Implications of Myographic Research*

HAROLD T. PERRY JR., D.D.S., M.S.D.**
Chicago, Illinois

A continual quest for knowledge is a characteristic of the human animal. Man is forever attempting to uncover the recondite secrets of nature and oft times his search is restrained only by the limitations of his investigational nature.

In recent years a newer concept of dynamics and function has entered the dental profession and is increasingly challenging the static concept for the dominant role. It might be very broadly interpreted as the entrance of physiology into our diagnosis and treatment concept. The findings and teachings of such men as Brodie, Sicher, Thompson and others on the movements and positions of the mandible have affected all fields of dentistry.

Brodie has concentrated on the stability of the facial pattern, Sicher on the mechanism of growth and functional interpretation of anatomy and Thompson has, in his emphasis on function, stressed the importance of correcting functional malocclusions early and structural malocclusions perhaps at a later, more feasible time. It is essential in the consideration of these problems to understand the normal anatomy of bone and tooth relations. However, the recognition of a functional problem necessitates an approach from a direction other than static.

The relations of teeth to bone are fixed in the anatomical specimen, the head plate or the stone model; however, our patients are not so limited as these duplications of their bony profile and tooth-to-bone counterparts. Interposed between bone and bone, across the bony joints of our bodies are the sources of forces to accomplish function—the skeletal muscles. These muscles provide power, under direct control of a central source, ready to act at any instant. Between the muscle and the central control agency, which is the brain, are thousands of direct connections to the various muscles. These direct circuits from brain to muscle are the motor nerves which initiate the muscle contraction. Muscle not only receives orders from the brain but may also return messages back to the brain. In the language of the cyberneticist this is a feed-back-system and through it the brain is informed of the speed, position and range of muscle movements via sensory nerves. These sensory endings located in muscles, tendons and joints may also signal the presence of such danger as fatigue, injury, over-extension and over-contraction. The brain is the control center and interprets these messages in the order of their importance to the body as a whole, and then relays them to appropriate motor nerves which stop, grade, or reverse the various movements.

Anatomically the nervous and muscular systems are separate but functionally they are inseparable in the normal, well-integrated bodily movements. Together they are termed the neuromuscular system and it is their normal interaction in activity which gives a smoothness and purpose to all bodily movements.

*Paper read before the Mid-Western Component Edward H. Angle Society, January 24, 1955, Chicago, Illinois.

**United States Public Health Post Doctorate Research Fellow.

From Departments of Orthodontics and Physiology, Northwestern University Dental School.

In the past few decades medicine and electronics have teamed their resources to study the separate and interrelated phenomena of muscle and nerve. First came the electrocardiograph, a machine designed to portray the muscular activity of the beating heart. It was possible with this device to study the pattern of the active heart and from its pattern of activity differentiate the beats of the pathologic heart.

The recognition that nerve and muscle each had characteristic electric discharges while active prompted the study of the brain. To this purpose the electroencephalograph was specially developed. For many years the findings were misinterpreted and poorly understood until Berger classified and demonstrated the importance of the various waves in the neurologic examination.

Utilizing the electric advancements found in these two instruments the electromyograph was designed to study the bioelectric phenomena of active muscle.

Prior to the advent of electromyography, interested men in medicine and dentistry had palpated and observed a few of the features of muscle contraction. Combining these observations with known anatomical features of the skeleton and muscle physiology, they would describe the function or so-called action of certain muscles and muscle groups. This clinical method of investigation, when coupled with mature judgment and logic yielded a beneficial harvest to our storehouse of knowledge concerning muscle physiology. Our particular field of orthodontics has had the services of some of the more astute men of dentistry contemplating this problem of muscle long before the dental debut of electromyography. Among these men the names of Brodie, Rogers and Thompson stand out as eminent thinkers with vision and foresight directed to one of dentistry's and particularly orthodontic's most perplexing problems.

Dental electromyography, the long awaited method of choice for studying the neuromuscular system, was originated by Robert Moyers with his pioneering work at the University of Iowa on the muscles of the temporomandibular joint.

As has occurred in many other instances in science, others were engaging in studies similar to Moyers' at the time of his original publication. Carlsoo in Sweden; Rix, Tulley, and Gwynne-Evans in England; Eschler in Germany; and Pruzanski at the University of Illinois in Chicago. Many of their findings corroborated the pronouncements and theories of each other as well as the interpretations of muscle action as determined by the clinical studies which preceded the electromyograph. Of course, there have been differences of opinion, some of them quite basic, but such is a healthy situation for a new research method because it stimulates further investigation.

Prior to consideration of the various findings by this new research method one should have some understanding of the mechanism of the instrument as well as its practical and theoretical limitations.

Muscles are composed of a large number of functional units. The basic functional components of the muscle are individually formed by muscle fibers and motor nerves. They are the motor units and each is composed of an anterior horn cell, or motor nucleus cell, its axon and all of the muscle fibers supplied by that one motor nerve process. Muscles have motor units of different sizes. In recognition of size, we refer to the number of muscle fibers supplied by one anterior horn cell. The number of muscle fibers in a single motor unit is a good delineator of the muscle's power and speed potential. Muscles with a low nerve to muscle fiber ratio are said to consist of small motor units, an example of which is the extrinsic musculature of the eye, which is capable of very precise, rapid movements. The motor nerve to muscle fiber ratio in these muscles may be as low as 1:6. Motor units with a nerve to muscle fiber ratio as high as 1:350 are found in the coarse, long contracting, heavy work muscles.

Voluntary muscle in normal individuals is activated by neural stimuli. The original stimulus may have originated in and passed through the sensory system to the cerebral cortex, thence through interconnecting neural pathways to the motor cortex, then to the proper pyramidal tract or basal ganglia out to the muscles through the respective anterior horn cell. Upon receipt of the minute electrical stimuli the resting mass of protein, ions and water assumes the functional posture we usually associate with muscle.

Muscle cells undergo several different changes in awakening from the resting to active state. Tension is immediately apparent as there is an attempt by the muscle to shorten. There is an apparent shift of volume resulting in a distinct physical bulge. The chemical reactions accompanying contraction produce heat and waste products. To the electromyographer the most interesting change occurring with the contractive wave is the electrical discharge from the active motor units. These bioelectric features of action are termed "action-potentials" and are so small that they are measured in microvoltage quantities.

Since the electrical changes within the muscle are so minute, some accurate means of amplification is necessary if suitable records are to be registered. The electron valve or electron tube developed for radio following the First World War provided a key to the solution of the problem. Therefore, it is possible today, with a series of electron tubes, to magnify these very small action potentials to a scale that will permit visual study without the introduction of appreciable distortion or error.

The gradual development of this new research method has introduced a host of new terms and confusing words. It is hoped that most of this new vocabulary will become well integrated in the dental literature within a few years. In an attempt to avoid confusion later, it is essential at this point to mention and define just a few of these words.

The electromyograph is a machine which receives, amplifies and records the various electrical changes occurring in muscle.

The present day instrument is a rather complex maze of electron tubes and wire circuits. The intricate details of its anatomy need not concern us at this time. It will be sufficient to mention only the main features of the machine.

The electron tubes and preamplification system enlarge the inappreciable muscle voltages to a measurable and recognizable quantity. Amplitude changes may be controlled by manual adjustments in the circuit. Records of muscle activity may be recorded by one or more means simply by circuit changes.

There are at the present time two general methods of detecting the electric activity from the muscle and carrying it to the electromyograph. They are the surface electrode and the needle electrode.

The surface electrode resembles a small pie tin with a diameter of 5-8 mm. It is attached to the skin overlying the muscle and records the activity from a general area under and approximating the electrode.

The needle electrode is usually a very fine gauge hyperdermic needle with a small copper wire in the needle lumen.

The needle is inserted directly into the muscle.

Each of these methods have their own advantages and shortcomings. In general, the surface electrodes are limited in their scope of study to muscles which lie close to the body surface. Surface electrodes record the activity of an area and not an isolated section.

Needle electrodes are utilized in neurologic examinations when searching for pathologies of muscle and nerve. They are much more limited in their area of "pick-up" since only the motor units near the needle tip are recorded, however, they are capable of reaching deeper muscle structures than the surface electrodes. Needle electrodes are traumatic when inserted into the muscle and do create additional problems of interpretation because of the injury currents created.

In attempting to compare the electrical activity of one muscle to another, or of one muscle group to another group, some standard means of comparison must be established.

The method of choice for doing this is to establish a portion of the body as a reference area. If the accuracy of the method is critical, a reference area must be selected which is nearly electrically inactive. This procedure will then give the near total electrical activity of the contracting muscle.

In the particular studies of the head musculature to be cited below, the lobe of the ear was selected as a reference because it may be considered electrically inactive for all practical purposes. Since most of these studies were conducted bilaterally, reference electrodes were attached to each ear lobe.

The lead from the muscle is termed the active electrode while the ear electrode is the ground wire.

While the electrodes are attached to the patient, the patient is "hooked up." A useful record may be obtained if the reception conditions are favorable. If recording conditions are imperfect, distortions will enter the system and mask the true electric character of contraction. This will necessitate a search for the improper connection or faulty grounding.

The records are known as electromyograms or traces. These records are recorded by pen writers, oscillioscopes and sound-unit.

In the study of the electromyographic records, many terms have been borrowed from physical electronics. The excursions of the pens on the electromyogram are in the form of spikes. These spikes have a single, double, or multiple peak feature.

Frequency and amplitude of the spikes are other features which interest the electromyographer. Many medical studies have been conducted on frequency changes which accompany pathologies, but the amplitude is the most productive feature for our type of study. The present day electromyographic equipment and technics are not reliable enough to permit detailed analysis of discreet or subtle changes in the wave form, frequency, or amplitude. Therefore, any measurement made of these features must be gross in nature and concern itself with variations in the type and manner of response. Frequency and amplitude components of the pen-written records are separable and measurable but must be approached from a more qualitative direction rather than quantitative.

In the study of mandibular kinematics, one muscle may act before another in certain movements. The difference in time lag between the action of the first and that of the second is referred to as the latency period for that particular motion. The length of contraction is the duration.

Interpretation of study of the action

potentials requires the records to be suitable for storage and later handling. There are three methods of doing this. An ink-writing mechanism, similar to an ink-writing barometer, utilizes pens and rolled paper to write quantitative and qualitative changes occurring in the muscle with contraction. On the machine we have at Northwestern there are four channels. This indicates the number of muscle areas which may be recorded simultaneously, it is also an indicator of the number of pens present on the penwriting unit.

A second method of recording the electrical activity is with an oscillioscope and camera. Since the action potentials are electrical, they have a definite electron stream character. This stream is illuminated on a small oscillioscope tube, similar to the television tube, and the desired portion of the record is photographed.

The third recording means is with a magnetic tape or wire recorder. The electric potentials from the muscle are amplified and then played through a regular radio speaking unit. The electrical activity is transmitted as sound waves and recorded on the tape. This method of recording muscle activity is rather dramatic and certainly offers a provocative new means of functional analysis in various mandibular movements.

The present series of electromyograph researches were begun at Northwestern University Dental School in 1952. Geltzer[1] in the following year studied the reliability of day-to-day recordings from the same muscle. He found that the variations were sufficiently small to impart reliability to the method. He also noted that the temporal muscle "appeared to attain its maximum potential of contraction before the limit of total masticatory force was achieved by the patient." He reasoned that the temporal initiated the closing movement but that the masseter muscle provided power. This is consistent with the predictions of Sicher and certain muscle physiologists who feel that the temporal and other similar muscles are possessed of long fibers of a bipennate nature to provide rapid movements. The masseter, in contrast to this, is composed of many short pennate fibers attached to vertical facial threads giving a greater cross-sectional area of muscle fibers for power.

Following Geltzer's establishment of the statistical reliability of the method, Zwemer and Perry studied the temporal and masseter muscles.

Zwemer's[2] study was conducted to determine the variations in temporal and masseter discharge in overclosure found in cleft-palate patients. He concluded that the masseter muscle showed a greater participation in mandibular closure to occlusal contact where large interocclusal clearance existed. With the restoration of normal occlusal clearance, the amplitude of the masseter muscle returned to a discharge more nearly equal to that of the temporal.

Perry[3] compared the activity of the masseter and temporal muscles during chewing in a group of clinically normal occlusions and patients of the Class II, Division I group.

Again the findings pointed to the dominant role of the temporal muscles in the initiation of mandibular movements. The temporal muscle of the working side occlusion was first to show action potential discharges in all of the normal occlusion group. The more severe Class II, Division I cases, however, displayed masseter activity on the working side before the opposite masseter or either temporal. It is rather difficult to understand this unless it is an attempt to protrude the mandible slightly to a more suitable occluding position.

In these studies utilizing the classification of Angle it is interesting to note the neuro-physiological differences in the functioning dentures. Angle's original classification was one of general anatomic relations but it appears that there is also a definite functional pattern illustrated in the neuromuscular system for each class of malocclusion.

In the normal occlusion group very little if any activity was apparent in the masseter and temporal muscles when rolling gum from one buccal segment to another. This may indicate the dominance of the tongue in this movement in normal occlusion. In contrast to this the Class II, Division I subjects all displayed a great deal of irregular masseter and temporal activity in the same movement.

The clinically acceptable occlusion group manifested a marked synchrony and harmony in the achievement of peak amplitudes. It has been assumed that peak amplitudes would occur in each muscle unit as the teeth reached the centric position. With normal inclined plane relations, these peak amplitude discharges were harmonious on both the working and balancing sides. The malocclusion group did not display any of this cadence of peak amplitudes but rather exhibited a multiplicity of peak discharges, perhaps a "searching" pattern in the contracting units, as well as a greater proportional expenditure of energy. This possibly indicates the effect on the neuromuscular system of tooth interferences and structural disharmonies.

Mention has been made of the electrical changes which occur in the active muscle and the apparent use of these action potentials on the study of muscle has been demonstrated. It is probable and even possible that the absence of these discharges may also aid dentistry in the solution of certain clinical problems.

A muscle at rest is electrically silent to surface electrodes. The maintenance of muscle tone is carried out by the contraction of only a few motor units in isolated sections of the muscle. Tone, or tonus, is recognized as the tension present in muscles when they are relaxed, or as their resistance to passive movements in the absence of volitional control. Tonus is a fixed state of tension by which muscles are held in a given position in a constant alert to either contract or relax when proper signals are dispatched to them by means of an increase or a decrease of neural impulses. This steady state of contraction is required of the voluntary musculature to hold all parts of the skeleton in proper relations in the many and varied attitudes of bodily posture. This exhibits itself as a slight tension in the musculature, offering constantly maintained resistance to stretching, preventing undue mobility in the joints and assuring the maintenance of posture. Tonus is greatest in the bodily muscles which maintain us in an erect posture; these are the antigravity muscles, practically speaking, the flexors in the upper and extensors in the lower extremities.

This state of continuous tension or limited contractions of muscle is dependent upon the integrity of the muscle tissue, the myoneural junction, the peripheral nerves, the anterior horn cells and the reflex connections. When a muscle fiber contracts, it contracts maximally or not at all. Even in apparently relaxed muscle there is a constant slight degree of tension, due to contraction of some of its fibers, and normal muscle shows a slight resistance to passive movements in spite of voluntary relaxation. The constant firing of a rhythmic volley of motor impulses from the anterior horn cells is in part responsible for comparatively steady contraction of various fibers which comprise the individual muscles. Thus, the electrical activity associated with rest is a well spaced firing of individual motor units.

In mention of this phenomenon, it is interesting to note that certain authors have been able to record single motor unit activity by utilizing needle electrodes. This method is successful when the surface electrode is not because of electrode proximity to the area of electrical discharge. The needle electrode is inserted directly into the bulk and within the fiber distribution of the motor units, but in the case of the surface electrodes the recording is through the integument, fascia and inactive muscle bulk.

These same authors have been able to roughly estimate the size of individual motor units by very slight movements of the needle. In the larger muscles the investigator may wait several minutes for a discharge because of the large number of individual motor units and the character of the tonus discharge.

We had noted in previous studies that a quantitative summation of action potentials is necessary for successful surface electrode recordings. This particular feature of electromyography coupled with a knowledge that very slight mandibular movements required the synergetic activity and simultaneous discharge of many motor units suggested an interesting study.

Several subjects were selected at random from the patients and students at Northwestern University Dental School. Surface electrodes were at-attached bilaterally to the temporal and masseter muscles. The electrodes on the temporal muscles were attached over the middle group of fibers and those on the masseters were near the gonial angle of the mandible. The subjects were not informed of the purpose of the test; they were merely told that head radiographs would be taken at certain intervals.

The individual under study was next placed in the chair of a Broadbent-Bolton cephalometer with the ear-rods, nose-post and cassette all in place. The subject was observed and when it was apparent that he was relaxed the sound unit of the electromyograph was turned on.

The absence of motor-unit activity from the broadcaster was the signal to take the lateral headplate.

The subject was then released from the chair and requested to stand. After a few minutes, the same individual was reseated and the identical procedure repeated.

This technique was also repeated on subsequent days with certain of the subjects from the group.

The findings were of interest for they have pointed to certain features which may affect the clinical determination of the rest position.

It was found that to record actual silence or minimal activity from the temporal and masseter muscles required a great deal of care and caution on the part of the investigators. In certain patients it was found helpful to place a stool under their feet when the feet were not flat on the floor.

One female, with dentures, was apparently very apprehensive about the electrodes and the electronic setup. During the attachment of the electrodes, her questions were numerous and when the sound unit was on, the foreground noise of the motor unit activity was continual. It required several minutes of watchful waiting for her anxiety to disappear. The second radiograph of her rest position required only a few seconds and it was apparent that she no longer was worried about her surroundings.

We have also noted that if the patient's head is in the near Frankfort horizontal position and the eyes are closed, the audio-rest is much easier to obtain.

Tracing the radiographs on each individual and superimposing the tracings we found that the mandibular outlines were identical in each subject, when the rest position was obtained with the silent-audio method.

A disheartening feature of any investigation is the exception to the proposed hypothesis. This particular facet of our electromyographic work presented two.

In two of the subjects complete silence was unobtainable; these patients just would not or could not cease certain of the motor unit discharges. The tracings of their rest positions were not identical but rather displayed a millimeter or more of discrepancy. By a process of gradual elimination we found that the temporal muscles were the active members of the group. One of the patients displayed activity from both temporals while the second patient had only a unilateral temporal discharge.

These two errant subjects offered a challenge to the method. The discharge from these muscles was not very great amplitude-wise but the activity was not characteristic of other resting muscles.

This problem prompted a review of all myographic records obtained in the past three years. In these records two other cases with similar temporal muscle activity were found, and one with a unilateral masseter discharge while the mandible was supposedly in a resting position.

One of the nonconformists was a dental hygienist and further studies of her temporal muscles were undertaken. When electrodes were placed upon the posterior fibers and the middle fibers of each temporal, it was found that the posterior fibers of the right temporal demonstrated the motor unit discharge at rest.

Examination of the young lady's occlusion showed that she had previously lost the maxillary third molars. This resulted in an over-eruption of the mandibular third molars. There also was present a clicking in one temporamandibular joint but further evidence of other joint dysfunction was not noted.

Armed with this knowledge, the second exception to the rest position findings was re-examined. Her mandibular incisors showed marked attrition of the labial incisal edges and the lingual surfaces of the maxillary incisors showed a similar pattern of wear. The path of closure to occlusion was upwards and backwards. This subject had no other symptoms usually associated with temporomandibular joint disturbances. These findings at once suggested something concrete upon which to base the exceptions to our initial study.

In each of these cases mechanical interferences of the occlusion set up a protective reflex arc from the teeth and temporomandibular joints to the voluntary musculature.

The beginning of the sensory component of this reflex arc is found in the periodontal membrane and the temporomandibular joints. The sensory stimuli are carried through the mandibular division of the fifth nerve to the mesencephalic nucleus of the brain stem and then to the motor nucleus of V and out through the motor division of the mandibular nerve to the posterior fibers of the temporal muscles. In short, the trauma and pain associated with continual occlusion of the mandibular incisors against the maxillary incisors in functional movements initiated a retractive contraction of the temporal muscle. This was an involuntary (noncortical or thalamic level) protective mechanism on the part of the neuromuscular system in an attempted adjustment to an injurious condition.

The subject with the supra-erupted mandibular third molars had the identical reflex pattern established;

however, the exact etiology was defferent. In her case functional movements created a rocking of the mandibular third molar upon the maxillary second molar. Since her chewing pattern was predominantly right-sided, the greatest activity was found in the posterior fibers of the right temporal muscle.

In each of these individuals corrective measures were instituted. The one subject required occlusal equilibration of the offending molars while in the second a bite splint was placed.

Following a three week trial period for each subject electromyographic records were again taken. At this time there was no evidence of posterior temporal fiber activity and a reproducable rest position was obtained cephalometrically. The clicking of the temporomandibular joint of the one girl had subsided but had not completely disappeared.

These two cases when first discovered in the rest position study were rather unwelcome; the results of further investigation pointed the way to a better understanding of the clinical determination of the rest position.

The possibility of such cases in an orthodontic practice are numerous. In the absence of temporomandibular joint symptoms, these patients could give two or three positions, any one of which the clinician may select as the "rest position." If, after treatment and the removal of the reflex initiating mechanism, the orthodontist takes another rest position radiograph he will, with care, probably get the true position. Now should he trace the first radiograph of what he thought was rest position and compare it with the second which is the true rest position, he may note a distinct change. Immediately the cry arises, "the mandibular rest position is unstable."

The mandibular rest position is not unstable for there is a definite physiological basis for it both from a neurologic and muscular viewpoint. The exceptions that exist are pathologic in origin and as these studies have suggested, involuntary reflexes may initiate retraction of the mandible, by muscle spasms, which in themselves are considered pathognomonic.

Our studies on rest position are not yet completed.[5] We need many more cases and, we hope, a few more exceptions. A complete statistical evaluation will be required to ascertain the reliability of the method and its findings. The results thus far are encouraging and we hope we have a method that will prove beneficial to all of dentistry.

Another one of the problems being studied electromyographically is that of temporomandibular joint dysfunction. This particular investigation has pointed to many interesting avenues of research. Here again patients suffering from abnormal occlusal relations have complained of unusual pain patterns. Most of these pains have a physiological basis of explanation and very few are of psychogenic origin.

We have been able to demonstrate that the muscle pain these patients complain of and so easily describe is the result of muscle spasm. These spasms may occur in the masseters, the temporals (any of its three principal fiber groups), the internal pterygoid and the external pterygoid. Spasms in the latter muscles may account for the deep pain so frequently located by the patient at the "side of the throat." With the establishment of a more physiologic occlusion or jaw relation, the irregular electromyographic pattern of the spasm diminishes and in some cases disappears.

Many of these and other findings are an interesting story in themselves and will be presented more thoroughly at a later meeting of this group.[6]

Other studies have been completed or are in progress, including a serial study of poliomyelitis cases with involvement of the muscles of mastication. In these patients the dominant and guiding role of muscle function upon bone can readily be seen in the cephalometric radiographs that have been taken in conjunction with the myographic tracings. The weakness or absence of activity in particular muscles or muscle groups all have their characteristic areas of bone deformity.

The importance of proper inclined plane relations of the teeth in the maintenance of muscular harmony and efficiency was shown earlier. This feature has been further studied electromyographically by recordings immediately before and immediately following occlusal equilibration. The appearance of muscle synchrony and harmony of wave forms in chewing becomes rapidly and strikingly apparent.

Severe periodontal cases have been recorded wherein continual discharge from the masseter occurs. This possibly has resulted in an over application of occlusal stress upon the periodontal tissues and a resultant breakdown of normal tissue. This particular finding has also been reported by Eschler in Germany utilizing needle electrodes in sleeping subjects.

Our electromyographic records contain interesting cases of habit patterns before and after correction, muscle patterns before and after condylectomies, mandibular resections and hemisections. More of these various problems must be studied before any definite announcements can be made. Of course, interesting phenomena from the neuromucsular apect have been oberved in each group but a few cases do not constitute a study and caution in making prediction is necessary.

The recording of action potentials from a muscle does not mean that the active muscle is the prime mover for that particular movement. All that is certain, at the present time, is that the particular muscle is contracting and aids in the action. The recording itself does not indicate the direction, range, force, or speed of the movement. The myographer who ignores these basic tenets will make speculative and fallacious observations. These errors in interpretation will lead to conflicting reports and loss of faith in a potentially beneficial method of physiological research.

We have in the electromyograph a new means of tapping a vast source of information. At the present time its sole dental purpose is in basic research problems. The many limitations of the present day technics and machine require refinement and more positive reliability studies before the true value of the electromyograph will be realized in dentistry.

311 East Chicago Avenue

1. Geltzer, B. A Study to Develop a Standardized Method by which Electromyographic Data may be Recorded for Serial Evaluation. M.S D. Thesis, Chicago: N.U.D.S., (March) 1953.
2. Zwemer, T. An Electromyographic Study of the Temporal and Masseter Muscles in Cleft-Palate Patients, M S.D. Thesis, Chicago: N.U.D S., (March) 1954.
3. Perry, H. An Electromyographic Study of the Temporal and Masseter Muscles of Individuals with Excellent Occlusion and Angle Class II, Division 1, Malocclusion, M.S D. Thesis, Chicago: N.U.D.S., (June) 1954.
4. Hoefer, P. Electromyographic Study of the Motor System of Man, Mon. Rev. of Psych. and Neurol., 117:241-256, 1949.
5. Ryan, F. and Perry, H. A Coordinated Study of the Mandibular Rest Position Utilizing Cephalometric and Electromyographic Methods. Unpublished data.
6. Perry, H. Electromyographic Studies of Temporomandibular Joint Dysfunction Cases. Unpublished data.