A Revised View of the Dynamics, Physiology, and Treatment of Occlusion: A New Paradigm

Martin D. Lerman, D.D.S.

ABSTRACT: A new perspective is proposed regarding the functional dynamics of occlusion, the masticatory muscles, and mandibular placement. Each is analyzed on the basis of a new criterion: *force*. Stomatognathic function is represented as an ongoing equilibrium maintained between the three-dimensional set of individual occlusal forces and the three-dimensional set of bilateral muscle forces. Mandibular placement is of prime importance, mediating as it does between the two. The conclusion is drawn that occlusion and the muscles can correlate optimally with each other only when the mandible occupies its neuromuscular position (NMP), herein defined as that placement where muscle accommodation is at its absolute minimum. The conclusion is that only the muscles themselves are capable of establishing the NMP and that customary conventional technology is inadequate. A new technology, hydrostatics, is needed to create the special (not existing naturally) occlusal conditions essential to optimally integrating occlusion, mandibular placement, and muscles. Preliminary EMG data is offered in support of this conclusion.

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Address for reprint requests:
Dr. Martin D. Lerman
P.O. Box 5252
Carefree, AZ 85377
E-mail: lesboblyn@aol.com

Despite one hundred years of dental practice, there is still basic disagreement about occlusion, most specifically, about which mandibular placement should underlie occlusion's intercuspal position (ICP). Resolution of this disagreement requires a new perspective. To construct this perspective, this article analyzes occlusion, muscle function, and mandibular placement both individually and in relation to each other in stomatognathic terms. This analysis utilizes a new criterion: *force*. It proposes *ideal* standards for both occlusion and muscle activity. It draws the conclusion that the ideal base for the ICP should be that mandibular placement in which the mandibular muscles are least distorted from their natural, inherent activity and configurations. This placement can be termed the mandible's neuromuscular position (NMP). The conclusion is drawn that establishing the NMP clinically requires new technology. That technology is proposed herein.

An entire dimension, the fundamental issue of occlusion-mandibular placement-muscle compatibility or incompatibility, is virtually missing from both dentistry's current paradigm and its literature.[1] The role of the muscles is dealt with only in passing,[2-3] while correlation of muscles with mandibular placement is barely touched upon.[4] The relationship between occlusion and muscle

Dr. Martin D. Lerman *received his D.D.S. degree in 1944 from the University of Illinois. He is retired from an associate professor of prosthodontics position at the University of Illinois. Dr. Lerman has lectured widely, nationally and internationally. He was instrumental in the development of the hydrostatic device mentioned in this article while at the TMJ Research Center at the University of Illinois College of Dentistry. Currently, Dr. Lerman is Director of Research and Development at Jumar Corporation, Prescott, Arizona.*

has remained unclear. The literature deals with it almost universally in generalities with little reference to specifics.[5-15] As a consequence, many fundamental questions remain unanswered.

Occlusion is so vast a subject that no one article can hope to deal with it in its entirety. For this reason, this article deals only with what may be considered the single most important core movement of stomatognathic activity: closure from a resting position to maximal intercuspal occlusal contact (ICP). Mastication is outside the scope of this article and will not be considered because of its myriad of food-induced variations.

The term *centric occlusion* is not used in this article, since it is defined differently by differing schools of thought. The following conditions are presupposed: completely pathology-free and normally functioning temporomandibular joints, ligaments and muscles, and unchanging, *neutral* unstrained posture and gravitational orientation. While the term *neuromuscular* is used throughout for brevity, it is meant to include all elements involved in the proprioceptive reaction: muscles, nerves, periodontal ligaments, temporomandibular joints, ligaments and capsules, etc. Although it is recognized that all of the muscles of the stomatognathic system are involved to a greater or lesser degree, this analysis focuses on the masticatory muscles which best illustrate the adjustments involved. The slight normal tooth movement imparted by healthy periodontal tissues is seen in its primary role of registering occlusal forces.

It is essential that occlusion be seen not by itself but in context, as one element of the stomatognathic system. Therefore, closure into ICP is analyzed in stomatognathic terms: first in the theoretically ideal situation, i.e., perfect correlation of occlusion, mandibular placement and muscles, and then contrasted with the imperfect situation, where occlusion is disharmonious with muscle action and mandibular placement.

Force in the Stomatognathic System

When trying to correlate the action of occlusion and the neuromuscular apparatus, a basic problem is obvious: how to correlate the action of two structures as dissimilar as teeth and muscles. Muscles are soft and highly reactive, changing their shapes constantly in split seconds. Teeth are immobile and concrete-like: change is measured in terms of years. A common denominator is required—an element both react to. This article holds this denominator to be the element of force: all conclusions derive from a force-based analysis. It is essential that the manner in which stomatognathic force is organized and regulated be understood. The logic underlying the conclusions in this article becomes clear only when occlusion, stomatognathic function, and the muscles are seen in terms of force.

Force is the core element which underlies all stomatognathic function. Basically, stomatognathic function consists of maintaining two complex three-dimensional sets of forces in constantly updated, instant-by-instant equilibrium: the set of combined muscle forces from the whole of the bilateral masticatory muscle complex balanced against the combined set of occlusal forces from all teeth that contact in ICP.[16-18] Each of these two sets of forces is made up in turn of multitudes of often-tiny forces, each contributing its individual effect to the resulting mandibular movement. A proprioceptive servomechanism, a reciprocal split-second feedback mechanism,[19-21] keeps these two sets in optimally effective and atraumatic equilibrium by continuously adjusting motor unit activity in the muscles.[22-23] Each set of forces is examined individually.

Muscle Forces

Force within the masticatory muscles is understood most clearly when examined at the level of individual motor unit activity,[24-25] the motor unit being the basic functional unit of muscle activity. At this level, the role of the individual motor units in generating and adjusting the forces transmitted to the mandible is best seen. Focus here is on the tiny tensional force vector each motor unit generates and contributes to the overall force delivered to the mandible.[26] Each motor unit's vector is orientation-specific, i.e., has a specific fixed direction, aligned with its fibers.[27] As a result, motor units are not freely interchangeable in function. Only motor units whose vectors are directionally compatible with the closure into ICP are utilized[28] (but assisted secondarily by some number of differently oriented units for stabilization [*bracing*]). Within the closing movement (or any movement for that matter), only motor units having identically oriented vectors are able to substitute for one another. How many of these identically oriented vectors are available to power closure, therefore, assumes great significance.

The muscles are capable of generating a vast variety of forces exquisitely graded in both magnitude and direction[29-30] by combining differently angled motor unit vectors. The individual muscles in the bilateral masticatory muscle complex[27,31] have vectors that are oriented differently from one another (**Figure 1**). Some muscles, such as the temporals, have multiple fiber orientations, so the direction of the force they generate can be adjusted depending on which motor units are activated.[27] Additionally, the masticatory muscle complex's right and left sides each angle toward the midline, in effect doubling

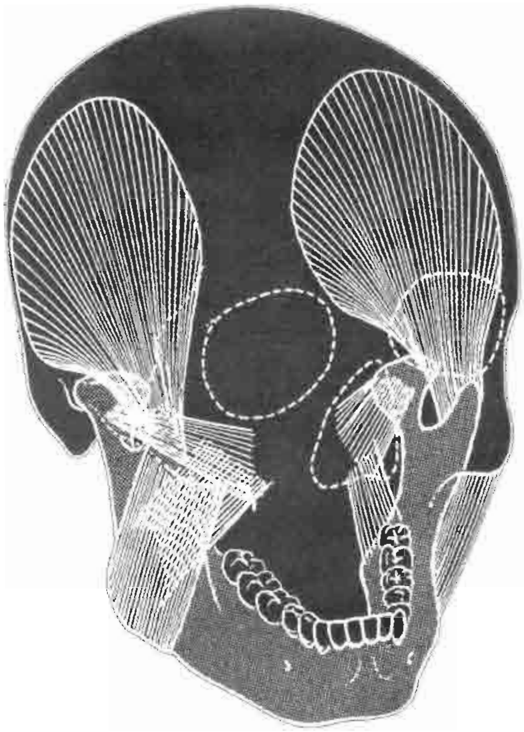


Figure 1
The neuromuscular position of the mandible in the ICP (showing the *sling* of masticatory muscles as they suspend the mandible) is defined as the mandibular placement in which accommodation is at its absolute minimum in every one of the masticatory muscles, i.e., that position where each muscle is least distorted from its inherent anatomic configuration. Given the vastly differing fiber orientations in the muscle complex, wide dispersion of origins on the skull and insertions on the mandible, it is apparent that there can be *only one* mandibular placement in which *none* of the muscles is distorted from its inherent configuration. If occlusion's ICP is to be made harmonious with the muscles, U/L cuspal relationships must be established only *after* the mandible already occupies its NMP.

the number of different vector orientations. Activa-tion of different motor units changes force direction and modifies the mandible's placement and cuspal entry into ICP, usually so subtly that it cannot be detected clinically.

Proprioceptive feedback from periodontal sensors enables the muscles to *read* occlusal forces[22,23,32,33] from both individual teeth and the dentition as a whole. The muscles thus have a comprehensive overview of the entire dentition's occlusal forces[34] which enables them to detect and then compensate for any individually unbalanced occlusal forces by activating appropriately oriented motor unit vectors.

Occlusal Forces

Occlusal forces are a *secondary* set of complex forces that arise when the primary muscle force elevates the mandible into IC tooth contact. Separate pairs of upper and lower, equal and opposite occlusal forces arise at every point of tooth contact.[35] The force of each tooth's single or multiple occlusal contacts, geometrically summed, is transmitted to its periodontal sensors and then to the muscles. The muscles look upon these occlusal forces as a *set*, ideally one in which all of the individual forces are absolutely identical. It is this combined set of occlusal forces that regulates muscle action.[36,41] As part of a set of identical occlusal forces, each tooth's force can be seen as critical, judged on the basis of how perfectly it conforms to the forces generated by the other occluding teeth. It can be considered certain, therefore, that even a single aberrant occlusal force (one differing from the others in any tooth in occlusion) will elicit a protective accommodative reaction in the muscles. On this basis the rules for ideal occlusal force at each individual tooth in ICP contact[42] can be inferred:

1. All forces must arise at the same instant (avoiding premature contacts);
2. All forces must be of the same magnitude (all occluding teeth generating the same degree of force)[43]; and
3. Each occlusal force must be axially oriented to its individual tooth (to avoid mandibular displacement).[38,44,45]

Though simple in concept, such forces are the ideal that treatment should aim for.

To avoid an accommodative muscle reaction, the set of occlusal forces must be balanced to the level of exquisite sensitivity and reactivity of the muscles. Even the slightest discrepancy between the individual occlusal forces triggers a protective, but otherwise undesirable accommodative response in the muscles, increasing stress and reducing the effectiveness of occlusal treatment. Unfortunately, conventional technology[46-50] cannot balance occlusal forces to the level of precision required to avoid a muscle reaction. Technology more effective in dealing with force is needed, and such new technology is proposed later in this article.

The ideal occlusion-muscle relationship in IC, therefore, can be defined as an occlusion requiring no adjustment of motor unit activity in the muscles when the teeth come into IC contact. It is defined not in customary terms of a particular upper/lower cuspal relationship but in terms of force and the system's reaction to force. It can be deduced that *the muscles are in a sense blind* to cuspal relationships per se. They react only to force. Avoiding an accommodative reaction in the muscle requires only an input of ideal occlusal forces. This holds true regardless of the cuspal relationships giving rise to these forces.

Muscle Perspective: Work and Accommodative Functions

The basic principles underlying the organization of masticatory muscle activity have never been made clear.

How to explain muscle activity that differs so greatly between apparently normal individuals? A new approach is needed, and the following is proposed: the whole of masticatory muscle activity can be visualized as a two-tiered system incorporating two separate *functions*, the work function and the accommodative function, each with its own organizing principles and goal. The work function's goal is to physically carry out the raising of the mandible into ICP. However, if on initial contact the muscles should detect the presence of even a single aberrant, potentially traumatic occlusal force, the accommodative function is implemented instantaneously to prevent trauma to the teeth, periodontal, and other tissues. The aberrant forces' potential for trauma is minimized by superimposing appropriate modifications on the work function's fundamental pattern of motor unit activity. Additional motor units can be activated, or others inactivated, thereby subtly altering the mandible's entry into ICP. It is this final modified, combined, and minimally traumatic activity pattern that is seen clinically.

Muscle activity is most likely initially organized on the basis of the work function enumerated below. This initial organization, however, is never seen. It is always modified accommodatively to compensate for imperfections in the individual occlusion or changes in posture and gravity. While it is probable that the primary organization of motor unit activity is identical in all individuals, the final, clinically visible patterns differ greatly. This is because occlusal forces differ so greatly from occlusion to occlusion as do the accommodative muscle responses each occlusion's imperfections call for.

The Work Function

In order to define ideal muscle activity precisely, a basic assumption must be made: that the body is so well-designed anatomically that the work function's organization of motor unit activity is perfect, i.e., in the perfect situation, where anatomy, mandibular and TMJ relationships, and occlusal configurations all conform perfectly to their inherent design, all elements similarly relate to each other perfectly. This assumption is the basis for everything that follows. Since absolutely no protective reaction is required, ideal muscle activity can now be more clearly conceptualized, deduced on the basis of what we know about function in other areas of the body. They are: 1. ideally effective (activating only those motor units whose vector orientations are to be best angled for successful IC closure)[51]; 2. ideally efficient (activating only motor units so strategically placed in the bilateral muscle complex that their vectors have the greatest mechanical advantage or *leverage*)[52]; and 3. ideally economical in terms of expenditure of energy (activating only the exact number of motor units needed to carry out IC closure, no more or no less.[53] The work function's theoretically perfect organization should determine which motor units are activated. Unfortunately, however, this never happens clinically.

Accommodation

Accommodation is the muscle reaction triggered automatically when the body is forced to work under less than perfect circumstances,[54] which is *always* the case. Accommodation thus overrides and modifies[55] the work function's perfect organization of motor unit activity. Since our basic assumption is that the work function's undistorted organization is theoretically perfect, and since any change in a perfect situation always lowers the degree of perfection, it stands to reason that accommodation's modification of motor unit activity always degrades the work function's ideal organization. Accommodation may make function less effective, less efficient, or increase the expenditure of energy. This can be considered the price the body pays for protection from trauma. However, despite its unfavorable aspects, accommodation is absolutely essential. Accommodation has a special impact on dentistry: it can overwork accommodatively-involved motor units by involving them in movements for which they were not designed.

Accommodation changes the number and distribution of motor units[56] involved in the entry into ICP.[57] The number of motor units involved must be considered, as well as their locations in the bilateral masticatory muscle complex (in terms of the mechanical effectiveness of their vectors). Critical, also, is how often a given motor unit is activated, because this can lead to muscle problems. Motor units are activated on the basis of need.[57] Each occlusal disharmony requires its own specific muscle *avoidance pattern*[14]: the specific pattern of motor units needed to compensate for that particular occlusion's imperfections. This avoidance pattern alters the mandible's entry into ICP.

The objective is to bring the lower teeth directly and cleanly into ICP closure without a potentially traumatic hit-and-slide. Since each avoidance pattern is tied to its own occlusion-muscle disharmony (activating different motor units in different occlusions), their effect on the muscles (and resulting symptoms, if any) differs from patient to patient.

At this point a fundamental question arises: What triggers muscle accommodation? It can be theorized that the trigger is distortion of the muscles' internal force pattern. To generate the force needed to elevate the mandible into ICP, every muscle develops within itself an internal pattern of tensional force—a highly sensitive pattern extending throughout its body. While a muscle's primary function is contributing appropriate force while working, it at the same time avoids trauma. Accommodation is the result. Occlusal imperfections in ICP displace the mandible microscopically, changing the entry into ICP. A differently oriented force is now required to bring the mandible cleanly into its newly distorted ICP. Displace-ment subtly changes muscle length and angular relationships between each muscle's origin on the skull and its insertion on the mandible, changing preexisting force patterns. The potential for trauma is increased: intramuscular force may now be too little in some muscle areas and too great in others (in extreme cases to the extent of tearing muscle fibers). New, more appropriate force patterns are needed, so motor unit activity is adjusted accordingly. The essence of the accommodative response may be readjustment of the motor unit activity pattern to create new functional and atraumatic force patterns in order to provide clean entry into a distorted ICP.

Ideal and Accommodated Entry into the Intercuspal Position

The accommodative reaction triggered by occlusion-muscle disharmony can best be illustrated by examining entry of the lower teeth into ICP as occurs in nonpathological empty swallowing. Inter-cuspal entry will be analyzed first in the theoretically ideal situation, where all three elements of the occlusion-mandibular placement-muscles triad relate perfectly to each other and then in the situation where they relate imperfectly to each other.

The ideal entry is when the very first instant of tooth contact brings all occluding teeth directly and cleanly into simultaneous stable contact in their final IC relationships. Identical forces, all simultaneous, of identical magnitudes, and each optimally axially oriented to its individual tooth, are generated and transmitted to the periodontium of every tooth in occlusal contact. The potential for occlusal trauma is minimal. No alterations in muscle action or mandibular placement are needed to compensate for occlusal or anatomic imperfection. The entry into ICP is perfectly clean and atraumatic. There is no hit-and-slide. The pattern of motor unit activity in the muscles remains ideally effective and efficient using minimal energy for closure. Occlusion-muscle compatibility is perfect, all activity being ideally correlated with anatomic design. The mandible's *muscle position* and *tooth position* coincide.[58]

By contrast, closure becomes much more complicated where occlusion and the muscles correlate imperfectly.[59] An accommodative reaction affecting every component of the occlusion-mandibular placement-muscles triad is now required to protect teeth and periodontal tissues. Suppose, for example, that a prematurity is introduced into the occlusally ideal closure described above. The very next closure would encounter the prematurity first and the other teeth a fraction of a second later. Initially, occlusal forces are unbalanced[55-60]: increased at the prematurity (potentially traumatically) and decreased elsewhere. Occlusal vertical dimension is increased only at the prematurity, disturbing both occlusal and bilateral muscle balance, and subtly displacing the mandible from its primary ICP position to a distorted secondary position. This displacement most frequently remains hidden by accommodative changes in motor unit activity, so a traumatic hit-and-slide may or may not occur. Let us say in this example that the mandible is displaced distally and no hit-and-slide is apparent. At completion of this closure, the mandible occupies a secondary, less than perfect placement relative to the muscles.[61,62] Occlusal forces are still imperfect, but balanced as well as accommodative changes in motor unit activity can adjust mandibular placement.[56,63,64] These compensatory muscle adjustments, if within the muscles' dimensional capacity for adjustment, successfully avoid a hit-and-slide. The muscles then apply this exact pattern of accommodated motor unit activity to the next closure, bringing the mandible directly to the identically distorted mandibular placement and occlusal relationship of the previous closure.[62,65,66] The muscles continue to accommodate invisibly.

As previously stated, accommodated closures are more complicated than ideal closures. In the above example two separate mandibular movements, elevation and retrusion, must be combined and performed simultaneously. Retrusion would be unnecessary if the occlusion-muscle relationship were harmonious. Retrusion in repeated closures can have important muscle consequences. Muscle anatomy now becomes a consideration: the bilateral masticatory complex's approximately ten thousand motor units can be divided roughly into three functional groups, (elevators, protruders, and retruders), based on how they move the mandible. Motor units are not interchangeable functionally. Only elevator motor units can elevate the mandible, only protruders can protrude it, and only retruders can retrude it. The quantity of motor units in each of these three functional groups differs greatly. Elevator motor units probably make up over eighty percent of the muscle complex, making elevation the most powerful movement. Protrusion and retrusion are both comparatively weakly powered movements, having far fewer appropriately oriented motor units.

Accommodated closures are more stressful than are ideal closures.[56] In addition to activating more motor units, they in effect activate the wrong ones. Ideally, the pattern of motor unit activity in closure should conform to anatomic design. Muscle areas involved in ideal closures, whether repeated or not, normally have enough appropriately vectored motor units to avoid exceeding the physiologic capabilities of the individual motor units involved. In accommodated closure, the additional motor units called into play in this example are those that, design-wise, should not have been involved in closure to begin with: retruder motor units whose numbers are inadequate for repeated closures. Anatomically, the reservoir of retruder units is comparatively tiny. The muscle complex can call for retruders only in several small muscle areas[29,67,68] whose motor unit vectors are capable of retruding the mandible[69,70]: the profound portion of the masseters[34] and the almost horizontally oriented motor units in the distal portions of the temporals.[71]

Motor units *cycle* during function.[72,73] When a motor unit works, it fatigues.[74,75] When fatigued, it drops out of the movement to rest, while a rested motor unit with a similarly oriented vector takes its place. Note the emphasis on *similarly-oriented*. Accommodation is generally benign as regards the overwhelmingly numerous elevator units, but not necessarily so with retruders or protruders. In the given example, accommodation inappropriately involves retruder units in the closing movement. Elevator motor units, because of their vast numbers, can continue functioning indefinitely. When one elevator unit fatigues, another rested, similarly vectored unit is always available to take its place. By contrast, if the functional demand on the far smaller retruder group continues long enough, all its motor units may become fatigued, leaving no rested similarly oriented units to substitute for the fatigued ones.

It should be noted that the elevator motor units control the closing movement. Driven by normally functioning elevators, swallowing and clenching continue uninterrupted despite exhaustion of the retruders. The retruders are forced to continue working and must participate in *every* closure, in effect against their will. This overwork[76,77] can force them into a pathological sequence,[78] going beyond fatigue to exhaustion, and then to incoordination and spasm, ultimately becoming painful.[78-81] This type of muscle pain can be termed functional pain, caused not by organic pathology within motor units themselves, but rather by accommodation-induced overwork in otherwise healthy motor units. This author holds occlusally instigated muscle accommodation to be a major cause of myofascial pain-dysfunction syndrome.[82] This being the case, reducing the accommodative activity of affected motor units by occlusal treatment that restores occlusion-muscle harmony is indicated. Functional demand to involved motor units would then be reduced to the point where it is once again within each unit's physiologic capacity, thereby relieving symptoms.[83] A technology capable of selectively eliminating undesirable accommodative muscle activity is proposed.

Muscle Programming: Continuity from Closure to Closure

At termination of accommodated closure into ICP, an imperfect balance has been established. Though occlusal cuspal relationships may be unchanged, mandibular placement is distorted, as is the degraded pattern of motor unit activity in the muscles.

The human body is ingeniously designed. In response to distorted mandibular placement there is assembled in the muscles a three-dimensional pattern of the precise motor unit activity needed to bring the teeth directly into the accommodated ICP.[84] Empty swallowing, with its closure into ICP, is repeated roughly every minute. Instead of going through the process of repeatedly reconstructing this accommodated pattern of motor unit activity for the next closure, the muscles *remember* this pattern and then apply the previous closure's exact accommodated pattern of motor unit activity to the next closure[66,85] thereby avoiding the interference(s) previously encountered. This muscle *memory*, the engram,[51,86,87] is commonly referred to clinically as *muscle programming*.[88,89] This engram is carried forward intact to the next closure, except when occlusion, gravitational orientation, or head posture change between swallows. If any such change occurs, the engram is adjusted at the next closure, to be carried forward to the succeeding closure. The continuity of closures into ICP would be incomparably more wearing on the body if this muscle *combination* were lost between closures and had to be reassembled afresh at each closure. The engram thus greatly facilitates continuity of closures into ICP. However, the engram creates the potential for causing muscle problems by activating the same motor unit time and time again, thereby overworking the motor units involved.

The engram, while enormously beneficial overall, creates a serious but generally unrecognized everyday problem for the clinician: it *hides* occlusion-muscle disharmony. In cases of occlusion-muscle disharmony, the engram from the previous closure reflects a motor unit pattern already compensated to bring the mandible and the lower teeth cleanly and atraumatically into a distorted ICP. This occlusion-distorted compensatory motor unit pattern is carried forward within the engram from closure to closure. When the clinician asks the patient to close (into the ICP) while evaluating occlusion, closure is usually direct, without a hit-and-slide, despite the distorted occlusion, distorted mandibular placement, and distorted muscle action, none of which the clinician can see. The clinician seems justified in concluding this occlusion to be compatible with the muscles. This conclusion, however, is not justified. The engram *hides* the pattern of muscle accommodation compensating for the underlying occlusion-muscle disharmony, thereby hiding the hit-and-slide that would ordinarily alert the clinician to the presence of occlusion-muscle disharmony.[14] In this sense, the engram tends to work against the clinician.

Mandibular Placement: The Neuromuscular Position

Mandibular placement, in mediating between occlusion and the muscles, affects both. Every change in mandibular placement, however miniscule, changes both muscle action and entry of the teeth into ICP. A critical question regarding the muscles then follows: which mandibular placement correlates best with the muscles (requires least accommodation), and is therefore the ideal, most physiologic base for occlusion?

Ideal mandibular placement requires that all muscle fibers be undistorted from their inherent angulations and lengths,[85] and that each muscle's natural minimally traumatic working force pattern not be disturbed. The mandible can be visualized as occupying the center of bilateral three-dimensional webs of masticatory muscles (**Figure 1**). The individual muscles attach onto widely separated points onto the right and left sides of the mandible.[86] When fiber angulations and muscle lengths of every one of the mandibular muscles are undistorted from their inherent state, the muscles, with their widely spread areas of origins and attachments, *themselves* position the mandible relative to the skull. This is similar in concept to a wheel's spokes establishing its center. Such three-dimensional placement, perfectly correlated as it is with both muscle anatomy and motor unit activity (and where accommodation is absolutely minimal), is by definition its neuromuscular position (NMP). It is the optimal placement for occlusion, the only mandibular placement that can correlate optimally with all of the muscles[87] and which triggers the least muscle accommodation. This point is vital, and because it is at variance with much current thought, the logic underlying it should be considered carefully.

At this point, we again encounter the limitations of customary, conventional techniques in controlling and minimizing accommodated muscle activity to the muscles' exquisitely sensitive level of responsivity. The same limitation applies to our human senses. It has not been possible to consistently establish this theoretically ideal NMP when using conventional therapy.[88] The conclusion is drawn that only the muscles themselves are capable of establishing the NMP and only when special occlusal conditions, which do not exist naturally, are created.

Condylar Placement within the Temporomandibular Joints

The issue of *proper* condylar positioning within the TMJs[89-95] has long been controversial. This article holds condylar positioning to be but one aspect of a larger consideration, that of placement of the mandible as a whole relative to the skull and muscles. It holds that this issue would resolve itself automatically if and when the muscles themselves are able to establish the mandible's NMP. The condyles are fixed to the mandible as a whole; therefore, if the muscles can establish the ideal position of the mandible as a whole, it stands to reason that they would also position the condyles most physiologically within the TMJs. What this position actually is has never been measured. If the new technology proposed in this article proves capable of establishing the mandible's NMP, determination of the most physiologic condylar placement needs only appropriate research studies.

Incorporating occlusion into the occlusion-mandibular placement-muscles triad requires that the process start by dealing first with the muscles. While muscle activity can be influenced by the clinician, muscle anatomy, origins, and insertions cannot. The muscles must be accepted as an anatomic given. However, the clinician *is able* to change both mandibular placement and occlusion. If occlusion, mandibular placement, and muscles must correlate with each other, and if one of these cannot be changed, the unchangeable element must be the starting point, i.e., starting with the muscles. Optimal muscle activity (optimal motor unit activity and inherent fiber angulations and lengths) must be established first, as the initial requirement. By definition, this would place the mandible in its NMP. Only with the mandible in its NMP, with optimal muscle activity and mandibular placement already established, should occlusion be added. The overriding requirement for incorporating occlusion is that cuspal relationships not displace the mandible from its NMP when the teeth enter ICP, which would trigger accommodation. Interestingly, this statement holds true regardless of whether or not occlusal cuspal relationships conform to the classical standard.[96-97] Note this departure from the current view. The teeth as such can be regarded as inanimate mechanical positioners of the mandible. Each tooth's periodontal sensors register only the forces resulting from occlusal contacts, rather than the cuspal character of these contacts. It is conceivable that a combination of different, less-than-ideal tooth contacts could give rise to a resultant force the muscles consider ideal for that particular tooth. As such, any given scheme of cuspal relationships can be seen as secondary to two primary considerations: 1. that occlusal contacts maintain the mandible stabilized in, and not displaced from, its

NMP, while 2. at the same time providing each occluding tooth's periodontal sensors with the ideal forces required by the muscles to avoid triggering an accommodative response.[98-100] This does not imply that currently advocated occlusal contact relationships[98-100] should be discarded. These relationships take into account mastication and the other functional and parafunctional jaw excursions which this article excludes from consideration in order to focus on the ICP. It is important that the basic mechanisms underlying function be understood. This requires recognition of the role of force as the most fundamental controlling element of occlusion and stomatognathic function.

Hydrostatics Applied to Occlusion and the Stomatognathic System

Pascal, in his Law of Hydrodynamics (1652),[101] set forth the proposition that an enclosed fluid equalizes force. His theory states that an enclosed fluid equalizes (and balances) force throughout the fluid. Hydrostatics may prove a technology particularly well suited to our occlusal needs, since occlusal forces must be equalized and balanced as perfectly as possible. If occlusal forces to all the teeth can be established and balanced systematically, it would represent an important clinical advance. The hydrostatic appliance (*Aqualizer*, Jumar Corp., Prescott AZ 86301) (**Figure 2**), introduces Pascal's principle into occlusion and the stomatognathic system. It encloses fluid in a thin bilateral flexible-walled (rather than the customary rigid-walled) enclosure. This new type of fluid system, interposed between the arches, conforms to the upper/lower tooth contours and is able to transfer equalized force to the teeth. This is a new application of a fundamental natural principle.

The hydrostatic appliance itself is a simple preformed removable self-adjusting appliance constructed of thin plastic film, usually worn on the upper arch. It requires no retention, being held in place by the buccal and labial musculature. It is ready for immediate use: no impressions, laboratory work or adjustments are needed. The appliance is essentially a prefilled fluid bearing cell consisting of two bilateral interocclusal thin fluid-filled pads that communicate with each other via a thin channel positioned under the upper lip. Fluid (purified water), the appliance's active element, is thus able to flow freely both within each pad and from side to side. The mandible, in effect, *floats* on a thin layer of fluid the appliance interposes between the arches. The hydrostatic appliance has been in clinical use for over fifteen years, used primarily for relief of muscle pain and treatment of myofascial pain-dysfunction syndrome.[102-105]

Hydrostatics affects the stomatognathic system in ways never before possible. It changes both the manner in which occlusal force (the controlling element of occlusal and muscle function) is generated and the way it is transmitted from arch to arch. Hydrostatics restructures occlusal force. Normally, occlusal forces generated in ICP closure arise individually at the multiple points of occlusal contact. The hydrostatic appliance's action eliminates the need for protective (accommodative) muscle reactions. The fluid layer it interposes between the arches eliminates all direct tooth contact and cuspal guidance, and compensates for all prematurities and displacing con-

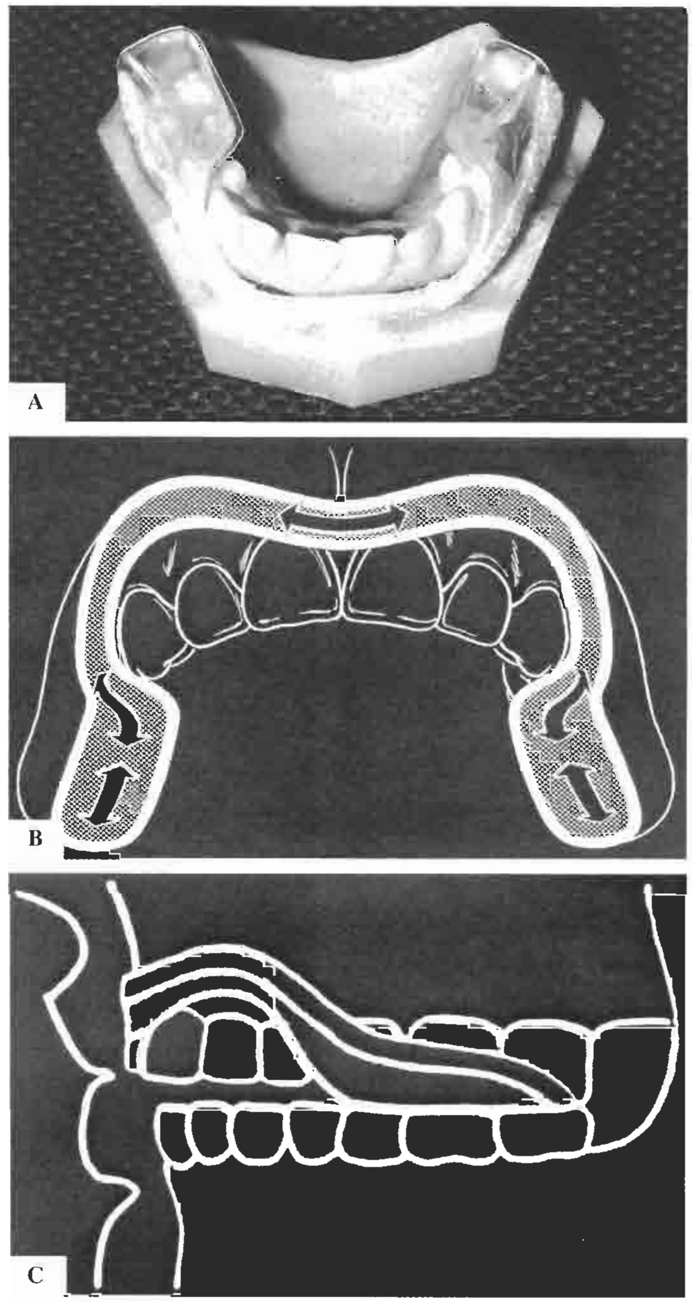


Figure 2
2A: (top) The hydrostatic appliance as worn on the upper arch;
2B: (middle) Distribution of fluid within the hydrostatic appliance;
2C: (bottom) Lateral view of the hydrostatic appliance as worn.

tacts automatically (by being thinner at the prematurities). Interferences are *neutralized* for the time being, thereby eliminating their undesirable effects on muscle action. All U/L tooth-to-tooth contact having been eliminated, occlusal force must pass through the appliance's fluid system, where in accordance with Pascal's Law, all force is equalized, creating a single unified force within the appliance. Then, when transmitted back from the fluid pads to the upper and lower teeth contacting them, the occlusal forces transmitted to the individual teeth are transformed to optimal: all forces arise simultaneously, are of the same magnitude, and because displacing contacts have been eliminated, are axially oriented to their individual teeth. Optimal occlusal forces are established systematically at every point of occlusal contact on a pro tem basis. Conventional procedures cannot do this.

The newly equalized occlusal forces initiate a series of readjustments throughout the stomatognathic system. Since the appliance's fluid has compensated for imperfect occlusal forces and prematurities, the muscles no longer need to do so. *Deaccommodation* begins: accommodation-instigated distortions in muscle anatomy begin reversal, the process aimed at restoring previously occlusally distorted inherent muscle conditions. It is as though the entire overlay of accommodative muscle activity (muscle activity's least desirable component) has been eliminated selectively. In theory, hydrostatics gives the stomatognathic system the ability to realign occlusion, muscles, mandibular placement, and TMJ condyle-fossa relationships to their natural, intrinsic, undistorted, and optimal physiologic states. Muscle deaccommodation starts the process of mandibular migration.

Mandibular Migration

Mandibular migration is the change in mandibular placement that occurs automatically following removal of occlusal interferences that have previously displaced the mandible from its NMP. Normally the clinician cannot recognize whether the mandible is or is not displaced: mandibular displacement usually is hidden by muscle accommodation. Displacement becomes apparent only after the restricting interferences have been removed and migration has taken place. Hydrostatics gives the muscles the freedom to restore inherent muscle conditions by enabling the muscles to bring the mandible all the way back to its NMP. This rationale for mandibular migration is based on the fundamental law of body function, that when forced to function under less than perfect circumstances, the body protects itself by accommodating. The converse of the fundamental rule of body function also applies: when circumstances improve, accommodative physiologic adjustments are similarly reduced, the body's goal being to return as closely to its inherent state as occlusal circumstances permit.

The potential for mandibular migration is created when occlusal prematurities and/or displacing contacts in ICP displace the mandible to a secondary, distorted position. Such displacement subtly changes the spatial relationship between each muscle's cranial origin and its mandibular insertion. Muscles may become longer or shorter[106]; fiber angulations may change[107]; and intermuscle balance[108] may be disturbed. However subtle, these changes are sufficient to make obsolete each muscle's previous internal force pattern[109] making it potentially more traumatic. The muscles then readjust to the displacement: motor unit activity is redistributed,[110-112] increased in some areas and decreased in others. When the displacing occlusal contact(s) is removed, muscle accommodation is also reduced automatically to the degree permitted by the occlusal correction. The muscles begin moving the mandible toward a less accommodated placement. This process of reversing occlusion-induced mandibular displacement involves astronomical numbers of exquisitely subtle adjustments within each muscle, which only the muscles themselves are able to correct to the level of their own sensitivity.

Once begun, migration should continue to completion to where the mandible is no longer displaced and where every muscle has been restored to its original anatomic condition. When that point has been reached, muscle accommodation is reduced to its absolute minimum. This mandibular placement is, by definition, its neuromuscular position (NMP). Unfortunately, in clinical practice the muscles are prevented from migrating the mandible all the way to its NMP. Migration stops dead in its tracks to avoid trauma to the teeth and periodontal tissues the instant an occlusal interference is encountered. Migration goes no further than this first encounter, which leaves the mandible still displaced to some degree. Since the clinician cannot recognize whether or not the ideal end point of migration (NMP) has been reached, the mandible often remains displaced, leaving occlusal therapy incomplete.

The dilemma faced by clinicians is that since only the muscles are capable of establishing the NMP and since even a single occlusal interference encountered during migration instantly stops muscle deacommodation, and because innumerable occlusal interferences arise as U/L intercuspal relationships change progressively during mandibular migration, how can these interferences be avoided and occlusal forces be kept perfectly balanced throughout the migratory journey to permit the muscles to carry the mandible all the way to its NMP? Since the goal is optimal correlation of occlusion with the muscles, this issue is critical, because such optimal correlation is possible only when the mandible already occupies its NMP (and muscle accommodation is minimal). How then can the NMP be established clinically?

Hydrostatics creates the special occlusal force conditions (that do not exist naturally) that enable the muscles to carry the mandible all the way to its NMP. These special occlusal conditions are:

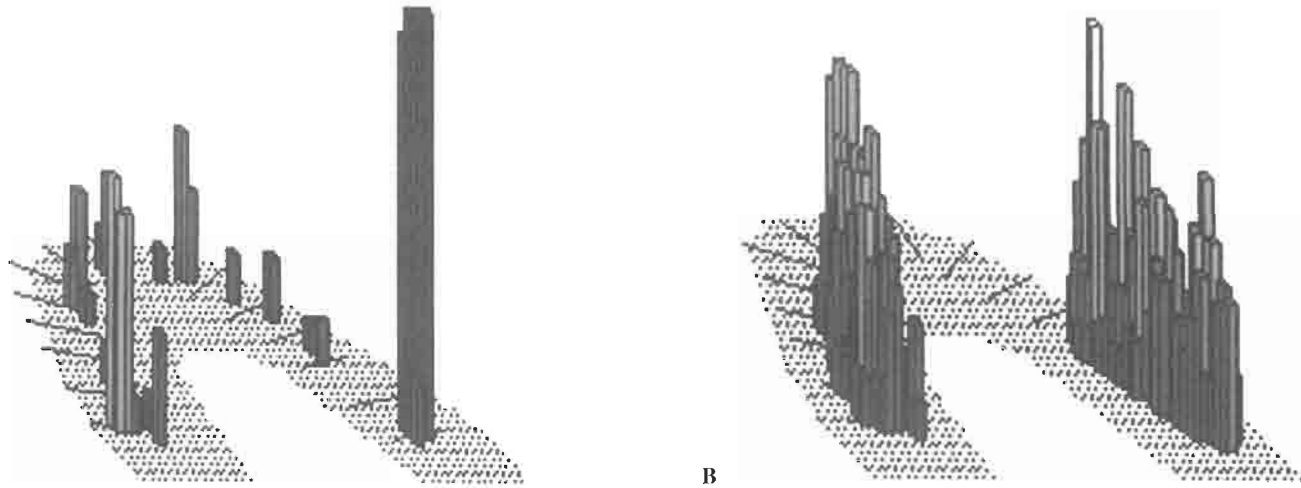
1. The total absence of interfering cuspal contacts throughout the entire migratory pathway (the layer of fluid the hydrostatic appliance interposes between the arches eliminates all U/L tooth contacts, including interferences);
2. That occlusal forces remain perfectly equalized throughout the migratory journey (Pascal's Law);
3. That perfect occlusal balance and stability be maintained throughout migration (again, Pascal's Law); and
4. That cuspal configurations in no way restrict free movement of mandibular cusps across the pads (the fluid pads' flexible walls conform progressively to all cuspal movements, while the OVD is opened enough to allow the cusps to *float* past each other).

Taken together, these factors create what may be termed a supernatural occlusal condition—a broad zone of optimal occlusal balance (the fluid-bearing pads), over whose entire width occlusal forces remain optimal regardless of changes in cuspal placement on the pads or mandibular movement across them. Since no accommodation is triggered anywhere within this entire zone, and since the body automatically reverses undesirable accommodative (compensatory) adjustments when the interferences requiring accommodation are eliminated, the muscles are able to reverse completely all occlusally instigated muscle accommodation. The muscles are freed to establish the mandible's NMP, quite possibly for the first time.

Analyzing the above, the action of hydrostatics momentarily supersedes a natural law of occlusion—it reverses the natural order inherent in occlusal function. In normal ICP closure, the cusps lock the mandible into a tooth-determined mandibular placement, to which the muscles must conform by adjusting their motor unit activity appropriately. The teeth dominate both muscle activity and mandibular placement in the closure into ICP. Hydrostatics reverses this natural situation. By creating the aforementioned broad occlusal *zone* which supplies optimal occlusal forces, balance, and stability regardless of cuspal movement across its entire surface, the muscles are given the freedom to select that mandibular intercuspal placement most harmonious with inherent muscle anatomy without external influence. The muscles are able to gain dominance over occlusion in determining the mandible's ICP. This represents a reversal of the natural order of occlusal priorities. The muscles are able to establish the mandibular placement that represents the greatest degree of muscle-occlusion compatibility. Physiologically, this should be the optimal placement for occlusion's ICP. The clinician makes no decision regarding mandibular placement. At no time should the mandible be manipulated by the clinician in any way, because any such manipulation would overwhelm and distort the NMP's delicate muscle balance. This represents an important departure from conventional current technique.

Supporting Evidence

Only a limited amount of data has been developed to this point.[113,114] However, it is clear that hydrostatics has a powerful effect on both occlusal balance and the resulting muscle activity. **Figure 3** compares the occlusal forces generated at the individual points of occlusal contact in ICP before (**Figure 3A**) and immediately after insertion of the hydrostatic appliance (**Figure 3B**). Apparent in **Figure 3A** are extreme variations in individual occlusal forces, a severe prematurity in the right molar area and severe bilateral imbalance. **Figure 3B**, taken immediately after insertion of the hydrostatic appliance, shows *neutralization* of the severe prematurity, greatly improved equalization of occlusal forces, and improved bilateral occlusal balance. In both cases, these are the forces that the muscles react to. **Figure 4** shows resting EMG activity (teeth separated, with the mandible occupying a resting position) in the right and left anterior temporal and masseter muscles. Before insertion of the hydrostatic appliance (**Figure 4A**) three of the four muscles tested exhibited hyperactivity. Five minutes after insertion of the hydrostatic appliance (**Figure 4B**), activity has been reduced in all of the muscles. In three muscles, activity was reduced to less than half of what it was five minutes prior to insertion of the appliance. This finding suggests that muscles responding to unbalanced occlusion can neither work nor rest properly. **Figure 5** represents EMG readings in these same muscles comparing maximal clenching activity before insertion of the hydrostatic appliance (**Figure 5A**) and five minutes after (**Figure 5B**). **Figure 5A** shows extreme bilateral asymmetry in muscle action: the right masseter barely working, and only a relatively small amount of activity in the left temporal. In **Figure 5B**, five minutes after insertion of the hydrostatic appliance, muscle activity has improved remarkably. Activity in the right masseter has increased approximately fifteen times what it was in **Figure 5A**, while activity in the left temporal increased over four times. Activity more than doubled in the right temporal and left masseter (previously the best performing muscles). Bilateral symmetry has also



A B

Figure 3
A: Before: Natural dentition, habitual occlusion. Occlusally directed mandibular placement. Severe bilateral imbalance, unequal forces at the individual teeth and a severe prematurity in the right molar area are apparent. **B**: After insertion of the hydrostatic appliance: Hydrostatically balanced and muscle-directed mandibular placement. Equalization of occlusal forces and bilateral balance is greatly improved. NOTE: Theoretically, force readings taken with hydrostatic equalization of occlusal forces should produce identical flat "blocks" of force bilaterally. While the above reading shows obvious and greatly improved balance and occlusal forces, the bilateral blocks lack the anticipated perfection. It is obvious that Pascal's Law cannot be faulted. Artifacts probably can be held responsible: strains introduced by the necessary resistance of the appliance's plastic film wall to stretch which interferes with perfect strain-free adaptibility to the irregular occlusal tooth contours being measured. Another unknown is the accuracy and precision of the technology employed in the force measuring device.

improved. It has been widely noted clinically (but largely anecdotally) that relief of muscle pain usually occurs quickly, within five or ten minutes, which is consistent with the results apparent in **Figures 4** and **5**.

Though obviously only fragmentary, these results support the theoretical framework presented herein, this article's conclusions, and hydrostatic technology's action on the stomatognathic system. Results such as these call for replication in full-scale, rigidly controlled studies. These results also address an important question: is there a correlation between the improved occlusal forces shown in **Figure 3B** and the improved muscle reactions shown in **Figures 4B** and **5B**? Such unusual improvements call for an explanation.

Conclusion

In the broadest sense, dentistry's main goal is to provide the patient with the best possible treatment. This calls for both greater understanding and more effective technology. The paradigm proposed herein offers both. It more accurately sets forth the dynamics inherent in both occlusal and stomatognathic function and puts them in proper context. Treatment-wise, it offers new technology, hydrostatics, that in theory may enable the clinician to establish occlusion's ICP on its most physiologic base, the mandible's NMP. It is easily understood why the present paradigm with its limited focus on cuspal relationships and TMJ-condyle relationships[115-119] has survived as long as it has. The new paradigm's two fundamental elements, the dominating effect of occlusal forces and the mandible's NMP, are both hidden from the clinician. These vital occlusal elements come to light only *after* hydrostatics *frees* the muscles, allowing mandibular migration to restore the stomatognathic system's previously hidden inherent relationships. It is hoped that this hydrostatic physiologically muscle-determined approach, essentially independent of clinician influence, can resolve the present long-standing dogma-based controversies regarding occlusion and mandibular/TMJ condylar placement. This article's conclusions require critical evaluation and experimental testing. However, if the conclusions are validated, one of dentistry's long-standing goals will be achieved: optimal integration of occlusion within its natural environment—the stomatognathic system. This, in essence, represents the heart of the new paradigm, which can be summarized as follows:

1. Occlusion must be seen in context as one element of the stomatognathic system with whose other elements it interacts intimately. Occlusion must not be viewed in isolation.
2. Force is the fundamental element that controls stomatognathic function. Effective, atraumatic, and economical balance is maintained continuously (via a neural servomechanism) between the 3-dimensional set of muscle forces powering the mandible and the three-dimensional set of occlusal forces

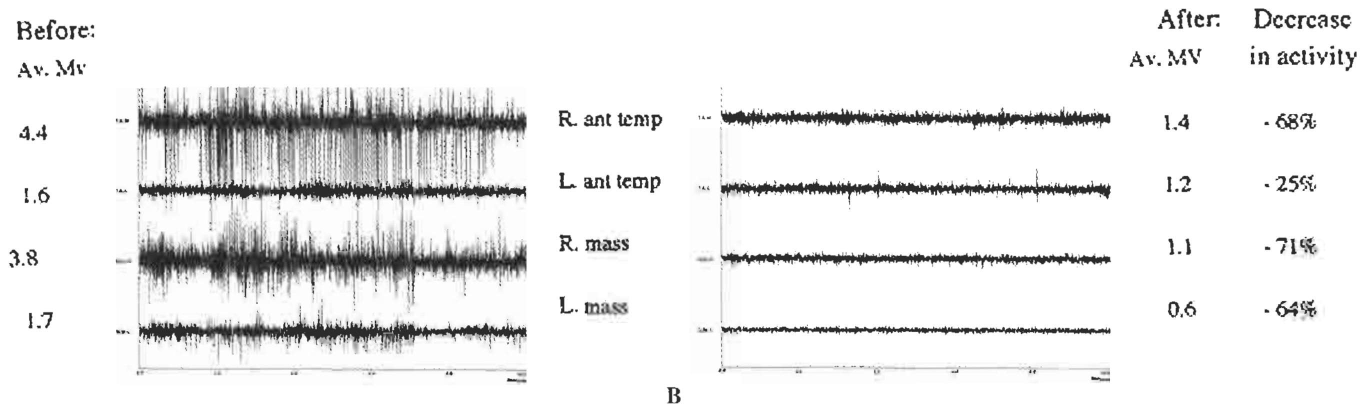


Figure 4
A. Natural dentition, resting; **B.** Resting, five minutes after insertion of the hydrostatic appliance. EMG muscle activity levels before and after insertion of the hydrostatic appliance: resting activity.Note the reduction in resting muscle hyperactivity even though the teeth are not in occlusion and no occlusal forces are being generated. This suggests that occlusal imbalance affects muscle activity in general, *not only* while the teeth are in occlusion.

generated when the teeth contact in IC closure.

3. Optimal integration of occlusion and mandibular (and condylar) placement with the neuromuscular complex requires that the mandible occupy its NMP in ICP. The NMP by definition is that mandibular placement which requires the least muscle accommodation, i.e., where motor unit activity, intramuscular force patterns, intermuscle balance, individual muscle lengths and fiber orientations correspond most closely to their inherent anatomic states.
4. Only the muscle complex itself is able to establish the mandible's NMP precisely, and then only after hydrostatics has created the broad zone of optimal (equalized) occlusal force which "liberates" the muscles. Such an occlusal situation does not exist naturally. Human senses are inadequate to establish NMP because of the uncountable number of subtle muscle readjustments required throughout the muscle complex. Accurate integration of occlusion, muscles, and the other elements of the stomatognathic system requires that the muscles *themselves* guide the occlusal correction process. Theoretically, only the hydrostatically created occlusal conditions can allow the muscles to bring the mandible to its NMP without outside intervention in muscle action. When "deaccommodation" is complete, the mandible can then be held to occupy its NMP.
5. The muscles require the following occlusal conditions to bring the mandible to its NMP: 1. an input of simultaneous forces of equal magnitudes, each axially oriented to its own tooth; occlusal forces generated simultaneously at every point of occlusal contact in ICP; 2. the complete absence of cuspal interferences during the entire migratory process; and 3. that optimal forces, occlusal balance and mandibular stability be maintained continuously over an occlusal zone broad enough to permit mandibular migration to continue to the point where

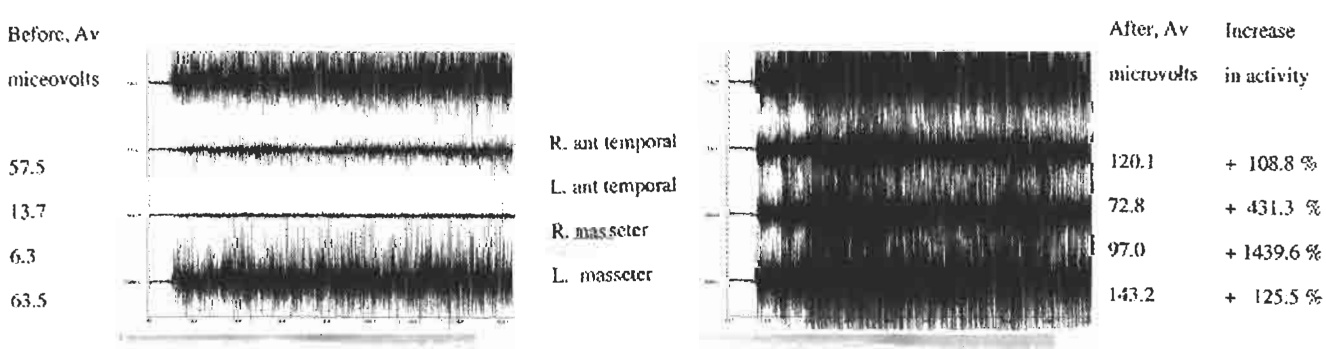


Figure 5
Maximal clench EMG muscle activity levels before and after hydrostatic equalization of occlusal force levels and elimination of cuspal guidance. A: Before: Natural dentition. Habitual occlusion. Occlusally-directed mandibular placement. Extreme bilateral asymmetry is apparent. Left side: minimal temporal activity, high masseter activity. The reverse is apparent on the right side: high temporal activity, low masseter activity. B: Five minutes after insertion of the hydrostatic appliance. Muscle-directed mandibular placement. Markedly improved muscle function, both sides. Bilateral symmetry restored.(Amplification 1x; sampling rate 1000 Hz.; readings two second sweeps; electrode placement unchanged between readings.)

the muscles themselves have completely reestablished inherent intramuscular functional force patterns, intermuscle balances, lengths and fiber angulations. This is the mandible's NMP.

6. Such a norm, presently lacking in dentistry,[46-50] is essential to more clearly defining the goal of clinical treatment. Such a norm is also essential in research to serve as a physiologic frame of reference (a valid base for comparison). To date, the absence of such a valid physiological reference point has seriously undercut the scientific validity of much dental research.

It is hoped that the perspective set forth herein will stimulate a fundamental reevaluation of stomatognathic function and occlusion.

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