treatment. Ignoring the diagnosis of forward head posture and not treating the etiology of forward head posture will ultimately result in treatment failure of

CMD/TMD, orthodontics and comprehensive occlusal/ restorative treatment! [57-59] Although, some may choose not to treat upper cervical problems, interdisciplinary communication and coordination must be developed with qualified health care providers to bring optimal benefit to the patient. Dentists should screen and recognize forward head postural dysfunction and it can be readily carried out through clinical CMS (computerized mandibular scanning-jaw tracking) trajectory evaluation, EMG muscle activity and radiographic evaluation. [8, 60, 61] (Figure 11)

A B

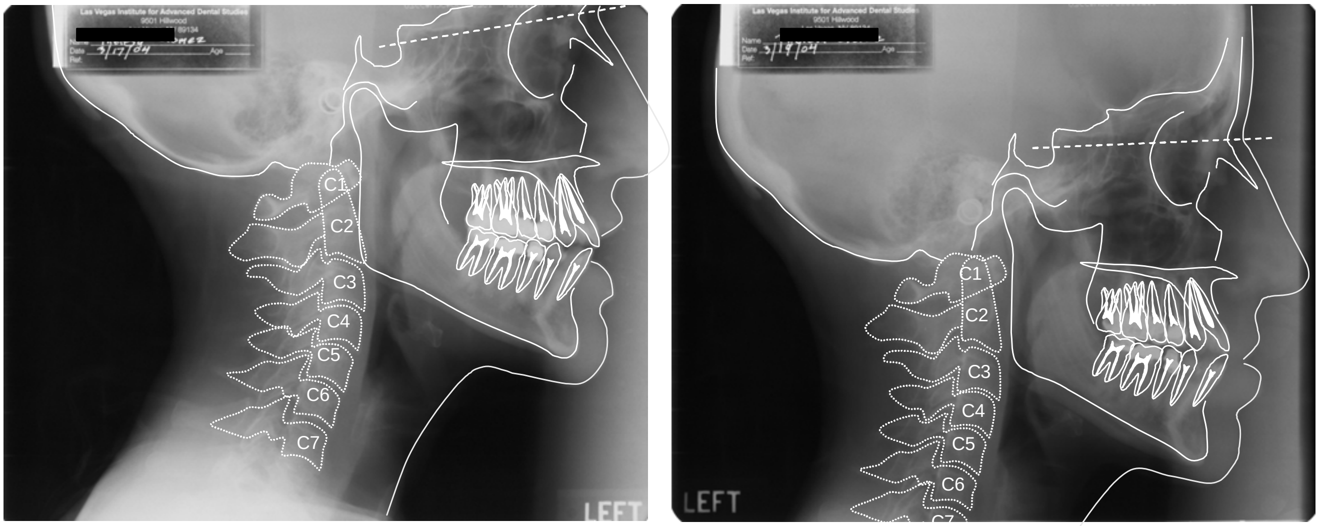
Figure 11: ICAT images of a 56 year old male who desires a new smile and full mouth rehabilitation because of severe wearing teeth.[χ] The mandibular position was changed from a habitual trajectory to a neuromuscular trajectory and stabilized with a lower orthosis. (A) Unposed upward head tilt position before treatment with an occlusal plane that has parallel tendency relative to horizontal level. (White arrow indicates incisive foramen and white line indicates HIP plane is level – pathologic orientation). (B) Improved head position after correcting mandible on an optimized neuromuscular trajectory – occlusal plane slopes anterior downward. (White line and arrow indicates HIP is sloping downward – physiologic orientation).

EMG amplitude recordings can be used to confirm muscle balance of the cervical group of muscles and *should not be ignored* during the diagnostic and treatment phase. Monitoring sternocleidomastoid (SCM) and trapezius muscle groups alone via EMG amplitude monitoring is not a substitute or replacement for cervical group EMG monitoring. The major function of the SCM is to assist the head in rotation. (The SCM on the side opposite the direction of the head turn is active). Asymmetrical EMG patterns can be seen in torticollis (abnormal twisting of the neck) and may be seen in patients with acceleration injuries to the neck, but on average this muscle is typically quiet and shows low EMG activity.[62] EMG monitoring of the cervical group (upper posterior cervical triangle/posterior of the ear region) allows the clinician to assess abnormal versus normalized head posture as it relates to the semispinalis capitis, splenius capitus, sternocleidomastoid and trapezius activity as a group giving further insight as to the postural health of both the mandible and the head. [60] Clinical studies have shown that SCM muscle activity alone is consistently low in amplitude during resting modes compared to higher EMG muscle activity of the cervical group muscle activity with patients with forward head posture.[63, 64] The cervical group EMG muscle activity should not be overlooked or ignored during the diagnostic and evaluation phase. Recognizing the status, activity and condition of these muscle groups should impact the clinician's prudent diagnosis, treatment plan, prognosis and long term stability of his/her patient.

Head Position and Teeth - A Dominating Proprioceptive Factor In the Postural Chain
The head tilting and head leveling response is an inter-dependent balancing response of many complex systems which include the ear organ, gravity, craniomandibular muscles, the cervical neck muscles as well as the proprioceptive mechanism of tooth position within the oral cavity. Through growth and development the formation and alignment of the teeth triggers signals through the central nervous system that controls mandibular jaw position as a final stabilizing mechanism to support the postural chain from head to toe. This dynamic postural mechanism accommodates with positional changes due to environmental and structural influences throughout ones life.

The teeth orientation and mal-alignment within the cranial and mandibular base are clearly recognized as the dominating force that significantly contributes to abnormal jaw positioning during both resting and functioning modes. It is the role of the teeth (the occlusion) and their influences that commands the postural accommodating responses of the head, the mandibular jaw position and cervical neck positioning which in turn impacts the lower portions of the body's posture. Ishii (1990) revealed a clear correlation between imbalances and asymmetries of the craniofacial morphology and imbalances within the functional masticatory system and gravity's upright postural position using EMGs.[65]

Radiographic imagery has also confirmed that as the mandible moves forward the cervical spine also accommodates.[8] (Figure 12) Improved cervical alignment in both sagittal and frontal relationship has also been confirmed through studies of Chan and Jenkins that both lateral and frontal cervical vertebral alignment has occurred after neuromuscular alignment of the mandible on an optimized myo-trajectory using computerized mandibular scanning (CMS).[66] (Figure 13)



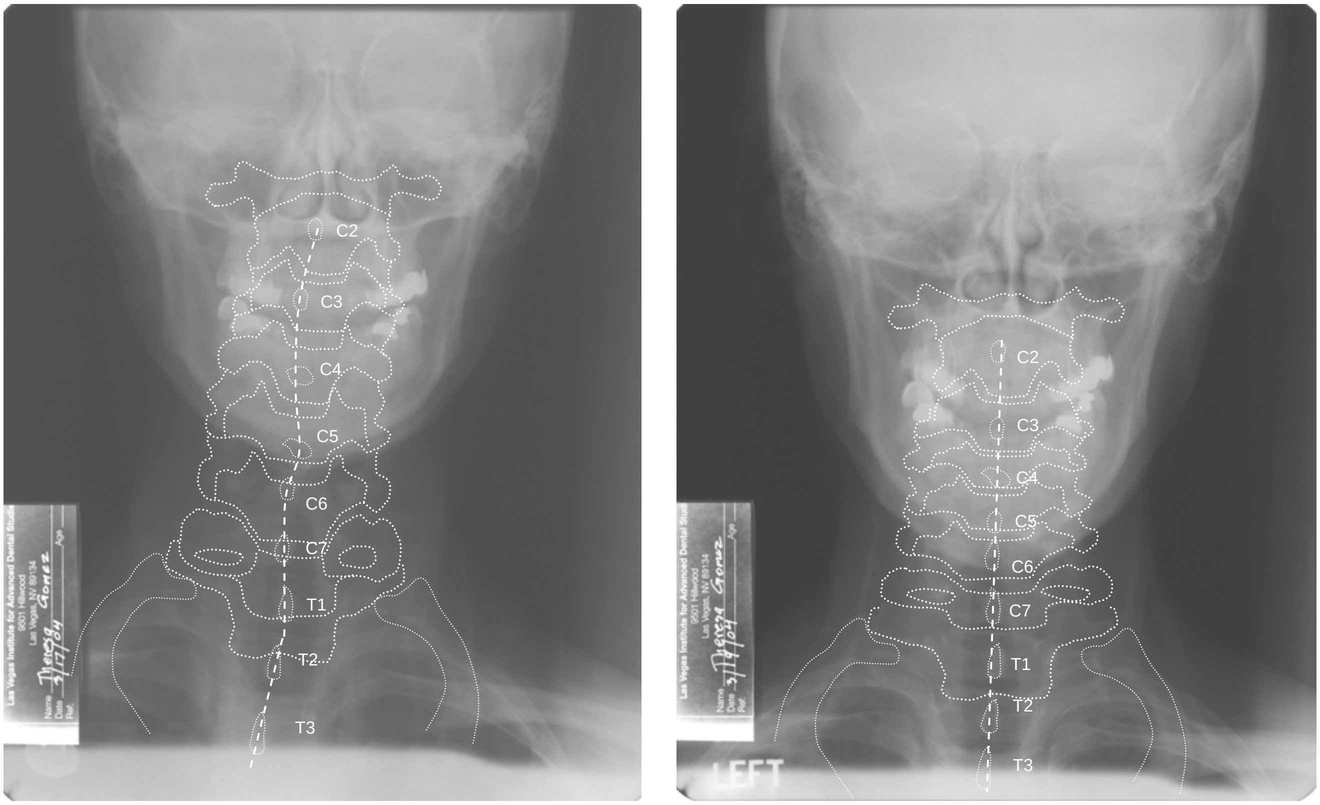
Before Orthotic

A

After Orthotic

B

Figure 12: A 51 year old female presents with numerous musculoskeletal occlusal signs and symptoms. She has had a history of chronic migraine headaches and diagnosed with myocitis gravis by her medical doctors. Sagittal lateral cervical spine films: (A) Patient with upward head posture before neuromuscular orthosis. (B) Improved head posture and cervical alignment three (3) days after neuromuscular orthosis treatment *only*, after finding an optimized neuromuscular trajectory with CMS (Computerized mandibular scanning). As mandibular jaw is posteriorized the head/cranial base tilts upward, as mandible moves anterior, head tilts downward improving cervical alignment. (A retrusive maxilla becomes apparent).



Before Orthotic
A

After Orthotic
B

Figure 13: Frontal cervical spine films of same 51 year old female. (A) Intervertebral mal-alignment is noted with existing habitual occlusion. (B) Note improved downward head tilt and cervical alignment three (3) days later after orthosis therapy alone. Quick improvement comes from objectively identifying an optimized neuromuscular trajectory with CMS.

THE USE OF REFERENCE PLANES IN ESTABLISHNG HEAD BALANCE

Various reference planes have been established both sagittally and frontally to assess head balance. The common sagittal plane, the external auditory meatus to nasal spine (AN) plane or line called the auriculo-nasal plane has been identified by many. The frontal plane: a line drawn through the center of the pupils which should be parallel to the horizontal plane with respect to the earth's surface has also been used.

Another frontal reference plane is the otic plane which correlates to the three inner semicircular canals in each vestibular apparatus. These canals are arranged by nature at right angles to one another so that they represent all three planes in space. Any disturbance of an optimal head orientation and relationship to these canals relative to earth's level surface transmits a series of nerve impulse to the central nervous system, relaying messages of imbalance to earth's gravitational pull. As the posture changes throughout life, there is a constant accommodation of the vestibular organ system to maintain a level optimal relationship to earth's level. When the head no longer is able to maintain an optimal physiologic relationship to the gravitational pull of the earth, a patient's equilibrium is disturbed resulting in postural compromises. [30]

Correlating Head Position and the Occlusal Plane

The design and positioning of the human maxilla and positioning of the mandible to the cranial base effects all the other musculoskeletal occlusal systems that, as a coordinated entity, functions together to support one another in all bodily functions. Through growth and development the occlusal plane in the human commonly slopes downward and forward relative to horizontal level. The Frankfort plane (a plane from the top of the auditory meatus to the inferior rim of the orbits) is approximately parallel to horizontal level. (Figure 14 and 15) This aligns the jaws and cervical system in a functional position relative to the visual, olfactory, and hearing organs.

The literature is repleat with discussion as to what reference planes to use when referencing to a horizontal level and head positioning and determining the slope of the occlusal plane. Classical thought as to how to determine the occlusal plane has been discussed extensively and studied using cranial-mandibular cephalometric analysis, soft tissue references as well as various planes as they relate to reference points and head positioning to a horizontal level.

Traditionally the Frankfort plane has been commonly used as a convenient reference for the face-bow transfer (porion-orbitale). It was first conceived for the orientation of skulls in anthropology in the late nineteenth century (1882) during the International Agreement for Unification of Craniometric and Cephalometric Measurements in Monaco, 1906. This plane **appeared** horizontal when the skull was put in the natural head position (NHP) with the subject *standing and looking* at the horizon. This plane was later applied in dentistry for a "natural" orientation of the head for cephalometric films and orientation of dental casts on articulators. Porion is a radiographic landmark not directly visible in living subjects. Some pioneering clinicians advocated the use of an axis point (axis-orbitale) to determine a new plane. It has been **assumed** that this plane and the hard-tissue Frankfurt plane were roughly coincidental. The patient's Frankfort plane (line from the superior portion of the external auditory meatus to the inferior border of the orbit) laterally has classically been used as a boney reference to parallel the head to horizontal level.

Ferrario, et al. (1994) in this classic study reported differing Frankfort planes between the sexes. Males tended to have a plane going upward more than females. Porion was lower than orbitale with a mean angle of 3.13° in males and a mean angle 4.28° in females. [67] The soft tissue Frankfort planes (tragus-orbitale) relative to horizon in NHP of both male and female groups were never coincident in all subjects; the tragus was always lower and more anterior than the porion. On average, the angle tragus-orbitale-porion was about 6 degrees.

The possible correlations between the intracranial measurements and the position of the soft tissue Frankfurt plane in NHP were further analyzed. The Angle dental class (first molar relationship) was perhaps somehow correlated with the head position: 67% of Class II subjects had extended head, and 33% had flexed head. This ratio was inverted in Class I subjects: 64% of them had flexed head and only 36% had extended head. [67, 68] *Once again there is an underlying neuromuscular message indicating a significant antero-posterior jaw position correlation to head flexion and extension positions.*

Other international studies have shown that both planes are not horizontal, and mounting a maxillary cast according to these planes can result in an inaccurate mounting.[69, 70] International studies comparing caucasian to Asian populations using lateral cephalograms confirm the Frankfort horizontal plane and arbitrary axis-orbitale plane can assume a steeper anterior inclination, thus modification of the mechanical inclination of the maxilla is required.[71] Hung reported an average of 7.26 degree difference of the SN (sella-nasion) plane relative to horizontal when evaluating both male and female Chinese test groups.[69]

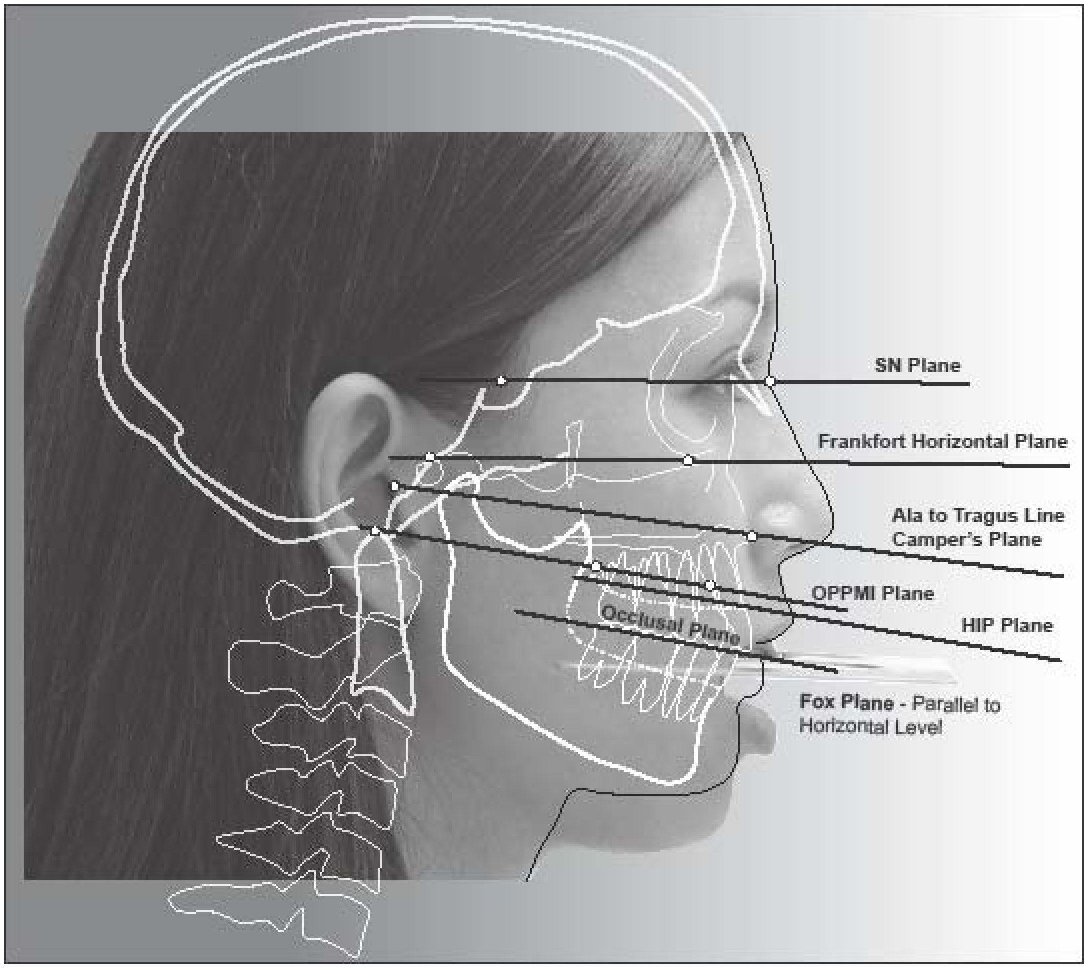


Figure 14: Sagittal boney and soft tissue reference planes relative to the occlusal plane.[δ]

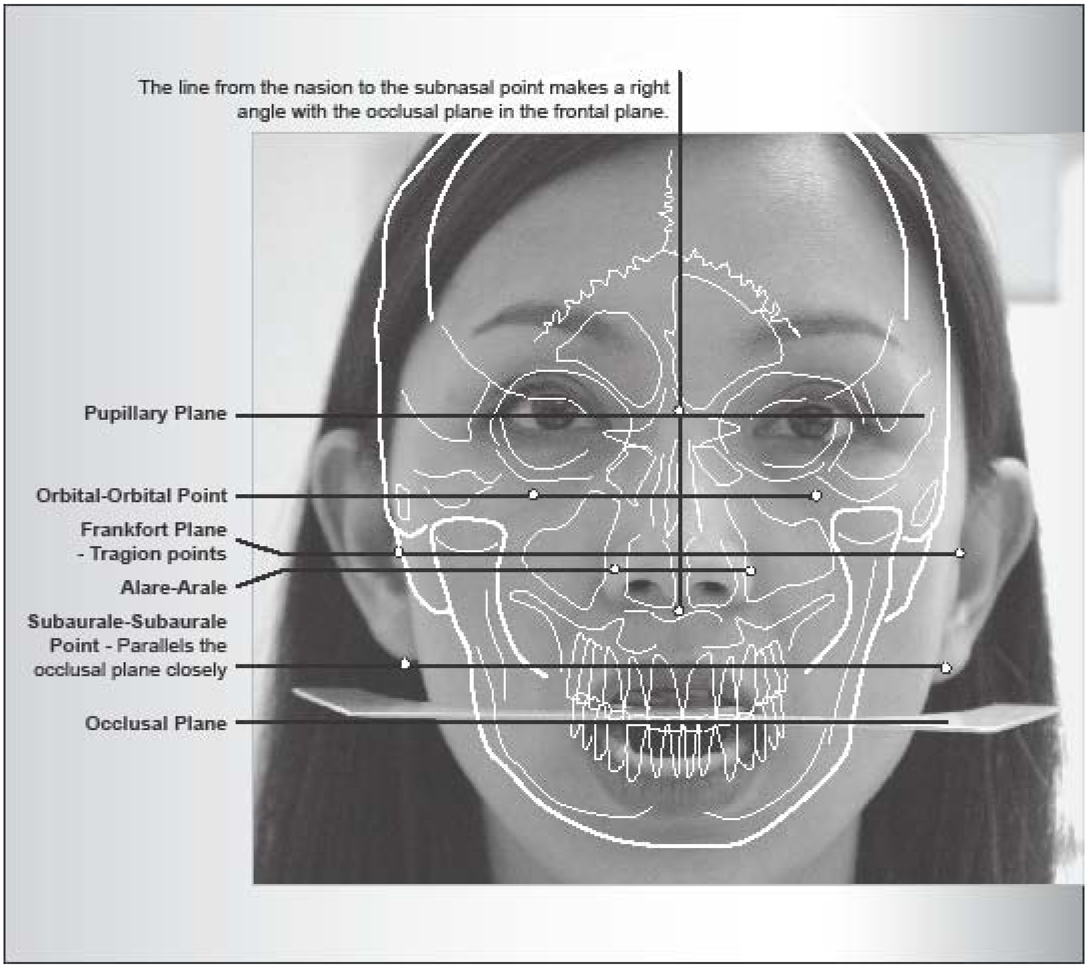


Figure 15: Frontal boney and soft tissue reference planes relative to the occlusal plane.[δ]

Other Reference Planes

All references including the SN Plane, Frankfort Horizontal Plane, Camper's Plane, HIP Plane, Ala-Tragus Line, Canthomeatal Line and others change to some degree over time based on research and ethnic types.[72, 73]

- FRANKFORT HORIZONTAL PLANE – Porion to Orbitale (Bony)
- CAMPER'S PLANE – Acanthion-external auditory meatus plane (Bony)
  Acanthion – a point at the base of the anterior nasal spine.

- SN PLANE – A line from sella to nasion – considered to represent the cranial base. (Bony)

- OPPMI PLANE - Odontoid Process – Pterygomaxillary Fissure – Incisive Foramen (Bony)
- FRANKFORT HORIZONTAL PLANE – Tragus to Orbitale (Soft Tissue)

- HIP LINE – Hamular Notch – Incisive Papilla (Soft Tissue) – "Transit Line Plane"

- ALA-TRAGUS LINE – Ala of nose to tragus of ear (Soft Tissue)

- CANTHOMEATAL LINE - line from center of the external auditory meatus to the outer canthus of the eye (Soft Tissue).

- HELICO-TEMPORAL FOLD- EXOCANTHION LINE – A line from the fold of the ear to the corner of the eye (Soft Tissue).

Definition of Terms

- Acanthion – a point at the base of the anterior nasal spine.
- Nasion – a point between the frontal and nasal bone.
- Orbitale – The lower point on the lower border of the orbit.
- Pterygomaxillary Fissure – an oval-looped radiolucency resulting from the fissure between the anterior margin of the pterygoid process of the sphenoid bone and the profile outline of the posterior surface of the maxilla.
- Porion – the highest point on the superior surface of the soft tissue of the external auditory meatus.
- Sella – The center of the hypophyseal fossa (sella turcica). A reliable constructed center.
- Subaurale –the lowest point on the inferior border of the ear lobule when the subject is looking straight ahead.
- Pogonion – the most anterior point on the symphasis of the mandible

Table 2

Traditionally, the ala tragus line has been recognized as a good reference paralleling the occlusal plane. [1] The occlusal plane is at an angle of approximately 10 degrees relative to the Frankfort horizontal plane, when viewed in the midsagittal plane.[74] Many studies have reported the occlusal plane relative to horizontal level varied from 6-14 degrees, average 10 degrees.[75-78]

Xie (1993) in a more recent study showed through cephalometry using 90 dentate cases correlating the line connecting the inferior nasal alar and mid-point of tragus was much more parallel with the occlusal plane. This study showed that it was the “line of closest fitting” and represents a proper reference plane for determining the occlusal plane and hence a valuable index in clinical dentistry.[75] Sinobad and Postic (1996) confirmed that the lower border of ala with upper border of the tragus is the recommended line that parallels the occlusal plane in skeletal Class II jaw relationships and middle of the tragus for skeletal Class I and lower border of the tragus for skeletal Class III jaw relationships.[76]

Ferrario, Sforza, Serrao, and Ciusa (2000) in their classic occlusal plane studies have confirmed through in vivo measurements that the occlusal plane deviates from the true horizontal by about 14 degrees. Camper’s plane (acanthion-external auditory meatus plane) deviated at a steeper angle by 18 degrees from true horizontal. A three-dimensional orientation of the occlusal plane both sagittally and frontally using: 1) natural head positioning relative to the ground, 2) orientation of the occlusal plane relative to the subjects intrinsic facial planes and 3) antero-posterior discrepancies of the dental bases were studied using several dental and soft tissue landmarks using 24 healthy subjects with

Angle Class I occlusion. Their measurements were found to be repeatable and easily determined.[76] D'Souza and Bhargava (1996) also concluded the validity of Camper's plane as a guide to determine the occlusal plane for both edentulous and dentate subjects using 40 dentulous and edentulous patients.[78]

Head Posture and Its Relationship to TMD

Ciancaglini (2003) reported in frontal view, the Frankfurt plane was right rotated relative to the true horizontal both in TMD subjects ($P < 0.01$) and controls ($P < 0.05$), but rotation was larger in TMD subjects (mean difference between groups, 1.1 degrees, 95% confidence interval, 95% CI, 0.2-2.0 degrees). No significant deviation from the horizontal or difference between groups was observed for the interpupillary axis and occlusal plane. In lateral view, the Frankfurt plane was upward-orientated relative to the true horizontal in TMD groups (mean angular deviation 2.8 degrees, 95% CI, 1.0-4.6 degrees). The occlusal and Camper planes were downward-orientated in both groups ($P < 0.0001$), but inclination of occlusal plane tended to be less steep in angle relative to horizontal level in TMD subjects (mean difference between groups, -3.8 degrees, 95% CI, -7.6-0.1 degrees).

These findings show that in young adults with normal occlusion, an association existed between the orientation of craniofacial planes in natural head position and signs and symptoms of TMD. Furthermore, they suggested that, within this population, TMD might be mainly associated with head posture rather than with craniofacial morphology.[80]

Facial Angle of the Maxillary Arch and Cranial Base

The maxillary arch in relation to the cranial base is often overlooked among the restoratively minded clinicians, since a focus on restoring the health and appearance of the dentition and surrounding periodontal structures have been of primary emphasis in this discipline of dentistry. Upper to lower tooth relationships is often given more emphasis (dental Class I, II, and III) rather than cranio-maxillary to mandibular base (skeletal Class I, II, and III) relationships. Little emphasis and education has been given in traditional dental training regarding the maxillary complex and its growth, development and position, leaving these issues to the orthodontic trained specialist who often evaluate the maxillary base during cephalometric evaluation, yet with very little training in physiologic mandibular orientation and positioning relative to the cranium and maxillary base.

It has been well established that the angle between nasion-pogonion and Frankfurt horizontal (FH) can be used to measure the degree of protrusion or retrusion of the mandible.[19] The mean facial angle is 87.8 + 3.6 degrees.[19, 20] Tipping the head either upward or downward will not affect the facial angle, however, the spatial location of the anatomic landmarks such as porion and orbitale to each other are variable in different subjects. (Figure 16) Any superior or inferior position of these landmarks will in turn affect the angles that are often used in cephalometric analysis that relate to the Frankfurt plane. If protrusion or retrusion of the mandible is compared with average normative values (87+3.6 degrees), morphogenic pattern differences could result in readings that are misleading. Others such as Linder-Aronson correlated the SN line and the vertical plumb line angle as a means to measure head posture. They found a reduced SN-Vertical angle in patients with forward head posture.[81]

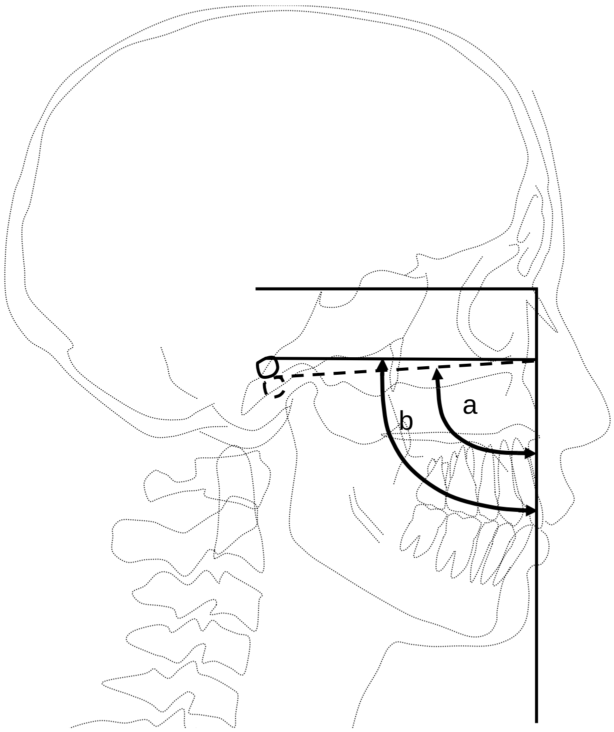


Figure 16 – The facial angle (a and b) will vary depending on the horizontal reference line relative to the location of porion and orbitale. Morphologic variations should be considered when evaluating the degree of protrusion and retrusion of the mandible. Relying only on normative facial angles or any horizontal line reference points relative to the maxilla or mandible should be used prudently by the clinician.

Reference Landmarks and Planes – Their Clinical Implication

The examples given clearly indicate that care must be taken when attempting to interpret single cephalometric readings, single computerized mandibular tracings as well as hard and or soft tissue reference lines. The validity and reliability of single measurements, and often even groups of measurements, in a description of craniofacial and dental variations are often questioned. Variations in the location of landmarks, such as sella, nasion, orbitale, porion, which are often used as baseline landmarks as well as soft tissue landmarks on dental casts such as the hamulus and incisive papilla (HIP), could result in incorrect conclusions as to how to relate the maxillary cast and what is a correct level relative to horizontal level.[82] Care must be taken to understand these variations and their geometric, biologic and aesthetic consequences. While measured data has been recognized as a gold standard in objective diagnosis and treatment planning, the treating clinician must also recognize its limitations when applying it to the TMD patient, orthodontic patient, restorative aesthetic patient during the smile designing process. Caution must be exercised in the interpretation of how these measurements are applied and used. *There is no substitute for prudent and analytical clinical judgment both objectively and subjectively when evaluating radiographs, dental study casts, photographs of both hard and soft tissues, electromyographic and jaw tracking data.* The same is true as applied to the diagnosis, evaluation and treatment performed on patients. Dentistry is an art as well as a science!

THE OCCLUSAL PLANE AND ITS RELATIONSHIP TO THE CRANIOMANDIBULAR COMPLEX

The design of the occlusal plane is one of nature's most beautiful expressions of dynamic harmony between the cranio-maxillary complex and the mandibular cervical complex. The intricate subtleties and morphology of each occlusal joint opposing one another combined together create a dynamic supportive system for function, posture and aesthetics. The dynamic spiral formation that each buccal to lingual cusp forms antero-posteriorly from tooth to tooth functions as a network system that coordinates the atlanto-occipital joint as well as the temporomandibular joint system together. The logic of how these systems function and interrelate is important to better understand the variations that can exist when diagnosing and treating cervical-occlusal instability.

The Glossary of Prosthodontic Terms defines the occlusal plane as: 1) the average plane established by the incisal and occlusal surfaces of the teeth. Generally, it is not a plane but represents the planar mean of the curvature of these surfaces, 2) the surface of wax occlusion rims contoured to guide in the arrangement of denture teeth, 3) a flat metallic plate used in arranging denture teeth comparable to the CURVE OF OCCLUSION.[74]

Interestingly, this definition does not acknowledge nor make reference as to the position of the occlusal plane as it relates to the cranial or mandibular base. Historically the center to upper one third of the retromolar pads on edentuluous cases have been used as the posterior landmarks in establishing the posterior end of the plane of occlusion. The anterior of the occlusal plane is referenced at the upper lip line. These three points establish the plane of occlusion and have classically been used in denture construction.[84]

The plane of occlusion can be defined as the average curvature (not flat) of the imaginary surface of the occluding surfaces of the teeth. This average upward curvature of the occluding surface of the teeth is determined by the anterior esthetic "smile line" and its relationship to the mandibular functional neuromuscular trajectory, the posterior curvature, called the "curve of Spee" (lower arch), and the "curve of Monson" (upper arch) which comprises the transverse curve referred to as the "curve of Wilson". Vertically this plane of occlusion optimally exists as a position in space where all the masticatory muscles including all antagonistic muscle groups such as elevators and depressors are in the state of minimal electrical activity necessary to maintain postural rest. Together, the anterior curve of the incisal edges, the posterior curve of the cusp tips comprising the curve of Spee, curve of Monson and curve of Wilson make the occlusal plane. It is not uncommon for clinicians to visualize a straight line from maxillary incisal edge of the anterior teeth to the mesial buccal cusp tip of the first molar, to visualize this plane from a lateral view perspective.

Finding the Occlusal Plane

How best to determine the occlusal plane has been of interest to many within the prosthetic and restorative field. Downs originally defined the occlusal plane as that line bisecting the overlapping cusps of the first molars and the incisal overbite. In cases in which the incisors were grossly mal-positioned, Downs recommended cephalometric tracing the occlusal plane through the region of the overlapping cusps of the first premolar and first molars. The cant or slope of the occlusal plane is a measure of the angle from the Frankfort plane to the occlusal plane.[85]

Many clinicians abroad have determined and confirmed that the occlusal plane has a great influence on the functional articulation and aesthetic aspects of stomatognathic system. Clinicians have recognized that the occlusal plane should be at a right angle to the occlusal forces for stability of the occlusion, head and neck musculature. The path of mandibular closure (neuromuscular trajectory) as previously mentioned is dependant on the head and cervical neck postural angle and inclination and should be perpendicular to the long axis of occlusal forces produced by an optimal cervical posture and an optimized mandibular closing trajectory (path).

With the introduction of Downs' analysis (1952) a number of enthusiastic investigators and clinicians began to evolve their own analyses.[85] The number of newly evolved analyses that followed did little more than to confuse the issues amongst the clinicians with too many landmarks and reference points identified and measurements advocated, subsequently leaving a quagmire of inconsequential details to ponder caused frustration. Steiner (1953) however, proposed the appraisal of more meaningful parameters of the skull (skeletal, dental and soft tissue). The skeletal analysis related the upper to lower jaws to the skull and to each other. The dental analysis related the upper to lower incisor teeth to their respective jaws and each other. And finally, the soft tissue analysis related the balance of lower facial profile.[86, 87, 88] Steiner elected to use the anterior cranial base (sella nasion) as the line to reference the jaws with the advantage that using these two midline points had the least amount of movement whenever the head deviated from a true profile position. This holds true even if the head is rotated slightly while taking a cephalogram. Having an established reference plane, the antero-posterior apical base relationship of the maxilla to the mandible and to the cranial base could now be determined.[115]

Rotational Effects of Jaw and Occlusal Plane

Rotational effects of the jaw relative to the cranial reference planes (S-N) can effect the maxillary and mandibular base as well as the occlusal plane angulation relative to horizontal level. (Figure 17 and 18) Orthodontic literature confirms clockwise or counterclockwise rotations relative to the cranial base (S-N) reference plane produces the effect of Class II type jaw relationships (clockwise rotation) and Class III type jaw relationship (counterclockwise rotation). The rotational effect of the S-N line virtually has no effect on the antero-posterior position of nasion point.

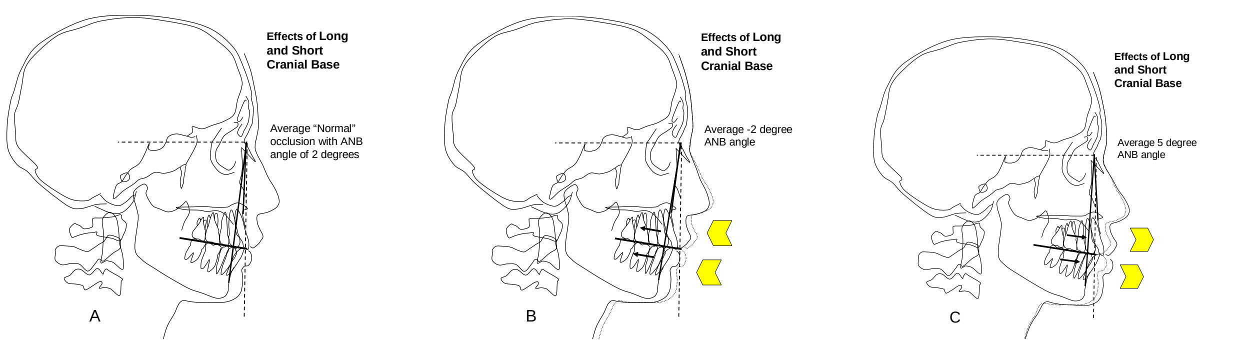


Figure 17: The effect of short and long cranial bases on the ANB angle relative to S-N plane. As the maxillary to mandibular jaw relationship is maintain, both jaws can be positioned either forward or backward relative to nasion in the cranio-facial complex. (A) Normal facial profile, (B) Retrognathic profile, (C) Prognathic profile.

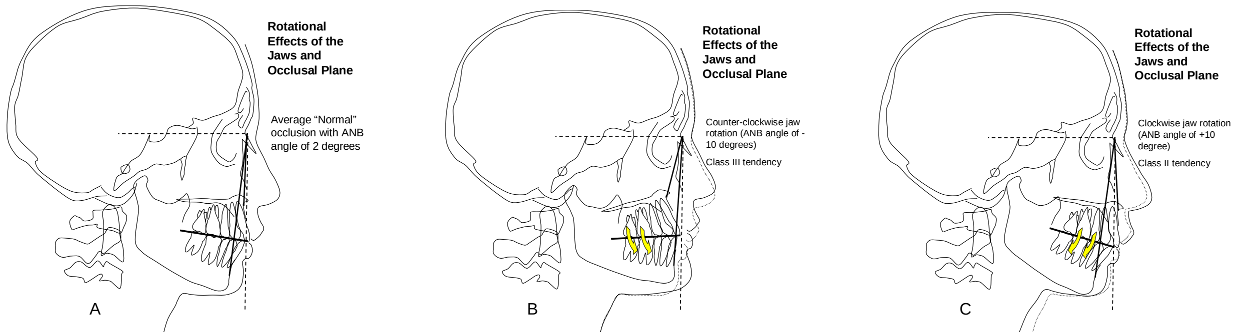


Figure 18: The rotational effects of the maxillary and mandibular occlusal plane relative to the anterior cranial base on the ANB angle. (A) Normal Class I dental and skeletal profile (occlusal plane slopes downward) with even distribution of lip posture. (B) Counter-clockwise rotational direction of the jaws relative to the S-N plane produces a Class III type jaw relationship, upward sloping occlusal plane, short upper lip and prognathic lower jaw tendency. (C) Clockwise rotation of the jaws relative to the cranium produces a Class II type jaw relationship, steep downward sloping occlusal plane, longer upper lip and retrognathic lower jaw tendency.

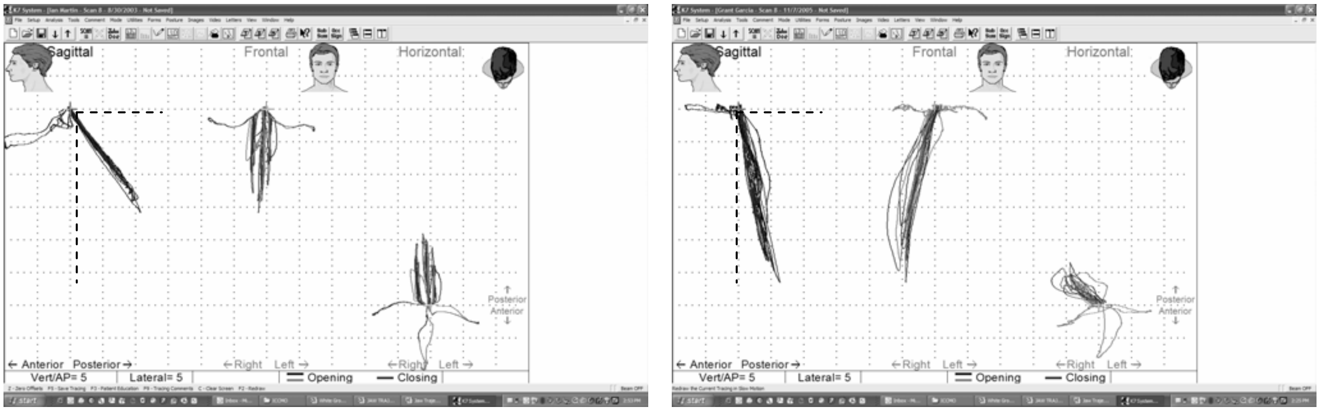
It is known that dental occlusion is influenced by changes in the cant of the occlusal plane. Braun studied and defined the geometric and mathematical relationships between dental occlusion and rotations of the occlusal plane in the sagittal view. As a general clinical guide, he reported that each degree of rotation of the occlusal plane will result in a half millimeter change in the dental occlusal relationship. This is of importance, because changes in the cant of the occlusal plane are sometimes unintentional, as well as intentional during orthodontic or restorative therapy. An earlier study has also documented that the occlusal plane rotates naturally upward and forward approximately 6 degrees during growth and development. This phenomenon tends to develop a Class II dental relation and therefore has important implications for the developing dentition.[89]

Inclination of the Occlusal Plane (IOP)

The inclination of the occlusal plane (IOP) is one of the key factors governing occlusal balance.[90] Studies using cephalometrics have shown that the occlusal plane inclination during craniofacial growth relative to various facio-cranial reference lines varied in anterior rotation during growth. The most significant changes of the occlusal plane inclination were from maxillary base, Frankfort horizontal and cranial base reference lines. Small but significant correlating changes have been reported with these reference lines. It has also been reported that no significant differences according to sexes have been observed.[91]

Okuda (1990), in his investigative study, reported the importance of a correct occlusal plane and fundamental factors in establishing a correct occlusal plane was based on correct mandibular positioning and dental arch form. Using cephalograms and functional EMG studies of masseter, anterior and posterior temporalis activity, results of the occlusal plane angle showed; 1) close correlations with the mandibular plane angle, Camper's plane angle and palatal plane angle, 2) correlations with the duration of activity of anterior temporal muscles and the sagittal angle of chewing pathway. These results also conclude that the occlusal plane inclination and angle is an important factor which harmonizes morphology and function of the stomatognathic system.[92]

Ogawa (1997), showed how the inclination of the occlusal plane also influenced the masticatory closing pattern in the sagittal plane. (see Figure 19 and 20) Anterior convex closure patterns dominated when the occlusal plane inclined in the anterior direction. In contrast, the majority of posterior convex closure patterns were induced by the posteriorly inclined occlusal plane. The appearance of these types seemed to reflect a harmonious relationship between the inclination of the occlusal plane, tooth guidance, and other central and peripheral control. The correlation between the inclination of the occlusal plane and masticatory closing movement serve as a functional background to the significance of the occlusal plane inclination.[93]



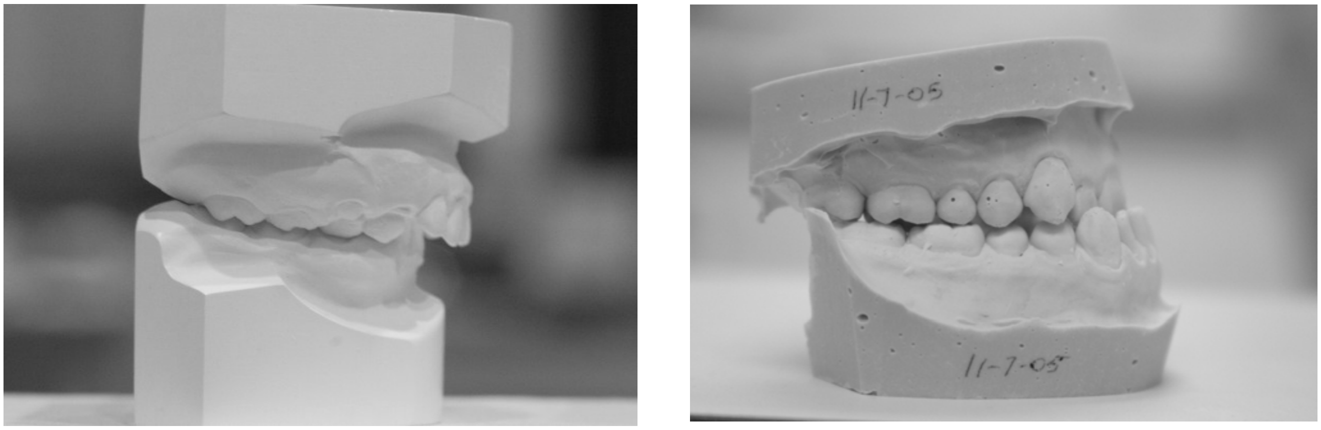
Class II – Retrognathic Class III – Prognathic

Figure 19: Chewing patterns of Class II and Class III type occlusal plane inclinations. (A) in the retrognathic (skeletal class II) shows a dominating anterior angled chew pattern (Scan 8 chew cycle - Myotronics K7 Kineseograph*). (B) Prognathic (skeletal class III) chewing patterns shows a more vertical closure pattern.

Class II – Retrognathic Class III – Prognathic

A B

Figure 20: Supportive lateral cephalograms of Figure 19: (A) Class II retrognathic (clockwise rotation) male age 10.5 years old. (B) Class III prognathic (counter-clockwise rotation) male 17 years old.



Class II – Retrognathic

A

Class III – Prognathic

B

Figure 21: Supportive diagnostic study casts of Figure 19 and 20.

Clinical Significance of the Occlusal Plane

Determination of IOP is an important step before construction of full arch restorative, orthodontic and full denture type cases. Evaluating and assessing the bilateral occlusal plane of the maxillary arch for symmetry, balance and form is desirable to meet the demands of function and appearance. Antero-posterior IOP is typically determined with a device called the Fox occlusal plane,[94] which is commonly positioned parallel to Camper's plane or can be used to capture the occlusal plane slope by orienting the Fox plane (modified) parallel to the horizontal level (the floor) and patient's head positioned at level using bite recording material.[95] Ear bows or face bows have been traditionally been used in the gnathologic arena to register the steepness and tilt of the occlusal plane using the auditory meatus, nasion and orbitale as reference points.

The IOP often reflects occlusal dysfunction along with often associated periodontal problems as well as temporomandibular disorders. Determination of IOP has been found to be of value during the diagnostic and rehabilitation treatment phases. It is the opinion of many that right- and left-side antero-posterior IOP should be evaluated before any major treatment/rehabilitation program, whether prosthetic or orthodontic, is undertaken. Tooth intrusion or extrusion should aim not only to align occlusal surfaces, but also to correct for alterations in IOP, and thus improve aesthetics. Similarly, taking a correct IOP into account during the planning of a prosthetic or orthodontic program may reduce the risk of unnecessary tooth removal, intrusion or extrusion, especially in the posterior regions.

Shimazaki, et al. (2003) reported on the effect occlusal alteration and masticatory imbalance has on the cervical spine. Results from a 3D comparative model study indicated strong implications that lateral inclination of the occlusal plane and imbalance between the right and left masticatory muscles antagonistically act on displacement of the cervical spine, i.e. the morphological and functional characteristics in patients with mandibular lateral displacement may play a compensatory role in postural control.[96]

The occlusal plane inclination or slope is an important and critical aspect during functional movements of mastication, especially in the posterior region during excursive non centric positioning and when the chewing functioning path is outside the intercuspal range. The masticatory path of closure near the intercuspal range has shown to be only influenced by occlusal guidance. Ogawa (1998) reported the gliding or grinding type masticatory pattern was observed predominately in cases with flat or posteriorly inclined occlusal planes. In contrast, a chopping or more vertical type closure pattern was observed predominately in cases with an anterior inclining occlusal plane.[97] The importance of the inclination of the occlusal plane during masticatory movement in the excursive functional movement is much greater and of significance through the closing phase, except near the terminal intercuspal position.

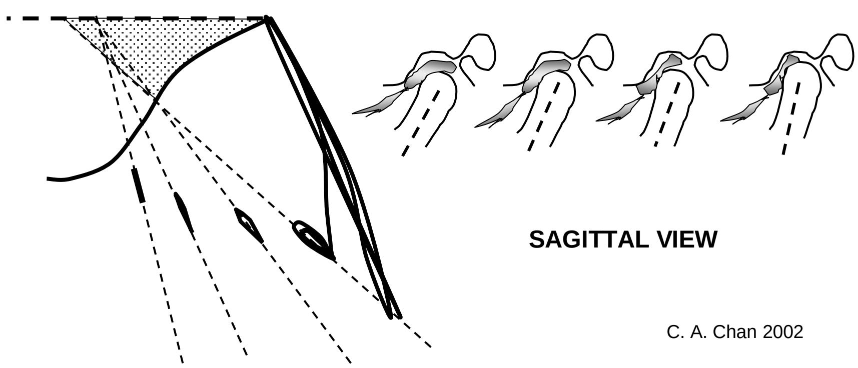
These observations once again confirm that an anterior occlusal plane inclination or slope is important and significant in order to optimize the masticatory and cervical system toward homeostasis. Ignoring the functional excursive closing movements, including those masticatory movements that occur beyond cuspid rise, will lead to continued pathologic grinding and further unresolved hyperactivity of muscle. It is these finer nuances of neuromuscular occlusion that are often overlooked and often ignored during *clinical* occlusal management of the TMD and the restorative/prosthetic case.

Abnormal Jaw Closure Patterns and its Effect on Cervical Neck Posture
Mounting evidence has shown that mandibular jaw positioning and the neuromuscular myo-trajectory can significantly affect head and cervical neck posture. When the mandible rests and functions posterior to a neuromuscular trajectory an abnormal jaw closure pattern is produced resulting in an accommodating forward head posture response. With an upward head tilt over time tender and sore muscles in the cervical neck, upper trapezius and back regions will persist. Mandibular opening and closing paths or trajectories that are along an *isotonic* path of closure will exhibit a leveling of the head position that improves cervical alignment with a decrease in cervical neck symptomology. As the head tilts upward so does the cranial base along with the accompanying occlusal plane. As the head tilts downward and becomes level so does the cranial base and occlusal plane.

The Neuromuscular Trajectory
Jankelson (1975) recognized that a myo-trajectory existed anterior to the habitual trajectory up from the physiologic rest position.[98] Wessberg, Epker and Elliot (1983) concluded that a physiologic rest position of the mandible can be induced reproducibly by either TENS or *minimal integrated masticatory activity*.[62] Chan (2002) recognized a parallelism existed between an *optimized* neuromuscular trajectory and the habitual trajectory when cervical, masticatory and temporal joint alignment existed.[99] The optimized neuromuscular trajectory is often observed anterior to the myo-trajectory as a result of the combined improvement of the cervical and maxillo-mandibular alignment as the mandible is allowed to drift to its physiologic and anatomical position anteriorly over time. (Figure 22) A myo-trajectory diverging away from the habitual trajectory (as is often observed) is often influenced by posteriorizing mandibular restrictions and impingements of the craniomandibular joint complex and influences of the cervical region. These findings have been observed, well documented and confirmed by Chan as a result of optimization of the muscles of mastication including the superior and inferior head of the lateral pterygoids, masseter, temporalis anterior, anterior belly of digastric, geniohyoid muscles and cervical muscle groups.[25]

It is the optimization of the neuromuscular trajectory that results in an efficient six dimensional change to occur to the bicondylar mandibular complex resulting in decompression of the temporomandibular joints. Muscle relaxation to the craniomandibular complex allows the complete mandibular body to auto rotate and re-posture with an optimized posterior vertical dimension and freeway space. Re-establishing a physiologic maxillo-mandibular vertical dimension reverses the pathologic restrictions that hinder physiologic jaw closing patterns to occur. The optimized neuromuscular trajectory is a measured expression of the mandibles bi-condylar six dimensional movement of not only each condoyle within their respective glenoid fossae, but also accurately represents bodily movement of the mandibular complex in vertical, antero-posterior/sagittal, lateral/frontal, pitch, yaw and roll dimensions as it relates to the maxillo-mandibular-cervical complex. Having an ability to objectively measure and quantify both sagittal, vertical and frontal coordinates using computerized mandibular scanning (CMS-jaw tracking) technology with low frequency TENS confirms that a physiologic condylar/disc to glenoid fossa relationships must exist to establish the next level of postural health. It is these findings that have taken the clinician yet another step forward to further experience and study what some have realized in their neuromuscular journey.

As the Myopulse moves in an anterior direction, the angulation of the myopulse becomes more parallel to the habitual trajectory.



Note: Physiologic Rest (vertical position) may also change inferiorly to a more superior isotonic position as the cervical muscles also realign. Optimization of the musculature is conservative (correlating the vertical dimension of occlusion to proportional ratios).

Figure 22

A balance of forces that act on the craniomandibular-cervical system and the temporomandibular joint complex must be maintained relative to earth's downward gravitational forces, the visco elastic resistant to stretching jaw closing muscles, ligamentous constraints and the digastric-geniohyoid muscles.[100-102] As balance of forces are neutralized the fundamental horizontal level eye gaze takes priority in the human being when posture is optimized and maintained relative to the horizon. If the neck is forward (kyphotic) as in forward head posture (FHP) then the skull will dorsally extend (pathologic). When the neck is in the military posture (increased lordosis) the skull will flex ventrally (pathologic). In the neutral position when cervical lordosis exists the skull will be oriented neutrally (physiologic).

Computerized mandibular scanning (CMS) studies have clearly demonstrated that as the mandible comes forward relative to the habitual opening and closing mandibular path along a more optimized myo-trajectory, a noticeable shift from the extended upward head tilt position to a downward level head position relative to horizontal level occurs. (Figure 11 and 12) This is after muscle relaxation using low frequency TENS (the J5 Myomonitor*) occurs. Muscle relaxation of the masticatory and cervical muscles by stimulating the trigeminal nerve and the facial nerve via standard Myotrode* placement protocols over the coronoid notch and upper trapezius was implemented. Numerous CMS tests have demonstrated that optimization of the neuromuscular trajectory has in fact allowed for improved head posture and cervical alignment relative to a horizontal level. This improved head posture and cervical alignment establishes a more physiologic cranial base/head alignment to record and reference the maxillary arch to a horizontal leveling table reference when proceeding to a more final mode of diagnostic analysis for restorative and prosthetic treatment.

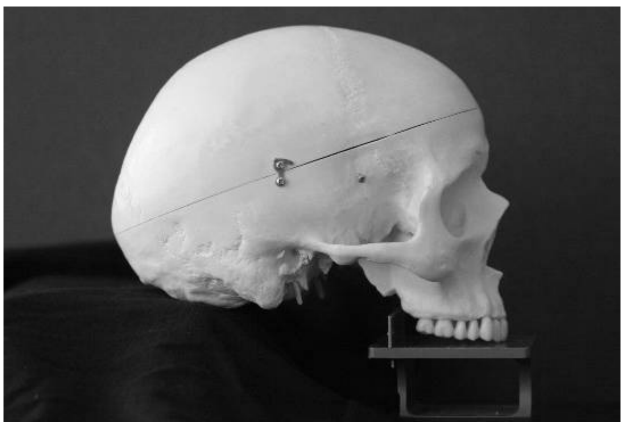
Chan (2002, 2005) demonstrated a consistent non arbitrary means to identify a more reproducible neuromuscular trajectory both in the sagittal and frontal domains using the low frequency TENS combined with over riding voluntary protrusive and relaxing jaw movements.[25, 83] (Figure 2, 9 and 22) This protocol has been found to shorten clinical treatment time and speeds resolution of the underlying musculoskeletal occlusal symptoms that contribute to “abnormal jaw closure patterns” that result from an array of craniomandibular dysfunctional problems. [25, 33, 103] Computerized mandibular scanning (CMS), EMG signaling before and after TENS and ICAT radiographic imaging has been used to confirm objectively that the mandible moves anteriorly along an optimized isotonic path of closure with an accompanying downward tilt, thus changing the orientation of the occlusal plane from a flatter occlusal plane (pathologic) as referenced from a horizontal level baseline to a more anterior sloping angle (6-10 degree) occlusal plane (physiologic). (Figure 3)

Clinician’s who have treated from an orthopedic perspective have discovered when optimizing the mandibular neuromuscular trajectory as per the Chan protocol, [25] that *it is not the mandible that is too far anterior relative to the maxillary cranial base, but to the contrary, a retrusive (posterior) maxillary positioned base is diagnosed.* (The mandible is optimally positioned craniomandibularly in a class I skeletal relationship and the maxilla is now recognized to be in a skeletal class III retro-maxillary alignment, deficient labially). Establishing an optimized neuromuscular trajectory is imperative when doing fixed restorative dentistry. Without stabilization of cervical and mandibular posture relative to the cranial base and establishing an optimal neuromuscular trajectory in the antero-posterior domain, a relapse of symptomology and instability of occlusion will result. Optimization of the neuromuscular trajectory is critical if the clinician desires to minimize needless hours of repeated occlusal adjustments and misdiagnosis and mistreatment of the maxillary base/occlusion and relapse of the many musculoskeletal occlusal signs and symptoms. Optimization of the mandibular trajectory is important in establishing a physiologic rest position of the cervical region and supportive musculature.

Hamular Notch Incisive Papilla (HIP) Maxillary Reference Plane

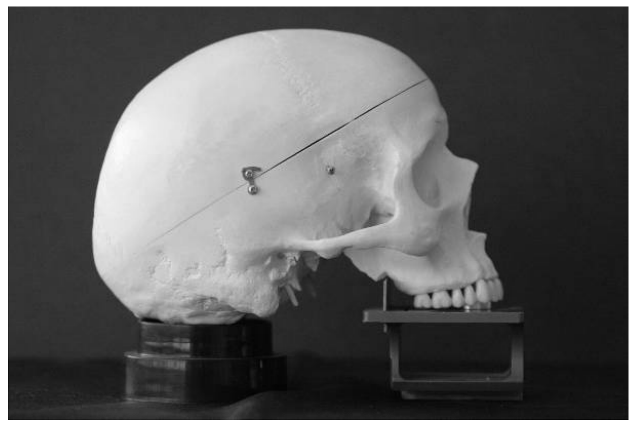
The hamular notch and incisive papilla (HIP) reference plane has been recognized by Cooperman and Willard (1960) as representing a “transit line plane” to diagnostically relate the maxillary arch to a horizontal reference table to disclose the degree of diseased occlusion in the natural dentition and in prostheses. The HIP plane was used as a diagnostic aid in relating medical problems to head and neck syndromes.[104-106]

The use of the HIP was intended as a prosthetic means to conveniently orient the maxillary *edentulous cast* to soft tissue references to a level horizontal analyzing table using a vertical incisive pin and vertical plane in the hamulus notch region to support and orient the maxillary edentulous dental cast. The vertical pin and vertical plate are classically of equal vertical dimensions. Clinical radiographic studies have shown that the *edentulous HIP* although mounted to a horizontal level does not represent a true head level position. Although claims have been made that HIP is level and parallel to an occlusal plane it does not necessarily translate to a head position that is level to earth's horizontal level, especially with dentate casts. Studies have confirmed that the HIP reference plane is parallel to the occlusal plane, but confusion has arisen when using classical vertical incisive pin and vertical hamulus plate references to mount the maxillary casts which results in an inaccurate orientation of occlusal plane slope relative to horizontal level.[82] (Figure 23)



Physiologic level head posture

A



Pathologic upward head posture

B

Figure 23: (A) The maxillary arch is mounted according to the Fox Plane technique to an occlusal reference table. The skull is positioned at a physiologic horizontal level (Hamular notch vertical post is not used). (B) The maxillary arch is mounted using classic HIP – vertical hamular vertical post and incisive pin (Hamular notch and incisive papilla plane is parallel to the pterygomaxillary fissure and incisive foramen plane). Note the skull position and occlusal plane angulation of each mounting.

Cephalometric and radiographic imaging studies clearly show that the occlusal plane typically slopes downward and anteriorly relative to horizontal. If the clinician were to mount the maxillary arch as per the classic HIP protocol the head would have to be tilted upward or the radiographic film would have to be re-oriented as in Figure 24 to accommodate to the proposed classic HIP position. It has been determined that the classic HIP mount does not accurately represent a physiologic head position neither does it realistically relate an accurate relationship of the occlusal plane relative to a horizontal level position.

A B

Figure 24: The lateral head cephalogram and occlusal plane orientation is important: (A) Natural head position and occlusal plane slopes anteriorly downward. (B) Re-oriented cephalogram representing proposed classic HIP orientation when maxillary model casts are mounted to classic HIP method. (The white bars indicate the vertical hamular plate and incisal pin position in mounting the maxillary study cast at the hamular notch and incisive papilla).

Some have ardently advocated the accuracy of the HIP soft tissue references to mount the maxillary casts as representing an anatomically correct occlusal plane (relative to what?), but science and clinical investigative studies have all reported that no matter what technique or method used that the human occlusal plane shows on average a downward sloping incline (postero-anteriorly) when the head is level to earth's horizontal level. (Figure 25 and 26)

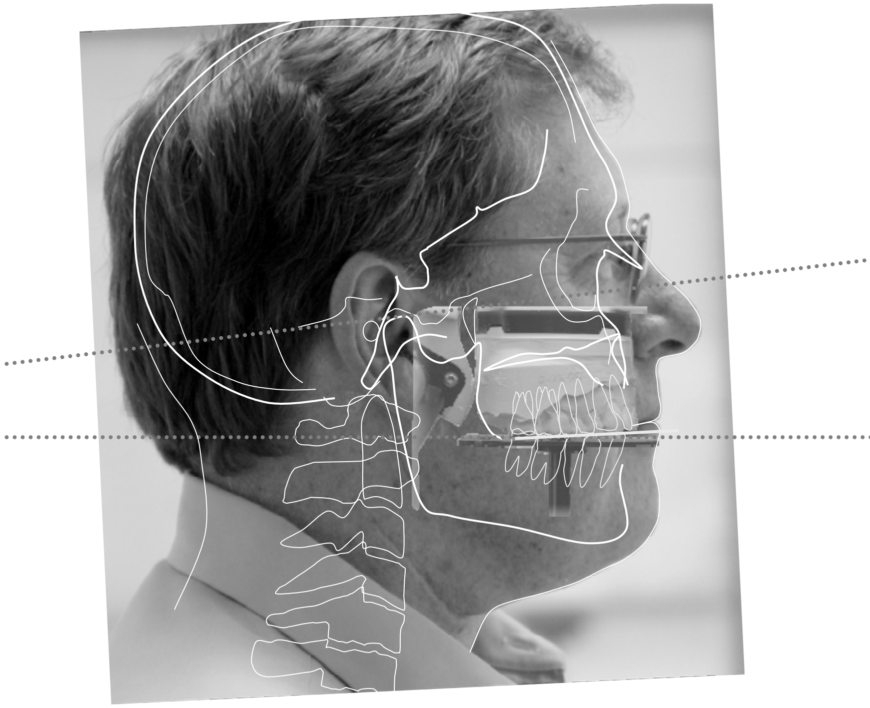


Figure 25: Maxillary cast mounted to classic HIP protocol with accompanying upward head tilted position. Note classic anterior upward sloping occlusal plane, which will further perpetuate a posteriorization of the mandible and an unstable craniomandibular cervical posture (pathologic).[δ]

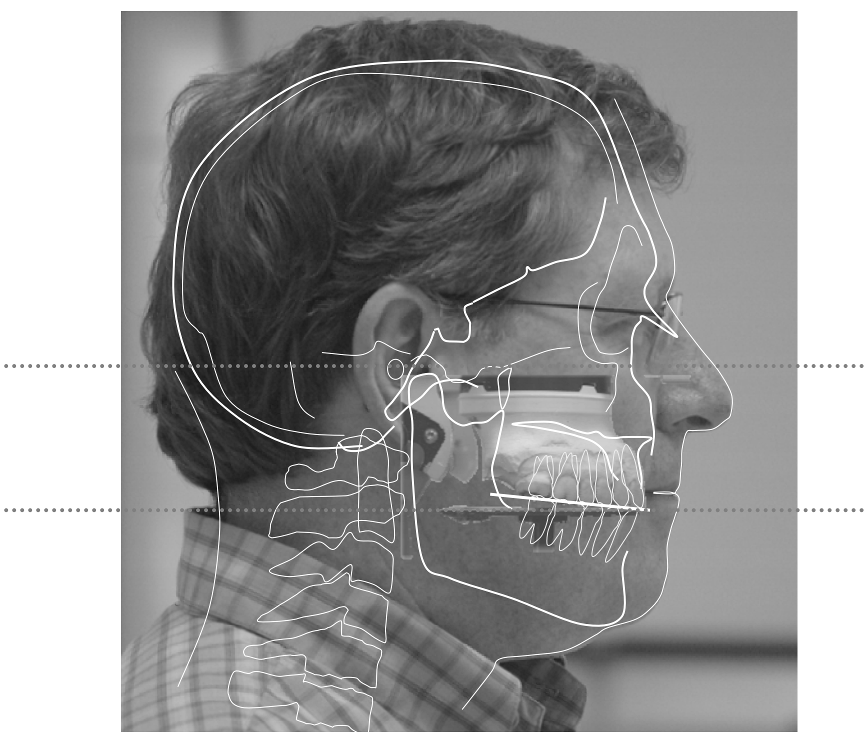


Figure 26: Maxillary cast is mounted to a level head and cervical position which is recorded with the Fox plane at horizontal level. Note the resulting replication of a natural anterior downward sloping occlusal plane representative of proper form for optimal function (physiologic).[δ]

Karkazis and Polyzois (1991) cephalometrically predicted the occlusal plane and hypothesized that the angulation of the occlusal plane was generally related to the skeletal base of the maxilla. Statistical analysis revealed that: no parallelism between the occlusal and HIP plane relative to horizontal level existed (a mean angle of 4.57 degrees (standard deviation 2.57 degrees) and a range of 0 to 9.5 degrees).[107]

An investigative clinical research group studied 82 asymptomatic participants in a combined series of four separate studies (2004-2005) confirming the reliability of the HIP plane and Fox Plane for mounting the maxillary cast and their effectiveness as diagnostic leveling planes as they relate to the cranial base and the human occlusal plane in both diagnosis and treatment procedures. A combined 154 maxillary model casts were used to compare both techniques for accuracy, variability and levelness as they related to the facial occlusal photographs, cephalograms and participants occlusal plane.

The first study concluded the overall reliability of the classic HIP mounting was more reliable (84.6%) compared to the traditional stick bite reference (53.8%) relative to the frontal horizontal and sagittal occlusal plane inclination. The second study concluded that the Fox plane represented more closely a level that better matched the participant's photographic occlusal-facial level (60.0%). The classic HIP plane mount compared to the modified Fox plane mount were similar and equal in occlusal-facial levelness 30.0%. The classic HIP plane when comparing the frontal perspective was only 10.0% similar to the occlusal-facial photographic view.

The classic HIP mounting based on 33 participants (study #3 and #4) showed an over all average anterior upward to a horizontal sloping tendency of the occlusal plane 57.6% of the time when using the classic incisive pin and vertical plate (vertical height of incisive pin and vertical hamular notch plate are equal). (Figure 27 and 28) Radiographic evaluation using volumetric cone beam (ICAT$^{\chi}$ imaging was also used in the evaluation. 52.4% of the model casts mounted to HIP showed a very horizontal occlusal plane orientation which did not represent the cephalometric findings of other orthodontic and prosthetic/restorative studies. The modified Fox plane level technique showed on average an 82.4% anterior downward sloping occlusal plane which more closely related to the actual patient's occlusal plane slope to the cranial base. Right and left sagittal occlusal planes were measured resulting in an average 5.0-6.0 degree angle slope of the occlusal plane. (Figure 29) Volumetric ICAT digital radiography showed the participants occlusal plane more closely related to the ala tragus and Frankfurt horizontal plane. When the maxillary casts were mounted using the Fox plane at a horizontal level and the sagittal orbital level plane (eyes balanced in the orbits when viewed frontally), the mounted casts occlusal plane appeared similar to the participants occlusal plane confirmed by the ICAT.[82]

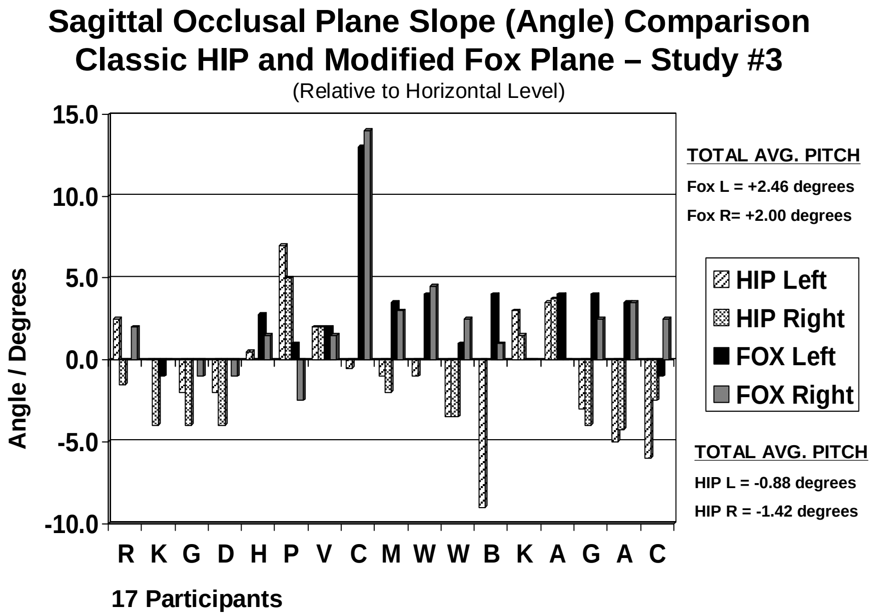


Figure 27: Occlusal Plane Slope Study #3 comparing classic HIP and modified Fox plane level technique. Results show a positive angled slope with the Fox Plane group compared to the HIP group which showed a negative to low angled sloping tendency.

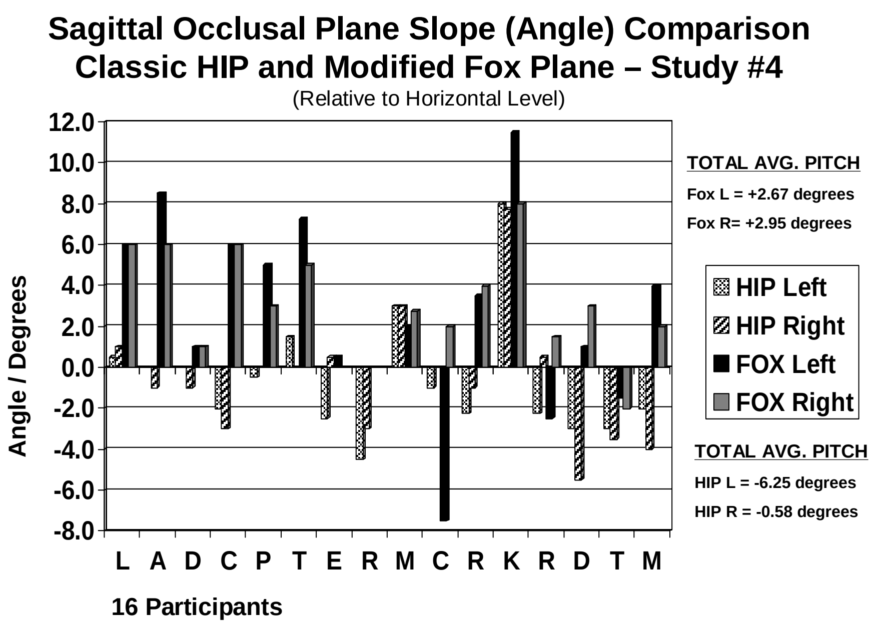


Figure 28: Occlusal Plane Slope Study #4 comparing classic HIP and modified Fox plane level technique. Results show once again a positive angled slope with the Fox Plane group compared to the HIP group which showed a negative to low angled sloping tendency.

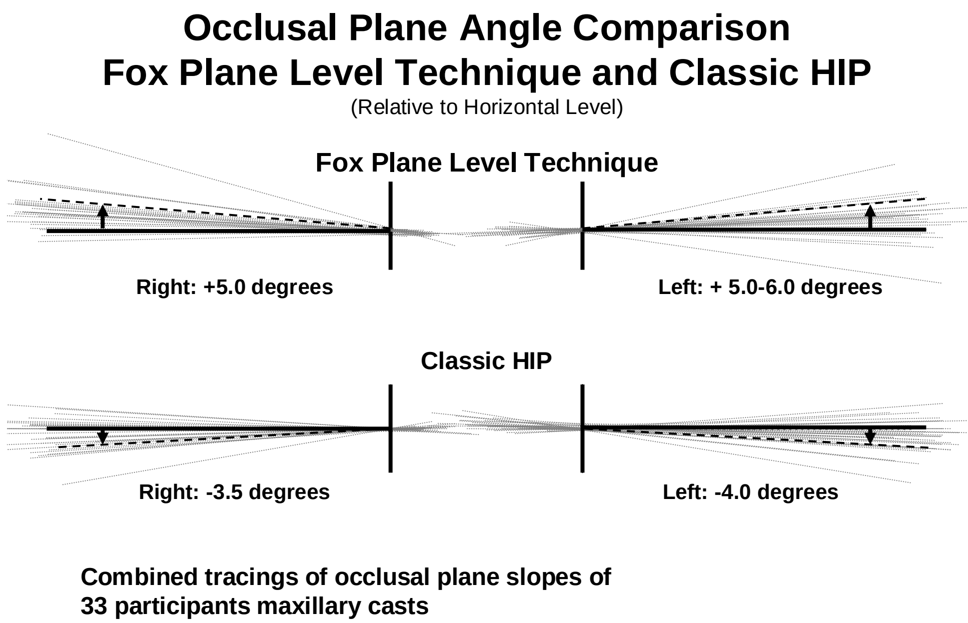
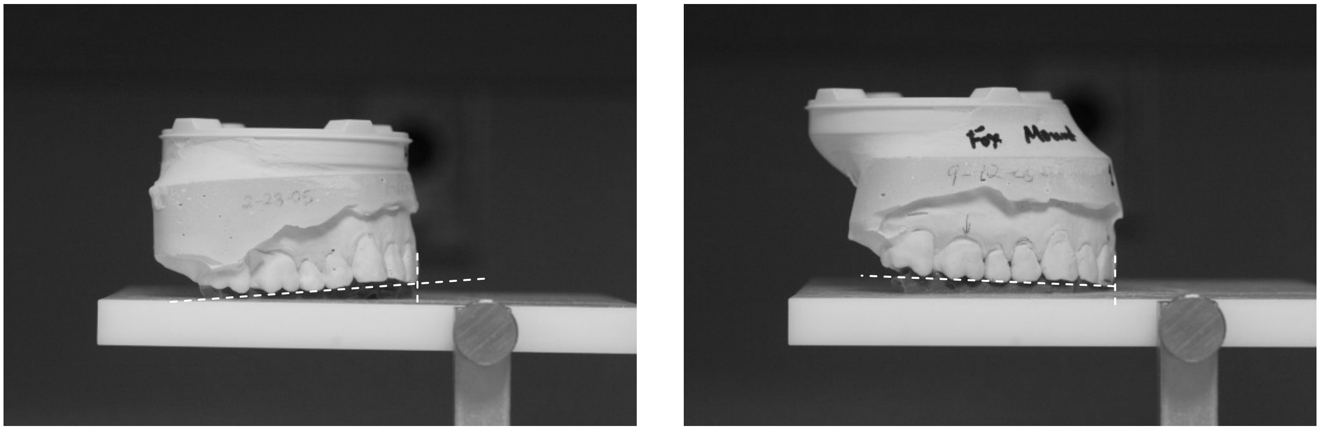


Figure 29: Combined angles of 33 maxillary mounted casts were over laid to compare slopes relative to a horizontal reference position for the modified Fox Plane level technique and the classic HIP technique. The occlusal plane slopes were measured when models were mounted to the horizontal occlusal analyzing table. Angles were tallied and measured. The Fox plane group showed a consistent positive 5.0-6.0 degree occlusal plane slope relative to horizontal level compared to the classic HIP group which showed a negative -3.5 to 4.0 degrees parallel to upward occlusal plane slope tendency relative to horizontal level.

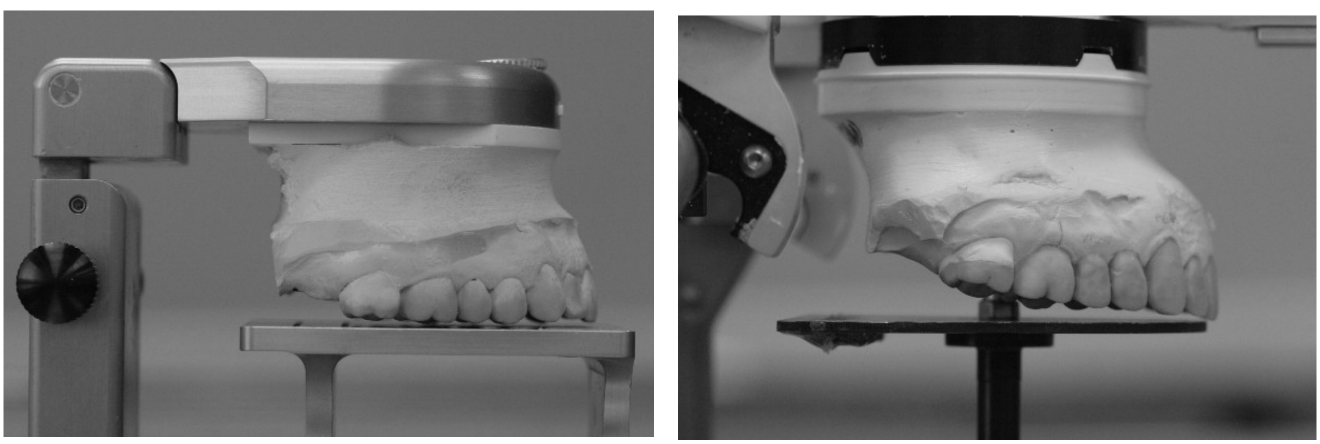
Studies show that HIP is parallel to the occlusal plane, but the HIP reference plane as classically taught (incisive pin and vertical hamulus plate of equal vertical height) *does not* represent on average a correct occlusal plane orientation relative to a natural head position. Mounting the maxillary cast using both incisive pin and a vertical hamular notch plate will often result in an erroneous mounting which numerous studies have confirmed. The actual HIP plane of reference, as literature and clinical studies have shown, is a reference plane that shows a downward sloping incline relative to horizontal level when the head is level. (Figure 30 and 31)



HIP Plane Mount | Modified Fox Plane Mount

A | B

Figure 30: The same pre-treatment model cast was oriented to the classic HIP (A) and to the modified Fox Plane at horizontal level (B). Note the difference in the sagittal view of the occlusal plane slope and angulation of each mount. Consider what the technician and dentist must do to accommodate a full arch wax up in re-establishing a corrected plane of occlusion and curve of Spee for each of the casts when designing and establishing a new plane of occlusion.



HIP Plane Mount | Modified Fox Plane Mount

A | B

Figure 31: Maxillary arch orientation is critical in establishing a proper diagnosis for treatment. (A) Maxillary cast is mounted to HIP and waxed (Acculiner ™ System, Woodinville, WA). Note minimal posterior vertical space to establish curve of Spee in the posterior region (flat). (B) The same maxillary cast is mounted according to a level Fox Plane and level head position (Stratos, Ivoclar Vivadent AG, Principality of Liechtenstein). Note: Increased posterior vertical and adequate space to develop a curve of Spee and plane of occlusion.

Studies have concluded overall that:

1. When the posterior points of Camper's plane are at the lower part of the tragus, it is parallel to the occlusal plane within the sagittal plane.
2. There is no difference between Camper's planes whether the frontal points are at the lower part of the alare or the subnasal point.
3. There are few differences between the Frankfort planes whatever 3 points are chosen from both orbital points and both tragus in the sagittal plane.
4. There are few individual differences between the Frankfort planes based on points at the right tragus and the left tragus in the frontal plane.
5. The HIP plane shows a slight upward sloping tendency relative to the occlusal plane in the sagittal plane, but parallels the occlusal plane closely in the frontal plane.
6. The inclinations toward the occlusal plane in the sagittal plane of the three lines of the nasion to the left alare, the nasion to the right alare, and the nasion to the subnasal point, are similar.
7. The lines from the center of the upper first incisal edge to the left subaurale point, and from the center of the upper first incisal edge to the right subaurale point, are parallel to the occlusal plane in the sagittal plane.
8. The three lines from the left orbital point to the right orbital point, the left alare to the right alare, and the left subaurale point to the right subaurale point parallel the occlusal plane closely in the frontal plane.
9. The line from the nasion to the subnasal point makes a right angle with the occlusal plane in the frontal plane. [67, 78]

CLINICAL APPLICATION AND CONSIDERATIONS

Mounting the Maxillary and Mandibular Casts to Cranial Base

From dental school training much focus has been placed on mounting the maxillary dental casts as the primary focus of evaluation before mounting the mandibular cast to some referenced occlusal position. With the advent of articulating devices and the evolution of the face-bow or ear bow, dentists have focused their attention not only from the temporomandibular joint concerns, but how best to anatomically relate the maxillary dental cast to represent the cranial base of the human on a mechanical device. Extensive thought and study was done mainly to accurately determine how best to relate the maxillary cast for diagnostic and treatment purpose, but to date after 100 plus years since Campion (1900), clinicians still debate as to how to orient and record the upper cast accurately when mounting the casts in the laboratory. Head positioning and its connection to orienting the maxillary cranial base to some horizontal level has challenged numerous clinicians as to how best to relate the diagnostic maxillary dental cast during finalizing orthodontic and restorative treatment.

In most articulators, the upper and lower members are parallel to each other and to true horizontal when the incisal pin is set at zero. The occlusal plane and the condylar inclinations are usually transferred to the upper member of the articulator with the *assumption* that the Frankfurt plane and the axis-orbitale plane are parallel to the ground. However, previous studies have shown that in natural head position (NHP), the Frankfurt plane can vary in inclination. [67-71]

Alignment of maxillary casts according to the Frankfurt plane and the axis-orbitale plane therefore implies inadequate mounting in articulators with a design assumption that places the axis and the orbitale on a plane parallel to the true horizontal. The result is an overly steep angulation of the occlusal plane with the incisal edges of the maxillary anteriors placed too inferiorly when compared to NHP. The use of NHP in conjunction with the true horizontal plane can eliminate individual and racial variations that have been commonly described for the classic intracranial reference planes [69, 71] and eliminate the described orientation errors that occur when the maxillary casts are mounted on the articulator.[108, 109] The elimination of these reference planes, to which relate the functional determinants of occlusion, avoids an additional source of error during the mounting procedure.

Recording the Occlusal Plane Slope with the Fox Plane Analyzer and Occlusal Plane Index (OPI)

A simple and reasonable clinical technique using the well known Fox Plane (Dentsply International, Trubyte) [94] can be used to record the maxillary arch with the patient's head at horizontal level (Figure 32). This phase II technique should be used once the patient has resolved all cranio-mandibular and cervical muscular hyper-tonicity. Once an optimized neuromuscular trajectory is identified and recorded and the head posture is leveled and balanced, the Fox Occlusal Plane can be used in a modified manner to record the maxillary occlusal plane inclination accurately.

Figure 32

Using the Modified Fox Plane Clinical Technique – *This Is How I Do It*

All soft tissue facial reference planes as well as bony cephalometric references planes should be considered when assessing the levelness of the patient's head position. The author proposes to use a horizontal reference, Temporal-Helical fold to Exocanthion (THE) line visualized sagittally from the temporal-helical fold (a point at the function of the helix of the ear and temple) to the corner of the eye. THE reference line is often parallel to Frankfort plane (Porion to orbitale) and horizontal to earths level and the ala tragus line. (Figure 33 and 34)

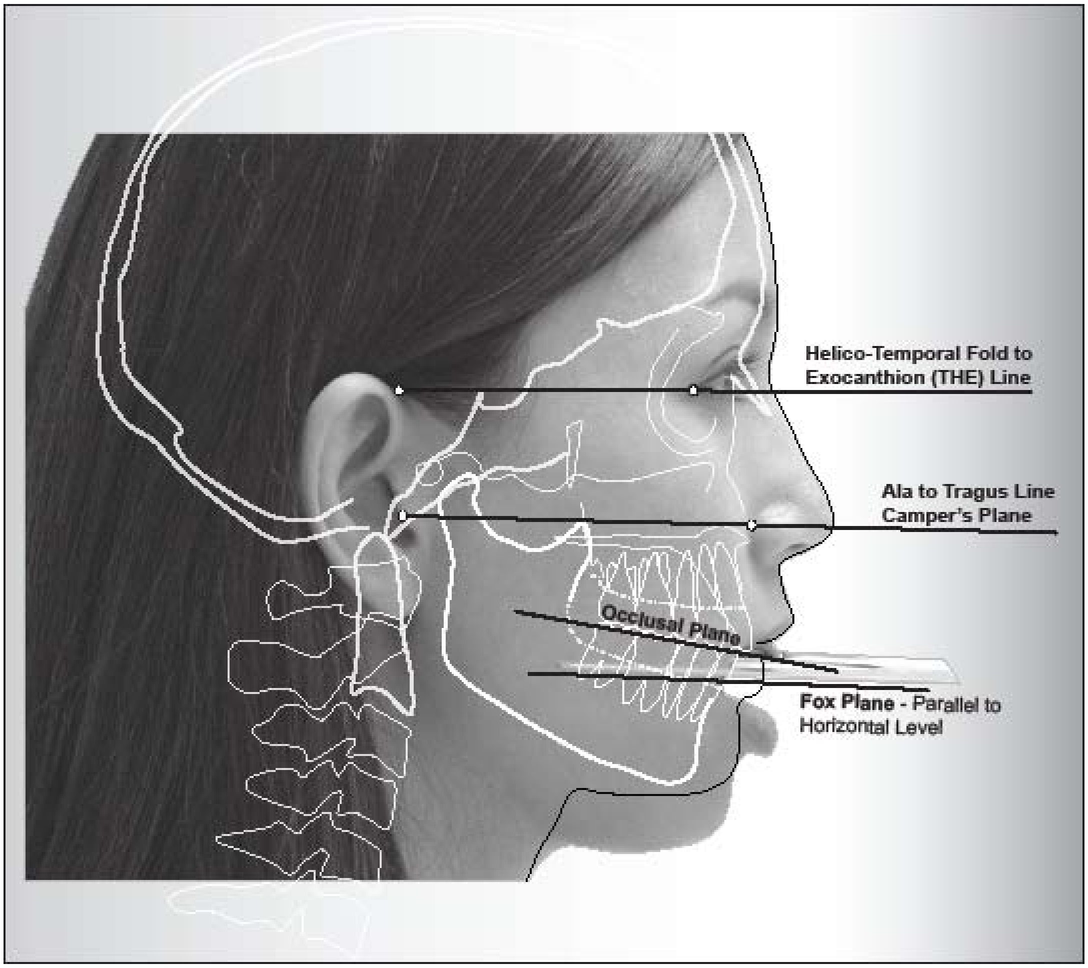


Figure 33: Clinical Soft Tissue Reference Planes from the Sagittal View. The Fox plane is aligned parallel to the floor (horizontal) with head correctly aligned at level using the Temporal Helical fold to corner of Eye (Exocanthion) as visual horizontal reference (THE reference line). [δ]

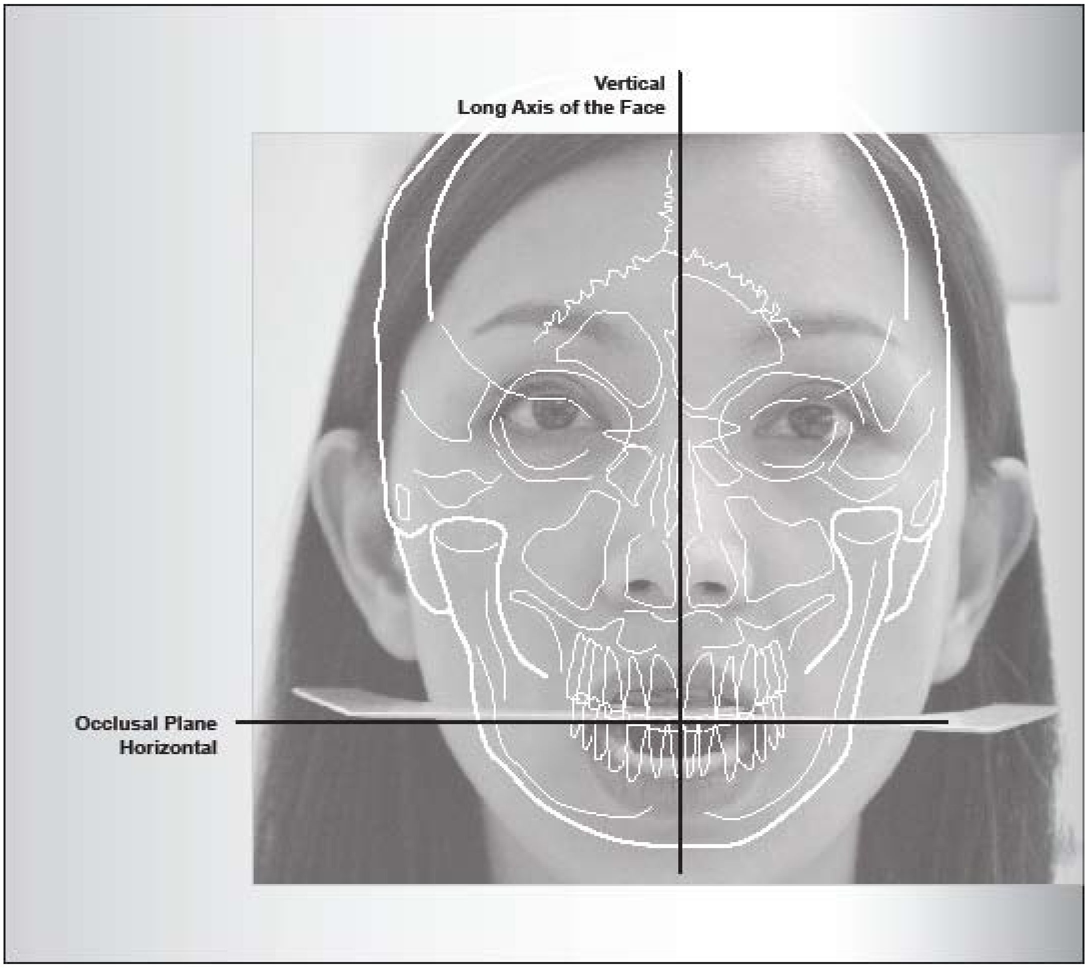


Figure 34: Clinical soft tissue reference planes from the frontal view. The Fox plane is aligned perpendicular to the long axis of the face. $^{\delta}$

1. With the patient standing straight and the head is positioned with eyes looking straight at the horizon, the sagittal head tilt is often with the eyes in the center of the orbits. (Natures leveling bubbles). The eye position assessment will assist in determining whether the head is correctly oriented to level. Subjective assessment of the long axis of the face is required to visualize the inter-pupillary level relation of the eyes, but should not be used alone to reference to frontal horizontal level, since some patient's eyes may be different from one side to the other. Ear levelness, eye brow heights, nose orientations and corner of the lips may not always be reliable references for facial symmetry.

2. With the patient's head maintained at level, syringe any fast set bite recording material (e.g. 30 second polyvinyl bite registration material) on the Fox Plane bite fork and insert it into the mouth upward against the maxillary anterior teeth keeping the Fox plane also level to the ground (The patient is instructed to open the lower jaw and not tilt the head up and back). *Do not press the posterior region of the bite fork up on the upper posterior occlusal surfaces!* It is important to have the patient maintain their head at level when opening the lower jaw with the eyes looking straight ahead. Check to confirm the pupils are centered of the eye sockets/orbits) and the head is

level. Make sure the Fox plane is parallel to the temporal-helical fold to corner of eye (THE) plane relative to the ground when viewed sagittally. (See Figure 33).

3. Orient the Fox Plane to level and perpendicular to the long axis of the face as well as level sagittally/lateral level to the ground (Figure 34).

4. Allow the fast set bite registration material to set firm while holding Fox Plane with light finger pressure anteriorly and parallel to the ground. Take a moment to confirm frontal and sagittal levelness to the ground and the THE line. If the recording does not look right repeat the above steps until correctly leveled and recorded. After the bite registration material hardens, remove the Fox Plane and occlusal plane index (OPI) from the mouth.

5. Peel away the bite registration (OPI) from the Fox Plane bite fork and place the OPI on any level mounting table and orient it to the center/midline and anterior of the flat occlusal analyzing table. Place the maxillary dental cast into the OPI index registration and mount the upper cast.   (See Figure 35-37)

6. After the upper cast is set and mounted remove the OPI from the mounting table and evaluate the occlusal table slant or angulation (pitch) as it relates to the horizontal table.

7. Mount the lower cast to the upper via the myocentric bite registration.

Now you have the upper and lower casts mounted physiologically and accurately, relating the patient's maxilla and mandible on any articulating "model holder".

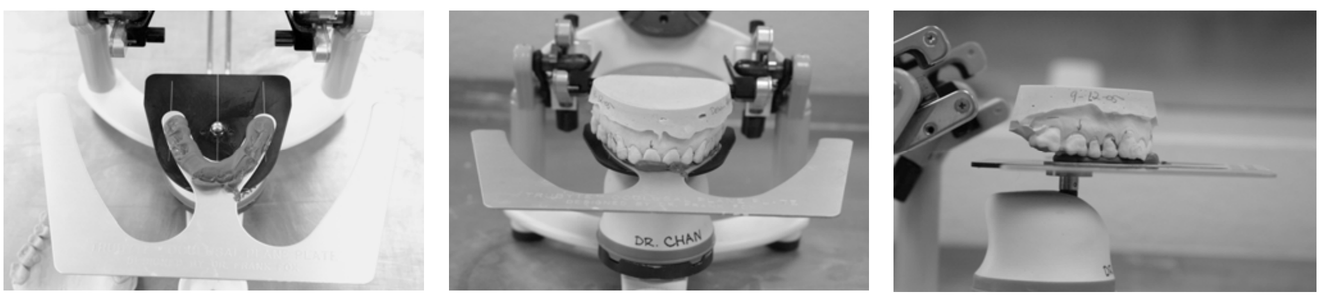


Figure 35: Occlusal Plane Index (OPI)/ Level Fox Plane is positioned on any flat analyzing table to demonstrate the maxillary cast orientation for mounting.

Figure 36: Occlusal Plane Index (OPI) is removed from the Fox plane bite fork (flat surface against flat table) and positioned anterior and centered to midline to mount the maxillary cast.

Figure 37: Mounted maxillary cast using the modified Fox plane technique. Note: Pre treatment diagnostic casts indicate a 6 degree occlusal plane angles and anterior downward slope matching the patient's maxillary arch.

Significance of Mandibular Positioning

Within the neuromuscular arena, focus has been mainly away from traditional mechanical articulating devices. A greater emphasis on mandibular orientation to the maxillary cast has been placed because most craniomandibular dysfunction (CMD, TMD, MSD, MPD, TMJ, etc) is muscular related and most of the CMD problems are related to a misalignment of the mandible to the fixed maxillary cranial base. Establishing a physiologic resting position via the Myomonitor TENS has been proven to be an effective means to first establishing a starting reference point in space. It is also a necessary "treatment tool" combined with CMS (jaw tracking) to identify a neuromuscular trajectory which the clinician is able to help objectively identify a myocentric target up from the rest position through freeway space to capture a physiologic unstrained bite.[110, 111]

Phase I Treatment – Relating the Mandible to the Maxilla

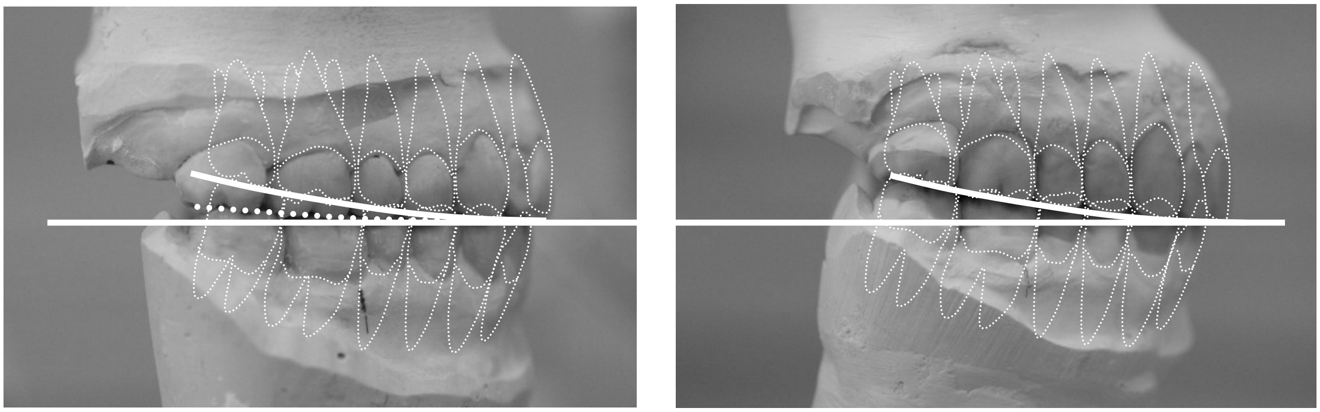
During an initial phase I stabilization stage of diagnosis and treatment the dentists discovered that mounting the upper dental cast to the lower on any articulating device ("Model holders") would work since the importance of establishing a terminal end point could effectively be accomplished without using the hinge axis concept and manual manipulative techniques in establishing a bite relationship. Therapeutic effectiveness has been well established by simply mounting the dental cast to one another on any simple model holding device regardless of occlusal plane orientation. The occlusal plane orientation was determined only when the maxillary orientation to the cranial base was necessary to complete a phase II level of restorative or prosthodontic phase of treatment, such as full arch restorative and or full or partial dentures. It is at this stage of treatment that smile design, maxillary anterior teeth alignment and proper smile curvature is important to establish the necessary parameters of good facial form, smile to lip design and overall aesthetic appearance for optimal function.

Phase II Treatment – Relating the Maxillary Cast to Horizontal Level

It is in the finishing phase II stage of treatment that the neuromuscular clinician is faced with the challenges of relating not only the mandible to the maxilla physiologically in all six dimensions, but finds that in fixed restorative treatment that the alignment of the maxilla to the cranial base is very important to record in a manner that would easily transfer to a horizontal reference table in the dental laboratory setting.

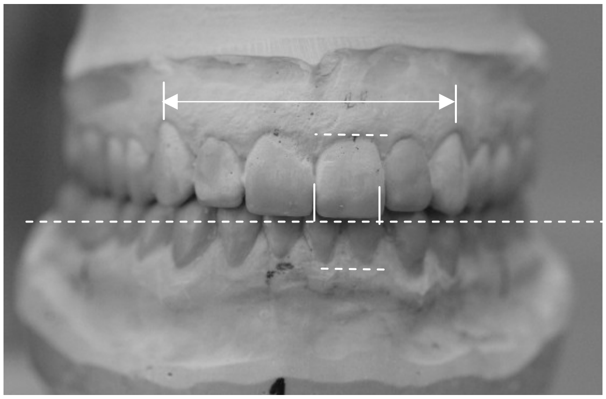
In removable prosthodontics where edentulous ridges are present and wax and denture teeth can be easily manipulated and oriented through softened wax over the alveolar ridges of the upper and lower mounted casts to an established occlusal plane, it soon becomes apparent that in fixed restorative dentate cases that the principles of prosthetic occlusal plane positioning does not easily transfer clinically to fixed restorative occlusal positioning procedures. It has been often realized by restorative clinicians abroad that the coronal crown to root ratios were not as easy to move as waxed denture teeth are easily manipulated in softened wax. Additionally, clinical considerations should be given to clinical crown lengths, intrusion and extrusion movements that affect the gingival crest to cusp tips when establishing a finished occlusal plane to produce a proper curve of Spee and curve of Monson within the inter-occlusal space. Establishing the occlusal plane from the mandibular arch may not always be appropriate especially in the fixed restorative dentate case since the flexibility of moving dentition and gingival crest contours is now always easy and convenient when smile designing and establishing/orienting the occlusal plane in most cases. (Surgical intervention maybe required in certain cases). In edentulous cases it is easy to shift and move wax and denture teeth, vertically, labio-lingually and antero-posteriorly without patient harm.

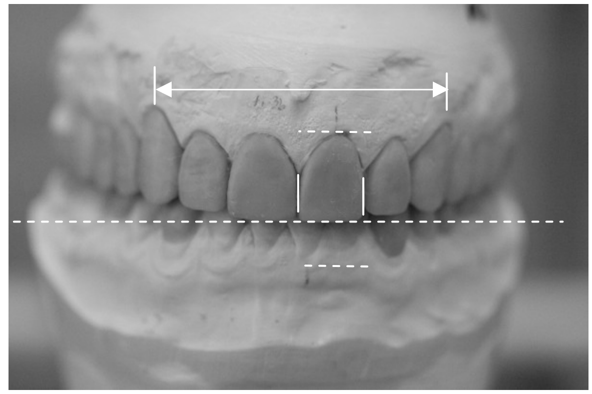
When comparing the same model casts which are mounted in two different manners (classic HIP mount and the modified Fox plane mount) for full mouth diagnostic waxing it becomes apparent as to the importance of the maxillary cast mounting. (Figure 38 and 39) While maintaining a curve of Spee in designing the occlusal plane, the classic HIP mounted maxillary cast will have shorter maxillary (upper) posterior clinical crown lengths, longer mandibular (lower) posterior clinical crown length and the maxillary anterior clinical crown length would commonly be modified to be waxed up off the occlusal analyzing table in order to maintain a proportional crown width to length ratio (minimizing excessive central incisor length). This is due to the upward occlusal plane slope that is often a result of the HIP mounting technique, giving the impression of an anterior open bite type mounting. Without this modification the central and lateral incisors will appear longer than normal. Maintaining the same curve of Spee in designing the occlusal plane using the modified Fox plane mounted maxillary cast will result in a natural curve of Spee that allows for an even distribution of posterior vertical length in both the posterior and anterior clinical crown without over reduction of the upper posterior teeth or upward modification of the anterior incisors. If the clinician were to maintain the same curve of Spee with the classic HIP mounting as with the more natural modified Fox plane mounting the dentist would have to remove more tooth structure occlusally with the HIP mounted cast than the cast mounted with the modified Fox plane technique. *The only alternative to prevent over reduction of the posterior teeth is to alter the horizontal analyzing reference table by changing the slope of the table to closer match the modified Fox plane mounting subjectively.*



HIP Plane Mount | Modified Fox Plane Mount
A | B

Figure 38: Model casts are mounted in two ways for neuromuscular full arch wax up comparison. (A) HIP mount shows a flatter horizontal occlusal plane (dotted curve), shorter upper posterior clinical crown length and a longer lower posterior clinical crown length. (B) Modified Fox plane mounted maxillary cast show a natural curve of Spee and even distribution of upper and lower posterior vertical crown length. Overlaying tooth outline shows proposed crown lengths if the same curve of Spee is maintained in both mounting techniques.





HIP Plane Wax Up

A

Modified Fox Plane Wax Up

B

Figure 39: The maxillary casts are mounted to the classic HIP and to the level Fox plane. The resulting full mouth wax ups give two differing results. (A) HIP wax up will result in shorter maxillary posterior crown height with longer mandibular posterior crown height when establishing the curve of Spee. The HIP mount will result in the central incisor edge not contacting the occlusal analyzing table to prevent an excessive longer central incisor. A flatter occlusal plane profile will result in a more tooth show in the smile line. (B) The Fox Plane wax up will result in normal curve of Spee with a proportional distribution of crown height between the maxillary and mandibular posterior teeth. This physiologic relationship supports golden proportional ratios not only anteriorly, but also posteriorly. A soft smile line naturally results.

If the maxillary study casts are referenced to a wrong level reference plane, the maxillary casts will be mounted with a cant (crooked) even though it may be mounted and centered to a level horizontal referenced table. As a result of this canted flatter mount, the clinician will end up with a canted toothier looking smile line and a mis-oriented occlusal plane when the new fixed restorations or removable prosthesis is inserted intra orally. Because of these observations, the experienced dental laboratory technicians commonly corrects the maxillary cast orientation *(admittingly or not)* by: 1) Visually establishing an anterior sloping occlusal plane based on the hamular notches *without* the incisive pin, 2) visually aligning the maxillary cast to a horizontal and vertical stick bite reference line and estimating the slope of the occlusal plane orientation, and or 3) Using photographs to assess facial symmetries and smile lines to visually orient the occlusal plane slope of the maxillary cast. Each of these techniques requires visual (subjective) assessment and artistic estimations as to the occlusal plane slope on the part of the laboratory technician.

Because educational programs lack a proper understanding of these concepts and also lack a reliable and accurate means to mount the maxillary cast anatomically, decisions are routinely made by the laboratory plaster bench technician instead of the dentist as to how best to orient the maxillary cast. Few dentists actually mount their casts, thus never comprehending these profound subtleties in mounting techniques. Using the incisive pin using the classic HIP technique certainly further induces a distorted maxillary cast orientation and is often purposely ignored in experienced dental laboratory technician's hands, altering the occlusal plane slope purposely toward a more natural and anatomically correct orientation. Dentists should record an anatomically correct maxillary occlusal plane slope and mount multiple casts on their own to discover these truths. The laboratory technician should consider mounting the cast with a properly taken occlusal plane index (OPI) by the dentist that reflects a correct maxillary occlusal plane slope anatomically. A physiologic and anatomic mounting of the maxillary cast is critical to anatomic crown to root ratios in restorative crown and bridge fabrication. The maxillary cast orientation is a reflection and expression of the cervical neck alignment. Accurately relating the maxillary cast to a horizontal level is critical in the diagnosis and treatment planning stages, especially in fixed restorative full mouth reconstruction.

Flat Maxillary Cast Mountings

Maxillary cast mounting and orientation is critical in phase II diagnosis and treatment. Maxillary cast that are mounted in a manner that depicts a flat to upward slope anteriorly (e.g. classic HIP flat mount) often times will unknowingly build in pathologic vector of forces due to an abnormal occlusal plane orientation.

- This will lead to toothy looking smiles, especially in the second bicuspid molar region and will also result in vertically taller mandibular posterior clinical crowns.
- A curve of Spee is often compromised and minimal due to inadequate space between the desired occlusal plane and tooth preparation during laboratory waxing and crown fabrication.
- To compensate for this the clinician will need to be more aggressive in maxillary posterior occlusal prep reduction which can lead to pulpal infringement and endodontic therapy.
- Skewed crown to root ratio in both the upper and lower arches will be present making arch and crown form lacking in natures anatomic proportions.

Downward Sloping Maxillary Cast Mounting

Maxillary cast mountings that show a natural downward sloping occlusal plane incline (e.g. modified Fox plane level mount) allows for balanced vector of muscular and occlusal forces due to a more physiologic plane orientation that matches an optimized cervical, head and craniomandibular posture.

- Softer natural smile line leads to a more pleasing aesthetic smile.
- Less posterior occlusal prep reduction in either maxillary or mandibular arches is required.
- Easy to develop a curve of Spee.
- Crown to root ratio tends to be closer to natures golden proportions.

It becomes clearly evident to the restorative neuromuscular clinician who is performing a phase II level of finishing treatment that establishing a proper physiological oriented occlusal plane becomes paramount to the long term stability of maintaining optimal head posture. This kind of relationship helps to prevent a re-occurrence of craniomandibular dysfunction. *As the mandible optimizes its trajectory from its previous posterior and superior position and now physiologically functions unstrained in a more anterior inferior relationship, the gearing of the occlusion becomes critical to the support and optimal function of this intricate proprioceptive mechanism, the masticatory system.*

Altering the slope and angle of the occlusal mounting table by the technician or dentist from the starting classic HIP mount to better accommodate a proper natural curve of Spee only emphasizes the fact that a natural anterior downward slope exists, is necessary and required to simplify the accuracy of occlusal plane analysis and design when establishing the slope of the occlusal plane. Recording the slope of the occlusal plane in an anatomically correct manner, regardless of technique chosen, must capture and record the slope that truly represents an anatomical maxillo-cranio-cervical relationship of a level head and cervical posture.

Cervical Postural Relapse Effects – *A Reversal of Neuromuscular Trajectory*
As the mandible moves or shifts posteriorly, due to an imbalanced occlusion and improper gearing of the teeth (flattening), the head will begin to regress back to an upward and forward posture. The forward head posture develops with the head tilting upward (flat occlusal plane tendency) due to a change in vector of forces of the occlusal plane slope from the hypertonic digastric/suprahyoid muscles, rather than a physiologic vector of forces that are perpendicular to a more anatomic sloping occlusal plane (isotonic digastric/suprahyoid musculature). As the head tilts upward so does the alteration in the maxillary occlusal plane referenced to the cranial base. As a result there is a domino effect of masticatory muscle forces shifting the isotonic myo-trajectory back to one of pathology (toward a habitual trajectory) resulting in a compromised function of the neck moving from a lordotic curvature to a kyphotic curvature of the cervical vertebral column. As inexperienced occlusal management ensues with repeated follow up occlusal adjustments a flattening of the occlusal morphology redevelops. The proprioceptive engrammed forces of a distorted worn occlusal morphology will now take over and dominate, dictating the relapse in an abnormal jaw closure pattern (neuromuscular trajectory) once again to further a pathologic cervical and head position.

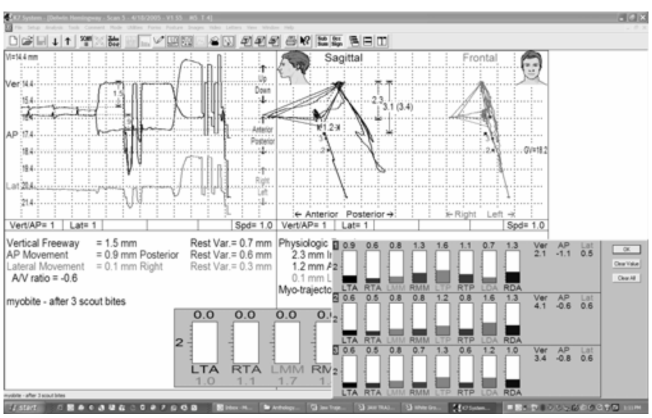
To maintain an optimal occlusal plane and optimal physiologic head positioning over the vertebral spinal column it must be recognized that a proper occlusal plane angulation must be present, supported by anatomically sound occlusal management. Flat occlusion with an occlusal plane that is posteriorly sloped (counter-clock rotation tendency) will lead to a posteriorized mandibular position over time with a reoccurrence of symptomology resulting in breakdown in the structural system of teeth, muscles, joints and the central nervous system. Anatomical micro management of cusp to fossa occlusal form maintained a neuromuscular trajectory will ensure physiologic form and function of the cranio-mandibular cervical postural system.

Phase II Treatment Demands
When treating phase II level cases which involve finalizing the CMD/TMD case, a higher level of demand and precision is required, due to the proprioceptive, emotional and physical requirements that are placed upon the clinician to meet the finishing appearance and functional challenges of the previous pain, muscular dysfunctional and joint derangement type patient (e.g. as in the case of aesthetic full mouth ceramic reconstruction procedures). (Figure 40-46) Once the challenges of pain, function and discomfort are resolved, the clinician who only performs the initial diagnostic and phase I level of CMD/TMD stabilization therapy with orthotic and or appliances will fortunately not have to address the significant detailed finishing issues that arise in the phase II stages of restorative treatment. The proprioceptive detail for precision of both micro occlusal management and neuromuscular pain management increases significantly when the clinician transitions from phase I orthosis appliance therapy to a finalized fixed restorative/ prosthetic level of therapy. Once phase II finalizing treatment begins, a whole new level of challenges are faced by the clinician, especially for those patients who may have been asymptomatic or who previously experienced pain, muscular dysfunction and joint derangement problems. An optimization of the neuromuscular trajectory (antero-posterior positioning) of the mandible, the reduction of both discs within the temporomandibular joint complex and the micro detailing of the occlusion (teeth) becomes paramount!

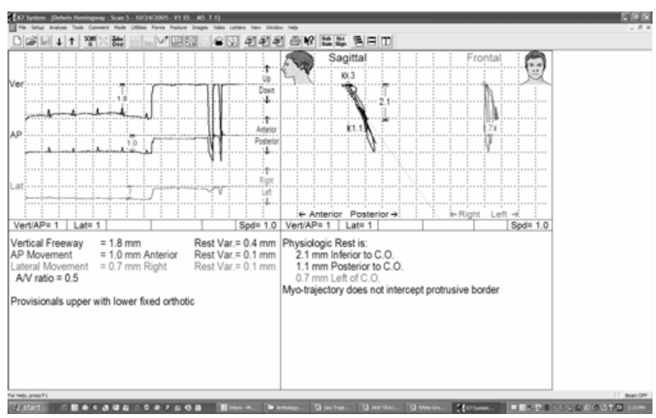
Accommodated Rest Position – Before

Optimized Neuromuscular Position - After

Figure 40: 56 year old male desires a new smile and full mouth rehabilitation as his primary goal and focus. He presents with worn down appearing teeth and wants to change the lateral cant of the occlusal plane. Note improved head position and occlusal plane.



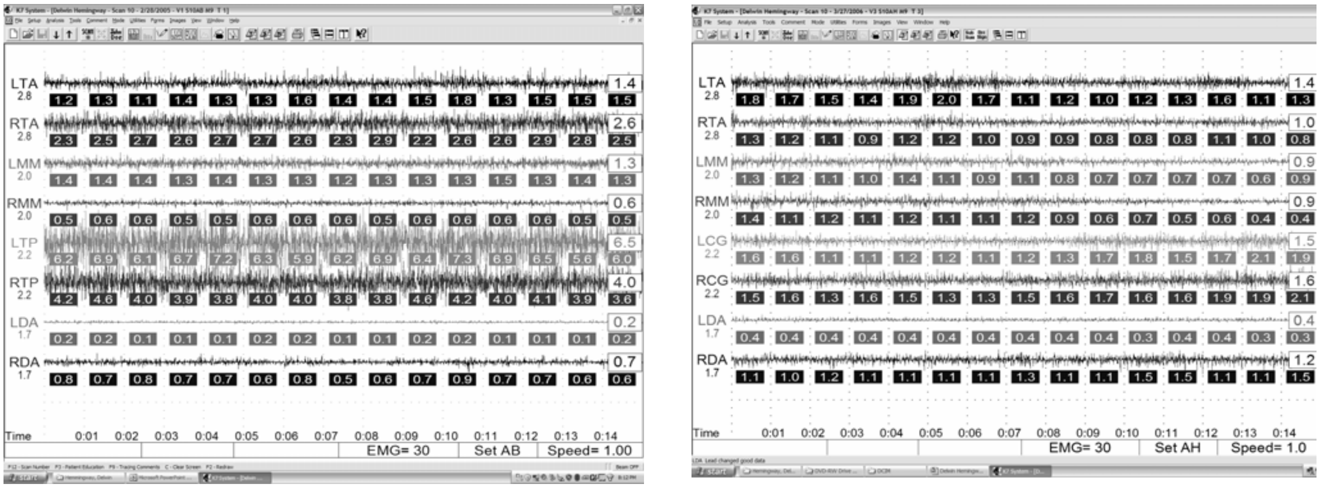
A



B

Figure 41: (A) Computerized mandibular scanning (CMS -Jaw Track, Scan 4/5*) shows an improved jaw closure pattern and angle along the optimized trajectory compared to the habitual

trajectory (Chan protocol). (B) After 6 months orthosis stabilization, the habitual trajectory is coincident with the optimized neuromuscular trajectory.



Accommodated Rest Position – Before

Optimized Neuromuscular Position - After

A

B

Figure 42: Electromyographic (EMG) studies have been used to objectively measure the postural activity of the cervical muscles (extension and flexion) in relation to mandibular posture. (A) EMG recordings (Scan 9) of the same 56 year old male shows increased muscle activity of the cervical group (LCG and RCG) and anterior temporalis anterior muscle groups (LTA and RTA) before full mouth rehabilitation. (B) After optimization of the mandibular position lower cervical group and anterior temporalis muscle EMG activity is recorded.

Head Postural Effects On Chewing Cycles Before and After Treatment

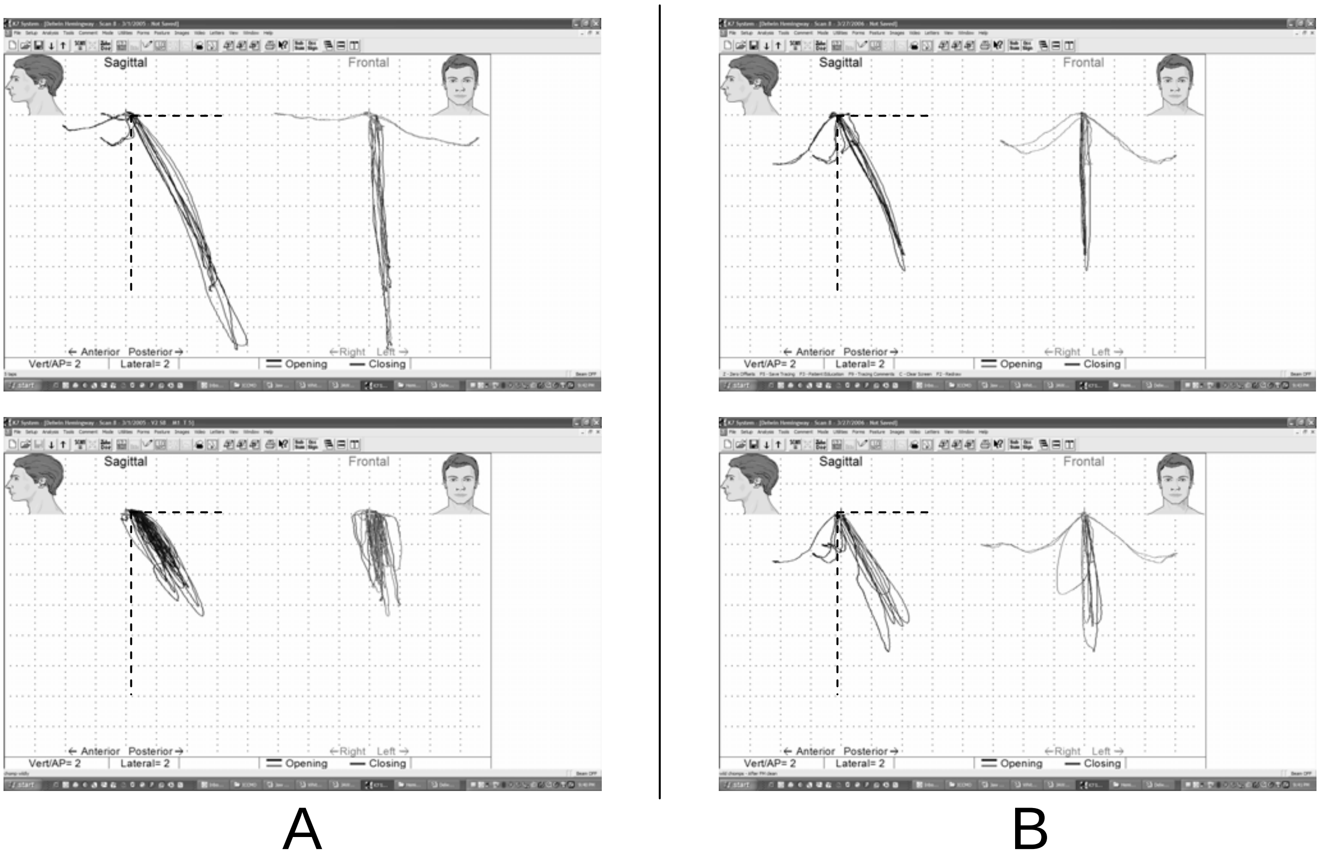


Figure 43: Head posture effects chewing stroke and vector of forces. Chewing cycle (Scan 8$^{\alpha}$) indicates: (A) Flatter angled chew cycle indicative of upward head tilt and posterior mandibular position– Class II tendency, before full mouth rehabilitation. Lack of a terminal contact with flat lateral discussion (B) Steep angled chew cycle indicative of physiologic head position – Class I tendency, after full mouth rehabilitation. Terminal contact position with freedom of lateral exit and entry indicative of muscular freedom and occlusal stability.

Figure 44: Worn habitual occlusion lacking posterior vertical support contributing to upward head tilt and abnormal cervical alignment. (See Figure 11 - Before and after ICAT).

Figure 45: Finished full mouth reconstruction on neuromuscular trajectory, supportive of improved head posture and cervical alignment.

Figure 46: Before - Anterior wear and faceting indicative of abnormal jaw closure pattern. After – Finished restorative crowns to optimized neuromuscular trajectory supported by a proper occlusal plane. Micro-occlusal coronoplasty principles were applied to support an improved cervical posture.

The appearance oriented concerns of a cosmetic patient demands meticulous and optimal supportive treatment protocols that allow physiologic form and function to come together both in the anterior and posterior regions. Establishing proper cuspal form, disclusion, entry and exiting of the mandible from a precise terminal contact position free of occlusal interferences and proper occlusal plane inclination is required and demanded when treating both the maxillary and mandibular arches. This is particularly true in cases requiring a higher level of precision for any esthetic minded clinician. The principles of neuromuscular dentistry and occlusion are the same for both phase I and phase II treatment, but when treating the craniomandibular compromised patient, further refinement in the application of operative precision, skill, experience, and clinical judgment is often required when applying the detailed coronoplasty skills to finish the neuromuscular position of phase II treatment. Phase II level of finishing treatment certainly challenges the understanding and appreciation of what it means to manage the aesthetically compromised dysfunctional patient.

DISCUSSION:

Over the recent years much discussion and debate have taken place as to defining the answers to occlusal plane orientation, HIP versus the Fox Plane determination for therapeutic restorative and aesthetic procedures. Jankelson, Garry, and numerous clinicians have succinctly pointed out that many early developmental anomalies, dysfunctions and pathologies can affect the basal plane of the skull. Basal growth patterns are affected by airway obstructions such as enlarged tonsils, adenoids, turbinates, deviated septums, allergic and non-allergic rhinitis and facial trauma. Cervical anomalies and instabilities will also alter postural and basal growth patterns. Early pathologic habit patterns such as thumb sucking, aberrant tongue habits, swallowing tongue habits, and obstructed nose breathing can also affect cranial base development. Thus, a much higher incidence of upward head tilt, abnormal cervical neck posture and HIP occlusal plane abnormalities can be found in a patient population requiring advanced restorative and/or orthodontic procedures. Form follows function. The equilibrium disturbance as mentioned by some results in cranial base, i.e. Incisive-Papilla-Hamular notch deviations from normal that we so often observe in our dysfunctional patients.

"Clinicians and dental laboratory technicians have found it important to DIAGNOSTICALLY identify the HIP plane so that the dentist does not restore to a distorted cranial base. Since the patient population with chronic TMD and postural problems obviously has a higher than normal HIP plane variance from normal basal plane parameters, it is important that the clinician does not replicate this distorted base. Ergo Hoc Procter Hoc, if clinicians restore this patient using the HIP reference it will only replicate the anatomic manifestations of the etiologic problems."[112]

The clinician does not want to restore his/her patients to an abnormal cranial base as represented by the classic mountings of HIP, but rather wants to identify an anatomically correct occlusal plane inclination based on a natural head position, thus the need to properly diagnose and identify cranial base distortions and cervical mal-alignments. As some proponents have stated, the HIP plane is an important DIAGNOSTIC protocol, but is an unpredictable anatomic reference for THERAPY.

It is only logical that patients presenting with complex restorative needs are going to have a higher incidence of distorted cranial bases. Once the occlusal plane is identified as abnormal the clinician must have a reliable technique to correct the cranial base distortions. This is the purpose of the modified Fox occlusal plane technique. As with all clinical techniques designed to optimize occlusal planes and compensate cranial distortions, the modified Fox occlusal plane technique involves arbitrary subjective visual determinates. However, the landmarks are well known by dentists and necessary adjustments to particular facial soft tissue asymmetries can *easily* be made. Physiologic muscular and postural responses can be objectively measured.

It is clear that the clinician must be able to diagnostically distinguish between a physiologic HIP occlusal plane orientation and a pathologic HIP occlusal plane orientation, like all other anatomical reference points and planes during clinical and laboratory DIAGNOSTIC MOUNTING phases. The Fox occlusal plane mounting technique as described in this paper is a TREATMENT MOUNTING technique that eliminates the dependency on cranio-facial morphologic distortions to finalize treatment.

CONCLUSION

It is concluded that change in occlusal plane inclination during growth and development is toward an anterior sloping incline relative to horizontal. The orthodontic, restorative and prosthetic literature substantially confirms time and time again that the human occlusal plane slopes anteriorly in physiologic normal states and has been confirmed beyond reasonable doubt with lateral radiographic imagery (Sato (2006), Vukusic, (2000), Ogawa (1998), Xie (1993), Kazanoglu, (1992), Koller (1992).[23,75, 91, 97] Literature concludes that there is variation in the use of the face bow transfer technique as it relates to cephalometric occlusal plane inclination measurement evaluation (Gateno, et al (2001), O'Malley and Milosevic (2000), Ellis 3rd (1992) and others.[108, 109, 115] A range of inherent errors attributable to the operator using these devices have been recorded.[113, 114] The modified Fox occlusal plane technique is an easy and convenient means for any clinician to record and transfer the maxillary cast to a horizontal level reference table for diagnosis and treatment.

Physiologic occlusion depends on the homeostasis of teeth, skeletal structures and surrounding soft tissues, but should not depend only on cranio-facial soft and hard tissue structures as reliable references. That is why the foundation of neuromuscular therapy has been founded on objectively addressing muscle physiology first and not referencing to pathologic skeletal and soft tissues structures as starting references for treatment. Electronic instrumentation and objective diagnostic tests available today improve the clinical outcomes and eliminate the subjective guessing. The intrinsic compensative mechanism of the cranio-mandibular complex plays an important role in forming an occlusal plane position and orientation. Doctors should choose the best diagnostic and treatment method to obtain optimal individual balance between the craniofacial structures and the occlusion.

Anything that might be performed on the body which lower its inability to function shows up later to add to the natural process of aging. The challenge as to what process and dental procedures performed that contribute to dysfunction of the craniomandibular/neuromuscular/cervical system should be considered, because initially they may not appear immediately, but over time they will impact these systems.

Opening vertical dimension and restoratively preparing teeth for full mouth reconstruction or performing restrictive orthodontic therapy without clear understanding of its impact on the craniomandibular and cervical postural system, even though the patient may appear more cosmetically pleasing, does not make one healthier or function better. Within a single dental office visit, irreversible restorative procedures on a single arch can undo what has taken the body years to perfect. The field of dentistry is rampant with individuals who resist clinical truths for self serving gain, rather than acknowledge science and objective evidence. An orthopedic understanding of the underlying growth and development factors is critical to comprehend a more complete perspective of physiologic occlusion. Proper cervical alignment cannot maintain a level of stability in the long run without acknowledging a physiologic plane of occlusion and an optimized neuromuscular trajectory. They go hand in hand.

It is clear that mandibular posture, as it relates to the cranio-mandibular cervical complex is influenced by postural changes distant from the head and neck. Intra and extra oral muscular balances impact mandibular jaw position as well as cervical head posture. Understanding the etiology of the cranio-facial morphology and the neuromuscular influences on growth and development allows the clinician to appreciate how to be a better diagnostician and treating physician of the mouth. You have learned how anatomical relationships are altered when upper airway obstruction impacts head posture and cervical mal-alignment, resulting in an accompanying mal-alignment in the occlusal plane and neuromuscular trajectory. You have also learned that the occlusal plane inclination recording is dependant upon proper head orientation to optimize clinical treatment outcomes for advanced restorative and orthodontic dentistry. It is my hope that the dentist will take serious look at his or her patient's posture and occlusal plane inclination and broaden their scope of care beyond just seeing what remedies maybe required for the teeth.

References:

1. Jankelson RR: *Neuromuscular Dental Diagnosis and Treatment*, St Louis: Ishiyaku EuroAmerica, Inc., 1990.
2. Travell, JG, Simon DG, p. 165-169.
3. 4-106Travell JG, Simons DG: *Myofascial Pain and Dysfunction – Trigger Point Manual*, Baltimore:Williams and Wilkins;1984;1-164.
4. Cram, JR and Kasman, GS: *Introduction to Surface Electromyography*. Aspen Publishers, Gaithersburg, Maryland. 1998.
5. Deregibus A and Bracco P: Chewing Cycle Analysis. Neuromuscular Dentistry the Next Millenium. *Anthology V ICCMO The International College of Craniomandibular Orthopedics*, Hickman D., Seattle, Washington, 1999.
6. Luschei ES: Neural mechanisms of mandibular control: mastication and voluntary biting. In: Brooks VB , *Handbook of Physiology, Section I: The Nervous System*, Vol. 2, Motor control, Bethesda: American Physiological Society: 1981;12371274.
7. Kaas JH: Plasticity of sensory and motor maps in adult mammals. *Annu Rev Neurosci* 1992;14:137-167.
8. Tilley, L and Hickman, DM: TMD-An Upper Quarter Condition. *Anthology of ICCMO.* Vol. V. 1995.
9. Ash MM, Ramfjord SP: Anatomy, Physiology, and Pathophysiology of Occlusion. In: Ash MM and Ramfjord SP, eds. *Occlusion, 4th Ed.* Philadelphia: W. B. Saunders;1995;1-29.
10. Gelb M: Diagnostic Test, In: Kaplan AS and Assael LA, eds. *Temporomandibular Disorders Diagnosis and Treatment, Philadelphia*: W. B. Saunders:1991;371-385.
11. Cooper BC: Craniomandibular Disorders, In: Cooper BC and Lucente FE, eds. *Management of Facial, Head and Neck Pain.* Philadelphia: W. B. Saunders:1989;153-254.
12. Guyton AC: Membrane Physiology, Nerve, and Muscle. In: Guyton AC, ed. *Textbook of Medical Physiology.* Philadelphia: W. B. Saunders:1986;87-148.
13. Sheikholeslam A, Moller E, Loos J: Pain, Tenderness and Strength of Human Elevator Muscles. *Scan J Dent Res* 1980;88:60-66.
14. Travell JG, Simons DG: *Myofascial Pain and Dysfunction – Trigger Point Manual:* Williams and Wilkins;1984;1-164.
15. Glossary of Prosthodontic Terms: *Centric Relation: Seventh Ed (GPT-7)*;Vol. 81: 1:1999.
16. Kraus S: *TMJ Disorders - Management of the Craniomandibular Complex*. New York: Churchhill-Livingston, 1988.
17. Cooper, B: Parameters of An Optimal Physiologic State of the Masticatory System: The Results of A Survey of Practitioners Using Computerized Measurement Devices. *Anthology of ICCMO*, Vol. VII. 2005.
18. Jacobson, A: Radiographic Cephalometry from Basics to Videoimaging. *Quintessence Publishing Co.*, Inc., Carol Stream, IL 1995. 77-85.
19. Downs, WB: Variations In Facial Relationships: Their Significance In Treatment and Prognosis. *Am J Orthod* 1948;34:812-840.
20. Downs, WB: The Role of Cephalometrics in Orthodontic Case Analysis and Diagnosis. *Am J Orthod* 1952;38:162-182.
21. Moorees, CFA, et al.: The Complexity of Facial Growth Analysis: Radiographic Cephalometry from Basics to Videoimaging. Jacobson, A: *Quintessence Publishing Co.*, Inc., Carol Stream, IL 1995. 137-163.
22. Braun S, Legan HL.: Changes in Occlusion Related to the Cant of the Occlusal Plane. *Am J Orthod Dentofacial Orthop.* 1997 Feb;111(2):184-8.

23. Koller MM, Merlini L, Spandre G, Palla S.: A Comparative Study of Two Methods for the Orientation of the Occlusal Plane and the Determination of the Vertical Dimension of Occlusion in Edentulous Patients. *J Oral Rehabil.* 1992 Jul;19(4):413-25.
24. Karkazis HC, Polyzois GL.: Cephalometrically Predicted Occlusal Plane: Implications In Removable Prosthodontics. *J Prosthet Dent.* 1991 Feb;65(2):258-64.
25. Chan, CA, Thomas, NR: Clinical and Scientific Validation of Optimizing the Neuromuscular Trajectory Using the Chan Protocol. *Anthology of ICCMO.* Vol. VII. 2005.
26. Yamada, R, Ogawa, T and Koyano, K: The effect of head posture on direction and stability of mandibular closing movement. *Journal of Oral Rehabilitation.* 26 (6)1999; 511.
27. Cooper, B. The role of bioelectronic instrumentation in the documentation and management of temporomandibular disorders. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1997;83:91-100
28. Huggare JA, Raustia AM: Head posture and cervicovertebral and craniofacial morphology in patients with craniomandibular dysfunction. *Cranio*. 1992 July;10(3):173-7; discussion 178-9.
29. Gray, VG: Upper Airway Obstruction and Dento-Facial Deformity. *Anthology of Craniomandibular Orthopedics.* Volume: 1, 1991. 47-80.
30. Garry, JF: *Upper Airway Compromise and Musculo-skeletal Dysfunction of the Head and Neck (MSD)*, 1977.
31. Garry, JF: Early Iatrogenic Orofacial Muscles, Skeletal, & TMJ Dysfunction. 1988.
32. Linder-Aronson S: Adenoids, Their Effect on Mode of Breathing and the Dentition. *ACTA-Otolaryngologica,* 1970. Suppl 265.
33. Wolford G: Classifications of Craniomandibular Disorders. *TMD Development Diagnosis and Treatment Planning Course:* Las Vegas Institute for Advanced Dental Studies, St. Clair Shores, MI. 2003.
34. Marks MB: Allergy In Relation to Orofacial Dental Deformities in Children. *J Allergy* 1965;36:293-302.
35. Harvold EP, et al.: Primate Experiments on Oral Respiration. *Am J Orthod* 1981;79:359-372.
36. McNamara JA: Influence of Respiratory Pattern on Craniofacial Growth. *Angle Orthod* 1981;51:269-299.
37. Meridith GM: The Airway and Dentofacial Development. *Ear Nose Throat J* 1987;66:190-195.
38. Rubin RM: Effects of Nasal Airway Obstruction on Facial Growth. *Ear Nose Throat J* 1987;66:212-219.
39. Sutera, Salvatore P., "The history of Poiseuille's law," *Annual Review of Fluid Mechanics*, Vol. 25, 1993, pp. 1-19.
40. Garry, JF: Early Iatrogenic, Orofacial Muscle, Skeletal, and TMJ Dysfunction. In Morgan D, ed. *Diseases of the Temporomandibular Apparatus – A Multidisciplinary Approach*, St. Louis: C.V. Mosby Co., 1989;35-69.
41. van der Linden FPGM, Duterloo HS: *Development of the Human Dentition. Hagerstown,* MD: Harper & Row; 1976:14,26,27.
42. Enlow, DH and Hans, MG: Essentials of Facial Growth. *W. B Saunders Company;* 1996.
43. Moyers, RE: *Handbook of Orthodontics for the Student and General Practitioner*, ed. 3, Chicago, 1973. Year Book Medical Publishers, Inc.
44. Graber, TM: The Three M's: Muscles, Malformation and Malocclusion, *Am. J. Orthod*. 49:418, 1963.
45. Enlow DH, and Hans MG.: *Essentials of facial growth*. W. B Saunders. 1996.
46. Harvold EP.: The role of function in the etiology and treatment of malocclusion. Am J Orthod 1968;54:883-898.
47. Linder-Aronson S and Woodside, DG.: Excess face height malocclusion: etiology, diagnosis, and treatment. Quintessence Pub. 2000.

48. Solow B, Sonnesen L: Head posture and mal-occlusion. *Eur J Orthod* 1998;20:685-693.
49. Lowe A.: Correlations between orofacial muscle activity and craniofacial morphology in a sample of control and anterior open bite subjects. *Am J Orthod* 1980;78:89-98.
50. Woodside, DG: The Channalization of Upper and Lower Face Heights Compared to Population Standards in Males. Between 6 to 20 Years, *Eu J Orthor,* 1979;1:25-40.
51. Linder-Aronson S: The Growth in the Sagittal Depth of Any Bony Nasopharynx in Relation to Some Other Facial Variables, In McNamara (editor) *Naso Respiratory Function and Craniofacial Growth Series,* Ann Arbor, Center for Human Growth and Development, University of Michigan, 1970.
52. Vig, PS, Showfety K, Phillips C: Experimental Manipulation of Head Posture. *Am J Ortho,* 1980;77:258-268.
53. Hellsing E., et al.: Changes in postural EMG activity in the neck and masticatory muscles following obstruction of the nasal airways. Eur J Orthod 1986;8:247-253.
54. Hellsing E. and L'Estrange P.: Changes in lip pressure following extension and flexion of the head and at changed modes of breathing. Am J Orthod Dentofacial Orthop 1987;91:286-294.
55. Yee, D: Weight of the human head. Department of Anatomy and Histology, University of Sydney, Australia. danny.oz.au/anthropology/notes/human-head-weight.html. December 13, 2006.
56. Racabado, M: Physical Therapy and Dentistry: An Overview, *J of Craniomandibular Practice,* 1982; Vol. 1, pp46-49.
57. Racabado M: *Dentistry I.* Racabado Institute for Carniomandibular and Vertebral Therapeutics, Atlanta: Institute of Graduate Health Sciences, 1984.
58. Saunders H: *Evaluation, Treatment and Prevention of Musculoskeletal Disorders,* Edina, MN: Educational Opportunities, 1985.
59. Kaplan AS, Assael LA: *Temporomandibular Disorders – Diagnosis and Treatment. Philadelphia:* W.B. Saunders, 1991.
60. Ceneviz C., et al.: Immediate effect of changing position on the EMG activity of the masseter, temporalis, sternocleidomastoid, and trapezius muscles. *Cranio.* 2006 Oct;24(4):237-44.
61. Zuniga C., et al.: Influence of variation in jaw posture on sternocleidomastoid and trapezius electromyographic activity. *Cranio.* 1995 Jul;13(3):157-62.
62. Wessberg GA, Epker BN and Elliot AC: Comparison of Mandibular Rest Positions Induced by Phonetics, Transcutaneous Electrical Stimulation, and Masticatory Electromyogaphy, *J Prosth Dent Jan 1983; 49:1:100-105.*
63. Chan, CA and Wade, W: K7 Training and Occlusion II Programs. Las Vegas Institute, Las Vegas, NV. 2004-2006.
64. Kumar S, et al.: Electromyography of superficial cervical muscles with exertion in the sagittal, coronal and oblique planes. *Eur Spine J.* 2002 Feb;11(1):27-37.
65. Ishii, H: A study on the relationships between imbalance of stomatognathic function and asymmetry of craniofacial morphology, and the center of gravity of the upright posture. *Osaka Daigaku Shigaku Zasshi.* 1990 Dec;35(2):517-56.
66. Chan CA and Jenkins K: Atlas Orthogonality Chiropractics. *TMD Development Diagnosis and Treatment Planning Course:* Las Vegas Institute for Advanced Dental Studies, Las Vegas, NV. 2004.
67. Ferrario VF, et al.: Three-dimensional assessment of the reliability of a postural face-bow transfer. *Functional Anatomy Research Center, Laboratory of Functional Anatomy of the Stomatognathic Apparatus, Faculty of Medicine and Faculty of Motor Sciences, University of Milan, Milano, Italy.* Vol. 106, No. 3, 1994.

68. Virgilio F. Ferrario VF, et al.:Head posture and cephalometric analyses: An integrated photographic/radiographic technique.
69. Hung, CH: The evaluation of horizontal reference planes of adult Chinese in natural head position. *Zhonghua Ya Yi Xue Hui Za Zhi.* 1991 Mar;10(1):20-9.
70. Ercoli, C, et al.: Face-bow record without a third point of reference: theoretical considerations and an alternative technique. *J Prosthet Dent.* 1999 Aug;82(2):237-41.
71. Ow, RK, et al.: The relationship of upper facial proportions and the plane of occlusion to anatomic reference planes. *J Prosthet Dent.* 1989 Jun;61(6):727-33.
72. Ferrario, MD, et al.: Head Posture and Cephalometric Analyses: An Integrated Photographic/Radiographic Technique. *J Prosth Dent.* Vol.106, No.3, 1994.
73. Ow RK, Djeng SK, Ho CK.: The relationship of upper facial proportions and the plane of occlusion to anatomic reference planes. *J Prosthet Dent.* 1989 Jun;61(6):727-33.
74. Occlusal Plane: The Glossary of Prosthodontic Terms, Seventh Edition (GPT-7). Vol. 81, No. 1, 1999.
75. Xie J, Zhao Y, Chao Y, Luo W.: A cephalometric study on determining the orientation of occlusal plane. *Hua Xi Yi Ke Da Xue Xue Bao.* 1993 Dec;24(4):422-5.
76. Sinobad D, Postic SD.: Roentgencraniometric indicators of the position of the occlusal plane in natural and artificial dentitions. *Eur J Prosthodont Restor Dent.* 1996 Dec;4(4):169-74.
77. Ferrario VF, et al.: A direct in vivo measurement of the three-dimensional orientation of the occlusal plane and of the sagittal discrepancy of the jaws. *Clin Orthod Res.* 2000 Feb;3(1):15-22.
78. Kato T.: A study on the reference planes and lines for dental practice. *Aichi Gakuin Daigaku Shigakkai Shi.* 1990 Mar;28(1 Pt 1):1-19.
79. D'Souza NL, Bhargava K.: A cephalometric study comparing the occlusal plane in dentulous and edentulous subjects in relation to the maxillomandibular space. *J Prosthet Dent.* 1996 Feb;75(2):177-82.
80. Ciancaglini R, Colombo-Bolla G, Gherlone EF, Radaelli G.: Orientation of Craniofacial Planes and Temporomandibular Disorder in Young Adults With Normal Occlusion. *J Oral Rehabil.* 2003 Sep;30(9):878-86.
81. Linder-Aronson S: Naso-respiratory function and craniofacial growth. McNamara., J. A, Ed., Mono-9. Craniofacial Growth Series. Center for Human Growth and Development, Univ. of Michigan, Ann Arbor, 1979. pp. 121-147.
82. Chan, et. al.: HIP Research Investigative Study. Four separate research studies at the Las Vegas Institute and four teams of participating Neuromuscular Dental Technician groups internationally participated in evaluating the HIP (hamular Incisive Papilla) mounting technique to level the maxillary dental cast. A combined total of 82 participants and 154 maxillary model casts were used to compare HIP, stick bite and Fox Plane mounting techniques for accuracy, variability and levelness as it related to the facial occlusal photographs, cranial base and the human occlusal plane. Investigative Clinical Research for Neuromuscular Dental Technology. Research and laboratory research investigations were carried out in March 2004, October 2004, May 2005 and June 2005.
83. Chan, CA: Modified TENS bite technique. Las Vegas Institute – Occlusion I courses. May 2005.
84. Mamootil, JA: Plane of occlusion-a new concept. *Aust Dent J.* 1994 Oct;39(5):306-9.
85. Jacobson, A: Down’s Analysis. In: Radiographic Cephalometry from Basics to Videoimaging. *Quintessence Publishing Co*., Inc., Carol Stream, IL 1995. 65-75.
86. Downs WB.: The role of cephalometrics in orthodontic case analysis and diagnosis. *Am J Orthod* 1952;38:162.
87. Steiner CC.: Cephalometrics for you and me. Am J Orthod 1953;39:729.

88. Steiner CC.: Cephalometrics in clinical practice. Angle Orthod 1959;29:8.
89. Braun S, Legan HL.: Changes in occlusion related to the cant of the occlusal plane. In: *Am J Orthod Dentofacial Orthop. 1997 Nov;112(5):17A-20A.* Am J Orthod Dentofacial Orthop. 1997 Feb;111(2):184-8.
90. Ogawa T, et al.: Inclination of the occlusal plane and occlusal guidance as contributing factors in mastication. *J Dent.* 1998 Nov;26(8):641-7.
91. Vukusic N, et al.: Change in the inclination of the occlusal plane during craniofacial growth and development. *Coll Antropol.* 2000 Jun;24(1):145-50.
92. Okuda, T: A clinical study on occlusal plane in relation with orofacial morphology and stomatognathic function. *Osaka Daigaku Shigaku Zasshi.* 1990 Jun;35(1):369-99.
93. Ogawa, T: Characteristics of masticatory movement in relation to inclination of occlusal plane. *J Oral Rehabil.* 1997 Sep;24(9):652-7.
94. Trubyte (Fox) Occlusal Plane Plate: Dentsply International, Trubyte, Occlusal Fox Plane Item # 92232, (800) 877-0020.
95. Chan, CA: Architecting the Occlusal Plane. Aurum Ceramic Continuum. Vol. 10, Issue 2, May 2006.
96. Shimazaki, T., et al: The effect of occlusal alteration and masticatory imbalance on the cervical spine. *European Journal of Orthodontics*. 25(2003) 457-463.
97. Ogawa, T, et al: Inclination of the occlusal plane and occlusal guidance as contributing factors in mastication. *J Dent.* 1998 Nov;26(8):641-7.
98. 97-109Jankelson B: Kinesiometric Instrumentation: A New Technology. J. American Dent, Vol. 90. April 1975.
99. Chan, CA: Myotronics 38th Anniversary Seminar. *Getting the Bite Right with NMD* "*Optimizing the Neuromuscular Bite with the Chan Scan".* Lecture given in Seattle, Washington, 2004.
100. Osborn, JW: A model to describe how ligaments may control symmetrical jaw opening movements in man. *J Oral Rehabil.* 1993 Nov;20(6):585-604.
101. Hiraba, K, Hibino, K, Hiranuma, K, and Negoro, T: EMG activities of two heads of the human lateral pterygoid muscle in relation to mandibular condyle movement and biting forces. *J Neurophysiol* 83:2120-2137, 2000.
102. Chan, CA and Thomas, NR: Clinical and Scientific Validation for Optimizing the Neuromuscular Trajectory Using the Chan Protocol. *Anthology of ICCMO*. Vol. VII. 2005.
103. Jankelson, RR: Effect of vertical and horizontal variants on the resting activity of masticatory muscles. *Anthology of ICCMO*. Vol. IV, 1997.
104. Cooperman HN.: _HIP plane of occlusion in oral diagnosis. *Dent Surv.* 1975 Nov;51(11):60-2.
105. Cooperman HN.: _New approaches to establishing the plane of occlusion and freeway space in complete dentures. *Dent Dig.* 1965 May;71:202-7.
106. Rich H.: Evaluation and registration of the H.I.P. plane of occlusion. *Aust Dent J.* 1982 Jun;27(3):162-8.
107. Karkazis HC, Polyzois GL.: Cephalometrically predicted occlusal plane: implications in removable prosthodontics. *J Prosthet Dent.* 1991 Feb;65(2):258-64.
108. Ellis E. 3rd: Accuracy of face-bow transfer: Effect on surgical prediction and postsurgical result. *J Oral Maxillofac Surg.* 1992 Jun;50(6):562-7.
109. dos Santos, J. et al: Geometric analysis of occlusal plane orientation using simulated ear-rod facebow transfer. *J Prosthodont.* 1996 Sep;5(3):172-81. Pitchford, J: A reevaluation of the axis-orbital plane and the use of the orbitale in a facebow transfer record. *J Prosthet Dent.* 1991 Sep;66(3):349-55.
110. Cooper, BC: The role of bioelectronic instrumentation in the documentation and management of temporomandibular disorders. *Oral Surg. Oral Med. Oral Pathol.* Vol. 83, No. 1, Jan. 1997.

111. Sheikholsslam A, Moller E, Loose J: Pain, tenderness and strength of human elevator muscles, *Scan J Dent Res* 1980;88:60-66.
112. Jankelson, RJ: Internet communication, Summer 2005.
113. Choi, DG, et al: Reliability of an ear-bow arbitrary face-bow transfer instrument. *J Prosthet Dent.* 1999 Aug;82(2):150-6.
114. Boyd, CH, et al: The Effect of Head Position on Electromyograhic Evaluations of Representative Mandibular Positioning Muscle Groups. The Journal of Craniomandibular Practice, 1987. Vol.5 No.1
115. Gateno, J, et al.: A comparison of 3 methods of face-bow transfer recording: implications for orthognathic surgery. *J Oral Maxillofac Surg.* 2001 Jun;59(6):635-40; discussion 640-1.

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