Design and Construction of an Apparatus for Measuring Intraoral Muscular Forces

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The apparatus was designed in particular to measure the muscular forces of the lips that this information could be used in the assessment of the patient's orthodontic problems.

The concept that teeth take up positions of balance between opposite forces has led many investigators to measure the pressures exerted by the lips. Among them are Werner,[8] Jacobs and Brodie,[5,6] Flanagan,[1] Gould and Picton,[2,3,4] and Luffingham.[7] A comparison of the various types of appliances used by these researchers enabled the elicitation of the primary design features. The essential points were that the apparatus should be accurate, sturdy, simple to operate, portable and that the intraoral measuring head should conform to the optimum sizes laid down by such researchers as Gould, Picton and Luffingham, with the addition of a special and primary design feature, that this particular equipment should be capable of routine day-to-day use, measuring intraoral pressures in the surgery as an aid to orthodontic diagnosis.

The size and portability ruled out many of the types of apparatus which had been used previously and it was eventually decided to use a transducer with amplifier and read out indicator. After studying several of the previous transducer investigation reports it became apparent that, although home-built transducers were very accurate and ideal for research projects involving relatively small numbers of patients, it was doubtful whether they would stand up to the repetitious and long-term use envisaged for this particular instrument. Jacobs and Brodie mention difficulties they had experienced with fracture occurring in the transducer head leads.

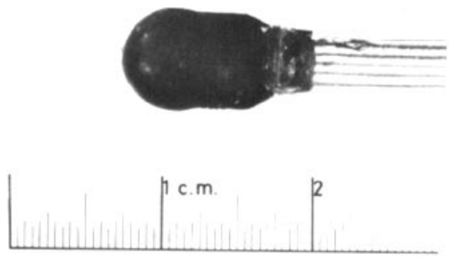

Fig. 1. The intraoral transducer supplied by Scientific Advances.

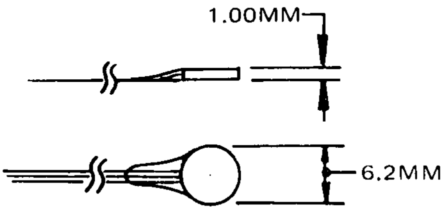

Fig. 2. Transducer size.

A search for a suitable transducer in the commercial literature brought to light the Sensotec type M/7BW. Its diameter is 6.35 millimeters and its thickness is 1.5 millimeters. The connecting lead wires are encased in a tough, flexible teflon ribbon 3 millimeters wide. The manufacturers agreed to produce a transducer with a pressure range of —100 millimeters of mercury to +500 millimeters (Figs. 1, 2 and 3). When converted to grammes per square centimetre this would cover the range of pressures found by other workers. The silastic coating on the transducer was also modified to cover only the face and edge of the head of the transducer. The metal back plate was left bare for ease in cementing.

The electronic details of the instrument are as follows:

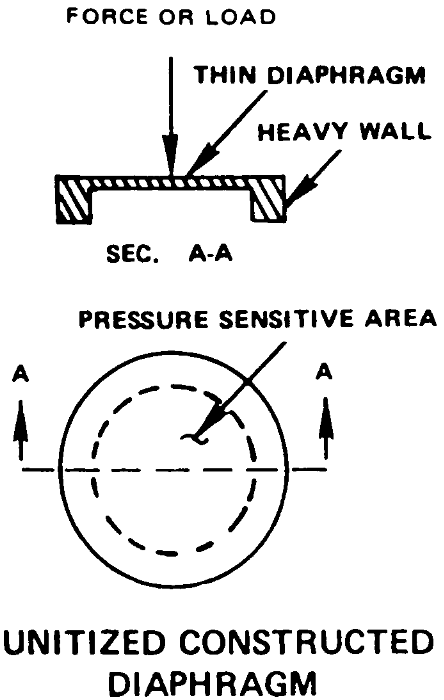

Fig. 3. Cross section of the transducer diaphragm, showing the active force area .03 sq. inch. This is used in comparison calculation.

The block diagram of the measuring system is shown in Figures 4 and 5. The sensitive transducer supplied by Scientific Advances is temperature compensated over a 16-50 degree centigrade range so that the maximum full scale error is less than two per cent due to temperature within the pressure range of —100 millimetres of mercury to +500 millimetres.

The transducer amplifier unit is a Fenlow ZA2 with a maximum possible gain of 1600. The system used was a full wave bridge with a three volt direct current excitation. ZA2 is fitted with a balance offset control but unfortunately this has insufficient range—seven millivolts to balance out the initial bridge mismatch. However, as the gain of the amplifier was constant at 800 throughout all the measurement tests, an isolated direct current supply was fitted between the amplifier and the meter indicator and this was used to balance out the acquiescent voltage to zero. Read out was by a sensitive voltmeter rather than a pen recorder as the apparatus was essentially designed to be diagnostic and portable.

During the initial experiments several pressure-measuring transducer devices were constructed and bench tested, using bonded resistance strain gauges mounted on stainless steel cantilever carriers. The carriers themselves were adapted to make the last cantilever elements of the transducers. These proved to be unstable as far as temperature was concerned. At times some appeared to measure temperature differences more accurately than pressure differences. These initial experiments suggested that commercially manufactured temperature compensated transducers would be much more efficient.

From the thermal details already described it will be seen that there is some small thermal drift but after using this transducer for over eighteen months the thermal drift remains constant each time the appliance is used and its effect may be taken into consideration and allowed for in the pressure calculation. The Sensotec transducer has also a specialised venting system which eliminates any effect which barometric pressure changes may have on the instrument.

Several calibration devices were constructed and tested but eventually a simple balance calibrator was constructed in such a way that a pressure pad on the calibrator gave a zero pressure on the face of the transducer and, as gramme weights were added to a scale pan on the calibrator, comparable readings could be taken from the read out volt meter. From these a calibration graph can be drawn. Although commercial pressure transducer calibrators, utilising monometer calibration which may be marginally more accurate, are

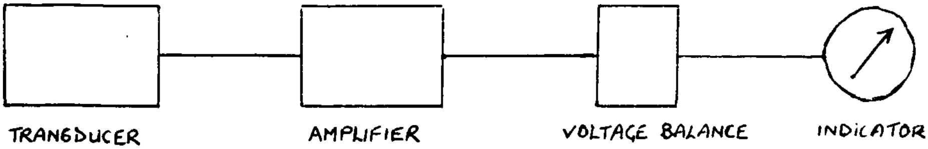

Fig. 4. A block diagram of the measurement system.

available, they are not transportable and would appear to negate the construction of a portable apparatus if its calibrator could only be moved from surgery area to surgery area with the greatest difficulty. The calibrator utilising the mechanical beam method was finally chosen in view of its accuracy combined with mobility.

The apparatus should be calibrated before and after use on a patient. The thermal stability of the transducer counteracts any inaccuracy due to the dry calibration method. Once the appliance had been tested for balance, stability and accuracy, various bench weight tests were applied and repeated at intervals to prove linear repeatability of the graphs made. No difficulty was encountered with this and there was a definite repeatability with the apparatus. Numerous static bench tests were also made with the equipment to prove temperature reliability, in which the transducer was placed in a water bath with known temperature variation. The zero drift of the transducer under normal operating conditions was assessed and recorded and the calibration device was checked against other types of calibrator and the equipment was also checked utilising known pressures.

Two methods of attachment to the teeth were tried and used. A direct attachment was made with the adhesive Eastman 910, gutta percha being used to contour the back of thc transducer. This method is described by Luffingham

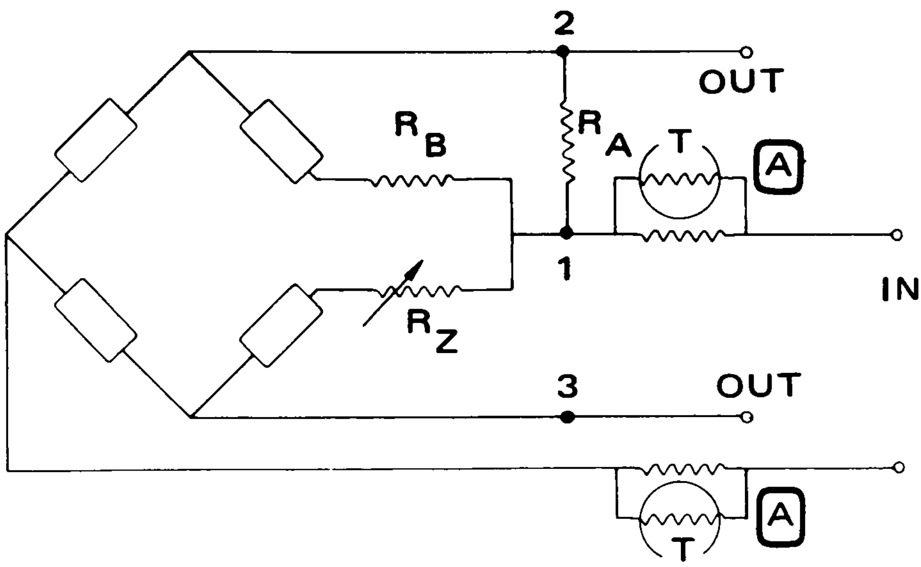

Fig. 5. The Sensotec transducer is connected in a Wheatstone Bridge circuit as shown. The leads marked 'imput' are the points where the applied voltage is measured. The leads marked 'output' are the points where the signal proportionate to the pressure can be monitored or measured.

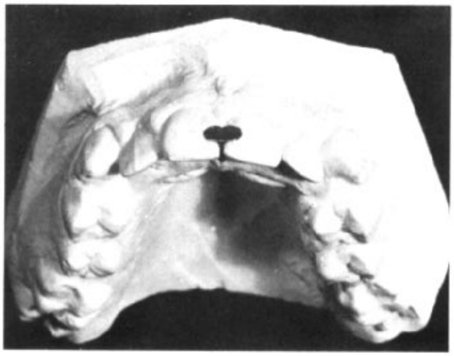

Fig. 6. Transducer mounting platform.

but it is time consuming and there is also the possibility of damage to the transducer and to the teflon ribbon when removing it from the tooth after the test. It was, therefore, decided to produce several small stainless steel mounting platforms (Fig. 6). The basic design was in the form of a T, the cross piece would be the mount for the transducer and the vertical part of the T would go between the interspace of the teeth in the area where pressure measurement was to be made. The transducer was first cemented to the mounting platform with Eastman 910 and the mounting platform was then cemented between the teeth concerned, using standard crown and bridge cement. No difficulty was encountered in removing the mounting platform, plus transducer, from the teeth at the end of the pressure measurement, a scaler being used.

The mounting platforms have sometimes had to be changed but this has been a relatively rare occurrence. Once a mounting platform had been made and tested it fitted extremely well a wide variety of patients. In some cases a lightening strip was passed between the two selected teeth prior to mounting the transducer to facilitate the insertion of the vertical section of the mounting platform. It was essential to see that no strain occurred at the joint of the teflon ribbon and the transducer or that the transducer itself was traumatized by the incisor teeth during the tests (Fig. 7).

The transducer may be mounted on the upper or lower incisor teeth. No particular difficulties have been experienced in positioning the transducer in the area desired. Unfortunately, the size and shape of the teflon ribbon connector precludes the use of the transducer for lingual measurements unless there is an extraction space to allow the lead to pass through to the lingual surface. After use, the transducer head and teflon lead can be cold sterilized.

The procedure for a typical lip-pressure measurement is as follows:

Fifteen minutes before the patient arrives the appliance is connected to the power supply and zeroed. This allows the amplifier to reach a steady temperature and gain level. The apparatus is then calibrated and the transducer and mounting platform cemented into the selected interspace. The patient is given the test card to familiarise himself with details of the spoken test and five to ten minutes is allowed for the patient to become used to the appliance in the mouth and also for any zero drift of the appliance to be ascertained.

Fig. 7. Patient during a "Test" showing the position of the teflon transducer lead.

The following measurements are then taken: 1. The resting force of the lip. The lip is removed from the transducer and then replaced. 2. The patient counts aloud from one to twelve. High and low readings are recorded. 3. High readings of the following sentences are then recorded (A) "We may buy paper for making a map." (B) "The sisters think they will return next Thursday." (C) "He gave enough coffee for fifty-five folk." 4. A measurement of the maximum lip pressure which the patient can exert on the transducer when grimacing. 5. A suck/swallow experiment using 10 cc. of water at mouth temperature. High readings are taken on the suck with a straw and then the swallow. All these measurements are repeated twice and after a pause the whole series of tests are again repeated.

The average testing time per patient with this instrument proved to be approximately thirty minutes. As soon as the measurements have been completed the transducer is calibrated and a calibration graph is drawn. The calibration readings are compared with the calibration readings taken prior to the arrival of the patient. In view of the type of calibrator used, in which the calibration beam is not suspended in the middle, a correction equation must be used to give a corrected volt gramme reading. If there is a difference between the first and second series of readings, an average is taken. The total measurements made per patient on the transducer are thirty-six. The test sheet, plus the calibration graphs, are then incorporated in the patient's orthodontic records.

Fifty-two patient tests have been completed at the present time. No attempt was made to group these by any clinical method and they were of different lip morphologies. Some of these patients have had tests repeated at different time intervals, some with days between the tests and some with as much as six months between the tests. These results, recorded at different times, have been correlated and as found by previous experimenters, the patients show little accurate repeatability from day to day and month to month. It would appear that as far as lip pressures are concerned patients fall into three main groups: those with little or no lip activity; those with a lip activity which I propose to call normal; those with a very pronounced lip activity. In the initial evaluation of the relatively small number of cases tested at present, the actual force shown in the different groups, when recorded in grammes per square centimetre, would appear to be similar to that shown by other experimenters, but on average they are slightly lower than most other workers found. A slight difference was shown when patients were tested on the same day, first with a transducer mounted on the mounting platform and then with the transducer on a gutta percha backing cemented to the interspace as described by Luffingham. There was an increase in pressure when the transducer was mounted on a gutta percha backing and cemented to the tooth. This, of course, brings the measuring surface of the transducer closer to the labial surface of the incisors, approximately 1.5 millimetres. The difference is minimal and in no way compensates for the relative increase in operator and patient time when the transducer is cemented in this way. Also there is more risk of damage to the transducer when the cement seal is broken on the completion of the pressure readings.

The labial surface of a transducer mounted on a mounting platform stands approximately 2.2 millimetres clear of the labial surface of the tooth. There is obviously some disturbance of the angle of the mouth by the teflon ribbon of connecting wires, but if the transducer is to be utilised as a routine measuring instrument with many thousands of measurements being taken on different patients for diagnostic reasons, rather than as a research instrument, all wiring and connections must be as robust as possible. In any case, although patients are allowed to become acclimatised to the equipment prior to the measurement recording, they must obviously to some small extent be aware of the intraoral section of the apparatus. Adults tested appear to be more sensitive to this than the children.

As previously mentioned, the size of the teflon ribbon connecting the transducer with the amplifier cable precludes using the transducer for lingual pressure measurements. Even when an extraction space exists in exactly the right place, it is very difficult to mount the transducer and lead in such a way that it will not be damaged during the recording. With this problem in mind a liquid-filled monometer system linked to an external transducer in a cardiac monitoring device is at present under test. Linkage between the monometer head and the external transducer in this case is by a high-pressure tube only 1 millimetre in diameter and this can be led intercuspally for lingual recordings to be made.

Table I shows standard test results on an average example of each of the three groups which have become recognisable in our test samples so far completed. Group A alludes to those patients with a very pronounced lip activity. They form twenty-eight per cent of the total patients tested. Group B are those patients previously designated in the text as normal and are forty per cent of the total and Group C are those patients showing little or no lip activity and account for thirty-two per cent of the total. All pressure measurements in the table are in g/cm2.

A clinical evaluation of the transducer pressure-measuring device will be reported when a much larger number of routine tests have been completed.

TABLE 1

Test Programme	A.	B.	C.
Resting Force	3.39	1.08	0
Counting 1-12			
High Reading	10.19	7.12	8.5
Low Reading	6.79	4.12	3.2
Sentence "A"			
High Reading	6.79	4.12	3.2
Sentence "B"			
High Reading	13.59	2.5	0
Sentence "C"			
High Reading	3.3	5.08	8.5
10cc. Water			
Suck Reading	95.17	12.7	9.6
Swallow Reading	64.58	10.16	8.5
Maximum Lip Pressure When Grimacing	575.8	29.15	19.2

Summary

The design and construction of an apparatus for the routine measurement of labial pressures is described, utilising commercially made components. Tests have so far proved the accuracy, temperature stability and robustness of design of the Sensotec transducer and its ancillary equipment to enable it to be used as a clinical pressure-measuring instrument.

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