The Adaptability of the Temporal and Masseter Muscles; An Electromyographical Study

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In the last three decades there has been a distinct metamorphosis in the orthodontic literature from the "static" to the "dynamic" concepts of occlusion. This was due, in part, to the advent of cephalometrics; and in part, to the orthodontist's appreciation of the fact that occlusal function is dependent upon muscular function.

Accordingly then, it is not uncommon to find such terms as "hypertonicity," "hypotonicity," "poor muscle balance," and "excessive muscular pressure" associated with clinical descriptions of the etiology of certain types of malocclusions. For example, the crowding of the upper and lower anterior teeth is frequently associated with the hypertonicity of the orbicularis oris-buccinator muscular complex. Likewise certain types of Class II Div. 1 malocclusion are believed to have at least a portion of their etiology in the hypertonicity of the mentalis muscle. There are also instances in the literature where these same types of malocclusion are ascribed to hypotonicity of the relating musculature.

There are times when in one breath the virtues of *good* muscle function are extolled with considerable fervor because sought-after treatment objectives have been attained; and in the next breath, *poor* muscle function is blamed with equal firmness when sought-after treatment objectives are not realized. The recurrence of original rotations, the breaking of contacts, and the failure of expanded arches to maintain their width after treatment, are, for the want of better reasons, variously assigned to such factors as "hypertonicity," "hypotonicity," "poor muscle balance," or "excessive muscular pressures." Such divergencies, as these, in our clinical attitudes relative to the part that muscle function plays in the maintenance of the teeth in good occlusion, or conversely, in malocclusion, need to be explored and reconciled. To this end a study was designed to show, electromyographically, the range of adaptability of the masseter and temporal muscles in various functional situations in normal occlusion and in one type of malocclusion. This is a preliminary report on one phase of this study and is designed to show electromyographically, (1) the contraction patterns from the right and left temporal and masseter muscles while a patient with normal occlusion chewed peanuts; (2) similarly obtained contraction patterns from another subject who had had a cleft palate and hare-lip surgically reduced in early childhood and whose teeth went through an excessive interocclusal space (17 mm.) in going from rest into occlusion; and finally (3) to show by comparison the differences in the myograms obtained from the contracting temporal and masseter muscles before and after the excessive interocclusal space was orthodontically reduced by an interocclusal splint. The likenesses, the differences, and the variations in these myograms will show the range of adaptability of these two pairs of muscles to functional stimuli under these conditions of occlusion and will be the theme of this paper.

Since Moyers (1949) introduced electromyography to the dental field of muscular studies, this physiological medium of research has been found to be clinically applicable to quantitating and qualitating the activity of the muscles of mastication under strictly physiological conditions. However, because the language of electromyography is new to the orthodontic clinician, it cannot have a meaning or a reality until its symbols for mastication and other muscular functions associated with the teeth are translated into a language that will be understood by him. Just as he has already learned to evaluate and understand facial and cranial growth by interpreting certain angles of the face and the cranium taken from a profile cephalometric radiograph, so also must the orthodontist learn to interpret myographic symbols (graphs of action currents derived from contracting muscles) in terms of motor activities related to specific muscular functions and their significance and relation to the occlusion of the teeth and the growing dental facial complex.

With this in mind, consideration will first be given to the neuroanatomical structure of muscles, then to a description of the recording instruments; and finally to an evaluation, classification, and interpretation of the myographic records taken from the masseter and temporal muscles of subjects chewing peanuts.

Neuroanatomical Structures

Since the elevation and depression of the mandible in mastication is performed by muscles attached to it, an explanation of some of the basic facts about muscle as a tissue and muscle as a system is germaine at this time to a clearer understanding of the dynamics

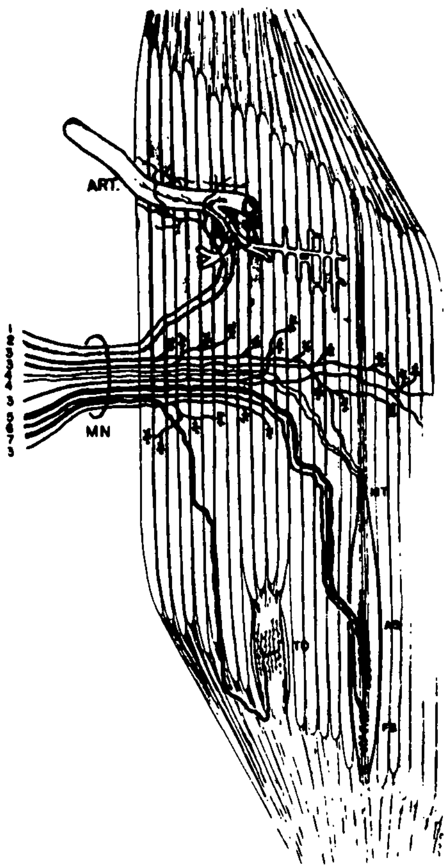


Fig. 1. A motor unit showing the motor nerve supply (1, 2, 3, 4) and the sensory (proprioceptive) nerve endings (5, 6, 7).

of mastication as it is recorded electromyographically. It is necessary to examine its structure, its color, what it does as a tissue, how it functions as a system, and finally, the work it does by virtue of its contractile properties.

A motor unit (Figure 1) is made up of a group of muscle fibers innervated by branches of a single axon (3, 4, 5 in Fig. 1) from an anterior horn cell whose body may lie either centrally (in the brain) or in the lower motor neuron (Sherrington 1893) (Krieg 1953. Hence it is possible for the axon to carry motor impulses that originate in the brain to the muscle by way of the lower motor neuron. It can also carry impulses mediated at a reflex level in the spinal cord. Structurally, the number of individual muscle fibers in any given motor unit will depend upon the function that a muscle, consisting of many such motor units, is called on to perform. For instance, the wing muscles of the fly, geared for rapid action and capable of making three hundred complete contractions per second, have very few muscle fibers per motor unit; the muscles governing the movements of the eye have an innervation ratio of one motor neuron for from six to fifteen muscle fibers (Denny-Brown 1929); and the large muscles of the body (where the movements of locomotions are slower and less specialized than those in the eye) have an innervation ratio of from 120 muscle fibers to one neuron to as many as 200 to 250 per neuron. A motor unit, irrespective of the number of muscle fibers, will respond "all or none" when it receives a stimulus.

In addition to the motor nerve supply, the motor unit also has a sensory nerve supply (Figure 1, Nos. 6, 7, 8). The sensory nerves carry messages from the muscles back to the central nervous system; thus, in a sense they serve as a "feed-back" mechanism advising the central nervous system (most generally on a subconscious level) of what is taking place in the individual motor units of the contracting muscles. This feed-back mechanism is known as the proprioceptive system. Structurally, the sensory feed-back system leading to the central nervous system has four types of nerve endings or receptors; two of them are situated in the substance of the muscle fibers of the individual motor units, and two are in the fascia and tendons. Generally speaking, some of the receptors found in the muscles send sensory impulses to the sensorimotor cortex (Gay and Gellhorn 1949) when the muscles are passively stretched while others are activated both by muscle stretch and by muscle contraction. Functionally this feed-back system acts in a "braking" or inhibitory capacity, guiding the degree of contraction within the motor unit.

In addition to the proprioceptive mechanism found within the substance of the motor units, the muscles of mastication are under the control of still another feedback system whose receptors are located in the periodontal membranes and gingivae surrounding the teeth and in the mucosa in the floor of the mouth. Through these receptors sensory stimuli of touch and pressure arising from the articulation of the teeth are conducted first to the mesencephalic nucleus where a reflex arc may be formed, or they may continue from here to higher brain centers in the cortex. Thus it is conceivable to visualize that a change in the proprioceptive stimuli originating in the teeth, caused by a malocclusion, may change the pattern of function of the muscles attached to and responsible for the movements of the mandible.

Muscles may vary in color (Denny, Brown 1929); some are dark red and others are pale red. The pale muscle, having less coloring pigments, is believed to be made up of highly specialized motor units capable of rapid contraction, whereas in the red muscle the motor units are thought to be structurally designed for slow movements. In the human body the color distinction is not as clearly defined as it is in the lower forms of animals; both red and white muscle fibers may be found in rapidly as well as in slowly contracting muscles.

This leads us to consider the arrangement of motor units according to the work they are called upon to perform. The motor units of muscles have been found to be arranged microscop-

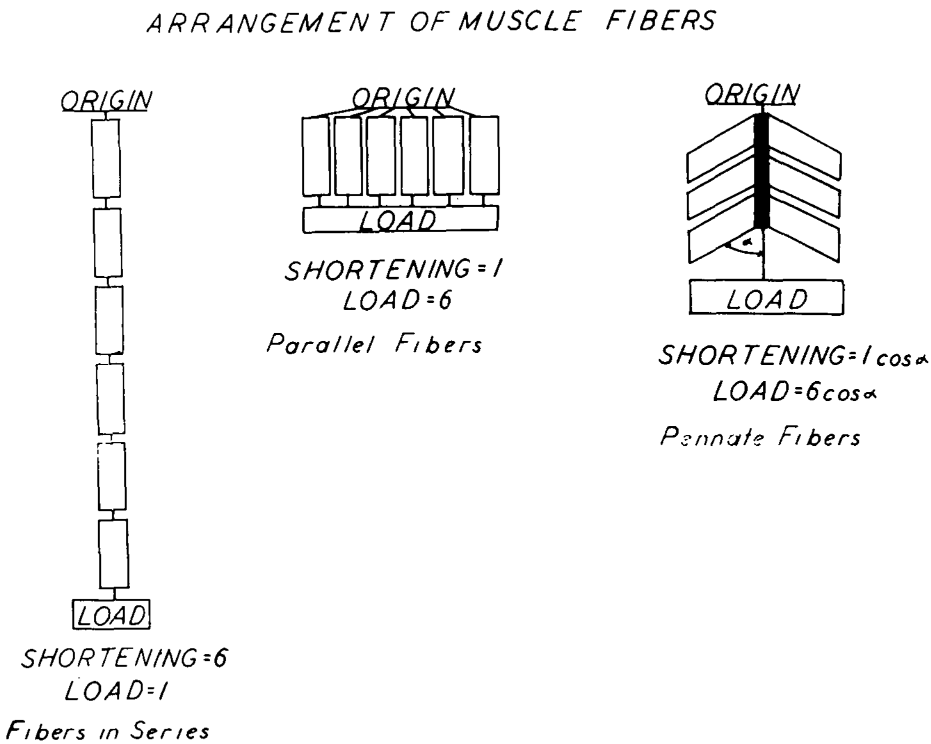


Fig. 2. Arrangement of muscle fibers according to the work they perform. Illustration redrawn from Beritoff's data.

ically according to a simple geometric formula that orients the individual motor units either in series, in parallel, or diagonally. Beritoff (1925) illustrated schematically (Figure 2a, b, c) the arrangement of the individual motor units in the various true types of the striate muscles. Interpreting Beritoff's chart which uses in its illustration six motor units, we see that muscles designed for greatest shortening have their units arranged in series.

To carry the greatest load, the motor units are arranged parallel to each other (Figure 2b.) And for the highest efficiency for both work and for shortening, the motor units are arranged in a pennate manner along a central tendon (Figure 2c).

True geometric forms described in the preceding paragraph cannot be clearly identified in the muscles associated with the elevation of the mandible. However, studies have revealed that the internal pterygoid muscle resemble a long, paralleled fibered muscle. The masseter muscle, particularly its deep belly, is similar to a muscle whose contractile motor units are arranged in series; while the motor units of the temporal and lateral pterygoid muscles are very nearly pennate in geometric configuration.

Structurally then the masseter and temporal muscles to be discussed in the electroymyographical portion of this study have their motor units arranged so that one of the muscles, the masseter, is equipped for power, and the other, the temporal, for both action and power.

Types of Muscle Contraction

As a result of early studies, Fick (1882) identified two types of muscle contraction, isotonic (constant load), and isometric (constant length). In isotonic contraction the muscle shortens as it contracts, while in an isometrically contracting muscle there is an increase in tension but there is no change in length. More recently contraction has been divided by Höber (1945) into three distinct types: (1) that which is accompanied by the shortening of the muscle, (2) that which is accompanied by lengthening, and (3) isometric contraction in which there is no change in length.

To illustrate the three types of contraction, the chewing reflex can be used. In the first part of the chewing act, while the mandible is being elevated, the elevators of the mandible, the temporal, masseter, and internal pterygoid muscles are shortening as the teeth are going through the food bolus and coming into occlusion. This is contraction by shortening. On the other hand, the muscles attached to the lower border of the mandible, the digastric, the supra hyoid and infra hyoid muscles are lengthening during this time. As they continue to lengthen a tension develops within these muscles that regulates the upward movement of the mandible. This is contraction by muscle lengthening. Isometric contraction is attained after the teeth have come into occlusion and there is no further physical shortening taking place in the elevating muscles of the mandible.

In addition to the physical changes that take place in contracting muscles there are chemical changes; these are accompanied by the liberation of heat and electrical energy. It is this electrical energy from contracting muscles, known as action currents, that makes electromyography possible.

Review of Dental Literature

The first attempt to study muscular activity under strictly physiological conditions in orthodontics was reported in two papers by Moyers (1949, 1950). Using an electromyograph to study action currents from some of the muscles responsible for the movements of the temporomandibular articulation he found among other things that in normal occlusion of the teeth there was a remarkable synergistic action between the anterior, middle, and posterior bellies of the temporal muscles of the right and left sides. However, in the Class II Div. 1 subjects he observed there was a lack of synergistic behavior in the same muscles, strongly suggesting that the occlusion of the teeth is a factor in the pattern of muscular function. Similarly, changes in action currents deviating from the normal were seen in cases where a transitional occlusal interference developed in young patients erupting permanent teeth. This indicates how strong the influence of proprioceptive impulses arising from these teeth is in determining the patterns of muscle contraction. Pruzansky (1952) also found that the synergistic behavior of the masseter and temporal muscles varied with the occlusion of the teeth, and that the action of these muscles could be correlated with the efficiency of the masticatory mechanism. By comparing the amplitude of the action currents from the muscles of mastication, Neumann (1950), studied the contraction forces from these muscles in the chewing of foods of different hardnesses. Gelzer (1953) quantitated the action currents from specifically identified parts of the three bellies of the temporal muscle against a known amount of inter-occlusal force. In a group of patients wearing artificial dentures, Jarabak (1952) observed distinct changes in the myographic patterns taken from the temporal and masseter muscles in denture-wearing subjects when the dentures were designed to a greater inter-occlusal space than was normally required by the patient. Likewise in other denture subjects, immediate changes were seen in the myographic patterns that were obtained from these muscles when occlusal interferences were removed by grinding or by milling the occlusion of the teeth into interference-free function.

Methods and Materials

Two patients were used in this study: a girl aged 14 years, who by orthodontic standards had an excellent occlusion; the other, a boy of the same age, who was born with a cleft palate and unilateral hare-lip and who had both of these surgically repaired in early childhood. The boy also had an excessively large inter-occlusal space (17 mm.) which had been reduced to 3 mm. by an orthodontic splint made in the form of a denture that was fitted over his upper teeth.

In the upper right buccal quadrant the boy's second bicuspid and first and second molar teeth were in a state of poor repair. The upper right first bicuspid, canine, lateral, and central incisor teeth all had small fillings. In the upper left buccal quadrant the first molar was lost, and the remaining teeth in this segment in addition to the canine and central incisor teeth in the anterior quadrant were filled.

This boy was used in these experiments for two reasons: (1) because myographic records could be obtained from the temporal and masseter muscles with the subject functioning through an excessive inter-occlusal space; and (2) because chewing could be repeated and electromyographically recorded with the splint in place. The girl with the excellent dentition was used as a control.

Peanuts were used in this experiment because they are a food that offers a variable resistance to crushing as the size of the particles is reduced by chewing. We were anxious to have this property because we wanted to determine, if possible, how a variable resistance to the crushing of the food bolus might change the electromyographically recorded chewing patterns obtained from the temporal and masseter muscles.

To facilitate the placement of the electrodes over the muscles bellies, the patients were asked to occlude their teeth forcibly several times. Then by placing the index finger over the principle belly of the temporal and masseter muscles on both ipsilateral, or chewing side, and contralateral, or balancing side, these muscles were palpated. Indelible ink marks were then placed on the skin over the apex of the area of greatest lateral distention to facilitate the replacement of the surface electrodes for future trials. Perforated surface electrodes one-fourth inch in diameter made from a silver alloy were securely attached to the skin by celloidin over the marked areas. The skin below the electrodes was freshened with a salt jelly applied through a small hole in the center of the electrode until a skin resistance of less than 5000 ohms was obtained.

Impulses originating in the right and left masseter and the corresponding temporal muscles were picked up by the surface electrodes, the wires of which were connected to a relay box. From this relay source the impulses were then fed into an amplifier system of an Offner Encephalograph Type A (Figure 3) that was converted into an electromyograph. The amplifiers were set to a gain of 3 with the "Hi" and "Lo" dials set at 2 and .002 respectively. With these settings there was adequate amplification for a 6 mm. deflection of the pens of the Crystograph at 100 micro-volts. A paper speed of

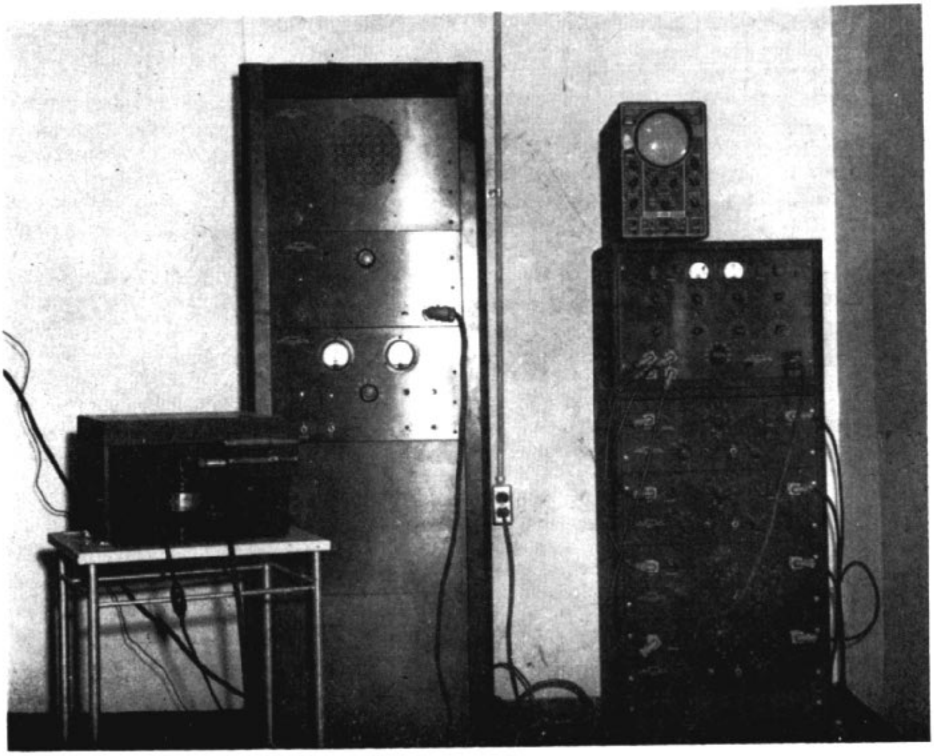


Fig. 3. Electromyographic instruments showing pick-up unit, oscilloscope amplifiers and crystographic inkwriters.

10 cm. per second was used for all of the recordings in this experiment.

Two series of electromyographic records were taken from each subject. Both of these were from the temporal and masseter muscles of the right and left sides, with the subject chewing peanuts first in the right buccal and then in the left buccal quadrant. The only instructions to the patients in the first phase of the experiment were that she or he chew three peanuts normally in first the right buccal quadrant for three minutes, and then three peanuts in the left buccal quadrant for three minutes. During this time a continuous record was being taken of the chewing, and the movements of the mandible were being carefully noted so that variations in the masticatory stroke could be identified and equated with specific myograms.

One of these (Figure 4) myograms, representing one chewing stroke which was obtained at the end of two minutes of chewing from the subject whose teeth were in normal occlusion, now will be described. A typical myogram like this has three attributes; time, amplitude, and form.

Time is in fractions of a second (shown in Fig. 4 between rest areas 1 and 2) and represents the duration during which the fibers of the temporal muscle are contracting for one chewing stroke. The time during which muscles may contract is a variable entity determined by the work that they are called upon to do.

Amplitude indicates either the number of motor units that are contracting at one time or it may mean that individual motor units are contracting with greater frequency.

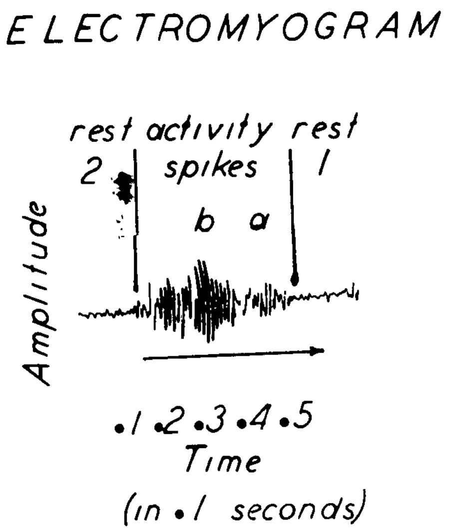


Fig. 4. An electromyogram representing one chewing stroke, showing amplitude, form and time.

The form of the myogram points out in variations in amplitude when the activity in the muscle begins, whether it occurs gradually, rapidly, or intermittently. It also shows whether its onset is slow or rapid and whether the decrease in its amplitude after the maximum contraction has been spent is slow or rapid. From this we can see that many combinations in form may be obtained; some of these will be elucidated upon more fully later.

Pursuing the theme of form to a specific illustration, let us now try to visualize how the position of the mandible is changed during the burst of muscular activity shown in the myogram in Figure 4. The rest 1 area in this myogram shows a low amplitude and low frequency tracing from the temporal muscle when the mandible is at rest. As the temporal muscle enters into a phase of contraction, there are two distinct bursts of activity which are represented as a group of action current spikes. The first burst illustrated by "a" is associated with the elevation of the mandible in part, and in part with the sliding of the teeth into centric occlusion through the food bolus. In this phase, the temporal muscle is shortening; therefore it is contracting isotonically. In this instance, when the teeth have reached centric occlusion there was a pause. This pause (shown to the left of "a") is accompanied by brief recession in the number of discharging motor units and is believed to be a mechanism of proprioceptive protection. There then follows a maximum burst of activity shown under "b" in Figure 4. This sharp increase in number of discharging motor units is, in our experience, believed to occur at the precise moment when the teeth have come into occlusion and a maximum force is given to the chewing stroke.

When a motor unit contracts it does so "all or none"; therefore, an increase in amplitude means an increase in the number of motor units or an increase in the frequency with which individual units discharge. Conversely, a decrease in amplitude means a reduction of the number of contracting motor units or a decrease in the frequency with which individual motor units contract. This phenomenon for muscles is similar to the Adrian-Bronk law for nerves which states "that the intensity of excitation is directly related to the frequency of the discharge of the individual neuron and to the number of active neurons."

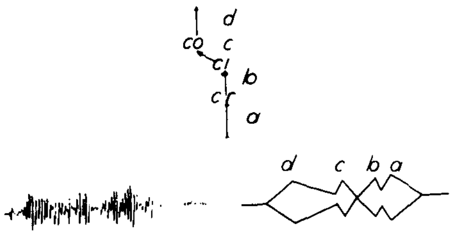
With the preceding description of what takes place electromyographically during one chewing stroke as a basis for comparison, we may now turn our attention to a classification of the types of masticatory strokes found during the pulverization of peanuts by a subject having a normal dental occlusion.

The myogram seen on the left in Figure 5, the schematic drawing on the right (showing the manner in which the motor units are discharging), and the directional vectors of mandibular movement shown in the center of this figure all are representative of one chewing stroke at the beginning of the mastication of three whole peanuts.

In order to simplify the identification of the myogram and its co-ordination to the mandibular movements and to the occlusion of the teeth we resorted to representing, schematically, the various changes in its amplitude. To do this a sheet of tracing paper was placed over the myogram to be studied and a ruler was then placed along the edges of the spikes of least amplitude to the edges of the spikes of maximum amplitude: a line was then drawn connecting the spikes. Thus the tracing on the right side in Figure 5, representing one chewing stroke, is divisible into four bursts of motor activity. This is clearly seen in the myogram on the left.

Interpretation of this myogram in terms of mandibular movements and in terms of the position of the teeth is as follows.

The first burst of activity (shown by "a" in Figure 5) is associated with the crushing of the peanut. During this act the mandible is elevating (shown by the arrow marked "a" in the center of Figure 5). As soon as the peanuts are crushed by the first phase of the masticatory stroke there is a brief reduction in the number of discharging motor units (shown between "a" and "b" in Figure 5). During this phase the mandible is continuing upward. There then follows the second burst of activity ("b" in Figure 5), further reducing the size of the peanuts, elevating the mandible a little more (shown by line "b" in the center of Figure 5), and bringing the teeth into initial contact (Ci). When initial contact is reached there is another brief pause in activity (between "b" and "c" in Figure 5). The third burst (shown by "c") of activity, slightly smaller in amplitude than the



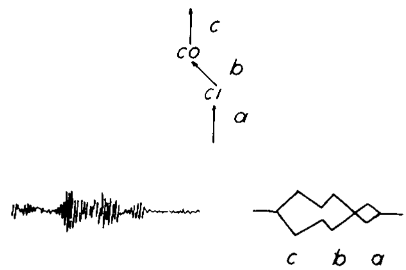


Fig. 5. (Above) Myogram of the temporal muscle on the left, the tracing of the myogram on the right. The figure in the center represents the vectors of mandibular movement upward in one chewing stroke at the start of peanut chewing in a subject with normal occlusion.

Fig. 6. (Below) Myogram showing three bursts of activity.

first two, is to the best of our knowledge believed to be associated with the movement of the mandible at a time when the teeth are sliding from the points of initial contact to centric occlusion (this is shown by a diagonal arrow from Ci to Co in Figure 5). The final phase of motor activity, longer in duration and of a slightly higher amplitude than the last, occurs when the teeth are in centric occlusion or approaching it and it is associated with the final phase of the chewing stroke (shown by "d"). During this time what movement, if any, of the mandible is in an upward direction. It is our belief that at this time the temporal muscle is contracting isometrically, that is, it is not shortening in length.

The three brief pauses between the four groups of motor discharges are protective and are under the control of the proprioceptive sensory system whose endings are in the periodontal membranes of the teeth and in the substance of the muscle.

After the size of the peanuts was reduced by chewing for one minute, myograms like those in Figure 6 began to appear with greater frequency. In this myogram the masticatory stroke is divisible into three parts. Since the size of the peanuts was considerably reduced by chewing, the number of contracting motor units required to elevate the mandible in the initiation of the chewing stroke was reduced ("a" in Figure 6). The remaining two bursts of activity correspond to the last two in Figure 5. This is significant because it illustrates the uniformity of the chewing stroke in its final phases.

Interpretation of the action current patterns that were taken after two minutes of chewing (Figures 7 and 7a) is more challenging than the records previously described. Mygrams such as these may be obtained from the contracting temporal muscle in two ways, either by having the teeth go through a "mushy" bolus of peanuts directly into occlusion, accompanied by a vertical vector of mandibular movement; or they may be obtained by having the teeth come into initial contact first and then immediately go into centric occlusion (Ci to Co in Figure7).

In Figure 7 the onset of the final burst of activity is slow, accruing gradually until it reaches peak amplitude. The maximum contraction having been spent, the decrease in the number of contracting motor units is almost as orderly as was the increase in the beginning stage of contraction. This type of myogram indicates that the masticatory stroke is a slow one. On the other hand, the myogram in Figure 7a has a rapid onset, reaches a maximum amplitude rapidly, the force having

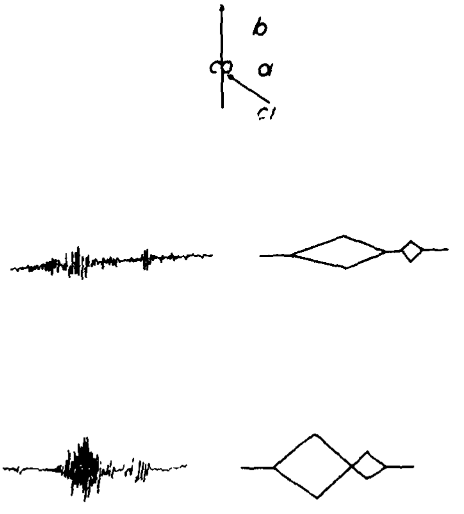


Fig. 7 and 7a. Myograms showing two bursts of activity.

been spent, it declines in the same manner as it commenced; is associated with a fast masticatory stroke and has been referred to as being ballistic (Pruzansky 1952).

In the final stages of chewing at the end of the three minute period it is possible to identify four distinct types of myograms. One characteristic common to all is that they show only one burst of activity (Figures 8, 9a, 9b, and 9c). This means that the teeth go through the inter-occlusal space, pass through the bolus, and go directly into centric occlusion without interruption or pause. The differences in these myograms is in the rate of onset of motor activity, the amplitude and the rate of recession in the number of contracting motor units after the maximum contraction was spent. In the myograms shown in Figures 8 and 9b the onset is slow, maximum amplitude is built up rapidly and the decay in activity is equally slow. However, in Figure 9a the onset of activity is rapid, a maximum amplitude is sustained and, when spent, there is a gradual recession in the

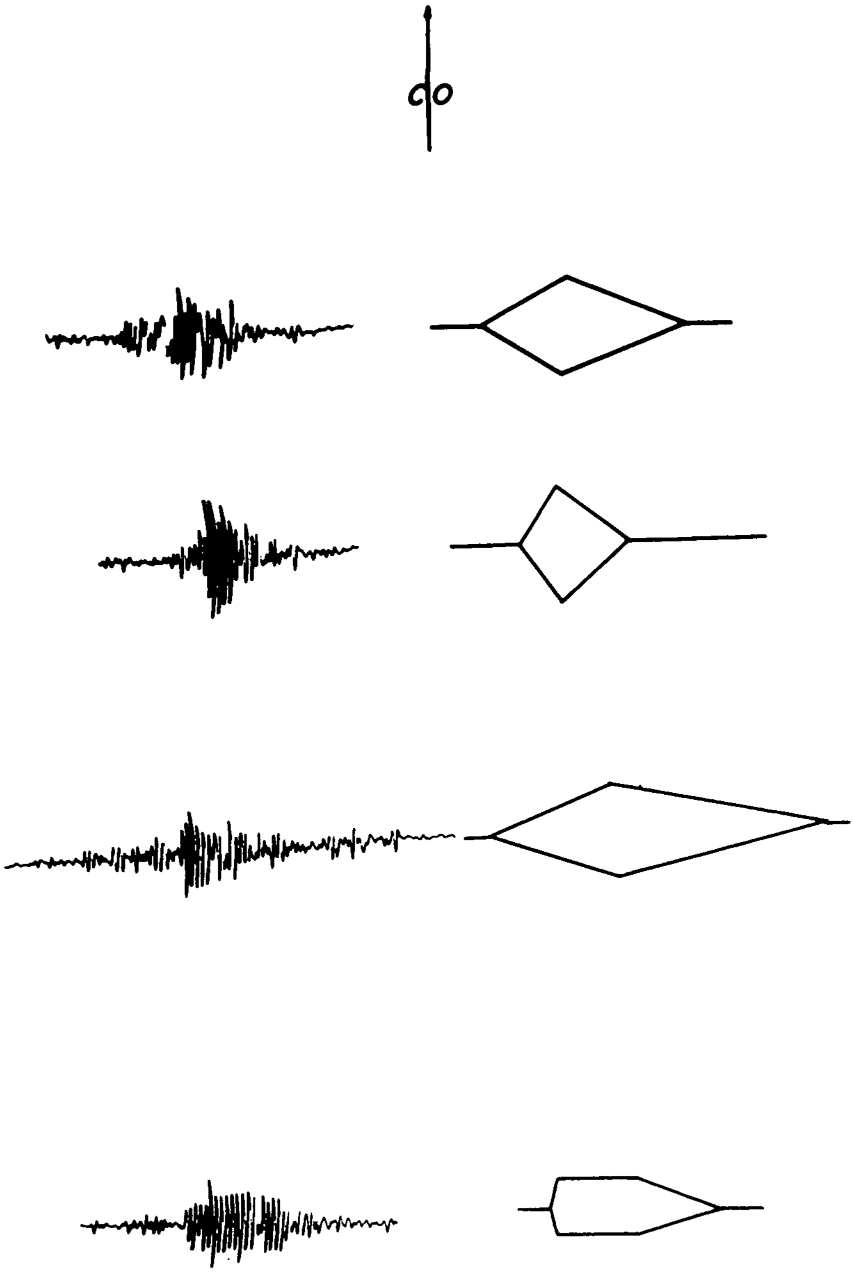
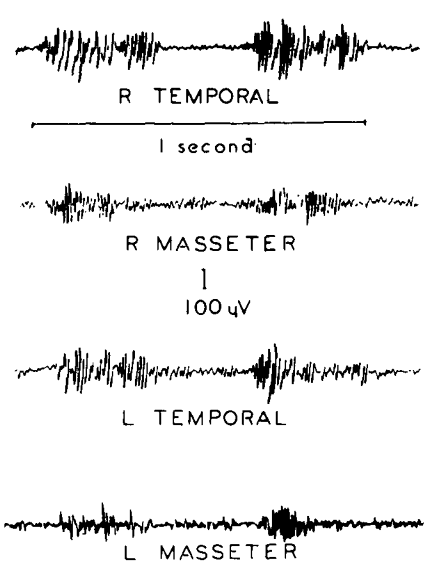
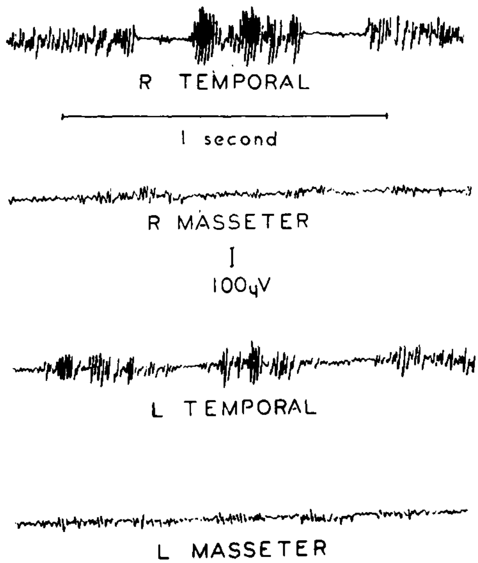


Fig. 8. (Top) Myogram depicting one burst of activity.
Fig. 9, 9b, 9c. Single burst myograms.

number of contracting motor units until rest has been reached. Rapid onset followed by a very short period of maximum contraction and an equally rapid recession in activity are shown in the myogram in Figure 9c. Thus in the final stages of chewing there are three types of chewing strokes, one is slow in





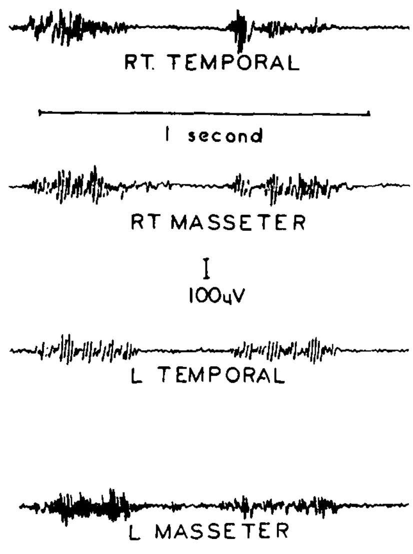


Fig. 10a. (Above left) Myograms representing two chewing strokes taken from the beginning of a continuous chewing record from a patient with normal occlusion.

Fig. 10b. (Above right) These myograms represent three chewing strokes taken from the beginning of a continuous chewing record of a patient with malocclusion and a large interocclusal space.

Fig. 10c. (Below) Myograms representing the chewing strokes from the beginning of a chewing record of the subject in Fig. 10b whose excessive interocclusal space was reduced with an orthodontic splint.

its onset, gathers tempo until maximum force is reached and then the fibers of the temporal muscle relax slowly from their activity. In the second, the muscle fibers contract rapidly and remain contracted for a prolonged period and then relax quite rapidly. In the ballistic chewing stroke the onset of contraction is fast, it is sustained for a brief period, and the muscle fibers go into rest in a relatively short time after maximum contraction is reached. This masticatory stroke is characterized by a "chopping" action.

Consideration to this point has only been with the myograms obtained from the contracting fibers of the temporal muscle on the chewing side of a subject whose teeth are in normal occlusion. The purpose of this was to obtain a basis for comparison of the myograms to be considered in the second portion of this paper. The myograms for the second part of this report were taken from the ipsilateral and contralateral temporal and masseter muscles of the subject with normal occlusion, as well as from the subject with a malocclusion (described in methods and materials) before and after orthodontic rehabilitation.

An interpretation of the first of these myograms, obtained from the subject with teeth in normal occlusion, is that at the beginning of peanut chewing in the right posterior quadrant, the right and left temporal and the corresponding masseter muscles (Figure 10a) contracted synchronously; they began to contract at about the same time and ceased to contract, at about the same time. In the right temporal muscle the chewing stroke was divisible, electromyographically, into four components. This myogram was similar to the one obtained from this subject at the beginning of peanut chewing in two trial runs and described previously. The form of the myogram taken from the left temporal muscle is unlike that obtained from the right temporal muscle in that it has a gradual onset and does not reach maximum amplitude until the end of the chewing stroke has been very nearly reached. It is not divisible into four constituent bursts of activity as is the myogram of the right temporal muscle.

The amplitude (obtained by measuring the height of the vertical lines on the myogram) is generally greater at the outset of chewing of peanuts on the side where they are being crushed, in this case on the right side, than it is on the balancing side. These slight deviations in amplitude indicate that there are more motor units being brought into a phase of contraction on the chewing side than on the balancing side. From these data it follows then, that in normal occlusion at the outset of chewing, the right and left temporal muscles will contract synchronously. In so doing they will most generally yield myograms on both balancing and working sides that are divisible into four parts. When exceptions to this form occur they do so with greater frequency on the balancing side. The continuous phase of low amplitude activity seen between the myograms of the temporal muscle on the balancing side are in all probability associated with the posture of the mandible.

Myographic patterns of the right and left masseter muscles (Figure 10a) in the subject with normal occlusion are quite unlike those obtained from the corresponding temporal muscles. The burst of motor activity from the right masseter muscle taken at the start of a continuous chewing record is divisible into two parts, both of which show a gradual increase in amplitude. The motor units are being recruited into action in a lower magnitude and slower tempo than those of the corresponding temporal muscle. A closer analysis of the myograms of the right temporal and right masseter muscles also reveals that peak amplitudes are not reached at the same time in the masticatory cycle during which these two muscles are contracting. In addition to these differences it is also apparent from the low amplitude record between the individual chewing cycles that the right masseter muscle on the working side does not come to rest between individual chewing strokes; whereas on the balancing side, the left masseter muscle during mastication gives myograms that very nearly mirror in form, and in some instances in amplitude, those of the left temporal muscle.

From this evidence of differences in the myograms of the right and left temporal and masseter muscles we may theorize that when the subject is chewing on the right side, the temporal muscle on that side elevates the mandible; while masseter muscle, contracting as it does, gives power to the chewing stroke.

The fact that there continues to be some low amplitude activity in the masseter muscles between chewing strokes leads us to believe that the masseter muscles not only give power to the chewing stroke but that they also are instrumental in maintaining the postural equilibrium of the mandible.

Excessive Inter-occlusal Space

Further pursuing the analysis of the factors that may cause similarities and dissimilarities in the myograms of functioning muscles at the outset of peanut chewing, we now come to the consideration of how the myographic patterns taken from the temporal and masseter muscles may be affected by an excessive inter-occlusal space.

Recognition first will be given to the functional patterns obtained from temporal muscles on the right or chewing side (Figure 10b). The center myogram, in form appears to resemble that of the temporal muscle in the subject with normal occlusion (Figure 10a), it is divisible into four short bursts of activity. While the myograms to the right and to the left of it yield a sudden low amplitude onset, the contracting units of this temporal muscle then continue to maintain this amplitude for the duration of contraction. If one were to assay these myograms, their amplitudes and their form might well fall into the same classification as those for the right masseter muscle (Figure 10a) in the subject with normal occlusion. Myograms from the balancing left temporal muscle, in a general way, resemble those of the right temporal muscle; however, they have a somewhat lower range of amplitude. This once again indicates that there are fewer motor units contracting on the balancing side.

The masseter muscles, much to our astonishment, were practically electromyographically silent. The low amplitude activity asynchronous to that of the temporal muscles is almost continuous and gives the appearance of the rest activity between the chewing strokes in the right and left masseter muscles (Figure 10a) in the subject with normal occlusion. This type of activity was previously referred to as being postural and associated with the rest position of the mandible.

Summarizing the data in Figure 10b, it may be said that this subject chewing, as he was, through an enlarged inter-occlusal space yielded myographic maps which for the want of a better term, suggest a "confused" pattern of muscular activity in both the temporal and masseter muscles. To the temporal muscles due to the silence of the masseter muscles fell the task of not only elevating the mandible but also of giving power to the masticatory stroke.

Effects of Orthodontic Rehabilitation

Myograms obtained from the masseter and temporal muscles after the placement of an orthodontic splint to reduce the excessive inter-occlusal space indicate that there were immediate changes in form, amplitude, and rate of discharge in the contracting motor units of these muscles.

The contraction phase of the right and left temporal muscles at the beginning of the chewing cycle was divisible into three bursts of activity. The first burst (Figure 10c), generally associated with the crushing of the peanuts, on the right side was small. The high amplitude activity came at the end of the chewing stroke instead of at the beginning as one might expect. On this basis it would seem logical to assume that after the denture is placed, the subject has to feel his way around with his teeth before he actually brings the fibers of the temporal muscle into a maximum phase of contraction. The temporal muscle on the balancing side yielded a three burst myogram just as did its fellow of the right side; however, each burst was of approximately the same duration and amplitude. Judging from the diminished amplitude it appears that at least in the beginning of chewing of the food bolus there were fewer contracting temporal muscle fibers in action in the subject whose inter-occlusal space was reduced than in the same subject before the space was reduced, or for that matter in the subject with teeth in normal occlusion.

The masseter muscles, silent before orthodontic rehabilitation, showed distinct activity after the inter-occlusal space was reduced to approximately 3 mm. The motor activity in these muscles mirrored that of the temporal muscles in amplitude, form, and duration for each masticatory stroke with perhaps one exception; and that the right masseter muscle on the working side and the left temporal and masseter muscles on the balancing side entered into the phase of contraction a fraction of a second faster than the right temporal muscle of the working side.

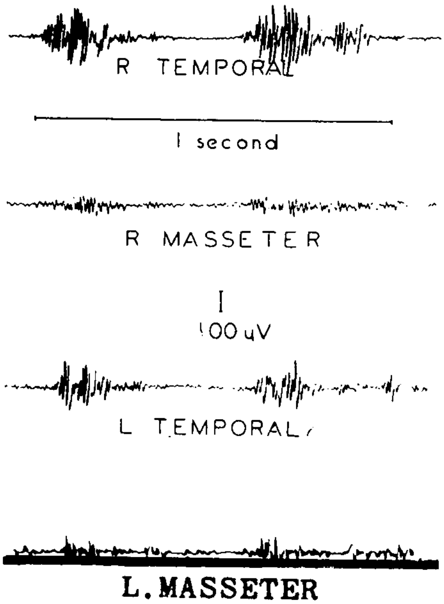
Now that some emphasis has been given to an analysis of the individual myograms obtained from the initial stages of chewing a reasonably resistant object, an evaluation will be made of myograms that were obtained from these same subjects and under the same conditions after the peanuts had been ground by chewing to a fineness obtained one-half minute prior to reaching the swallowing threshold.

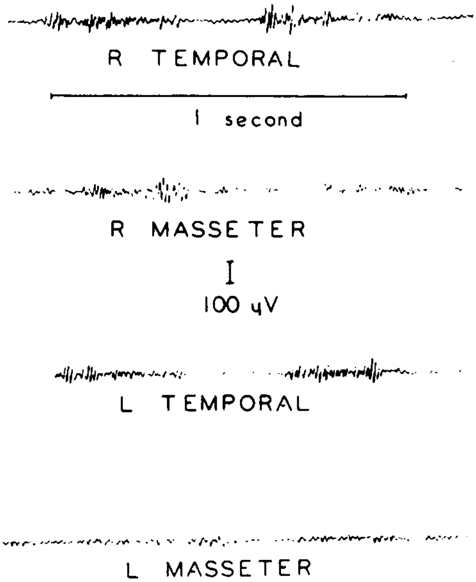
From the subject with normal occlusion, one and two burst contraction patterns (Figure 11a) were obtained from the temporal muscles on the working and on the balancing sides. These were similar to those that were seen in the trial runs. Higher amplitudes, indicating more contracting motor units in action, prevailed on the working side. There was no reduction observed in amplitude in the temporal muscle as the size of the peanuts was reduced.

Amplitude from the masseter muscles diminished (Figure 10a) with the reduction in the size of the food particles. Again this points out that the temporal muscles are principally the elevators of the mandible, and that the masseter muscles give power to the masticatory stroke. In this instance, since the size of the food particles was already reduced, power from the masseter muscles was no longer needed and therefore fewer motor units were brought into contraction, and there was a reduction in amplitude.

With the reduction of the particle size the myograms (Figure 11b) obtained from the contracting temporal and masseter muscles in the subject with an enlarged inter-occlusal space showed fewer contracting motor units in a phase of activity on both working and balancing sides. However, the period of time which these muscles were contracting was greater than when the peanut chunks were large.

At this particle size level the activity obtained from the masseter muscles was small and equivalent in amplitude to that of these same muscles when the food particles were larger, this indicates there was very little division of labor between the temporal and masseter





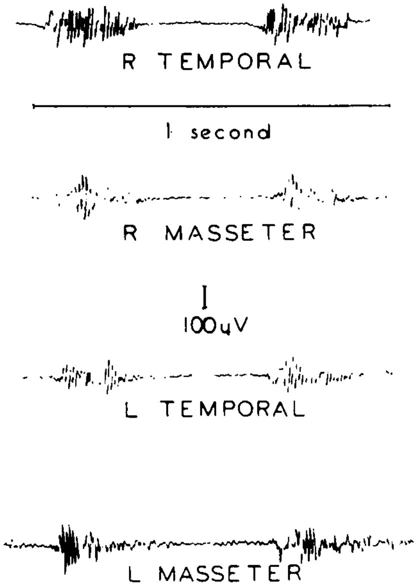


Fig. 11a. 11b. (Above) Myograms taken from the end of a chewing record of the same subject as in Figs. 10a and 10b.
Fig. 11c. (Below) This myogram is taken from the end of a chewing record of the same subject as in Fig. 10c.

muscles — a division in labor being very prevalent in normal occlusion and in this subject when the excessive inter-occlusal space was orthodontically reduced.

Myograms (Figure 11c) arising from the temporal and masseter muscles after the size of the peanuts was reduced by the subject whose excessive inter-occlusal space was reduced orthodontically were principally of the one burst variety, suggesting a chopping stroke. These were distinctly uniform in amplitude, form, duration, and synchrony.

The higher values in amplitude arising from the masseter muscles, after reduction of the large inter-occlusal space, above those obtained from the same muscles in the subject with normal occlusion may be explained on the basis of changes in the shortened distance through which the masseter muscles were contracting and on the loss in acuity of point to point discrimination stimuli (proprioceptive in character to the periodontal membranes arising in the individual teeth) that was caused by the placement of the inter-occlusal splint over the natural teeth. This then called for a greater occlusal force to obtain the same sensory stimuli and resulted in higher amplitudes.

Discussion

Electromyographically, in this study it has been pointed out that there is a distinct relationship between the occlusion of the teeth and the functional patterns taken from the temporal and masseter muscles in mastication.

Myriads of patterns can be recorded electromyographically from subjects having teeth in normal occlusion and from those having teeth in malocclusion while chewing food of different hardness, texture, size, and resistance. For the purpose of narrowing this study to manageable perimeters, an attempt was made to establish a correlation between specific myograms obtained from the temporal and masseter muscles, the functional position of the mandible, and the occlusion of the teeth in the chewing of peanuts. It was found that there were many similarities and equally as many dissimilarities in the myographic patterns obtained from both contralateral and ipsilateral temporal muscles. These patterns were not only influenced by the hardness, size, and resistance of the food particles but also by the occlusion of the teeth and the size of the inter-occlusal space.

In addition to the similar myograms obtained from the temporal muscles of the two subjects there were interspersed, at irregular intervals in the subject with the malocclusion, myograms alien in form, frequency, and amplitude to those found in normal occlusion. These had characteristics quite similar to those obtained from the contracting masseter muscles of the subject with normal occlusion. Characteristic to them was the slow onset, gradual accretion in amplitude, and peak amplitudes lasting for a longer duration than those previously described for the temporal muscles. After maximum contraction was spent there then followed an equally slow period of decay in activity to rest.

It is possible by using an analysis of the forms of myograms taken from the temporal muscles to hypothesize that the primary function of these muscles, in the subject with normal occlusion, chewing a food of a variable crushing resistance — as peanuts — is that of elevating the mandible. Variations in frequency and amplitude in comparable myograms, where the form was not changed, were due to changes in increase or decrease in the number of contracting motor units in response to differences in hardness, resistance, and texture of the food on the chewing platform between the teeth.

When the peanuts were large and unbroken, myograms were obtained from each masticatory stroke that were divisible into four sharp, short discharges. The following significance was given to each burst of muscular activity. The first burst was identified with the crushing of the peanut. The second with the elevation of the mandible to the point where the teeth came into initial contact. The third was related to the shifting of the mandible, a shifting that allowed the teeth to come into centric occlusion. Finally, the fourth and in most instances the highest amplitude burst of activity came when the teeth were in centric occlusion.

The various parts of the myogram were identified and correlated with the movements of the mandible and of the teeth. Briefly, let us consider what was taking place physically within the contractile units of the temporal and masseter muscles. Since in the first three phases of the myogram the mandible was elevating and shifting, it is logical to assume that the contractile units of the temporal and masseter muscles were physically shortening; therefore, muscles were contracting isotonically. On the other hand, the fourth burst of activity coming as it did after the teeth had reached centric occlusion and these muscles were no longer shortening physically, was isometric contraction.

When the size of the peanuts was reduced by attrition from a coarser to a finer consistency by the subject with teeth in normal occlusion, the myograms from the temporal muscles changed from a four burst to a three and then a two and finally to a single burst configuration.

The single burst myogram, coming as it did after the food was reduced to a "mushy" consistency, indicates that in the final phases of chewing prior to reaching the swallowing threshold, the chewing stroke was rhythmic and choppy. (Figures 8, 9a, 9b, 9c.)

Myograms obtained from the functioning masseter muscles of the subject with normal occlusion had a slow and gradual onset, reaching a peak amplitude gradually. When peak amplitude was reached and the stimulus activating the motor units was spent, the decay in amplitude came gradually until rest was reached. Since the peak amplitude in the masseter muscles came later than it did in the temporal muscles and because its onset was gradual we might, therefore, assume that the greatest portion of the power required for the masticatory stroke was obtained from the contraction of the masseter muscles.

It seems logical to assume from the evidence obtained in the myograms of the temporal and masseter muscles, that in the masticatory stroke of the subject with normal occlusion, there is a division of labor between these two muscles. To the temporal muscle goes the task of elevating the mandible while to the masseter is attributed the function of giving power to the masticatory stroke. The functional myograms from the temporal and masseter muscles in the subject whose teeth were in malocclusion, a malocclusion further complicated by an excessive inter-occlusal space, revealed that to the temporal muscle fell a dual task, that of elevating the mandible and also that of giving power to the masticatory stroke. This assertion is made on the strength of the fact that during the entire period when the peanuts were being chewed the masseter muscles were virtually silent electromyographically. There were myograms obtained from the contracting temporal muscles that gave the appearance in form, duration and amplitude similar to those obtained from the masseter muscles of the subject with normal occlusion.

When the excessive inter-occlusal

space was reduced and the size of the food table increased by an orthodontic splint the time of contraction of the temporal muscles was reduced; and there was an increase in amplitude from these muscles which indicates that a greater number of motor units were contracting for a shorter period of time. The masseter muscles that were virtually silent during the chewing cycle before the restoration was placed were reactivated and yielded functional myograms of approximately the same amplitude, duration and form as those obtained from the temporal muscles in this subject.

The rapid transition from the myograms that were typical of the functioning temporal and masseter muscles while the subject was chewing through an excessively large inter-occlusal space to those that followed after the inter-occlusal splint was placed serves to re-emphasize the extremely delicate balance that exists between the neuromuscular mechanism on the one hand and the occlusion of the teeth on the other.

In this study, as in those previously reported (Moyers, 1949 and Pruzansky, 1952), it was found that there is a distinct relationship between the occlusion of the teeth and the timing during which the ipsilateral and contralateral temporal and masseter muscles begin and cease contracting.

Although a very slight amount of asynchrony in the firing of the motor units in the respective temporal and masseter muscles is necessary to maintain rhythmic movements of the mandible, these asynchronies are not detectable in the crystographic record under normal circumstances. The comparatively wide variations in the time in which the respective temporal and masseter muscles entered into the contraction cycle in the subject with the large inter-occlusal space illustrate quite clearly that synchrony was practically non-existent in the contraction of these two muscles in this type of malocclusion.

The magnitude of asynchronous firing between the temporal and masseter muscles, ipsilaterally, was in the order of 1/10 of one second, with the temporal muscle contracting first. However, it is very significant to note that even though there was a distinct asynchrony on one side between the order of firing of the motor units of the temporal and masseter muscles, the same does not hold to be true when we consider the order in which the right and left temporal and the right and left masseter muscles contract in pairs. It was found that the right and left temporal muscles enter into contraction at about the same time, and also that the right and left masseter muscles enter into the contraction phase at about the same time (this begins 1/10 of one second after the two temporal muscles have started to contract).

In normal occlusion the ipsilateral temporal and masseter muscles enter into the phase of contraction at about the same time as the contralateral temporal and masseter muscles. In other words, all four muscles begin to show activity at the same time in each contraction cycle. This is synchronous contraction.

It was found that after the inter-occlusal space was reduced to 3 mm. and the food platform was increased by an orthodontic splint, the asynchronous order of firing between the motor units of the ipsilateral temporal and the motor units of the ipsilateral masseter muscles was immediately replaced by a synchronous order of contraction of these units. This illustrates succinctly how remarkably adaptable at least two of the muscles of mastication — temporal and masseter — are to change in proprioceptive stimuli originating in the teeth, periodontal membranes, alveolar bone, and indeed also in the proprioceptors of these muscles themselves.

The findings of the investigation indicate quite clearly that the role of the orthodontist in the treatment of malocclusion must transcend the static concept of occlusion. Our task is that of treating a dynamic machine composed of bones, muscles, and teeth. This triumvirate is indivisible because each is an entity dependent for it growth and for its function upon the other two.

In the past with the cephalometer and now with the electromyograph, gradually but ever so surely, blocks of knowledge are being accumulated and arranged in a distinct mosaic—a mosaic from which accurate information may be drawn to make the path clearer to a greater understanding of the problems that confront the clinical orthodontist.

Conclusions:

1. The myogram, a pen writer tracing of contracting muscles obtained from the crystograph, has three components. These are: (a) form, an arrangement in which motor units are firing in a contracting muscle; (b) time duration, the length of time during which individual motor units are firing or during which groups of motor units are contracting; and (c) amplitude, the number of motor units that are contracting at a given time or perhaps the number of times that individual units contract for a given time.

2. In normal occlusion the myograms for a given function as in crushing a food of given hardness and resistance were the same in several trials. As mastication pulverizes the bolus the myographic forms obtained from the temporal and masseter muscles change in form.

3. The masseter and temporal muscles, ipsilaterally and contralaterally, contracted synchronously in a subject with normal occlusion.

4. In a subject where the cleft palate and hare-lip were reduced and where there was an excessive inter-occlusal space the order of synchronous firing was lost in the temporal and masseter muscles both ipsilaterally and contralaterally. The motor units of the temporal muscles began to contract before those of the masseter muscles. However, it may be said that in this subject the right and left temporal muscles contracted synchronously and the right and left masseter muscles also contracted synchronously. The asynchrony was between the contraction of the temporal and masseter muscles and not between the two temporal or the two masseter muscles as muscle groups.

5. Reduction of the excessive inter-occlusal space coupled with an increase in the size of the food platform by an orthodontic splint restored not only the synchrony to the contraction of the temporal and masseter muscles on the two sides, but also brought the previously electromyographically silent masseter muscle back into action.

6. The function of the temporal muscles in normal occlusion is that of elevating the mandible and the masseter muscles give power to the masticatory stroke.

7. In the subject with the malocclusion the temporal muscles not only elevated the mandible but also gave the necessary power to the masticatory stroke.

8. Although there may be a division of labor between the temporal and masseter muscles in normal occlusion, the temporal muscle is capable of doing all of the work, in chewing under certain conditions. It may be logically assumed that one can not ascribe a true function to any given muscle for any given time. The function of the muscles is generally pre-determined by the *status quo* of the body in space.

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