A New Method for the Measurement of Normal Pressure between Amputation Residual Limb and Socket

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INTRODUCTION

The measurement of normal pressures at an interface is a universal problem in prosthetics (1, 2, 3). One difficulty is that the existing pressure pattern is disturbed by the sensor placed at the interface. A second problem is that, in general, the interface between the residual limb and the socket is not flat, but may be either concave or convex.

The first problem is often solved by countersinking the sensor in the socket wall. This, of course, requires removal of material from the socket wall, and if measurements were to be made at a large number of places in the socket, lasting damage might be done to the socket. For this reason, we decided to develop a sensor which can stick to the inner surface of the socket wall. In order to disturb as little as possible the existing pressure pattern, such a sensor should be very thin.

The second problem (of the curved interface) could be solved by making the sensor flexible.

We have not succeeded in finding a transducer which can be placed at the interface while satisfying the abovementioned requirements. Therefore, we have chosen a solution in which the pressure is transmitted first in the form of a hydraulic pressure signal. This hydraulic pressure is then measured with a transducer outside the socket, where more space is available.

This has been schematically represented in Figure 1.

FIGURE 1
Principle of interface pressure measurement system.
Construction of the Sensor

The sensor consists of a small plastic bag filled with liquid. This bag is connected to a pressure transducer by a thin nylon tube. The bag is made by heat-sealing two disks of PVC 0.25 mm thick and 30 mm in diameter. The pieces of PVC are separated by a small disk of Teflon, 0.007 mm thick and 7 mm in diameter. The Teflon disk locally prevents the two layers of PVC from sealing together, later allowing them to separate for the formation of the bag.

To create a hole in which the tube can be later fitted, a thin metal bar is placed between the two layers of PVC during the sealing operation. This bar has two diameters. The thicker part makes a hole with a diameter of 1 mm in which the tube can be glued, while the thinner part creates a capillary of 0.2 mm diameter to vent the air during filling. The latter hole is sealed after filling.

The heat sealing is carried out in a mold of aluminum, composed of two parts. In each part a small channel is made to make room for the metal bar. Both parts are bolted together with the sheets in between (Fig. 2). The mold is heated to about 140 deg. C and then cooled in water, after which the sensor is removed.

**FIGURE 2.**
Exploded view of the two-piece aluminum mold, showing also the two 30-mm PVC disks, the 7-mm disk of Teflon, and the thin metal bar, as described in the text.

**FIGURE 3.**
Schematic drawing illustrates stages in creating chamber. At left, small (7 mm) disk of 0.25-mm PVC has been cut out and removed from the upper 30-mm dia. disk. At right, a thin (0.1 mm) 30-mm disk is indicated moving into place to become a new top sheet or lid, creating the 7-mm X 0.25-mm chamber of the sensor. (The 0.007-mm thick Teflon disk described in text, above, appears in drawing as a dark line forming the bottom of the chamber.)

**FIGURE 4.**
Closeup views of the finished sensor. At A, a front (plan) view; at B on the page opposite, a side (edge) view.
After this first sealing operation, a disk of PVC is cut out just above the Teflon disk and another disk of PVC with a thickness of only 0.1 mm and a diameter of 30 mm is sealed over the gap created in this way (Fig. 3). Thus, a small chamber is formed, covered by a thin PVC sheet. The low stiffness of the top sheet allows the bag to expand without the application of a significant increase in pressure. For this reason the sensor is not very sensitive to changes in temperature.

After removal of the metal bar, a nylon tube with an outer diameter of 1.2 mm is glued to the bag, using a short connecting tube fitting inside the hole of the bag on one side and inside the first tube on the other side. Now the sensor is trimmed to a pear-shaped form (Fig. 4-A) to prevent the tube from buckling where it leaves the sensor due to a sudden change in stiffness.

Finally, the tube is connected to a National Semiconductor type LX 1600 pressure transducer. Then the system is filled with a silicone oil of a low viscosity. This oil is not aggressive and has a relatively high molecular weight, virtually eliminating its evaporation through the PVC.

The total thickness of the finished sensor is about 0.6 mm (Fig. 4-B). The flexibility of the sensor allows its use both on flat and on convex or concave surfaces. It is attached by double-coated adhesive tape.

**Signal Conditioning**

The transducer used has an integral integrated circuit amplifier system, giving an output voltage ranging from 2.5 to 12.5 V d.c. for a pressure variation from 0-to-700 kN/m² (0–700 kPa). The transducer alone has a frequency response from 0 to 20 kHz, but sensor and transducer together have a time constant of 20 ms, reducing the bandwidth to 0–8 Hz.

The transducer is connected to an amplifier, allowing pressure calibration, adjustment of the zero level, the selection of gains of 1, 2, 4, 8 or 16 times, and the selection of the sign of the output signal. To suppress some transient high frequency vibrations, transmitted mechanically to the transducer upon heelstrike when the patient is walking, the amplifier incorporates a first order low-pass filter with a time constant of 25 ms, limiting the bandwidth of the amplifier to 7.2 Hz.

The overall bandwidth of the system of about 7 Hz allows the measure of up to 7 harmonics of the basic pressure curves at a cadence of 1 step/s, which is sufficient for our purposes.

**Heel-Strike Triggering**

In order to compare pressure curves which have been obtained either at different locations at the stump-socket interface, or at different steps, it is necessary to provide for a synchronizing signal related to the step cycle. The moment of heel strike is a convenient instant for synchronization: we use a tape-switch strip under the heel of the prosthesis to detect heel contact.

Since all signals are to be recorded on an instrumentation tape recorder (HP 3560) and we wish to keep all of its four channels for pressure signals, we have combined the heelstrike signal with one of the pressure signals. This has been realized by emitting a short negative pulse upon contact closure and adding it to a pressure signal.

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**NOTE:** Figure 4-B, below, is a photographic effort to show the edge aspect of the 0.6-mm-thick sensor with its 1.2mm O.D. nylon tube.
Calibration Procedure

The complete system is calibrated by means of air pressure. Through a flexible rubber membrane the sensor is loaded with a certain air pressure (Fig. 5). Before and after each series of measurements this calibration is carried out. The calibration signals also are stored on tape.

Dynamic Calibration

The dynamic behavior of the system is investigated with the help of a ball. The ball is bounced on the sensor, generating a pressure pulse as an input for the system. The output of the pressure transducer is registered with a UV recorder: the shape of such an output signal is shown in Figure 6.

DISCUSSION

The method described appears to be a faithful manner of obtaining normal pressure measurements by means of cheap sensors. Unfortunately, this method up to now is convenient only for laboratory use, because the sensors have a rather short life and need to be handled carefully. The filling of the system, necessary when a sensor is replaced, especially needs good care, otherwise there will be some air enclosures when the capillary is sealed.

To get a clear picture of the pressure pattern over the whole socket, it is necessary to measure at least one hundred points, depending on the size of the socket. When a point being measured is on a curved surface, the bending of the sensor produces an increase of pressure of the liquid in the sensor; in effect, this represents a shifting of the zero point for pressure measurements made at that point. However, as long as the curvature is not exceptional, this phenomenon may be ignored.

References