# Oral Muscle Pressures

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INTRODUCTION

This paper is a step toward a comprehensive study of the muscles of the cheeks, lips and tongue with respect to their anatomical variability, functional patterns, and influences on the position of the teeth. A number of objectives have been defined for the present study. From an observation that the different muscles of the lips and cheeks could be easily palpated with the finger and that they appeared to differ in tension, width and course in various individuals, the development of a technique for recording their organization and relation to the dentition in the individual patient seemed a logical first objective.

From the belief that the musculature exerts its influence on the teeth through surface pressure follows the assumption that the quantitative measure of these pressures offers a direct approach to the examination of such influence. However, since dynamic pressures are a concomitant product of muscle function, a comprehensive evaluation of these pressures depends on an intimate knowledge of the functional patterns in the individual case. It became necessary, therefore, to develop miniature measuring devices that could be positioned anywhere in the mouth and used in sufficiently large groups to present a correlated picture of muscle behavior.

In addition to the functional dynamic pressures, static ones of substantially smaller magnitude are exerted by the musculature at rest. A further objective became, therefore, the development of a device possessing high enough sensitivity to discriminate between these minute pressures.

The final objective of this preliminary study was an exploratory application of the techniques and instrumentation with the intent of investigating the scope of information made available. Such application was expected further to define the limitations and artifacts inherent in the system. Upon translation of the pressure recordings so gathered into meaningful information it was hoped that fruitful avenues for future research on oral musculature would be discovered.

The stated objectives were reached in the following manner. First, by means of an alginate material injected into the vestibule, an impression of the muscles of the cheeks and lips was obtained and the relations of the muscle bands to the dentition and supporting structures were recorded. Wide variations were found in the course and relative strength of the perioral muscles and in their relation to the denture and supporting structures. This variability suggested a possible correlation with certain irregularities of the teeth.

Next, miniature electronic pressure measuring devices were designed and constructed utilizing the resistive wire strain gage elements mounted on an elastic cantilever beam. One group measured 0.140x0.250x0.065 inch thick. It had a recording sensitivity of 3.5 millimeter pen deflection per gram load.

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The other group measured 0.250x0.360 x0.070 inch thick and had a recording sensitivity of 4.5 millimeter pen deflection per gram load. The maximum safe loads were 80 grams and 150 grams respectively, being well above all functional pressures. The smallest discernible pressure was about 0.1 gram. The transducers were mounted and carried into place on a thin vinyl plastic sheet adapted to the desired hard surface of the mouth. A six channel amplifier recorder was used to obtain simultaneous pressure readings from strain transducers strategically mounted.

Finally, a survey study of the activity of the musculature in swallowing and speech indicated the feasibility of measuring the position, rate, sequence and intensity of function of the component segments of the muscle complex. In the case studied, a constant pattern was evident in swallowing water, a sample food (pudding), and saliva; however, the magnitude and rate of change of the pressures increased with an increase in the viscosity of the food taken. While the tongue was active in the introduction and swallowing of the foods, the perioral muscles in this clinically normal case showed no activity during deglutition.

With respect to speech, in addition to the differences in the contact areas of the tongue, the instrument revealed a quantitative difference in the pressure pattern in production of various sounds. Muscle activity was related to sound production by inclusion of a sound track in the oscillograph recording.

Static pressures exerted by the tissues were examined. The pressures due to maintenance of negative intraoral pressure showed considerable variation throughout the surfaces of the mouth. This inequality in pressures suggested that changes in the extent or intensity of the practice may well change the cumulative balance of pressures exerted on the denture.

An analysis of the pressures exerted by the postural drape of the tissues at rest indicated the presence of artifacts due to displacement of the tissues by the transducers. However, the fact that the resistance of the tissues to equal displacement was not uniform throughout the mouth suggests a different reaction of the tissues to a given orthodontic movement depending on the location of the tooth in relation to the musculature.

The study thus indicated paths for future research and gave some promise of application to diagnosis and treatment in dentistry and related fields.

## General Considerations

The muscles of the cheeks, lips and tongue have been widely accepted as a major force controlling the position of the teeth.[1,2,3] It is believed that the buccinator complex on the outside, pitted against the tongue on the inside, determines to a great extent not only the width and shape of the denture, but also, in turn, the dental arch length.

Clinical observations are overwhelmingly in favor of the assumption that the existing denture represents the point of balance between the opposing muscle forces, and that irregularity of the teeth results, in part, from disharmonious combinations of the opposing muscle forces in relation to the bony bases over which they operate.

It is not quite so generally recognized, however, that this point of balance between the opposing muscles changes with growth. The muscles not only grow at a different rate and over a different period than does the facial skeleton,[4] but the different components of this muscle complex also develop at varying rates. Thus the balance of muscle forces at which the denture is held is a variable function of time, especially during the period of rapid growth.

Acceptance of the above premises is of utmost clinical importance both in diagnosis and in treatment. If the denture is controlled by the opposing muscle forces, then, according to some clinicians, any attempt to alter the shape of the dental arches by artificial means is bound to fail. The muscles will return the teeth to the original point of balance. Yet, since the point of balance is a function of growth, an alteration of the denture form at the onset of treatment may well place the teeth in a position of balance at the end of treatment, eighteen months later. In addition, there exists a range of muscle adaptability. Reasonable changes of the dental configuration may well be within the adaptable range of the affected muscles.

The fact that failures are observed as a result of misjudgment in the anticipated reaction of the musculature to orthodontic treatment is enough to point to the need for more reliable information on the subject.

To date, a number of investigators have developed and tested devices for measuring muscle pressure with considerable success. Two basically different approaches have been used. In the first the pressure was mechanically transmitted via a closed air channel to a manometer system outside the mouth where the pressures were measured. In the other approach, intraoral pressures were first converted into electrical signals which were then conducted out of the mouth where they were amplified and recorded.

White and Sackler[5] in 1945, and Feldstein[6] in 1950 used the manometer system. Readings were made visually and maximum pressures were recorded. Prakash[7] reported a great improvement of this method in 1954. He connected the air chamber to a photoelectric system and recorded the pressures continually by means of an electromagnetic pen.

Kydd[8] experimented with the electronic method in 1952. He used a resistive strain gage to convert the elastic deformation of a metallic beam into an electrical signal which he amplified and recorded by means of a pen recorder. Alderisio[9] in 1953 and Winders[10] in 1955 improved the system substantially. In 1955 Stromberg[11] further applied the same principle to measuring the pressures exerted by artificial dentures on the tissues.

Stimulated by these reports the author set out to investigate more carefully the perioral musculature, the objectives being to throw some light on such subjects as the resting length of these muscles, their so-called "hypertonicity" and "hypotonicity", and the violation of states of equilibrium of muscle pressures by orthodontic manipulation.

However, it became apparent at the outset that the data available were misleading and the instrumentation inadequate. Attention was therefore diverted to the development of suitable instrumentation. The development of equipment of high enough sensitivity and of reasonably adequate flexibility consumed most of the available time. The findings presented in this paper are of necessity only an exploration of the type of information made available by the new methods and refined instruments.

In approaching the study of oral musculature the need was felt for a clearer comprehension of the organization of the perioral muscles and their relation to the dentition. In previous studies of the perioral muscles no distinction was made between surface pressure of certain muscles and the relation of these muscles to the dentition. Rather than likening the cheeks and lips to a uniform elastic sheet encircling the denture,[12] the structures are more accurately represented by a complex of elastic bands running in different directions and separated from the denture by a layer of sponge rubber. The picture presents lines and points of pressure concentration which depend on the disposition of the component elastic parts. It is obvious that the pressure exerted by this system against any point of the denture depends on the relation of the denture to the musculature. For example, it seems advisable to differentiate between the pressure developed by the caninus from the pressure measured against the buccal surface of the maxillary canine tooth. An equally active caninus muscle may overlay the cuspid in one mouth and the bicuspid in another.

For these reasons it was considered necessary to develop a method for mapping the course of the perioral muscles and additional means for relating their configuration to the dentition under study. This done, attention was directed to the measurement of muscle pressures.

A number of omissions as well as significant inaccuracies were observed upon careful evaluation of the previous studies. One is the disregard of duration of a muscle pressure when examining its magnitude. We are investigating a biological system, not a mechanical one. In biological systems a stimulus is significant only in relation to the response of the tissues involved. Without consulting the time factor of the forces we have no right to assume that the stimulus value of a heavy force applied to a tooth is greater than that of a weaker force. The weaker force may persist over a relatively long period, while the heavy force may act only momentarily. Witness for example the stability of the maxillary cuspid in face of the great lateral forces exerted on it during mastication compared to its submissive response to the continuous mild force of an orthodontic archwire. The periodontal membrane, it seems, is so constructed as to cushion against abrupt pressures, and the supporting alveolar bone is organized to resist such heavy forces, yet is seen to undergo changes in response to continuous mild stimuli. It might well be advisable to classify the forces developed in the mouth with respect to their rate of change, thereby reaching a clearer understanding of their significance.

The discrimination between magnitude and duration of pressures focuses our attention on the mild but constant pressures of the tissues against the denture. Here the available instruments were found grossly inadequate for measuring these mild forces. The resting pressures reported by Winders, for example, were from 4 to 8 gm representing a range of 4 gm. The calibration presented by Winders shows a pen deflection of only 0.08 mm per 1 gm load. With that sensitivity the entire range of recordings of resting pressures extends over a distance of only 0.32 mm, while the median pressure shows a pen deflection of only 0.48 mm. Prakash showed an even poorer sensitivity of only 0.6 mm pen deflection per 10 gm load. A deflection of less than 0.3 mm can hardly be considered a readable signal yet here it includes the entire range of pressures. It is obvious that the differences in resting pressures along the tongue, cheeks and lips could not be examined with any reasonable accuracy. It became necessary, therefore, to develop a new transducer having considerably greater sensitivity. The necessary sensitivity (mm deflection per gm load) can be easily computed. If we accept a tolerance of ±5% in measuring 4 gm load, we must be able to measure accurately at least 0.2 gm (5% of 4 gm). Since we can see a deflection no smaller than 0.3 mm, then 0.2 gm must produce 0.3 mm deflection. The sensitivity which would produce that deflection is equivalent to 1.5 mm per gm load or about twenty times the above reported sensitivities. Another deficiency was the inflexibility in positioning the gages in the mouth for they were attached only to teeth. If abnormal function results in abnormal dentures, then a clear picture of muscle function in the individual patient is necessary. An abnormal functional behavior of the tongue in deglutition, for example, implies an abnormal functional position of its parts, as well as an abnormal distribution of its pressures against the surrounding structures. For this reason a comprehensive study of the tongue in deglutition should consist of a simultaneous pressure measurement throughout the contact surfaces including the palate and mandible, as well as the denture. In order to meet the added requirements it became necessary to design a measuring device that may be placed at any position in the mouth, over bony surfaces as well as over the teeth, and to develop procedures for simultaneous recordings with respect to anatomical parts of the muscle complex and with respect to the distribution of the pressures on the adjacent structures.

At the end of the preliminary investigation it was obvious that the available methods and equipment were inadequate for a comprehensive study of the pressures of the oral musculature. Attention was therefore directed to supplying the following:

(1) a method for tracing the course of the perioral muscles, (2) a means for relating the muscle complex to the dentition, (3) a transducer for measuring functional as well as postural pressures with a sensitivity higher than 1.2 mm per gram, (4) procedures for placing the transducers in any position within the mouth, and (5) equipment and methods for simultaneous pressure recordings.

## Instrumentation

### A. *Impression Technique.*

The alginate impression is designed to outline the course of the muscles of the cheeks and lips. It reveals, from an intraoral aspect, their attachments, courses, shapes, and relative forces. It also correlates their configuration to the jaws and teeth. Since the muscles are overlaid with varying thicknesses and textures of integument, the impression presents a picture of the resultant surface pressure gradients.

An impression material was needed which could be injected into the vestibule and produce the desired recordings. It should meet the following requirements: high degree of fluidity, to respond easily to the weak muscle forces; sharp, rapid set, to avoid fatigue of the patient; ease of handling in preparation, conveyance, and removal; and reasonable stability upon removal from the mouth. After careful experimentation with many different types and brands of impression materials (including hydrocolloids, thermoplastics, rubber base polymers and silicon polymers), Coe-Flex, a hydrocolloid supplied by Coe Laboratories, was selected. It exhibits sufficient flow, rapid enough set. It is easily handled and lends itself to a number of simple methods followed in making permanent recordings.

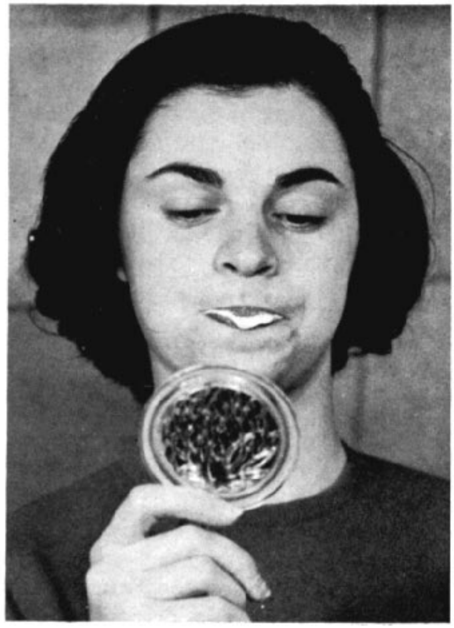
The impression material was carried to the patient and distributed in the vestibule with a syringe. The syringe, constructed of plexiglass, proved to be quite convenient and rather easy to clean. It consists of three parts: a barrel, a nozzle, and a plunger. The barrel was constructed from a 1.5 inch tubing, measuring 4 inches long, and having one end flared open to facilitate loading. The nozzle was made from .5 inch tubing and measured 2.5 inches long.

One end was stretched into a funnel shape and glued to an attachment made from a cylinder 1.5 inch inside diameter. The attachment friction fits over the barrel. The plunger consists of a proper size felt disc bolted to a metallic rod.

In order to obtain sufficient muscle impingement and avoid unnecessary distortion, the patient is trained in a standardized manner. He is first made aware of the presence of muscle bands in the cheeks and lips through palpation with the finger and tongue. To assure sufficient contraction of all muscles, he then exercises them by tensing them against finger resistance. With the aid of a mirror he is instructed in avoiding displacement of the lip line and in maintaining his habitual position of the angles of the mouth.

The impression material is mixed (using two units and following the manufacturer's instructions) and loaded into the barrel. It is injected evenly all around the buccal vestibule beginning with the distal portion of the inferior mucobuccal fold of one side and proceeding to the superior margin. The other side is then injected with the same quantity (two-fifths of the total). The remainder is placed first under the lower lip and then under the upper lip. Care is taken not to trap any air during the injection. With the aid of a mirror the patient tenses the muscles, Fig. 1,a. He is instructed to "wiggle" his muscles slightly while tensing, as he would do in working his fingers into clear sand. This movement facilitates the displacement of the impression material from the areas of tension and overcomes the viscosity of the alginate. The resultant impression appears as in Fig. 1,b. The patient releases it from the mouth by gently blowing into the impression and slowly opening the mouth.

The impressions, when kept in the open air, lose water and shrink. The



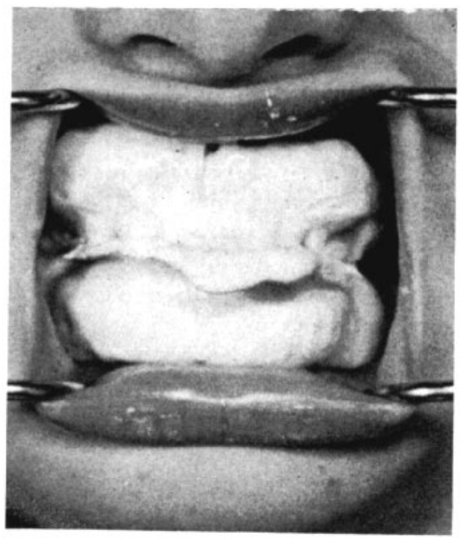


**Fig. 1** Procedure for taking perioral muscle impression. Upper) Patient tensing muscles but maintaining tissue orientation; Lower) completed impression.

resultant distortion is not significant when examining for courses of the muscle bands, but there is a serious distortion with respect to the relative depths of the muscle impingement. The shrinkage considerably exaggerates the differences between points of high and low pressures and narrows the widths of muscle bands disproportionately. Nevertheless, when dried, the impression keeps well for a permanent period.

A number of methods are available to record accurately and permanently the fresh impression. Any method, however, must show the relationship between the pressure outline and the denture. The impression may be:

a. Duplicated in clear acrylic in the manner of denture processing (a cumbersome yet very true record).

b. Embedded in plastic (also time consuming).

c. Allowed to dry, first on the model of the denture, and then in the open air. It becomes stiff and permanent.

d. Cross-sectioned and photographed.

e. Flattened and photographed from the tissue side. A tracing of the denture and alveolar outline is then made on clear paper and superimposed on the photograph. (This method has the advantage of a panoramic picture but results in loss of the arch shape.)

f. Mounted on the model and photographed. The model, without the impression, is then photographed in the same position. In order to show the relationship between the muscle complex and the teeth, the two negatives are combined in the following manner. The negative of the impression is first contact printed for only a portion of the time necessary for full contrast. The negative of the model is then superimposed over that of the impression, and the exposure is continued to completion. The proportion of the total time during which the model is exposed may be varied to change its prominence, Fig. 2.

g. The photographs are taken as in f. The picture of the impression is contact printed on thin photographic paper, whereas that of the model is made on positive film. The print is then superimposed over the film. When viewed by reflected light, a clear picture of the impression is available. When viewed with transmitted light, the teeth are clearly seen. The proper alternation of combination of reflected and transmitted light allows adjustment to the particular needs.

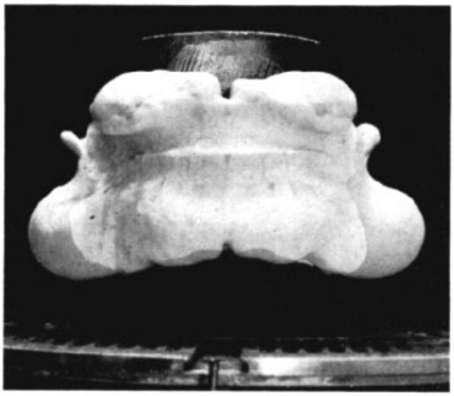


Fig. 2 A method for recording the perioral impression. The impression is mounted on the model and photographed. It is then removed and the model photographed alone in the same position. The negative of the impression is contact printed for only a portion of the time necessary for full contrast. The negative of the model is then superimposed over that of the impression and the exposure of both is continued to completion. Here denture was superimposed for 1/3 of the total exposure time.

In order to position the models properly a special holder was built. It consists of a rotating table with angle markings at the periphery. The mandibular model is positioned so that the axis of rotation is at the center of the denture, retaining the teeth at sharp focus when photographed from different angles. The model is fixed to the platform on double coated scotch brand tape. Side views are taken at right angles to the buccal segments, the frontal view taken at midsagittal plane, and the angles recorded. The impression is then removed and the model photographed at the same angular settings.

B. *Transducer*

The function of the transducer is to sense the muscle forces impinging on it and translate them into readable electrical signals. The pressures are sensed by an elastic beam which is deformed by the forces applied to its free end. The elastic deformation is then converted into an electrical signal in the following manner.

A resistive wire, cemented along the surface of the beam, elongates and shortens with the elastic member. The conductivity of the wire varies in direct proportion to the change in its length. The change in resistance of the wire is measured with a Wheatstone bridge and forms the readable signal.

The transducer, therefore, consists of two component elements, the elastic member and the resistive wire. The elastic member, made of a gold alloy, is shaped like the letter "T", Fig. 3a, part 1. The stem is a free end cantilever beam, while the top bar, part 2, is the clamping section. The beam is tapered from 0.0065 inch at the clamped end down to 0.0024 inch at the free end. A "U" shaped rail, part 3, is soldered to

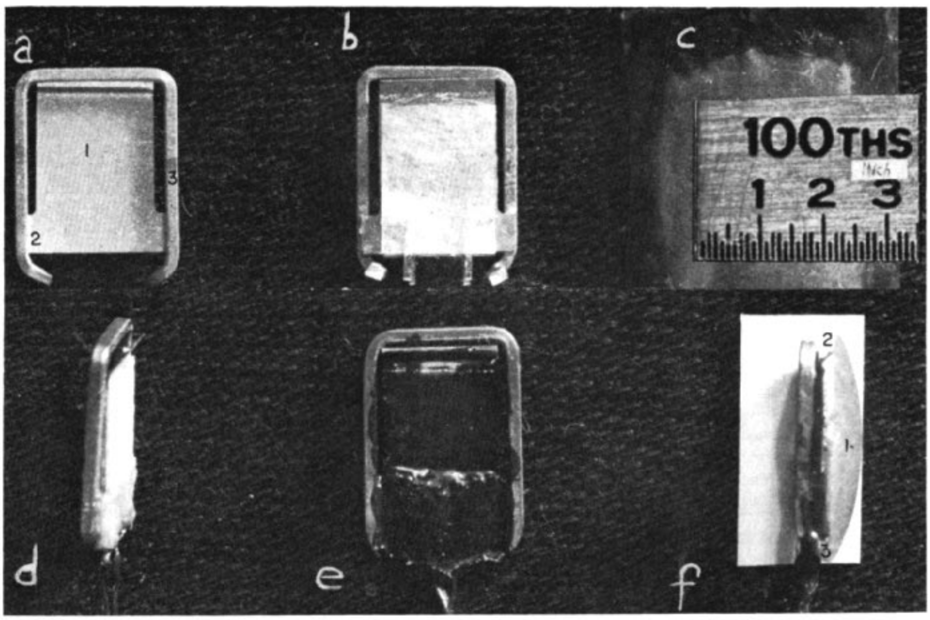



Fig. 3 Construction of transducers C-11. a. elastic beam and mounting rail: 1. free end cantilever beam 2. clamping end 3. mounting rail. b. cemented gages. c. rubber sheet and sealing adhesive tape in periphery. d. side view of mounted gage with acrylic protection for grid-to-lead joint. e. waterproofed transducer and braided external leads. f. pressure cap in position: 1. cap 2. raised end of cantilever beam 3. raised tip of mounting rail.

the top bar in order to elevate the beam from the surface and stabilize it under deformation.

The resistive wire is the SR-4 strain gage produced by the Baldwin-Lima-Hamilton Corporation. The SR-4 strain gage consists of a resistive wire grid in a paper sandwich. The resistive wire is woven back and forth to form the grid. The free ends are soldered to the heavier and softer wire leads. The transducer is assembled by cementing the trimmed strain gage to the surface of the cantilever beam with the leads running out the clamping end, Fig. 3b.

In order to concentrate the forces on the free end of the cantilever beam, a pressure pick-up-cap is placed over the entire assembly, Fig. 3f. Resting near the clamping section at one end, the pressure-cap spans over the length of the transducer to engage the tip of the elastic beam at the other end.

The transducers were calibrated in the following manner. Balance weights were tied to a very light cotton string and spaced with the smaller weights uppermost. The string was suspended from a thin wire which was hook-shaped like the number "7". The suspended load was changed by lifting the weights up the string one at a time, and then releasing one weight at a time to the string. The method was later modified so that each step was repeated a few times before proceeding to the next one.

## Findings and Discussion

### A. *Introduction*

The findings consist of an exploratory survey of the perioral and lingual musculature of a normal patient. An impression was first made to establish the course of the perioral musculature and its relation to the hard tissues. Next, dynamic and static pressures of the lingual and perioral tissues were taken. The findings are discussed and evaluated as they are presented. Although the patient presented a normal denture and musculature, he was not selected to depict the normal. The presentation is directed only to demonstrate the type of information that is available with the use of the present technique and instruments. For this reason, no statistical analysis is presented.

Furthermore, the measurements are not transposed into table form but rather presented in their original form for two reasons. First, the objective of the presentation is to illustrate the kind of information that is made available; simplification into 'table' form could result in masking certain significant aspects of the record, such as time and rate of change. And second, tabular presentation of measurements might tend to give more credence to numerical values than is justified in a survey of this nature.

### B. *Perioral muscle pattern.*

Impressions were taken in the manner described. Superimposed photographs were made (Fig. 2), and cross sections taken. As discussed in methodology, the impressions present areas of concentrated pressures in the form of troughs apparently formed by muscles, and areas of lesser pressure representing spaces between muscle bands. Attention is directed first to examination of the course and relations of the muscle bands to each other and to the denture, and next to the observation of areas between the muscle bands.

The muscle bands that can be identified include the following:

Orbicularis Oris. It is interesting to note that the point of greatest pressure seems to be at some distance from the actual margin of the lip. The angle of the mouth is seen to be over the center of the cuspid tooth. This is the area of greatest muscle pressure concentration.

Quadratus Labii Superioris and Caninus. The quad. lab. sup. and caninus attach to the angle of the mouth, blending with the other muscles at that area. In this case they run upwards between the cuspid and first bicuspid and seem to be weaker than the orbicularis and buccinator. They are displaced distally along their center by the distribution of the impression material anteriorly.

Buccinator. The buccinator presents two strands. One runs from the corner of the mouth at a slight angle upwards to attach in the maxilla above the first molar, relatively close to the mucobuccal fold. The other band runs along the occlusal plane, wrapping around the distal end of the arch.

Triangularis and Quadratus Labii Inferioris. The triangularis and quad. lab. inf. form a broad band at the attachment to the mandible tapering toward the angle of the mouth where they insert.

Areas bound by muscles (connective tissue spaces) can be identified as follows:

Midline to quadratus lab. sup. It should be noticed that the mucobuccal fold is displaced superiorly. The area is located primarily above the cuspid tooth.

Between quadratus lab. sup. and superior band of buccinator.

Between and below buccinator bands. The area lying below the buccal segment of the denture is the largest and consequently the most distended area.

The significance of the findings in this case, as in other cases observed, is not fully appreciated at this time. However, a number of features deserve special attention and justify some speculation.

The angle of the mouth seems to form an area of high muscle concentration and pressure. Its position in relation to the cuspid tooth, which is the pivot point of the denture, might be significant to the stability of treated orthodontic cases.

The connective tissue space above the angle of the mouth lies in the vicinity of the maxillary cuspid which is frequently high in buccal version.

Likewise, the segment between the bands of the buccinator falls near the position of the third molar, also found high and in buccal version. It would be interesting to observe the effect on the position of such teeth that would result from bringing them under the influence of the corresponding musculature by a downward extension of an orthodontic band, reinforced and covered with acrylic.

The presence of two bands in the region of the buccinator suggests that the buccinator may not be as simple as sometimes described. Considerable variation was found in the limited number of patients examined in relation to the width, course and relative strength of bands in that region. In addition, the relation of the horizontal buccinator band to the occlusal plane is of interest. Aside from the function of the buccinator in relation to the orbicularis oris complex, it enters into the masticatory process. Food is held in the vestibule and fed very carefully over the occlusal surfaces, apparently by the buccinator complex. The relation of the buccinator to the occlusal plane might be of some importance in masticatory efficiency, and of considerable importance in the field of prosthetic dentistry.

These findings seem to justify further study in an attempt to relate certain muscle patterns to malocclusions. Such studies might well result in application of the technique to orthodontic examination and case planning.

C. *Pressure Measurements.*

1. Orientation

For convenience in analysis, the pressures developed by the tongue, cheeks and lips have been classified as either dynamic, arising from active muscle contraction and characterized by rapid fluctuation and short duration, or static, arising from essentially nonactive states and characterized by stability and constancy.

The dynamic pressures studied were those developed in swallowing and speech. These functions were chosen because of their importance and because they were found to be readily reproducible. Swallowing exercises were made with water, sucked through a straw; pudding, taken with a teaspoon; and saliva, cleared as it accumulated.

Two sources of static pressures were examined. First were those arising from negative pressure maintained in the oral cavity after swallowing, and next were the pressures resulting from the postural drape of the tissues.

In designing the experiments, an attempt was made to obtain records which would identify the anatomical functional units and illustrate the sequence, duration, and relative magnitude of their action. By proper placement of the transducers and by certain simplified functions, the objectives were achieved.

The tongue, for example, is composed of a number of anatomically functional units, each performing an assigned task in proper sequence, thereby producing the desired overall result. The transducers were, therefore, placed not only to measure the pressures against the denture at different positions, but also to relate the pressures to the functional parts of the muscles involved.

A sequence between the pressures exerted by different anatomical units sheds light on the behavior of the whole and will be observed in analyzing the records.

The period over which a dynamic force is exerted is of importance for two reasons: first, it sheds light on the functional behavior of the part; and second, it might have considerable significance in evaluating the effects of such pressures on the denture.

The term "dynamic pressure" emphasizes the central characteristic of functional forces, which is change, change of magnitude with respect to time. Therefore, in reporting the magnitude of a functional force one must include the time factors. For example, the report that the tongue exerted 25 gm pressure in swallowing is materially inadequate when compared with a report stating that the tongue reached a peak pressure of 25 gm in 0.1 sec. from the initiation of deglutition, then tapered down to 5 gm in the next 0.3 sec., and returned to base line abruptly after an additional 0.4 sec.

Because of the obvious difficulty in describing all the aspects of dynamic pressures, the actual dynographic records are presented. The oscillograph record presents the total picture of pressure patterns in relation to anatomical distribution, sequence, duration and rate of change, as well as the magnitude of the pressures involved.

Each of the records presented in the following discussion was selected because of the clarity with which it illustrated the characteristics of the different pressure patterns under consideration.

Some explanatory remarks on reading the records, as for example Fig. 4, are offered now. Each record combines six separate channels, identified by the break in vertical grid between them. The horizontal grid is ruled each millimeter, and the vertical grid each half centimeter. A scale at the top of each record provides the calibration with respect to both pressure and time. In the sample record one millimeter pen deflection represents 0.909 gm load.

The scale notation "10 cm/sec" indicates the speed of paper movement (moving to the left, thereby leaving a

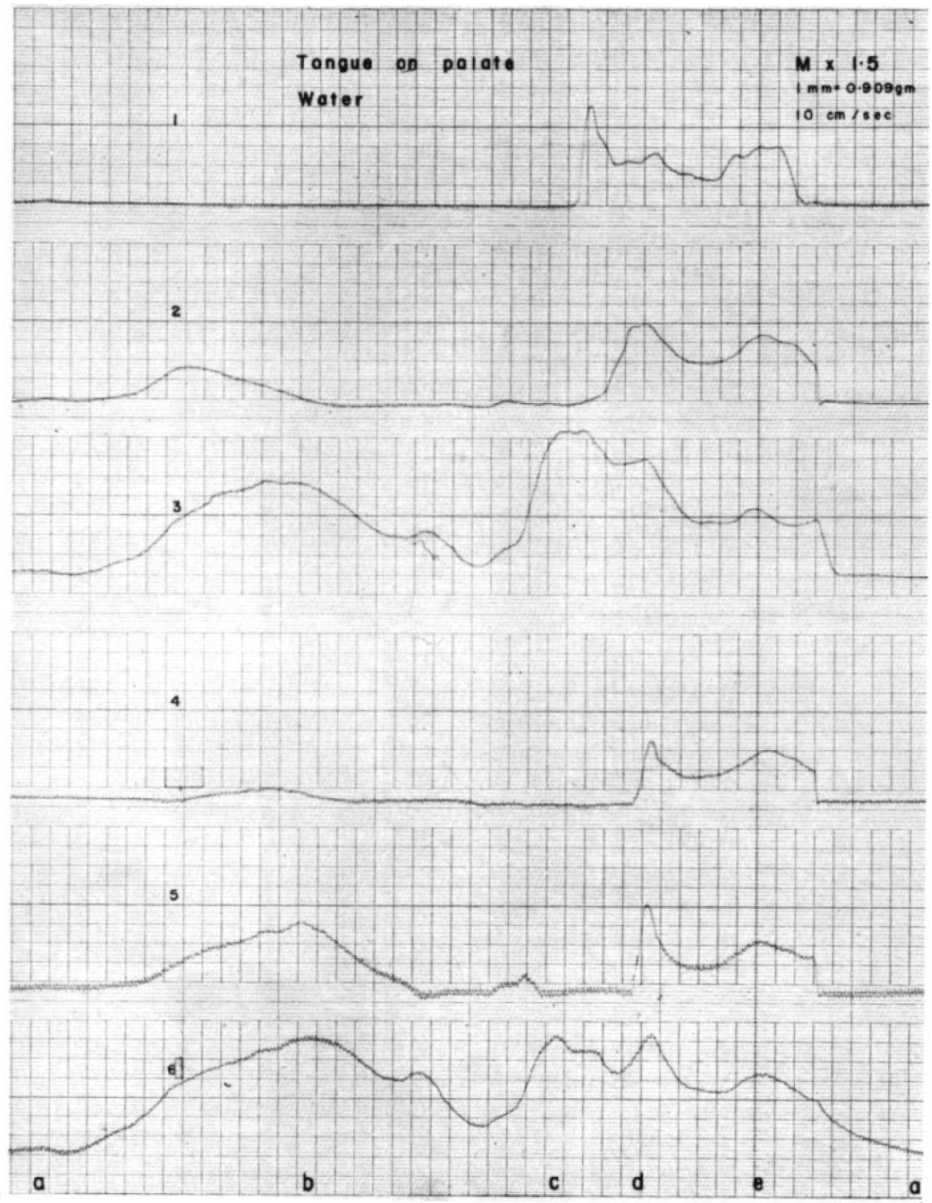



Fig. 4 Pressures of the tongue against the palate in sucking and swallowing water. For transducer placement, see Fig 5. a. base line b. sucking water through a straw. c. sealing the lateral and anterior margins of the palate d. ejecting the water from the vault e. bracing the tongue in pharyngeal clearance.

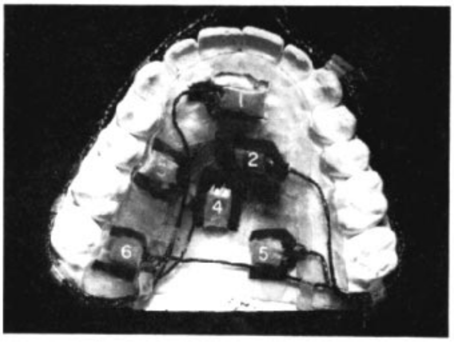


Fig. 5 Transducer placement (C-19) in measuring the pressures of the tongue against the palate in swallowing water (Fig. 4), pudding and saliva (Fig. 6). The transducers are mounted on a shield made of a vinyl plastic sheet 0.020 inches thick. They bear the numbers of the corresponding channels on the oscillograph.

trail from left to right). In the present case the time lag between points d and e is 6x.5 cm divided by the speed of 10 cm/sec, or 0.3 seconds. In the electric chart a vertical grid line marks the same moment of time throughout all channels. The letters at the bottom identify successive periods of time, usually associated with distinct cycles in pen movements and, of course, apply to all channels.

2. Dynamic pressures.

Dynamic records were taken of swallowing and speech. Swallowing will be discussed first as related to the tongue, then the cheeks and lips. The dynamic activity of the tongue was studied from the dorsal aspect, as related to the palate, and from the lateral aspect, as related to the mandible. The transducers (C-19) were mounted as shown in Fig. 5.

Water was sucked through a straw and swallowed. The resultant recordings (Fig. 4) present both quantitative and qualitative information regarding the behavior of the tongue. In sucking water (above b) the tongue is seen to brace itself laterally in an area extending from its lateral border half way to the midline leaving other areas free. In preparation for swallowing a seal is first formed laterally against the buccal segments of the palate (c-3, 6). The seal develops relatively slowly, reaching a maximum after 0.2 sec. At that time the anterior margin is raised abruptly (c-1) thereby sealing the vault of the palate from three sides. In ejecting the food from the mouth into the oral pharynx, the tongue does not exhibit a peristaltic wave-like action, but rather acts like a flabby plunger. While the intrinsic muscles function in modifying the surface configuration of the tongue, the extrinsic muscles apply the upward thrust. With the force directed at the center of the tongue, the surface engages the palate in a rolling contact up the vault toward the center of the palate. The rolling action is achieved apparently by a controlled uncurling of the raised margins of the tongue as it is forced against the palate. As the dorsum assumes a more convex shape, the rigidity of the tongue increases, reaching maximum at full palatal engagement. This hypothesis would tend to explain the gradual onset of force on transducers 1, 2, 3, and 6, which lie in the periphery of the tongue, in contrast to the abrupt application of pressure on gages 4 and 5 (d-2, 3, 6, but second wave on 1). It further explains the earlier onset of force often seen on transducer 5 as compared with 4, although 5 is actually in a more posterior position than 4. In addition, the hypothesis would clarify the fact that peak forces are reached at the same instant throughout the surface of the tongue. The thrust against the palate (seen best on channel 2 which was not involved in forming a seal) begins when the anterior seal is completed and reaches maximum contact in about 0.15 sec. The ejection of the food from the mouth is probably en-

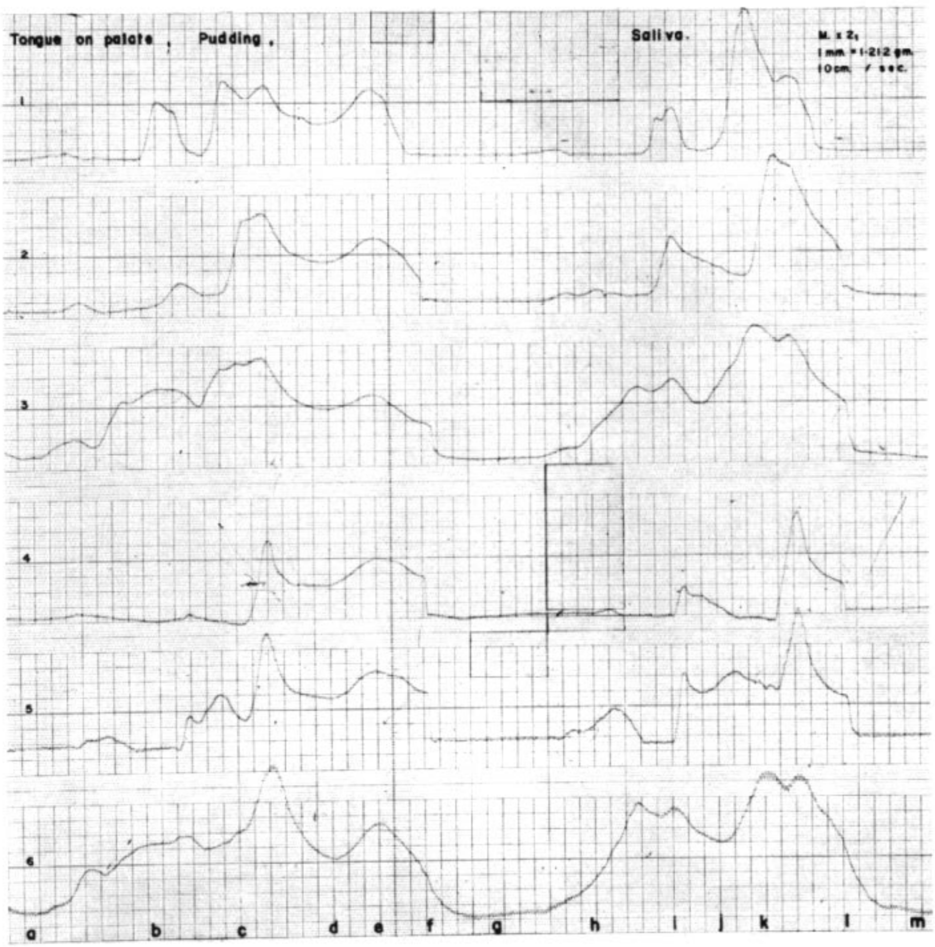



Fig. 6 Pressures of the tongue against the palate in taking and swallowing pudding (left), and in clearing saliva and traces of pudding from the mouth (right). a. base line b. taking pudding from a teaspoon c. forming a lateral and anterior seal (to left), and clearing the vault (to right). d. maintaining tongue contact e. bracing of tongue in pharyngeal clearance f. abrupt release of tongue contact g. return to base line h. forming seals i. oral clearance j. maintaining contact k. pharyngeal clearance l. abrupt release of contact m. base line.

hanced by the inclined plane arrangement of the palatal vault. It would be interesting to compare the swallowing behavior and its efficiency in mouths with flat vaults compared with those with high ones.

After the food is expressed from the oral cavity, the tongue maintains its pressure on the entire surface of the palate (trough between d and e). A second pressure wave is seen in the pharyngeal stage of swallowing as the tongue is braced against the palate. Contact between the tongue and palate is released abruptly at the termination of pharyngeal clearance with the exception of slight sluggishness in the posterior region of the tongue (e-6).

The pressures recorded in swallowing pudding tended to be higher than those observed in swallowing water, but the anatomical distribution of the pressures maintained its proportionality (Fig. 6).

A comparison between swallowing records for water, pudding and saliva illustrates the constancy of the pattern in spite of some variations in the magnitude of the forces involved. As seen, swallowing proceeds along the following stages: formation of a lateral seal and then an anterior seal; development of rolling contact towards the height of the vault, culminating in the application of maximum pressure simultaneously throughout the surface of the palate; maintenance of contact pressure after oral clearance; and, finally, bracing against the palate in pharyngeal clearance.

The anatomical distribution of these dynamic pressures shows considerable consistency. The pressures during oral clearance are nearly twice as large in the posterior, lateral segments as they are in the height of the vault, but nearly uniform during pharyngeal bracing. Differences were seen primarily with relation to the magnitude of the pressures involved. Peak pressures ranged from 15 to 50 gm, being as much as twice as large for viscid substances as for water. Likewise, contact pressure maintained throughout the act of swallowing varied from 1.2 to 6 gm in direct relationship with the increased viscosity of the foods taken.

The function and pressures of the tongue during swallowing were next examined in relation to the mandibular arch and body of the mandible.

The transducers were mounted on a shield adapted to the lingual of the mandible and mandibular denture as shown in Fig. 7. The transducers type C-11 were used in an attempt to detect the smaller static pressures. However, since these gages have a pressure surface twice that of gages C-19, the magnitudes reported here may be compared to those against the palate only with considerable reservation.

Water was sucked through a straw and swallowed as before (Fig. 8). The pressure records show stages of swallowing corresponding to those seen in the palate. However, the relative magnitudes of the forces exerted during suc-


Fig. 7 Placement of the transducer type C-11 in measuring the pressures of the tongue against the mandible and mandibular teeth in swallowing water (Fig. 8) and pudding (Fig. 9). The transducers are attached to a vinyl plastic shield 0.015 inches thick.


Fig. 8 Pressures of the tongue against the mandible in sucking and swallowing water. a. tongue retracted, no load b. postural pressure of the tongue at rest c. sucking water through straw d. ejecting water from the vault e. bracing of tongue against palate in pharyngeal clearance f. gradual settling of the tongue to resting position g. intentional withdrawal of the tongue, base line h. return to normal posture.

tion to those during swallowing are greater in the present recordings, and the anatomical distribution of the pressures is reversed anteroposteriorly when compared with those seen on the palate.

Pressures recorded in swallowing pudding were higher than those observed in swallowing water, similar to the findings with respect to palatal pressures (Fig. 9).

The combination of palatal and mandibular recordings give a reasonably clear picture of the distribution of tongue pressures in relation to the denture. This ability to map the lateral pressures of the tongue during swallowing is of special importance in relation to the interest in abnormal swallowing habits. The records suggest a promising tool for research as well as an accurate means for measuring progress of habit control in orthodontic therapy.

We turn next to the examination of the swallowing forces exerted by the perioral musculature.

*Cheeks and lips.*

Type C-11 transducers were mounted as shown in Figure 10. The gages were positioned to compare the pressures exerted along different muscle bands,

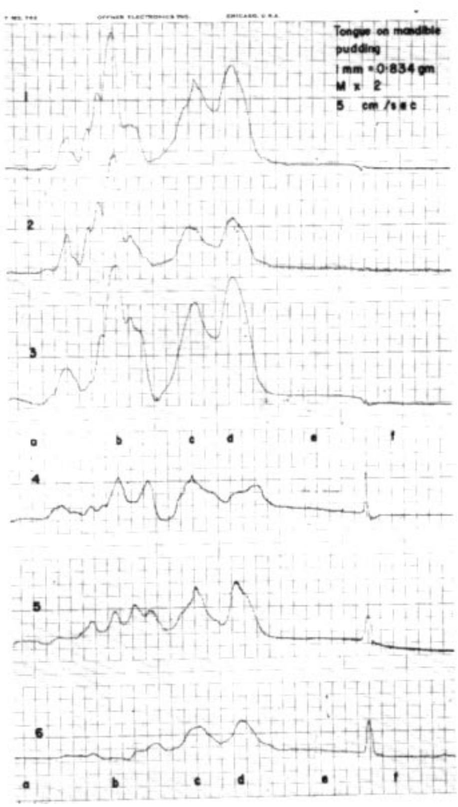



Fig. 9 Pressures of the tongue against the mandible in taking and swallowing pudding. a. postural pressures b. taking pudding from teaspoon c. ejecting pudding from vault d. bracing the tongue in pharyngeal clearance e. gradual return to normal resting position f. intentional withdrawal of the tongue from contact: base line.


Fig. 10 Placement of transducer C-11 on the buccal and labial surfaces of the maxilla and maxillary denture in recording the pressures of the cheek and lip in swallowing water (Fig. 11) and saliva (Fig. 12), and in measuring the postural pressures (Fig. 14 a, b). The shield was made of vinyl plastic sheet, 0.015 inches thick.

as well as to relate these pressures to those exerted in areas free of muscle impingement. The relation of the muscle bands to the hard tissues was established from the perioral impression, Fig. 2. The transducers were mounted as follows: No. 1 at the angle of the mouth; 2 in the free area above 1; 3 near the midline of the orbicularis oris; 4 barely above the orbicularis, between the midline and the angle of the mouth; 5 along the buccinator; and 6 between the superior and horizontal bands of the buccinator.

The active pressures of swallowing water (Fig. 11) and pudding were examined. Those for saliva were designed to observe the static pressures and will be presented later. The pressures recorded in active contraction of the perioral muscles (a), as in grasping the straw (b) or clearing the vestibule (e), show direct correlation to the picture presented by the impression technique. The active pressures are about twice as heavy along muscle bands as compared with areas free of muscle impingement.

The pressure distribution noted in grasping the straw is reversed during suction. A greater load is recorded in

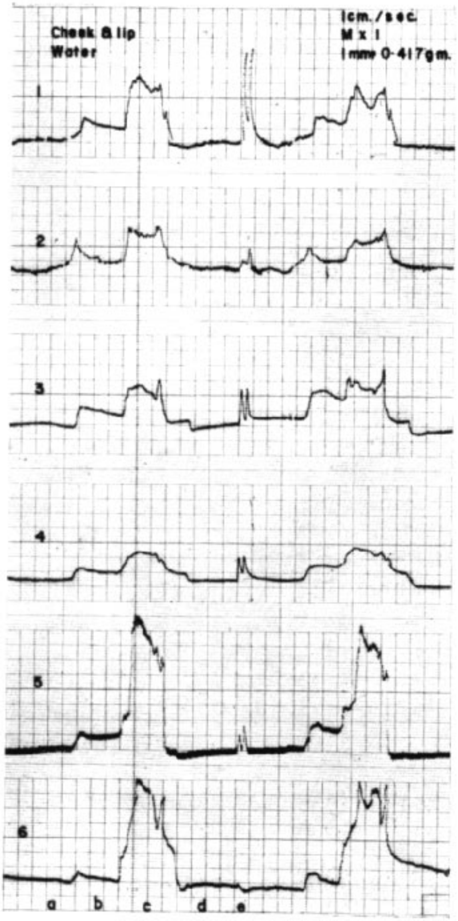



Fig. 11 Pressures of the cheek and lip against the maxilla and maxillary teeth in sucking and swallowing water. Two cycles. a. resting position b. puckering lips and grasping the straw c. sucking water through straw d. swallowing e. involuntary clearance of the vestibule and mouth from saliva.

the buccal segments (c-5, about 18.5 gm), less at the angle of the mouth (c-1, about 8.5 gm), and even less at the midline (c-3, about 6 gm). Since the perioral muscles are passive with respect to development of negative intraoral pressure, the greater pressure in the buccal region may reflect no more than the flabbiness of these tissues as their lower resistance to displacement as seen in the impression picture. The significance of the sharp pressure wave at the end of suction, a constant component of this record, is not appreciated at this time.

No significant pressures were recorded during ejection of water from the vault (d). The activity of the lips (left of d-3, 4) is probably related to change in the grasp of the lips on the straw.

Pudding was taken from a teaspoon and swallowed. Reaching for the pudding called for a different combination of muscle activity than seen in pursing the lips around the straw. As in the record for water, no significant pressures were recorded during deglutition.

*Static Pressures.*

Static pressures examined here consist of two types. One is the postural pressure of the tissues at rest; the other is the pressure maintained with negative intraoral pressure after deglutition. The swallowing exercises for saliva taken with the tongue against the mandible, and the cheeks and lips against the maxilla, were especially designed for this purpose. However, other swallowing records reveal similar information and will be referred to from time to time.

*Tongue.*

The C-11 transducers were mounted as shown previously in Figure 7. Saliva was swallowed (Fig. 12b) and the lips were maintained closed until the pressure against the transducers stabilized itself. At that time the negative intraoral pressure was broken by parting the lips (d). As soon as the postural pressures of the tongue became stabilized, it was withdrawn from the mandible thereby producing the base line of no pressure.

Three cycles are shown for comparison. The forces resulting from the production of negative intraoral pressure

**Fig. 12** Static pressures of the tongue against the mandible and mandibular teeth. For transducer placement see Fig. 7. After clearing the mouth and swallowing saliva (b), negative intraoral pressure was maintained (c). Upon parting the lips, the transducers recorded the postural pressures of the tongue at rest (c). The base line was obtained by intentionally withdrawing the tongue from contact with the transducers (a). Three cycles.

were most pronounced anteriorly (about 7 gm).

However, the postural pressures were greater posteriorly than in the incisal region. While the pressure against the molar was 2.4 gm (d-5), that on the centrals was only about 1.2 gm (d-1,2).

Whereas the postural pressures are relatively constant, maintenance of negative intraoral pressure is subject to variation with certain habits. The extent and intensity of its practice may well influence the pressure balance against this denture.

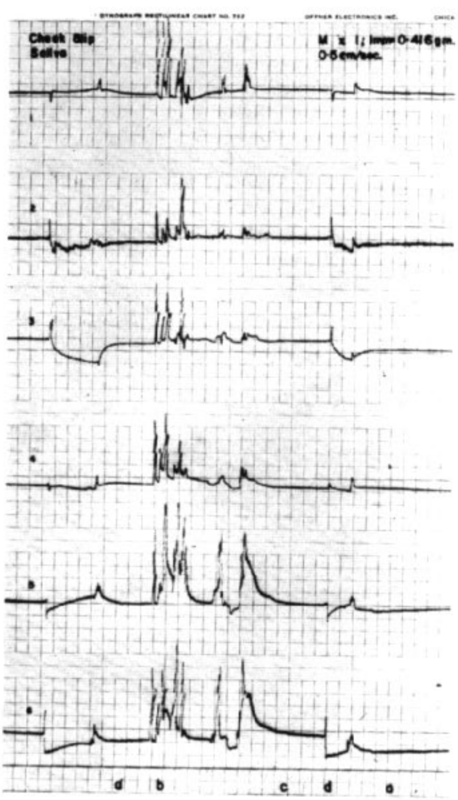


Fig. 13 Static pressures of the cheek and lip against the maxilla and maxillary teeth. Two cycles. After clearing the mouth and swallowing saliva (b), negative intraoral pressure was maintained (c). The base line was recorded by suddenly exhaling into the closed mouth, thereby inflating the perioral tissues (d). Upon parting the lips, the tissues assumed their customary postural drape (a).

*Cheek and lip.*

The transducers were mounted as in Fig. 10. Negative pressure is seen in Fig. 13. The vestibule was cleared and the saliva swallowed (b). The mouth was kept sealed sufficiently long to allow the strained condition to settle (c), and the pressures to approximate those habitually maintained by the negative pressure.

The pressures so obtained were compared with resting pressures measured in other ways, and the pressure differences were established. In order to relieve the pressure of the lips and cheeks simultaneously, air was exhaled suddenly into the mouth, keeping the lips closed, thereby displacing the perioral tissues away from the transducers. The distortion following the break in tissue contact precluded accurate measurement of postural pressures from this record. Special exercises were instituted for the establishment of the postural pressures.

The postural pressures were obtained in a relaxed sitting position with the head upright and the oral seal broken. Two methods were followed. In one, the head was tipped horizontally to the side and to the front allowing the tissues to sag away from the transducers, Fig. 14-A. In the other, the tissues were lifted away by grasping the cheek and lip between the fingers, Fig. 14-B.

Since the cheeks are not active in developing the "negative intraoral pressure" the records reflect only their relative flabbiness. The pressure developed in production of "negative pressure" (above the corrected postural reference pressure, compare a with c) is greatest in the buccinator region (c minus a in channel 5, about 1 gm). It is smaller under the lip (c minus a, channel 3, about 0.4 gm), and close to zero in the commissure area (1).

Postural pressures of the perioral tissues were quite small at the entire level of the denture. They averaged about 0.4 gm (Fig. 14 a, b; b minus a -1, 3, 5). (The larger pressures recorded above the denture level (2, 6) are artifacts caused by the proximity of these gages to the mucobuccal fold.)

The postural pressures of the lips and cheeks were indeed small, much smaller than anticipated. The pressures exerted against the hard tissues, without the displacement introduced by the gages, are probably even smaller. Never-

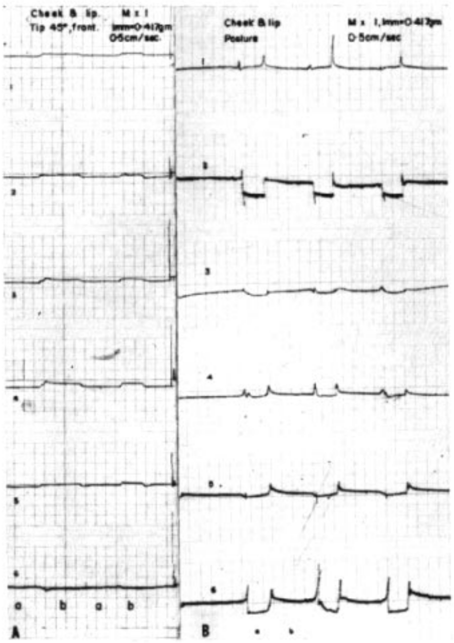



Fig. 14 Postural pressures (b minus a) of the cheek and lip against the maxilla and maxillary teeth. In order to record the zero base line, the pressure of the tissues was relieved in two ways: In Fig. A the head was tipped, and the tissues allowed to shift their weight away; in Fig. B the tissues were pinched and pulled away while keeping the lips closed.

theless, we still do not know what effect these small pressures may have on the biological system adjacent to them.

In evaluating the records of the lingual and perioral postural pressures we may justifiably conclude that a mild encroachment against the lip or cheek is resisted less than an equal encroachment against the tongue; a lingual displacement would be better tolerated by the tongue in the incisal region than in the area of the bicuspids; and that an increase in persistence or intensity of maintaining "negative intraoral pressure" is likely to result in a greater pressure by the tongue, especially against the incisors, as compared with that exerted by the perioral tissues. All this, of course, applies only to the present case. And, it is realized that these observations are made in relation to the immediate response. How the accommodation capability of the tissues will alter the expected response is another matter. Are the perioral tissues in any given case able to assume a new postural drape, or will they tend to return to their original position? Is the response of the tongue the same, in the long run, as that of the perioral muscles? The pressure readings presented here cannot supply the answers. It seems, however, that the system does offer a tool capable, in proper application, and probably after a long period of time, to shed some light on these important problems and inject value into mere numbers.

## Summary and Conclusions

It is hoped that the present study has yielded the instrumentation, techniques and degree of insight necessary to undertake a comprehensive study of the anatomy and physiology of the oral musculature in its relation to the dentition.

The impression technique provided a means for mapping the course of the perioral muscles and for recording their relation to the dentition in a given individual. It has proven to be a simple procedure quite acceptable to the patient. Photographic methods have provided a satisfactory system for making permanent records. Judging from the wide variation found in the course of these muscles and in their relations to the hard structures of the mouth, further study aimed at exploring the relationship between the muscle configuration and certain malocclusions is justified. Evaluation of the physiological relationship between the buccinator strands and the occlusal plane seems to present a fruitful subject for study by the prosthodontist.

The strain transducers have provided a successful means for studying the behavior of the perioral and lingual muscles in function. The miniature size of the transducers (0.140 x 0.250 x 0.065 inches), their high sensitivity (3.5 mm per gm), the flexibility in positioning them in the mouth, the speed (10 cm/sec.) and rectilinear nature of the recorder coupled with a linear response of the transducers have combined to give an accurate record with sufficient resolution to follow minutely the most rapid functions of the muscle complex. By placing a number of transducers in strategic positions the sequence of activity of the different functional units and their relative pressures were easily traced.

A survey was made of the behavior of the cheeks, lips and tongue in swallowing and speech to test the instrumentation and to evaluate the records produced. With respect to the case investigated, it was found, for example, that the tongue followed a consistent pattern in swallowing. A seal around the vault was first formed by the lateral margins followed by the anterior margin of the tongue. Then the entire tongue was suddenly elevated against the palate ejecting the food into the oral pharynx. The tongue was later braced uniformly against the palate during clearance of the pharynx. The pressures exerted by the tongue increased with increase in the viscosity of the food taken, while the pattern remained constant. The lips and cheeks, in contrast to the tongue, remained at rest during swallowing. They functioned only in sucking fluids or introducing solids into the mouth. Functional disorders, such as the "perverted swallowing habit", can now be subjected to measurement by an experimental tool. Likewise, a study of the effect of changes in palatal shape of artificial dentures on swallowing efficiency is now possible.

When applied to the study of speech, the system gave a continuous record of the position, rate, sequence and intensity of action of the functional units of the tongue and lips. Through the incorporation of a sound track into the oscillograph record, the relationship between muscle action and sound production was examined. Using this equipment, it was observed that in the production of different sound having the same contact pattern of the tongue to the palate, the pressure pattern exerted by adjacent areas of the tongue was distinctly different. In addition to its use in research and diagnosis the instrument shows promise in speech therapy, for it presents to the patient and therapist alike a visual picture of otherwise hidden muscle activity. In considering the influence of muscle pressures on the position of the teeth, great importance is attached by the writer to the time factor of pressure application. Since we are examining a biological system, not a mechanical one, it is argued that the significance attached to a given muscle pressure is to be determined not from its own magnitude but primarily from the tissue response to it. Judging from their primary function, the periodontal tissues seem to be capable of absorbing very heavy pressures, such as those exerted during mastication, without any ill effects, yet they will undergo major reorganization in the face of mild orthodontic pressure.

For sake of convenience the pressures exerted by the oral musculature against the teeth were classified as either dynamic — arising from function and characterized by rapid growth and decay, or static — present at rest and characterized by stability and constancy. Considerable attention was given to the static pressures in the belief that they may be the more significant influence on the position of the teeth. Two sources of static pressure were examined. First were those exerted in an attempt to maintain "negative intraoral pressure"; next were those present due to the resting postural drape of the tissues against the teeth. The transducers proved sensitive enough to measure the pressures exerted against the hard tissues in maintaining "negative intraoral pressure". The resolution was high enough to allow a valid comparison between these pressures at different points along the denture. However, while the system was sensitive enough to resolve the postural pressures of the tongue, it was inadequate to do so with the minute labial and buccal pressures (0.4 gm). Nevertheless, methods for increasing the sensitivity of the system were outlined.

Certain artifacts were discovered in the system. Because the static pressures were so small, the displacement of the tissues from their normal position became significant. The small postural pressures must therefore be thought of as the resistance of the different tissues to an equal displacement. They might be indicative of the resistance of the tissues to orthodontic manipulation. In addition to thickness, the surface area of the transducer presented to the tissues is a source of artifacts. Both the surface texture and the underlying rigidity, it is believed, combine in a nonuniform manner to disturb the simple proportionality between pressure and surface area. For this reason pressures were reported without the customary conversion to units of load per unit of area.

This exploratory survey has thus demonstrated the practicality of the instrument system and indicated the wide range of qualitative and quantitative information made available. The analysis of the recordings has clarified the limitation of the system and pointed to the great possibilities for further research on the muscles of the mouth.

*Box 945*

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