Lip adaptation to simulated dental arch expansion. Part 1: Reliability and precision of two lip pressure measurement mechanisms

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Understanding the influence of lip and tongue pressures on tooth position requires an ability to measure lip pressure in a reliable and precise way. A transducer with a beam mechanism has been used in many important studies in the past.[1-6] A transducer with a diaphragm mechanism has been recently introduced.[7,8] Comparative in-vivo tests of their reliability have not been published. The beam transducer responds to force by a bending (elastic deformation) of the beam. This results in a temporary elongation of the beam. Since the beam is one part of an electronic circuit (a Wheatstone bridge), this elongation alters the voltage signal that is sent to a computer from the beam. The beam in this transducer can deflect in only one direction, so this transducer can only record force that is exerted in one direction. Since forces from the oral soft tissues may be exerted in more than one direction, this design may impose some restrictions on the accuracy of intraoral pressure measurement.

The electronic design of the diaphragm transducer is similar, yet the diaphragm is capable of responding to force from more than one direction. As discussed above, this may allow greater measurement accuracy. In addition, this diaphragm transducer has a compact design and does not require mounting with space behind the transducer as the beam transducer does (space is needed to allow the beam to deflect). Consequently, the sensing surface of the diaphragm transducer can be placed closer to the surface of the tooth being studied. This may also increase the accuracy of measurement. Comparative in-vivo tests of reliability and/or precision have not

Abstract

Understanding the influence of lip and tongue pressure on tooth position requires a reliable method of measuring pressure. A transducer with a beam mechanism has been used extensively in the past. A transducer with a diaphragm mechanism has been recently introduced. Comparative in-vivo tests of these transducers have not been published. The purpose of this study was to investigate transducer reliability and precision. Transducers were placed intraorally in 22 subjects, and two lip pressure measurements were recorded. Paired *t*-tests and interclass correlations were used to evaluate repeatability and reliability. The error of the method was analyzed for each transducer type. Both transducer types produced measurements that were repeatable and reliable. The error was smaller for the diaphragm transducer. The diaphragm transducer is more precise.

Key Words

Lip pressure • Reliability • Precision • Repeatability

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Figure 1
Stent carrying two diaphragm-type transducers.

Figure 2
Stent carrying two beam-type transducers.

Figure 1

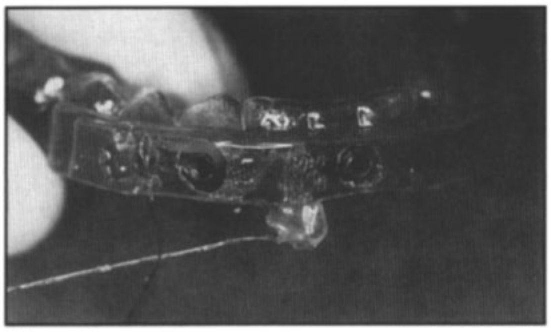

Figure 2

Table 1
Extension of the transducers from the tooth surface in millimeters. Each total measurement is the sum of the thickness of the material, the extension strips, and the transducer. The standard deviation (SD) for these measurements was also calculated.

Stent	Material thickness	Extension strips	Transducer thickness	Total extension (mean)	SD
Diaphragm transducer stent	0.28	None	1.05	1.3	0.1
Simulated expansion	0.63	2	None	2.6	0.1
Beam transducer stent	0.63	2	Flush	2.6	0.1

been published for these two transducer types.

The purpose of this study was to evaluate the reliability and precision of these two types of transducers.

Materials and methods

Age, gender, and orthodontic classification of subjects

Twenty-two subjects were identified and informed consent was obtained. The group included 10 males and 12 females who ranged in age from 20 to 30 years. The average age was 23.3 years (22.2 for males and 24.2 for females) with a standard deviation of 1.9 years. All subjects demonstrated an Angle Class I occlusion.

Transducer description and calibration

Commercial diaphragm-type pressure transducers were purchased (Model EPL6, Entran Devices, Fairfield, NJ). Preliminary tests with these transducers revealed apparent temperature-related voltage shifts that lasted for a few seconds just after the lip was allowed to contact the transducer. Believing that these shifts resulted from a difference in temperature between the transducer surface and the lip, the excitation voltage was reduced from 6 volts to 0.9 volt. The voltage shifts were eliminated.

Beam transducers were fabricated for the University of Kentucky using a design employed in a number of previous studies.[1-5] A custom-designed power supply and amplification unit was used to control and monitor both types of transducers.

Impressions of the subjects' mandibular teeth were made. From these impressions, stone casts were poured and thin, clear, plastic stents (TruTain Inc, Rochester, Minn) were formed over the casts using a Biostar machine (Great Lakes Orthodontics, Tonawanda, NY). For the diaphragm transducer-bearing stent, the transducers were glued to the surface of the stent at approximately the midpoint, occlusogingivally, of the crowns of the teeth to be investigated (right canine and midline area, see Figure 1). The sensing surfaces of the transducers were approximately 1.3 mm from the surface of the teeth (Table 1).

For the beam transducer, the stent was formed approximately 2.5 mm away from the surface of the cast by placing two wide rubberbands over the surface of the cast prior to forming the stent. A 4 mm diameter round hole was cut through the stent in the areas to be evaluated (same as described for the diaphragm transducer) and a 2 mm diameter round piece of plastic (0.5 mm thick) was glued to each of the beams to act as the sensing surface of the transducer. The transducers were then mounted on the cast side of the stent so that the plastic sensing surfaces were centered in the hole in the stent and were both parallel to and flush with the lip-side surface of the stent (Figure 2). The sensing surfaces of the transducers were approximately 2.6 mm from the surface of the teeth (Table 1).

The transducers were calibrated prior to place-

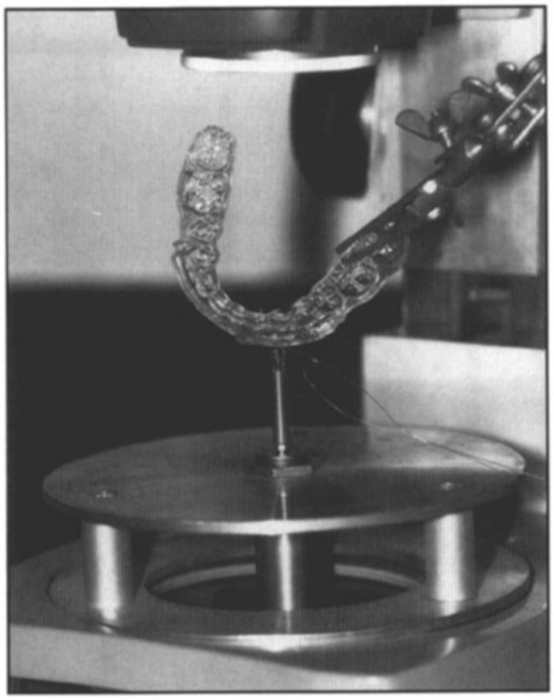

Figure 3

Figure 3
Force displacement gauge used for calibrating the beam-type transducers. The displacement gauge is positioned vertically in the center of a microscope objective table.

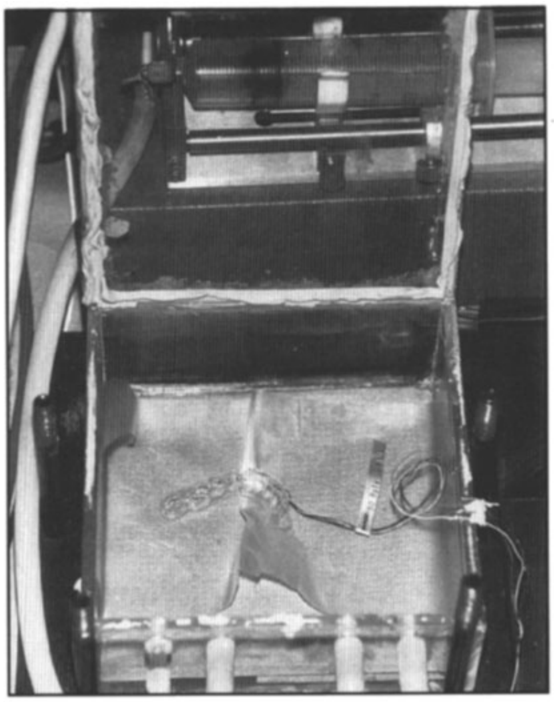

Figure 4

Figure 4
Custom-built pressure chamber used for calibrating the diaphragm-type transducers. Pressure is generated by an infusion pump (Harvard Apparatus, Dover, Mass.) and is monitored with a water manometer.

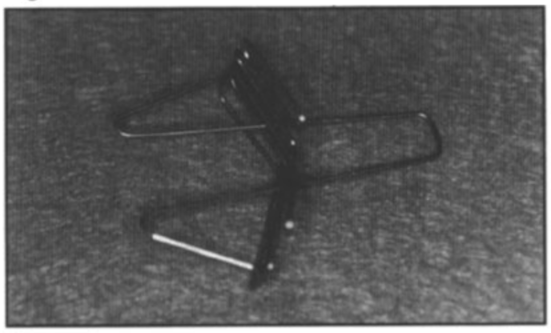

Figure 5

Figure 5
A custom-made appliance for retracting the lower lip. The appliance was placed intraorally between the lip and the transducers, the lips were closed, and the appliance was gently pulled away from the transducers.

ment. Each beam transducer, affixed to its stent, was mounted on a modified microscope that had a force displacement gauge centered in the objective table (Figure 3). The microscope lens and a custom-made guide were used to certify that the center of the sensing surface of the transducer was placed against the force displacement gauge during calibration. All the transducers, including the displacement gauge, were electronically connected to a computer (IBM Model 80 386) and changes in voltage were measured and recorded using data acquisition and playback software (Dataq Instruments, Inc, Akron, Ohio).

Prior to calibration of the beam transducers, the force displacement gauge was calibrated by measuring the difference in voltage recorded with and without a 2 gm weight. A calculation of the force-per-volt was then made. Calibration of each beam transducer was accomplished by pressing the transducer against the force displacement gauge. With this arrangement, the force acting on the transducer was equal to the force acting on the gauge. The force acting on the displacement gauge was calculated from the change in voltage (using the force-per-volt figure derived earlier). The calibration of the transducer to determine the pressure per volt was accomplished using the value of the force acting against it, the area of the sensing surface, and the voltage registered when deflected by the force displacement gauge.

The diaphragm transducers were calibrated by placing them in a custom-built pressure chamber (Figure 4). The transducers were heated to the subject's oral temperature (measured just prior to calibration, the average temperature was 96.3°F with a standard deviation of 1.3°) and pressure in the chamber was increased to approximately 10 cm of water using a water manometer as a guide. Actual pressure in the chamber was calculated with an in-line pressure sensor that had been calibrated to barometric pressure. The diaphragm transducers were calibrated by dividing the pressure in the chamber by the difference in voltage registered by the transducer (pressure in chamber {approx. 10 cm of water} / [voltage at 10 cm of water – voltage at atmospheric pressure]) to give a value of pressure per volt. The average value was 68.9 inches of mercury per volt with a standard deviation of 27.1.

Lip pressure measurement

Each subject was seated comfortably upright and the stent bearing the diaphragm transducer

Table 2
Resting pressure values as calculated from both types of transducers. Data listed in 10^2 N/m^2 ± standard deviation.

Location	Midline	Right canine
Transducer type		
Diaphragm	7.44 ± 6.8	4.53 ± 3.87
Beam	19.67 ± 14.8	10.92 ± 12.05

was placed intraorally. The voltage registered by the transducer was monitored until it stabilized as the transducer adjusted to oral temperature. This stabilization usually took 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 5) was then inserted in the subject's mouth to hold the lower lip away from the transducers while allowing the subject to maintain lip seal. This series of "lip-on" and "lip-off" recordings was performed at least three times to allow familiarization with the equipment and to produce two precise recordings. These two recordings, made one directly after the other in an attempt to eliminate the influence of any other variables, were used to test the repeatability of the measurement mechanisms. The stent bearing the beam transducers was then placed intraorally and voltages were recorded in a similar manner. Resting lip pressure was then calculated.

Statistical analysis

Repeatability was evaluated using the voltage recordings representing lip-on and lip-off measurements. Two sets of measurements, repeated immediately, were evaluated using paired Student's *t*-tests to determine the significance of any differences in the measurements (the level of significance was set at 0.05). The extent of correlation of the repeated lip-on and lip-off measurements was evaluated using an interclass correlation. The error of each method was also analyzed using these same voltage values. Dahlberg's formula: $\sqrt{\frac{\sum d^2}{2n}}$ was employed for this analysis.[9] Finally, the voltages for resting lip pressure were calculated (lip-on minus lip-off) and converted to actual pressure values to allow comparisons between these transducers and those in the published literature.

Results

The average resting pressures registered by the beam transducers were 19.7 x 10^2 N/m^2 in the midline and 10.9 x 10^2 N/m^2 in the right canine area (Table 2). The pressures registered by the diaphragm transducers were 7.4 x 10^2 N/m^2 for the midline and 4.5 x 10^2 N/m^2 in the right canine area (Table 2). When the voltage values for lip-on and lip-off (Tables 3 and 4) were evaluated with the Student's *t*-test for repeatability, all but one of the tests were shown to have no significant difference between the two repeated tests ($P < 0.05$). A significant difference was reported for the midline diaphragm transducer in the lip-on position (Table 4). When the lip-on and lip-off voltages were evaluated with the interclass correlation evaluation, all correlations were very high with the diaphragm transducers correlating slightly higher than the beam transducers (Tables 3 and 4). The error of the method was smaller for the diaphragm-type transducer than for the beam-type transducer for each measurement evaluated (Table 5). When the pressure values registered by the two transducers were compared, the beam transducers showed pressures slightly greater than twice the pressures registered by the diaphragm transducers in both measurement sites. Both types of transducers reported higher pressures in the midline than in the canine area.

Discussion

Transducer repeatability and accuracy

All but one of the repeated tests demonstrated no significant difference between the tests. Both types of transducers can thus be considered repeatable. The one anomalous finding was the significant difference found with repeated recordings of lip-on with the diaphragm transducer. The reason for this finding is not clear. One possibility is that the increased precision of the diaphragm transducers (as indicated by the smaller standard error values as well as by the results of the error of the method analysis) is responsible for making a very common mean difference (the mean difference for this lip-on test was very similar to that found with the beam transducers) appear uncommon.

Repeated measures from both types of transducers demonstrated high levels of correlation. They are both reliable for intraoral lip pressure measurements.

Studying the error of the method for each transducer allows us to compare the transducers for precision. The diaphragm transducers consistently elicited a smaller error than the beam

Table 3
Beam transducers. Average voltage outputs of repeated lip-on and lip-off measurements with standard deviations (data in volts). Mean difference between repeated measures with standard error, and P value of paired *t*-test (significance set at P < 0.05). Intraclass correlation of repeated measures.

	1st test	2nd test	Mean diff. ± std err	P value (*t*-test)	Intraclass correlation
Midline, lip off	-0.00638 ± 0.0132	-0.00586 ± 0.0128	-0.00064 ± 0.0015	0.6667	0.91
Midline, lip on	0.01063 ± 0.0204	0.00852 ± 0.0195	0.00258 ± 0.0027	0.3565	0.86
Canine, lip off	-0.00859 ± 0.0381	-0.00729 ± 0.0405	-0.00279 ± 0.0032	0.4042	0.98
Canine, lip on	0.00583 ± 0.0453	-0.00625 ± 0.0390	0.00639 ± 0.0078	0.4321	0.89

Table 4
Diaphragm transducers. Average voltage outputs of repeated lip-on and lip-off measurements with standard deviations (data in volts). Mean difference between repeated measures with standard error, and P value of paired *t*-test (significance set at P < 0.05). Intraclass correlation of repeated measures.

	1st test	2nd test	Mean diff. ± std err	P value (*t*-test)	Intraclass correlation
Midline, lip off	0.01817 ± 0.0105	0.01845 ± 0.0103	-0.00028 ± 0.0003	0.4064	0.99
Midline, lip on	0.01994 ± 0.0120	0.02123 ± 0.0118	-0.00129 ± 0.0004	0.0020	0.99
Canine, lip off	0.01451 ± 0.0150	0.01764 ± 0.0127	-0.00041 ± 0.0007	0.5423	0.99
Canine, lip on	0.01730 ± 0.0123	0.01786 ± 0.0124	-0.00050 ± 0.0007	0.4847	0.97

transducers. Thus the diaphragm transducers may be considered more precise than the beam transducers.

Comparision between transducers and with previous studies

The resting pressure levels calculated for the beam transducers were approximately twice the value of those calculated for the diaphragm transducers. The most probable explanation for this discrepancy is the difference in location of the transducers. The sensing surface of the beam transducers was approximately 2.6 mm from the surface of the teeth, while the sensing surface of the diaphragm transducers was approximately 1.3 mm from the teeth. Other factors such as the difference in mechanism of action (beam vs. diaphragm), possible differences in soft-tissue reaction to the different configurations of the transducers, etc., may contribute to the discrepancy in pressure levels reported.

The average resting pressures registered for the beam transducer in this study (19.7×10^2 N/m^2 in the midline and 10.9×10^2 N/m^2 in the right canine area) were very similar to those reported in other studies using this type of transducer. Proffit et al. have reported mandibular midline pressures in a range from 2.6 to 17 gm/cm^2 (2.5×10^2 to 16.7×10^2 N/m^2) and right canine pressures in a range from 2.4 to 20 gm/cm^2 (2.4×10^2 to 19.6×10^2 N/m^2).[1,3,4]

The average resting pressures registered for the diaphragm transducer (7.4×10^2 N/m^2 for the midline and 4.5×10^2 N/m^2 in the right canine area) were somewhat lower than those reported in a similar study conducted by Soo and Moore.[8] They related a resting pressure in the midline of 2.6×10^3 N/m^2 and in the left canine of 6.9×10^3 N/m^2. One factor that may contribute to this discrepancy is the difference in the age of the subjects in the two studies. Soo and Moore studied younger subjects (between the ages of 10 and 12 years) while our study enlisted older subjects. According to Thuer et al., lip pressure tends to decrease with age.[10]

Table 5
Error of the method for each type of transducer.

Function	Location	Transducer	Error
Lip on	Midline	Beam	0.00813
		Diaphragm	0.00149
Lip on	Canine	Beam	0.01894
		Diaphragm	0.00219
Lip off	Midline	Beam	0.00427
		Diaphragm	0.00109
Lip off	Canine	Beam	0.00713
		Diaphragm	0.00204

In addition to being more precise, a number of other factors may be considered advantageous for the diaphragm transducers. The diaphragm design is capable of measuring pressure from more than one direction, while the beam transducer can measure pressure in only one direction, the direction of bending of the beam. This may result in an increase in the accuracy and sensitivity of measurement for the diaphragm transducer. Also, the sensing surface of the diaphragm transducer can be placed closer to the surface of the teeth than the sensing surface of the beam transducer. The extra distance needed for the beam transducer is the result of its mechanism of action: The beam bends back toward the teeth in response to force, and space must be provided for this bending. As has been mentioned, the sensing surface of the diaphragm transducer averaged 1.3 mm from the surface of the teeth, while the sensing surface of the beam type-transducers averaged 2.6 mm in this study. This difference in distance may affect the accuracy of measurement in studies using subjects with intact dentitions. Weinstein has shown that pressure increases in a variable manner as distance from the teeth increases.[11] Finally, the diaphragm transducer is easier to place as it is simply glued to the surface of the stent. The beam transducer is glued to the underside of the stent and the sensing surface must be both centered in a hole cut in the stent and parallel to the surface of the stent. This difference in placement becomes a larger issue when one considers conducting long-term studies, especially if the transducer must be removed after one test and replaced prior to the next.

Conclusions

Both the diaphragm-type and the beam-type transducers used in this study are reliable for use in intraoral soft-tissue pressure measurements. Previous studies using these types of transducers with similar methodology are thus supported. The diaphragm-type transducers have a smaller error of the method. This finding, in addition to other issues such as ease of placement, proximity to the tooth surface, and the ability to measure pressure from more than one direction gives the diaphragm-type transducer an advantage for use in intraoral pressure measurement studies.

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