A prospective study of lip adaptation during six months of simulated mandibular dental arch expansion

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Maintaining treatment results is one of the greatest challenges facing the field of orthodontics today. Stability is less than desired with almost any orthodontic treatment, but it is particularly poor when the dental arches are expanded.[1-4]

One of the factors that may play a role in this instability is the pressure that the oral soft tissues exert on the teeth. Because pressures from the soft tissues at rest play a role in determining the pretreatment position of the teeth,[5] they also may play a role in repositioning the teeth after orthodontic movement.

The long-term response of the oral soft tissues to changes in tooth position resulting from conventional orthodontic treatment using fixed appliances is unclear. Short-term, it has been documented that displacing the cheeks (as would happen if the dental arch was expanded) results in an increase in pressure on the displacer (i.e., the teeth, if they have been moved orthodontically).[6] This increase in pressure from the cheeks would result in a disruption of the equilibrium that governs tooth position.[5] If nothing held the teeth in this new position, they presumably would return toward their original positions. If the increase in pressure is maintained indefinitely, retainers would be needed indefinitely to maintain the teeth in their new positions. Evidence to support the hypothesis that the increase in pressure may be maintained indefinitely is found in the recommendation from a long-term stability study on dental arch expansion.[1] The authors of this study recommend that retainers be worn indefinitely. Other factors, however, could

Abstract

The stability of dental arch expansion with conventional orthodontic treatments is disappointing. An increase in labial soft tissue pressure resulting from the expansion may contribute to this instability. An 8-month study of lip pressure changes resulting from lip bumper wear has been conducted, but no long-term studies have been conducted on pressure changes resulting from conventional expansion using fixed appliances. The purpose of the current study was to investigate changes in labial soft tissue pressures when conventional expansion was simulated. Twenty-two subjects wore a stent simulating mandibular dental arch expansion. They were instructed to wear the stent full-time. Lip pressure was recorded initially at 1 week, and monthly for 6 months. A repeated measures ANOVA was used for statistical analysis. A statistically significant ($P \leq 0.05$) increase in pressure was documented after initial insertion of the expansion-simulating stent. The increase was not maintained, suggesting an adaptation of the labial soft tissues.

Key Words

Lip pressure • Adaptation • Dental arch expansion

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play a role in this instability of treatment. Long-term studies of soft-tissue pressure changes resulting from conventional orthodontic treatment have not been conducted. This type of study is needed to elucidate the role of soft tissue pressures in posttreatment instability.

Treatment strategies to improve stability

A specific therapy (i.e., the function regulator appliance of Frankel) has been developed in response to the hypothesis that pressure from the labial soft tissues increases with conventional dental arch expansion and that the increase in pressure is maintained after expansion.[7] This appliance holds the labial soft tissues away from the teeth with acrylic shields. These shields not only allow the dental arch to expand (as the forces from the tongue on the teeth are no longer opposed by the forces from the labial soft tissues), they also are meant to encourage adaptation of the lips and cheeks so that the pressure they exert on the teeth is less that it would have been if the teeth had been moved labially with routine orthodontic treatment. This decrease in pressure should translate to improved stability of treatment. However, long-term studies of the stability of treatment with this therapy are few and the data thus far is inconclusive.[8,9]

The lip bumper expands the dental arch in a similar fashion, by holding the labial soft tissues away from the teeth.[10-12] No long-term studies of stability following lip bumper wear have been published.

Studies of soft tissue pressure changes

Long-term retrospective studies of posttreatment stability are very difficult to complete, and their results are often subject to criticisms that prospective studies do not incur. (It is more difficult to eliminate extraneous variables and bias in a retrospective study). If pressures from the oral soft tissues play a role in posttreatment instability, it may be possible to investigate the relative stability of different treatment protocols in a prospective manner by studying changes in soft tissue pressures. The soft tissues exert pressure against the teeth in a number of circumstances (i.e., during speech, during swallowing, during chewing, and when the soft tissues are at rest). Proffit and coworkers have shown that the pressures that influence tooth position most significantly are the long-acting pressures, those exerted when the tissues are relaxed or at rest.[13] These resting pressures have the duration needed to influence tooth position.

One study has been published of lip and cheek pressure changes associated with mandibular lip bumper wear over an 8-month period.[11] The authors measured pressure at two mandibular sites, the midline and the left canine. The two sites varied in their response, but over time both sites demonstrated decreases in resting pressures to significantly below the original values. These decreases in pressure occurred even though arch expansion was documented (the mandibular incisors flared an average of 1.5 mm). The results of this study might be taken as evidence that treatment with a lip bumper will lead to better stability than treatment with conventional orthodontics, but that conclusion would be premature without a comparable study of lip pressure when arch expansion was accomplished without the use of a lip bumper.

Short-term (1 week) changes in resting lip and cheek pressure secondary to simulated mandibular expansion have been studied.[14] In this investigation, as in the lip bumper study just mentioned, there were different responses in the two sites studied. In the midline, average pressure increased significantly with initial (simulated) expansion, then decreased to a point where it was no longer significantly different from the pressure found without simulated expansion. However, the pressure level was still higher than the original (pre-expansion) value, and it was not significantly different from the initial value with simulated expansion. In the canine area, average pressure increased significantly with expansion, and it did not significantly change during the 1 week period of the study. It was concluded that a pattern consistent with adaptation was found in the midline, but further long-term studies would be needed to compare the adapation seen with conventional dental arch expansion with that seen with lip bumper wear.

The purpose of this study was to evaluate changes in lip pressure over a 6-month period when dental arch expansion was simulated.

Materials and methods

Sample selection

This investigation was an extension of a previous study, and the sample selection, stent fabrication, and testing procedures were the same as described in earlier publications.[14,15] Advertisement of the study was made within the University of Kentucky Medical Center. Twenty-two subjects were selected for the sample, 10 males and 12 females. All subjects were young adults, ranging from 20 to 30 years

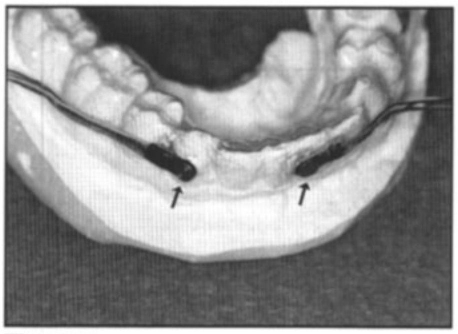

Figure 1

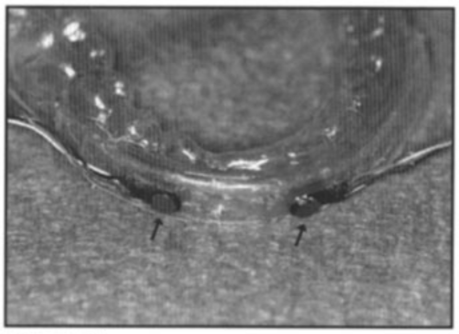

Figure 2

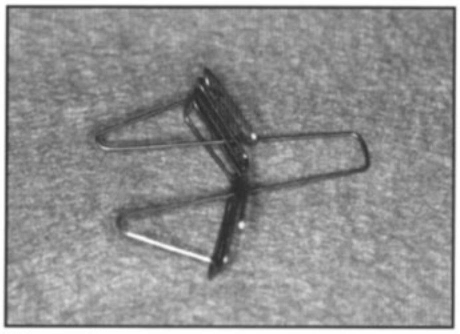

Figure 3

Figure 1
One of the non-expanded mandibular stents demonstrating placement of the transducers approximately midcrown over the right canine and in the midline. Arrows indicate transducers.

Figure 2
One of the stents fabricated to simulate expansion of the mandibular dental arch. This figure also demonstrates placement of the transducers (arrows indicate transducers).

Figure 3
A custom-made lip retractor used to hold the lip away from the transducers while allowing the lips to close.

of age. The inclusion criteria were: (1) Good health with no craniofacial anomalies or reported speech impairments; (2) No pharmaceutical therapy that might influence muscle tone; (3) No orthodontic treatment within the past 5 years; (4) No evidence of dental or periodontal disease; (5) Class I dental and skeletal relationship; and, (6) No habits reported that could affect lip pressure. Because adaptive changes over time were being examined, the pretreatment measurements served as controls.

Stent fabrication

Mandibular impressions were made, and stone casts were poured. This study focused on soft-tissue pressures against the mandibular arch because a long-term stability study found that the mandibular arch is less stable than the maxillary arch[3] and so that comparisons might be made with a previous study on lip pressure changes associated with lip bumper wear.[11] Three thermally sensitive polyvinyl plastic stents were constructed for each subject. One mandibular stent was formed directly over the cast and two pressure transducers (Entran EPL6 flatline pressure transducers, Entran Devices, Fairfield, NJ) were affixed to the buccal surface, approximately midcrown (occlusogingivally), over the right canine and in the midline (Figure 1). This stent was used to measure pressure acting on the teeth in their original positions (no simulated expansion). The second and third mandibular stents were formed to simulate approximately 2.5 mm of labial movement or dental arch expansion. One served to carry two transducers in the positions just described (Figure 2) and the other was prepared for the subject to wear full-time (no transducers).

Lip pressure tests

Resting lip pressure against the mandibular dentition was recorded, using a technique described previously,[14,15] at the beginning of the experiment, at 1 week, and once a month for 6 months. Briefly, each of the stents bearing transducers was calibrated in a pressure chamber that had been warmed to approximate the subject's oral temperature. The stent (and the transducers affixed to it) was placed in the subject's mouth and allowed to warm until the voltage registered by the transducers stabilized (approximately 1 to 2 minutes). The subject was asked to relax his or her lips and the voltage registered by each transducer was recorded for 10 seconds. A custom-made lip retractor (Figure 3) was used to hold the lip away from the transducers while allowing the lips to close (temperature changes resulting from inspired and expired air thus were eliminated). A 10-second recording of the voltage registered with no lip pressure was made. At least three series of lip-resting and lip-held-away recordings were made to allow familiarization with the measuring devices and to produce a precise recording.

The first session measured both pressure against the teeth (to provide a baseline) and pressure against the expansion-simulating stent. All of the following sessions measured pressure against the stent only.

A variation in the methodology from that described in earlier publications[14,15] was necessitated by an equipment malfunction. Approximately halfway through the experiment, the pressure sensor used in the calibration of the transducers ceased to function. In the earlier reported studies, the transducers were calibrated in a chamber in which pressure could be increased a known amount. This increase in pressure was determined visually by a water manometer (an increase of 10 cm of water was used), and was measured by an in-line pressure sensor. The malfunction with the pressure sensor occurred approximately halfway through the experiment, yet it was not noted until after the completion of data gathering. As every test was conducted with the same method (10 cm of water as measured by the water manometer), the valid pressure sensor readings

Table 1
Average midline pressures (x 10² N/m²). N denotes the number of subjects tested.

	Start, non exp	Start, sim exp	1wk, sim exp	1mo, sim exp	2mo, sim exp	3mo, sim exp	4mo, sim exp	5mo, sim exp	6mo, sim exp
Pressure	7.4	13.6*	9.2	10.1	10.3	6.6	8.1	10.6	10.6
S.E.	1.5	1.5	1.3	1.2	3.6	2.4	2.1	3.8	6.7
n	21	22	20	14	9	6	4	4	8

Non exp: Tests conducted with transducers placed close to the teeth (no simulated expansion).
Sim exp: Tests conducted with transducers mounted on a stent formed to simulate expansion.
*: Values that are significantly different from the initial value (Start, non exp) .

Table 2
Average canine pressures (x 10² N/m²). N denotes number of subjects tested.

	Start, non exp	Start, sim exp	1wk, sim exp	1mo, sim exp	2mo, sim exp	3mo, sim exp	4mo, sim exp	5mo, sim exp	6mo, sim exp
Pressure	4.4	9.2*	9.3*	6.3	8.2	2.9	4.4	-2.1	5.3
S.E.	1.0	1.7	1.4	1.5	2.1	3.2	2.3	1.3	2.7
n	19	22	21	13	8	6	4	3	8

Non exp: Tests conducted with transducers placed close to the teeth (no simulated expansion).
Sim exp: Tests conducted with transducers mounted on a stent formed to simulate expansion.
*: Values that are significantly different from the initial value (Start, non exp).

were averaged and this value was used in the calibration for all recording sessions. The average pressure increase in the calibrating chamber was 10.36 cm of water with a standard deviation of 0.54.

Subject instructions

At the conclusion of the first session, the subjects were asked to wear the expansion-simulating stents full-time and to report for the next scheduled measurement session.

Subject compensation

The subjects were compensated for participation in the project. Payment was made at the end of participation and was prorated at a level of $10 per recording session and $15 to $20 per month of continuation ($15 for the first 3 months, $20 for the final 3 months).

Statistical analysis

A one-way, repeated measures ANOVA was applied to the data for statistical analysis. This test was used to evaluate overall variance and to analyze the significance of differences between the initial recording without simulated expansion and all other recordings. In addition, the difference between the initial recording with simulated expansion and all other recordings with simulated expansion was evaluated. A probability value of $P \leq 0.05$ was chosen to represent statistical significance.

Results

Longitudinal lip adaptation

Resting lip pressure increased significantly ($P \leq 0.05$) in both measurement sites with the insertion of the expansion-simulating stents (Tables 1 and 2; Figures 4 and 5). The average pressure in the midline was 7.4 x 10^2 N/m² and it rose to 13.6 x 10^2 N/m² after the expansion-simulating stent was inserted. In the right canine area, the average pressure was 4.4 x 10^2 N/m² and it rose to 9.2 x 10^2 N/m² with simulated expansion.

In the midline, the average pressure dropped by 1 week of stent wear to where it was no longer significantly different than the initial value found without simulated expansion (9.2 x 10^2 N/m² at 1 week). The values varied somewhat during the rest of the experimental period, but they did not vary enough to become significantly different from the initial nonextended value.

In the canine area, the average pressure at 1 week was approximately the same as it was with the initial insertion of the expansion-simulating stent (9.3 x 10^2 N/m²). This value was significantly different from the initial nonextended value ($P \leq 0.02$) as was the initial expansion-simulated value. At 1 month, and for the rest of the experimental period, the pressure values dropped to the extent that they were no longer significantly different from the initial nonextended value. At 3 months, and again at 5 months, the pressure values were significantly lower than the value registered at the initial insertion of the expansion-simulating stent ($P \leq 0.03$ and 0.01 respectively).

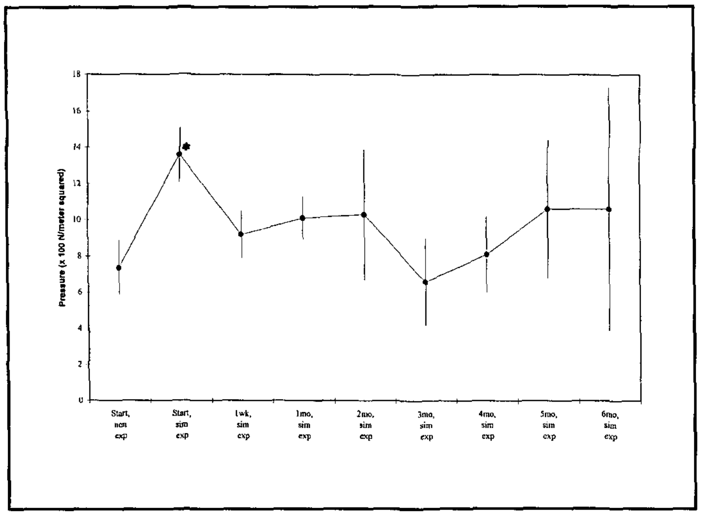

Figure 4

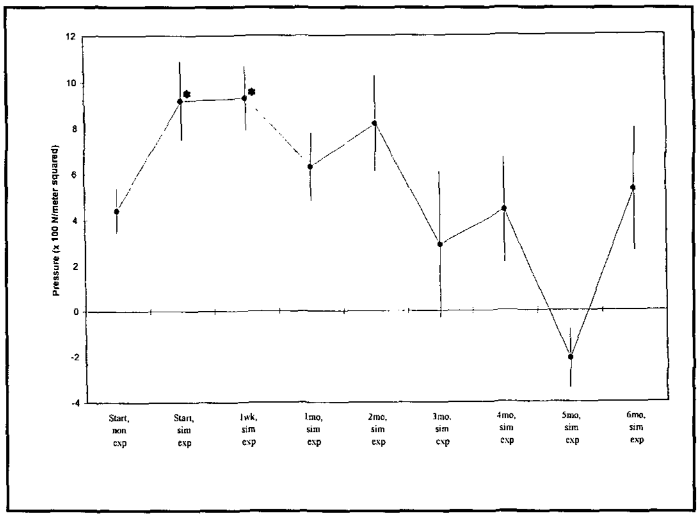

Figure 5

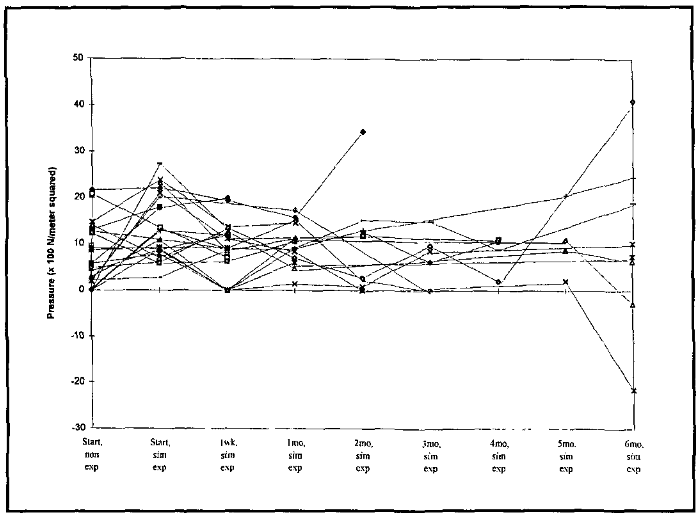

Figure 6

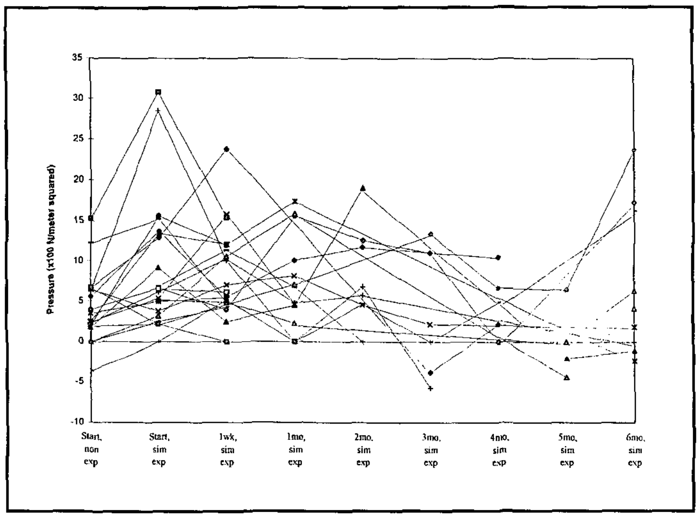

Figure 7

Variability

The subjects demonstrated considerable variability in their soft tissues responses to simulated expansion (Figures 6 and 7).

Subject compliance

The compliance of the subjects in attending the scheduled measurement sessions was less than ideal. Tables 1 and 2 give the number of subjects that had valid pressure measurements for each session. The range of subjects available was from 22 (the total number of subjects enrolled in the study) to 4 (only 3 subjects were recorded for month 5 in the canine area because the transducer in that area malfunctioned for one subject during that session). Fortunately, most of the significant changes occurred during the time when the level of compliance was reasonable.

Figure 4
Average midline pressures (x $10^2 N/m^2$). Vertical bars indicate one standard error. 'Non exp' indicates tests conducted with the transducers placed close to the teeth (no simulated expansion). 'Sim exp' indicates tests conducted with the transducers mounted on a stent formed to simulate expansion. Findings significantly different from initial (start, non exp) are marked with an asterisk (*).

Figure 5
Average canine pressures (x $10^2 N/m^2$). Same conventions and notations as Figure 4.

Figure 6
Midline pressures of all subjects (x $10^2 N/m^2$) demonstrating inter- and intra-subject variability. Same conventions and notations as Figure 4.

Figure 7
Canine pressures of all subjects (x $10^2 N/m^2$) demonstrating inter- and intra-subject variability. Same conventions and notations as Figure 4.

Discussion

Lip adaptation

The pressures exerted by the resting labial soft tissues on the teeth increased with the initial placement of a stent formed to simulate dental arch expansion. The pressures then decreased over the first month of simulated expansion to the point where they were no longer significantly different from the initial reading. In the canine area, the average recorded pressure dropped at 3 and 5 months to the extent that the readings were significantly different from the value recorded at the initial placement of the expansion-simulating stent. These decreases in average pressures over time indicate an adaptation in the oral soft tissues. Tissues in the midline adapt sooner than tissues in the canine area.

Mechanism of adaptation

How this adaptation occurs is not clear. The labial soft tissues are made of muscular and nonmuscular elements. The principle muscular element in the mandibular midline is the orbicularis oris (horizontal bands and incisive bands).[16,17] A number of muscles are found in the canine area, including the orbicularis oris (horizontal, incisive and oblique bands), the buccinator, the caninus or levator anguli oris, the zygomaticus major, the risoris, the platysma, and the triangularis or depressor anguli oris.[16,17] These muscular elements may adapt by elongating, or, for those that insert in bone, by migration of the bony attachment[18] or lengthening of the tendonous attachment.[19] Elongation of muscles occurs by the addition of sarcomeres, and this addition can take place during growth[20] or in response to a stretching immobilization.[19] In the orofacial area, McNamara has documented muscle lengthening in response to bite opening in monkeys,[21] and Oudet and Petrovic have shown the number of sarcomeres responds to the distance between two attachments in rats.[22] (An increase in the distance between attachments results in an increased number of sarcomeres and a decrease in distance results in a decreased number of sarcomeres.) A similar phenomenon must occur in the bone-lengthening procedures published by Ilizarov[23] and applied to the orofacial region (lengthening of the maxilla) by Altuna and coworkers in their primate studies.[24] Studies have not documented the time needed for the addition of sarcomeres in humans, so it is not known if this mechanism could account for the adaptation seen in this study.

The nonmuscular elements include collagen, tendon, skin, and interstitial fluid.[6] These soft tissues may adapt by changing shape, allowing a reduction in pressure. Weinstein and coworkers have shown that the cheeks react to pressure much as a fluid-filled double elastic membrane would.[6] Another possible mechanism for adaptation seen in this study is the displacement of the more fluid-like components of the involved soft tissues.

Finally, the presence of the stents may produce a new sensory input that, in turn, may alter the neuromuscular behavior of the soft tissues. Frankel suggests that this may be a mechanism for the vestibular shields of his appliance.[7]

Implications of adaptation

The implications of this adaptation on treatment stability are uncertain. Though it has not been tested, moving the teeth facially would likely decrease the pressure exerted on the teeth by the tongue. In order to reestablish equilibrium, the pressures exerted by the lips and cheeks therefore would need to be less than they were before the teeth were moved. In this experiment, the pressures dropped after simulated expansion to the point where they were no longer significantly different from the pre-expansion values. Occasionally the pressures dropped below the pre-expansion values, but there was no sustained drop from the pre-expansion values as would be needed to reestablish equilibrium and to aid in stability. Pressures from the lips and cheeks, therefore, are likely contributors to posttreatment instability when the teeth have been expanded by conventional orthodontic techniques.

Although comparisons are difficult due to differences in study design, it appears that the adaptation seen when dental arch expansion is accomplished with a lip bumper differs somewhat from that found in this study. Soo and Moore found that resting pressure in the left canine area decreased significantly 1 month after the beginning of treatment and continued to decrease when measured 7 months later.[11] In the midline, the pressure rose slightly (not significantly) at 1 month, then dropped at 8 months to a point where it was significantly lower than the initial value. These significant reductions in labial soft tissue pressure are more consistent with what is expected if equilibrium is to be reestablished. The stability of treatment with this type of appliance (lip bumper), as a result, may be better than the stability found when treatment is accomplished with conventional appliances. Well-controlled studies of lip and cheek pressure changes, comparing expansion completed with lip bumpers to expansion completed with conventional appliances, are needed to further address the potential differences in stability resulting from these two types of treatment.

Variability and subject compliance

Interindividual variation has been reported in many studies of intraoral soft tissue pressures.[11,13-15,25-27] Thus it is not surprising that a great deal of variation between subjects was found in this study as well (Figures 6 and 7).

What is perhaps more striking to those unfamiliar with this type of study is the degree of intraindividual variation found in this study (Figures 6 and 7). Other investigators have reported similar findings.[27,28] As the reliability of the transducers used in this study has been documented,[15] possible reasons for this variability include undiscovered methodological errors, variations in actual wear time prior to testing sessions (the subjects were asked to keep a record of wear time, but very few complied), variations in personal stress levels at the times of testing, and perhaps other unidentified factors that influence muscle tone.

Subject compliance was disappointing as reflected in attendance for measurement sessions. The number of subjects dropped from a high of 22 for the first measurement session to a low of 4 at the fourth and fifth months. Fortunately, the use of the ANOVA will account for the differences in the number of subjects at each time point.[29] It is not surprising to have difficulties in compliance with a prospective study such as this one, especially when the subjects receive no tangible benefit other than the financial compensation that was offered.

Averaged pressure sensor readings used for calibration

An equipment malfunction described earlier necessitated the use of averaged pressure sensor readings for the calibration of the transducers. The validity of using these averaged pressure sensor readings for calibration can be evaluated by comparing the results of this study with the results of an earlier study that analyzed a subset of these data.[14] The earlier study analyzed the initial and 1 week data. Actual (not averaged) pressure sensor readings were used for calibration.[14] Though there were slight variations in the results (e.g., the pre-expansion pressure value for the canine area was 4.4×10^2 N/m^2 in the current study vs. 4.5×10^2 in the earlier study), the statistical analyses of the results were identical. This similarity in results substantiates the use of the averaged pressure sensor readings.

Negative pressures

A few of the subjects recorded negative pressures during the study. Negative pressures have also been reported by other authors.[25,27] These pressures may be real or they may be due to errors in methodology. One conceivable error would involve allowing the device used to hold the lip away from the teeth to rest against the teeth (causing the "lip off" pressure recording to be higher than the "lip rest" pressure–resulting in a negative pressure value). Small negative values also could be attributed to imprecision in the measurement equipment.

Simulated expansion

Simulated expansion, as performed in this study, may or may not accurately reflect the changes that would occur if conventional dental arch expansion were actually carried out. In this study an immediate expansion of approximately 2.5 mm was simulated. It is possible that the soft tissues would react somewhat differently if brackets were actually placed, the teeth moved in a gradual manner, the brackets then were removed, and soft tissue pressures then were studied for a period of months. A study of soft tissue pressure changes with actual, not simulated, expansion is needed and is currently being planned in our laboratory.

Conclusions

1. The pressure exerted by the labial soft tissues increased significantly when mandibular dental arch expansion was simulated, then returned over time to its original level. It is concluded that the labial soft tissues adapted to simulated conventional dental arch expansion.

2. The pressure in the midline adapted sooner than in the canine area, but both adapted within 1 month.

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