Muscle Pressures and Tooth Position: North American Whites and Australian Aborigines

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The practice of orthodontics is affected to a surprising degree by the views of the practitioner on the importance of environmental factors in the etiology of malocclusion. Implicit in Angle's ideal of thirty-two natural teeth in perfect occlusion was his belief that this was possible for every individual, and that environmental influences had led to the malocclusion, preventing the original potential from being realized. Orthodontists in the early years of the twentieth century were quite concerned about the effects of various habits and muscular pressures on the teeth. Perhaps the greatest exponent of this point of view in recent years was Alfred P. Rogers, who used various exercises and muscle therapy to a large extent in his orthodontic practice.[1]

As extraction treatment became a permissible subject of conversation in the late 1930's and 1940's, orthodontists began to re-evaluate the roles of environment versus heredity in producing malocclusion in the first place. For Tweed, the basic reason for extraction was a hereditary discrepancy between tooth mass and jaw size.[2] For Begg, an additional reason for extraction was because modern man's diet prevented attritional reduction of excess tooth mass.[3] With both treatment approaches there was little concern about muscular environment and other philosophies which had concerned the orthodontic leaders of the earlier generation.

In the 1950's in the United States Walter Straub struck a responsive chord when he pointed out difficulties with open-bite problems, whether or not extraction treatment was used.[4] The muscular environment, and particularly the tongue, was blamed for these problems. The initial wave of renewed enthusiasm among American orthodontists for various muscle exercises and "myofunctional therapy" has subsided, but it has been picked up in the last few years by other groups in dentistry. At the moment, myofunctional therapy is being oversold to general practitioners of dentistry in somewhat the same fashion that the Crozat appliance was a few years ago, by marginally qualified "experts." This therapeutic approach has thus become once again a matter of concern to orthodontists who have achieved a more balanced view of such therapy themselves. Research in this area has been disappointingly slow to produce definitive answers, but much has been learned recently. Current views based on that research, especially as they apply to clinical questions, are the subject of this paper.

METHODS FOR STUDYING TONGUE AND LIP PRESSURE

Stetson in the 1920's used small balloons as pressure sensors within the mouth and pneumatic-mechanical linkage to record pressure waves on smoked kymograph drums.[5] Similar technology was employed by some of the first dental workers of the 1950's, but real advances required electronic pressure-sensing devices based on strain gauges, and on the development of high quality electronic amplification systems which can handle the small signals from miniature intraoral pressure transducers.

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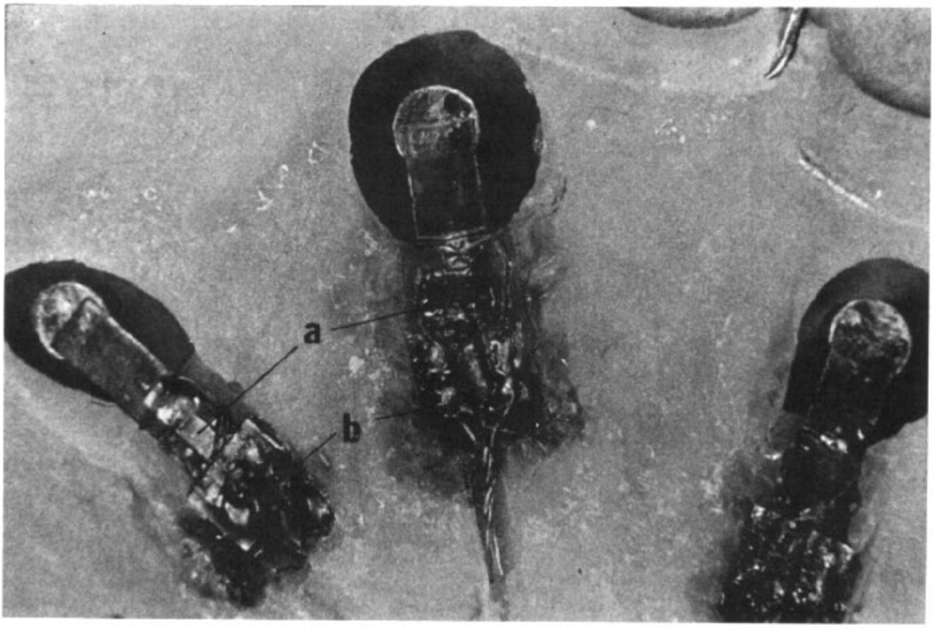

Fig. 1 Pressure transducers mounted in a thin plastic palate-covering device. A = foil strain gauge; B = mounting platform and attachment area for cable.

A number of investigators have played a role in the slow development of the necessary instrumentation.[6,7] Only recently, perhaps since 1963, has the instrumentation itself reached a satisfactory stage of reliability and accuracy.

A modern intraoral pressure transducer, designed and built in the orthodontic department at the University of Kentucky, is shown in Figure 1. Extremely small foil strain-gauges, carefully matched to the temperature coefficient of the beam on which they are mounted, have replaced the bulkier wire strain-gauges of earlier days. The pressure transducer is designed to be mounted in a thin plastic carrier, as shown in Figures 1 and 2. When it is mounted, only the pellet at the end of the cantilever beam is exposed to the pressure of the tongue or lips. The plastic carriers make it possible to position a pressure transducer at almost any intraoral location. It is also possible to place the transducer in a thin metallic housing and cement it directly to the teeth, attach it to archwires, etc. Since the mounting of a transducer can affect its sensitivity, accuracy requires that each transducer be individually calibrated after mounting (Fig. 3).

Fig. 2 Palate-covering appliance with five transducers, in a child's mouth.

Whenever instrumentation is introduced into the mouth or other areas of the body, there is a possibility that the physiologic activity being studied will be altered by the presence of the recording instrument. This phenomenon, originally termed "physiologic react-

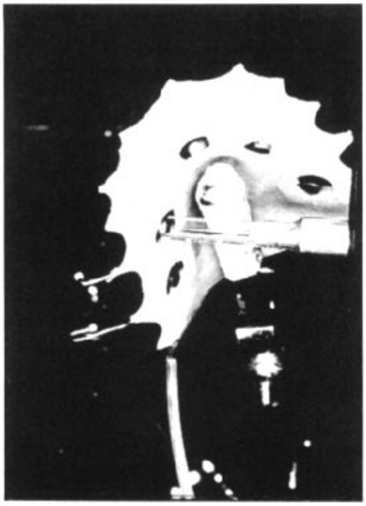

Fig. 3 Calibration of pressure transducers after they have been mounted is done by loading a reference transducer against the center of the pellet. The rectangular guides are used for precise positioning (under magnification) of the sharpened probe.

ance" by Code,[8] is a very real hazard in the mouth, particularly when tongue pressures are to be recorded. The pattern of tongue activity is likely to be changed as the tongue avoids the pressure transducers. If the devices cause discomfort, avoidance is all but guaranteed. To combat this, in our studies a dummy lingual appliance is worn by subjects for approximately forty-eight hours prior to placing the actual recording appliance. This allows accommodation to the appliance to take place, which can be evaluated by the disappearance of speech distortion. There are no sharp projections on the recording appliance which contains the transducers, and speech distortion does not reappear when it is placed.

Analog pressure waves are produced by tongue or lip contacts with a transducer. Pressures, duration of contact, area under the pressure curves (time-pressure integral), and time relationships between pressure curves at multiple recording locations may all be measured by hand, but the volume of data requires computer assistance for more than small scale studies. With the computer, data are reported in a few minutes. Computed data can also be retained on a magnetic tape for later statistical calculations. Developments in electronics in the late 1960's leading to improved stability of both the transducers and the amplifying system were necessary before such computer application was possible.

The most recent technical step has been development of a portable system which can be used for pressure recording outside the laboratory. Solid-state devices made it possible to construct a special portable amplifier small enough to carry on field studies, and exceptionally small data-tape recorders are now available. This equipment was used in central Australia in 1972 to obtain labial and lingual pressure measurements on members of the Walbiri group of aborigines whose dental development has previously been studied by Barrett, Brown and others at Adelaide University. The data tapes were analyzed by the computer at Kentucky in the same way as data generated in that laboratory. This has made it possible to compare tongue and lip activity in the Australian aborigines, whose arch form is notably different from that of North American whites, with individuals of similar age here.

Data on Australian aboriginal subjects were obtained in May 1972 at Yuendumu, Northern Territory, Australia during the tenure of my Fulbright research fellowship at the University of Adelaide.* Murray Barrett, Chairman of Restorative Dentistry at Adelaide and noted student of the aboriginal dentition, made the trip possible

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Fig. 4 Pressure transducers mounted to record maxillary labial pressure, in an aboriginal subject at Yuendumu, N. T., Australia.

through his local contacts and led the group. We were assisted by David Parker of the Department of Restorative Dentistry at Adelaide and by Les Reynolds, chief laboratory technician there. Labial and lingual pressure recordings were made on eighteen teenage aboriginal subjects who had previously participated in a longitudinal growth study. Ten pressure locations, labial and lingual to the maxillary molars, canines and central incisors, were evaluated in all subjects (Fig. 4). In nine of the subjects pressure recordings also were made labial and lingual to the mandibular first molars, canines and central incisors.

Pressures were evaluated while the aboriginal subjects were at rest, swallowing water, swallowing saliva upon command, speaking in English, and speaking in their native language (Walbiri). Pressure transducers were mounted in thin plastic carriers which were constructed in the field on casts made during this expedition. Procedure was exactly that employed in the laboratories at Kentucky: subjects wore a dummy plastic appliance for forty-eight hours prior to pressure recording; all transducers were calibrated after being mounted in the appliance for each subject; and the calibrations were monitored so that a revised mounting could be made if transducer sensitivity fell outside the normal range.

Comparative data on North American white subjects were available from several other studies carried out in our laboratories at Kentucky in recent years.

Comparison of Australian Aboriginal and American Subjects

The physical characteristics of the Australian aborigines are well-known to American orthodontists through the research of Begg. Studies of blood groups suggest that the aborigines are descendants of an early Caucasoid population which migrated south rather than westward into Europe as did the major Caucasoid group. Their ancestors seem to have arrived in Australia some ten-twenty thousand years ago and to have been isolated for that length of time.[9]

With regard to the face and dentition, the present-day aborigines differ from Americans in three major ways (Figs. 5 and 6): 1) the dental arches are larger in width dimensions, and dental crowding is rare; 2) there is a marked degree of bimaxillary dental protrusion; and 3) the facial skeleton has different proportions, with the skeletal mandible and maxilla positioned forward relative to the cranium. The lips give an indication of relative flaccidity. Parenthetically, it is interesting to note that as the aborigines have come to live in settlements analogous to United States Indian reservations, the degree of dental attrition characteristic of earlier years has largely disappeared. This does not seem to have been accompanied, however, by an increase in dental crowding.

Tongue and lip pressures in the aboriginal subjects are shown graphically in Figures 7-9. As with all other groups who have been studied, aboriginal tongue pressures during swallowing far exceed lip pressures (Fig. 7). This is true whether the longer duration of lip pressures is taken into account or not. Aboriginals have essentially no upper

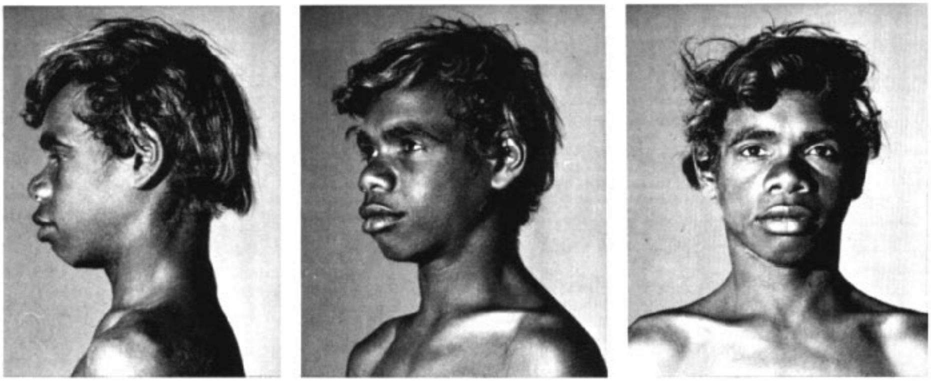

Fig. 5 Facial characteristics of a 15-year-old aboriginal boy, one of the subjects at Yuendumu.

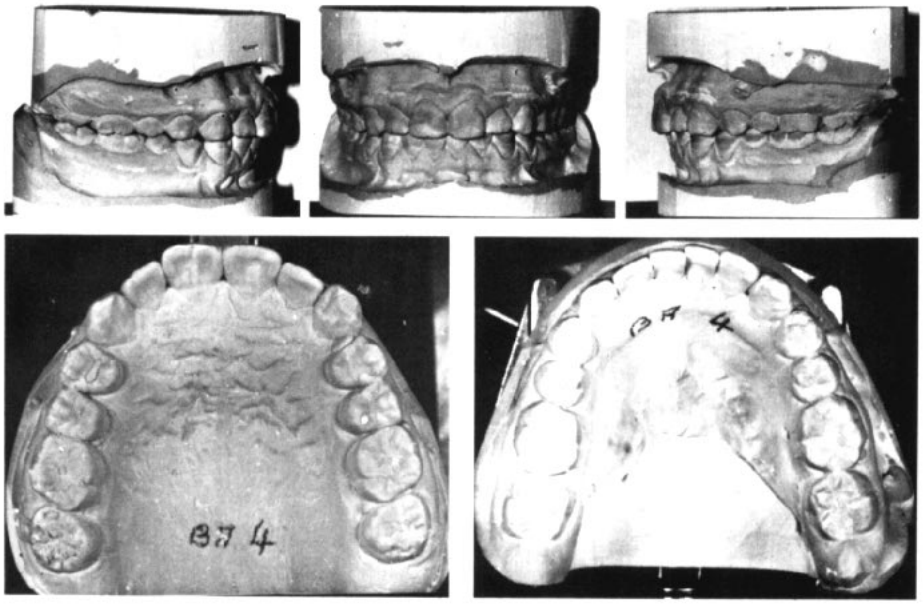

Fig. 6 Dental casts for the same boy. Arch dimensions are large, and occlusion is essentially ideal.

lip activity in swallowing (note that upper lip figures for swallow and rest are essentially the same). Cheek pressures are observed, however. If the tongue pressures while swallowing saliva are compared with those in a group of American children (Fig. 8), it can be seen that pressures in the aborigines are lower. Considerable individual variation occurs and pressures during swallows of water rather than saliva are more similar in both groups. Nevertheless, the over-all trend seems clear: the larger dental arches are associated with smaller, not larger tongue pressures in swallowing.

Resting pressures of tongue and lips in the mandibular arch are compared in Figure 9. Lingual resting pressures are slightly higher in the Americans, while resting lip pressures are almost exactly the same.

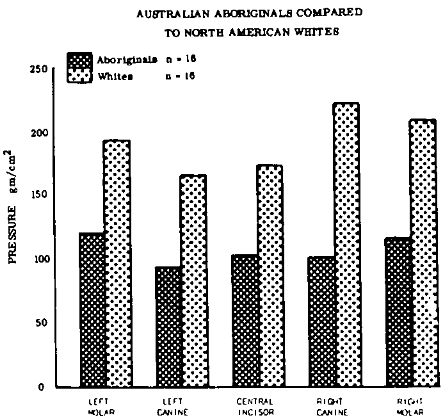

Fig. 8 Although there is large variability within both groups, the aboriginal subjects on the average have lower tongue pressures during swallowing than white children of comparable ages in Kentucky. There is an inverse relationship between tongue pressure and arch dimensions when these groups are compared: larger arch dimensions are associated with lower pressures.

American subjects produce considerably less tongue pressure during speech than swallowing. The swallowing/speech ratio ranges from 5:1 to 10:1. The swallowing/speech pressure ratio is less in the aborigines, usually 2:1 to 4:1. This is due both to lower pressures in swallowing and to higher pressures in speech in the native Walbiri dialect. Tongue pressure in the molar region is largely a reflection of tongue positioning for the vowel sound, and in Figure 10 it can be seen that this is comparable for aboriginal and American subjects. Many consonant sounds differ between Walbiri and English, and this contributes to the differences in Figure 10 for anterior pressures. Higher pressures for aborigines for many sounds do seem to be the rule, however.

If the aboriginal data are examined

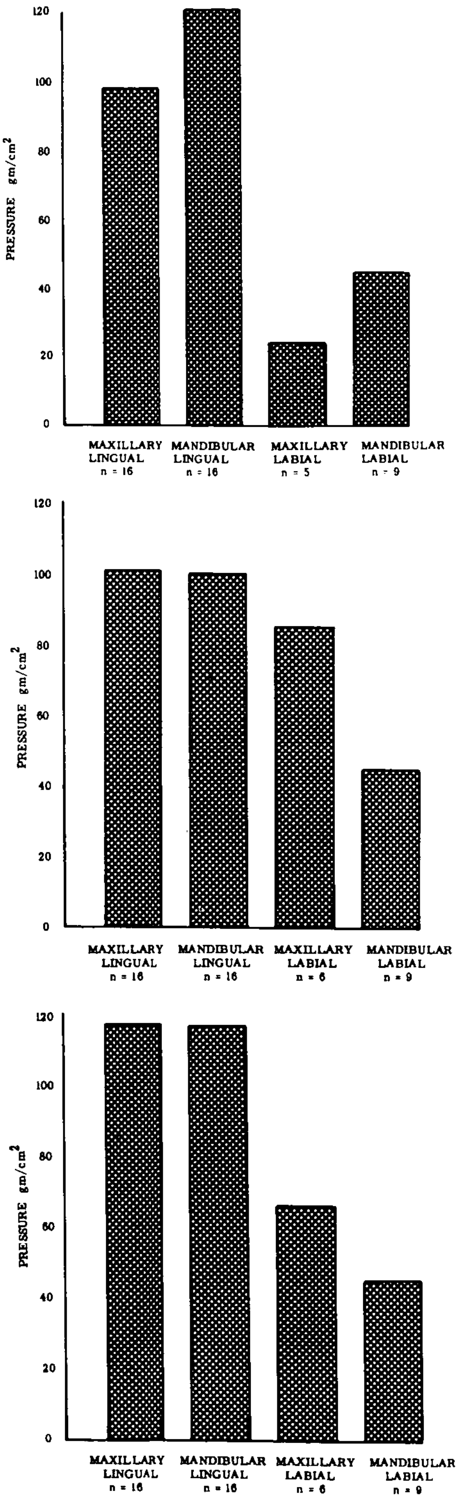

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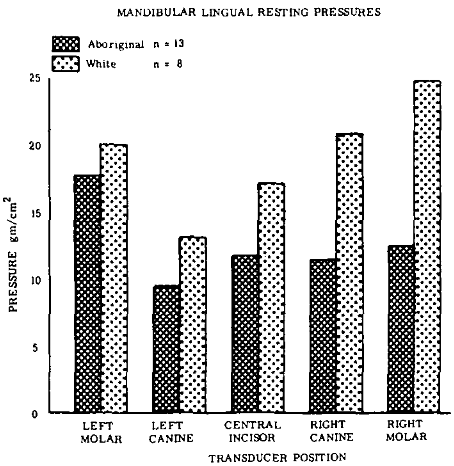
Fig. 7 Tongue and lip pressures during swallows of saliva in Australian aborigines at Yuendumu. Above, incisor region (midline); middle, canine region; below, molar region.



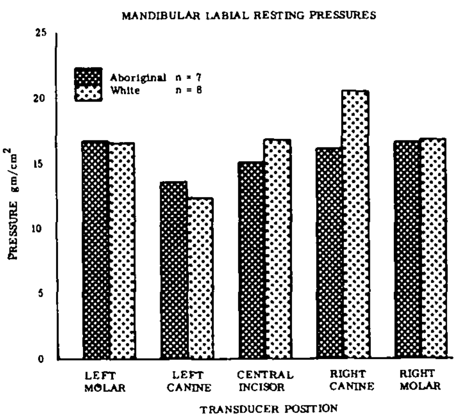


Fig. 9 Lingual resting pressures for the aboriginal subjects were slightly below those for the Americans. Labial resting pressures are quite comparable.

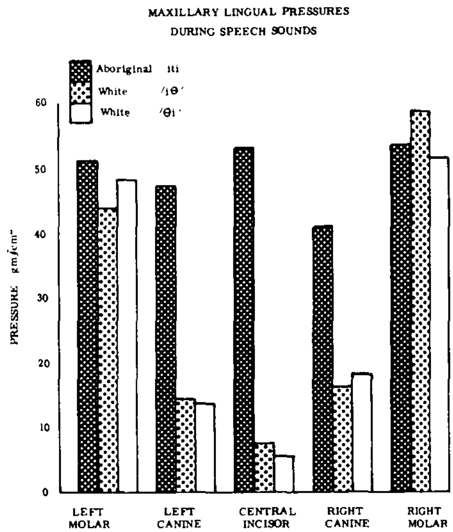


Fig. 10 Lingual pressure during speech sounds for aborigines are about the same or higher than for English-speaking white teenagers in Kentucky. Note that the consonant sounds are not the same for the two groups.

with regard to correlations between tongue-lip pressures and arch form, one area stands out. Despite their expanded arches, there is no indication that expanding tongue forces for the aborigines are even as great as in American subjects with the possible exception of some speech sounds. The restraining resting lip pressures, on the other hand, are almost precisely the same in both groups. The hypothesis which this suggests, that arches may expand until a certain level of lip restraint is encountered, is discussed below with regard to clinical implications.

Clinical Implications of Current Data

Two broad questions of interest to orthodontists may be asked with reference to studies of labial and lingual pressure, both those done in our laboratory and other studies: 1) what do they reveal with reference to the etiology of malocclusion, and 2) what are their implications for stability or relapse after orthodontic treatment?

Muscle Pressures and Etiology

The question of tongue-lip pressures in the etiology of malocclusion is basically a question of the validity of the "equilibrium theory" of tooth position. Since the teeth remain in a stable position most of the time in most people, and since tooth movement is observed when additional forces are added to the system (as by orthodontic appliances, by a poorly designed partial denture, or by contracting scar tissue after an injury), it is apparent that there is an equilibrium which can be upset. It does not follow, however, that the teeth rest in an area of absolute balance between tongue and lip pressures. More correctly then, the question to be considered is how important are the contributions of tongue and lips to the equilibrium. Direction, duration and magnitude of force or pressure are important variables which must be considered.

The data for aborigines in Figures 7-10 illustrate the same finding which other investigators have made repeatedly: even when the longer duration of lip pressures is taken into account, the muscular activity of the lips does not seem to balance the functional activity of the tongue. Maximum pressure magnitudes do not even come close to balancing. Time-pressure integrals come closer but still do not balance. Taking duration factors into account as fully as possible, Lear carried out an experiment using a summation of four-hour recordings, with extrapolation to twenty-four hours from a knowledge of the subjects' activities. Over this longer period there was still no balance of muscular forces.[10] Although our recording sessions with the aboriginal subjects were of approximately thirty minutes duration, there is no reason to believe that balance of pressures during functional activity would have been achieved over longer periods.

Several authors have suggested in the past that resting pressures, rather than pressures during functional activity, might be more likely to influence the position of teeth. Resting pressures are exceptionally difficult to evaluate because of the tendency for a subject to be less at ease with instrumentation in his mouth than without it, and this is particularly true of lingual resting pressures. Nevertheless, it is possible to obtain reasonably consistent measures when the subject's attention is distracted, and this technique was employed with aboriginal and American subjects. As illustrated, there still does not seem to be a lingual-labial balance, but the figures come closer to matching. Brader hypothesizes that the radius of curvature of the dental arch influences the stresses on it, just as is true for other closed containers, and that this factor added to resting pressure would reveal the equilibrium statement which has been sought.[11] In a study carried out at Kentucky, Gorbach failed to find the consistency between resting pressure and radius of curvature which Brader had predicted.[12] We have not completed the calculations for the aboriginal subjects, but it appears also that pressure times radius is not a constant for these subjects.

Brader's equation has certainly been a step in the right direction, and it will be possible in the future more and more to define boundaries for acceptable tooth position along mathematical lines. It appears that resting pressures are more important in determining arch form and degree of protrusion than pressures during functional activity. To achieve an understanding of the equilibrium components it may be necessary to eliminate pressures which are not maintained for a threshold time, or to weigh longer-lasting pressures considerably more heavily than short-acting pressures, giving functional activity a smaller role. Perhaps one should speak, not entirely facetiously, of a "semi-functional matrix."

All the above relates to *horizontal* position of the teeth in the arches. *Vertical* position, on the other hand, may well be influenced by functional activity. The mechanism of tooth eruption remains poorly understood, but the forces accompanying it are only a few grams. Vertically-directed intermittent forces accompanying swallowing and other activities might well influence the rate or amount of eruption and thus create an open bite. Clinical observations support this hypothesis.

Vertically-directed forces have recently been studied at Kentucky using a new transducer design which allows evaluation of the direction of pressure. Only a few subjects have been studied, but the results are at the same time surprising, and analogous to data from studies of equilibrium in horizontal planes. When subjects with an anterior open bite are compared with subjects with normal occlusion, horizontally-directed pressures on the incisors are similar. Vertically-directed pressures during swallowing, however, are less in the open-bite subjects, just the opposite of what might have been expected from equilibrium theory.[13] The results are reminiscent of the findings of an inverse rather than direct relationship between lateral tongue pressure and arch width.

Muscle Pressures and Relapse

To the extent that the etiologic factors which caused a malocclusion remain active after orthodontic treatment, relapse toward the original malocclusion can be expected. Putting the teeth into a stable position has often been equated with putting them into a position which the musculature will accept. This view again, of course, reflects an underlying concept of environmental factors as important in determining tooth position. Not only tongue and lip pressures, but the activity of the muscles which support and guide the mandible, must be considered in a discussion of such environmental factors.

Two types of relapse are often associated with tongue-lip factors related to the muscular equilibrium. The first of these is crowding of the incisors, particularly in the lower arch, when these teeth have been moved labially either to relieve crowding or in association with treatment of Class II malocclusion. It can be shown experimentally that cheek pressures increase as the cheek is displaced.

Crowding which occurs following labial repositioning of incisors, then, can be related with some confidence to increased resting lip pressures. This crowding has little to do with swallowing or functional activities of the lip. Individual differences in lip tonicity are observed in all populations. These differences extend to racial groups as well, so that the forward position of the lips due to the altered facial skeleton and the relative lack of muscle tone in the lips contribute to the beautifully expanded arches of the Australian aborigines.

The second type of relapse which bothers orthodontists is related to "tongue thrusting" and anterior open bite. Orthodontists frequently observe that there is a tendency for both anterior open bite and maxillary overjet to recur after correction in patients with a tongue-thrust swallow. Two inferences are often drawn: 1) the tongue is responsible for the changes in the occlusion, and 2) the relapse occurred as the tongue pushed the anterior teeth into new positions. The discussion above of equilibrium factors suggests that while the first inference may have some validity, the second is almost surely incorrect. Particularly in this situation, a broader view of the muscular environment is necessary.

It has been shown above that horizontal changes in tooth position due to functional pressures are unlikely. An increase in overjet, as well as return of anterior open bite, can accompany changes in vertical position of teeth. All that is required is rotation of the mandible with greater eruption of posterior than anterior teeth. Typical cephalometric findings in such relapse are shown in Figure 11. In this instance, as in most postorthodontic patients, vertical growth occurred after treatment. Even when there is no growth, however, open bite and increased overjet develop not through direct movement of the anterior teeth

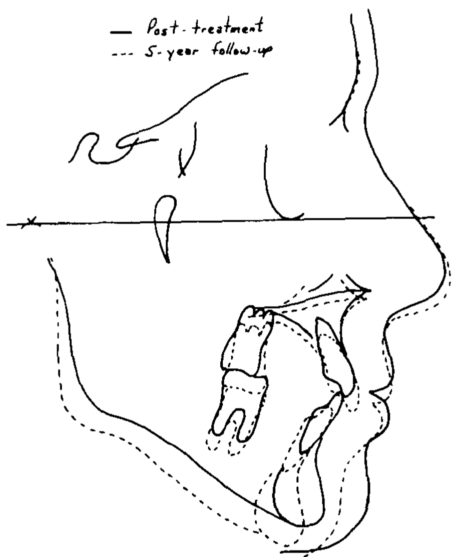


Fig. 11 Relapse into open bite after treatment has been accompanied by vertical growth and more eruption of posterior than anterior teeth.

to new positions, but through differential eruption of teeth and accompanying rotation of the mandible. The rest position as well as the occlusal position of the mandible may alter as this occurs. The muscles of mastication, of course, are an integral part of the muscular environment and would be expected to interact with any oral cavity changes.

Retention difficulties due to tongue and lip activity are frequently expected in the aftermath of orthodontic-surgical correction of severe malocclusions. Radical changes in the volume of the oral cavity are made quickly with surgery. In some European centers in the past it was common practice to reduce the size of the tongue at the time of jaw surgery in the hope of obtaining greater stability of the dental correction. Once again, an underlying concept of form adapting to function is revealed.

In fact, the experience with surgical orthodontics indicates that in the great majority of cases, function adapts to the change in form. Surgical procedures on the tongue have been shown to be unnecessary in most instances because of the marked physiologic adaptation which occurs postoperatively. When the mandible is set back in Class III correction, the tongue is carried lower in the mouth, as demonstrated by a change in hyoid position;[15] tongue pressures are usually lower rather than higher in the immediate postoperative period. Individuals who have maxillary dental protrusion usually have lower than normal tongue pressures against the maxillary teeth prior to correction. Retracting the anterior maxilla surgically in these patients results in increased tongue pressures during swallowing, but the increase brings the previously low pressures into the normal range.[16]

Occasionally, a marked change in lingual or labial pressure patterns is seen postoperatively, and then the failure of physiologic adaptation may require further treatment. It can be observed that when relapse not related to growth occurs after surgery, the jaw segments remain stable while the teeth alter their position on the supporting bone. It is not known whether the tooth movement which occurs in these cases is related to functional or resting pressures. These cases may represent the tolerance limits of imbalance in functional pressures.[17]

Summary and Conclusions

From the research in recent years relating tongue and lip pressures to dental arch form and tooth position, it appears that the form of the dental arches dictates the functional pattern of tongue and lips to a much greater extent than function alters form. To the extent that the form of the dental arches is influenced by the musculature, resting pressures and the resting posture of tongue and lips seem more important than pressures during swallowing or speech.

Muscular influences which affect the vertical position of teeth remain much less well-understood than those which affect horizontal tooth position. Direction, duration and magnitude of forces on the dentition are all important, but present studies have not emphasized force direction as much as is desirable. Intraoral devices which can record the component of force or pressure in any selected direction are now being tested, and new data from instrumentation of this type will be available in the next few years. An influence of the tongue on the vertical position of teeth seems likely from clinical observation, but there is little information as to the importance of resting pressures versus those generated during swallowing.

Our increasing knowledge of the extent to which oral function adapts to form should allow orthodontists to approach many severe malocclusions with increased confidence. At the present time it can be predicted that approximately 80-90 per cent of malocclusions in which an environmental cause is possible can be treated successfully without relapse and without any therapy directed specifically at altering muscular patterns. This, of course, means that function adapted to the altered anatomic form in these patients. Our challenge in the next few years is to learn how to predict which 10-20 per cent of patients will not adapt, and how to deal with the problems this failure of adaptation creates.

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