A DEVICE DESIGNED TO APPROXIMATE SHEAR FORCES ON HUMAN SKIN (A PRELIMINARY STUDY$^a$)

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Editor's Note

Because little is known about the magnitudes of the shear forces and the unit shear stresses acting between skin and cushion or bed, and even less about shear stresses and their effects deeper within body tissues, this preliminary study on an instrument attempting to estimate shear force on the skin is being published as a stimulus toward further work.

Neither the authors nor this Bulletin’s anonymous reviewers are certain as to what the gage actually measures. If the skin adheres only to the central disk (which is to be covered with a cotton sheeting material), the gage may actually measure a quantity related to the local shear force. On the other hand, the skin may adhere by frictional forces to the large plate-like annular structure surrounding the small central detecting disk as well as to the disk itself. Presumably there are complex forces (whether tension, compression, or shear) in the thin layer of skin (and its underlying variable tissues) bridging the very small gaps between the disk and the surrounding rigid structure. The relative influences of these conflicting stresses, the different areas involved, and thus the total forces between the disk and the plate are very difficult to assess. Therefore the actual shear forces, as modulated by the forces in the skin and in the nearby tissues between the disk and the surrounding material, can only

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be estimated or approximated by the easily measurable displacement of the small disk with respect to the surrounding plate.

Despite these uncertainties, the importance of attempting to estimate shear forces warrants publication of this preliminary proposal for an instrument. Actual trials on clearly defined situations seem indicated.

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Editor

ABSTRACT

A shear force on the skin, perpendicular to the forces applying pressures, is thought to be a contributing factor to the formation of decubitus ulcers. The gage described here has been designed to give some quantitative information about the extent of shear forces that exist between human skin and a support medium.

The basic operating principle of the device is the measurement of relative motion between a small area of skin surface and the larger surrounding area of skin. This is accomplished by having a small disk, in firm contact with the skin surface, mounted on steel wire so that it can move relative to the surrounding portion of the device which is in firm contact with the larger surrounding area of skin (as well as with the bedsheets or other support medium).

Measurement of the deflection of the disk supported by steel wire is accomplished by means of four pneumatic flapper valves set 90 degrees apart from one another. Opposing valves are coupled giving as their output a pressure differential. The portable system is energized through the use of a can of Freon gas. Utilization of fluidics techniques in design and fabrication contributes to the device’s precision and to its extreme thinness which is functionally very useful.

INTRODUCTION

Several physical factors such as pressure, shear force, humidity, and temperature have been cited as contributing to the formation of decubitus ulcers. Systemic factors such as undernourishment and anemia have also been cited. Of the several physical factors, pressure has been studied the most and is cited as the major cause of decubitus ulcers. This may be due in part to the fact that instruments have been readily available to measure pressure, whereas other instrumentation has not existed.

Shear force, as has been proposed by Reichel (3), occurs when the head of the bed of a recumbent patient is raised 30 deg or more. In
this case, a person tends to slide feet-first down the bed, while the skin at the bed surface essentially remains attached to the sheet. This obviously creates a shear force which is believed to act in the deeper portions of the skin. Little is known about shear force acting on skin, since gages have not been available to measure this force.

This paper then reports a gage that has been designed to approximate the shear force. The concept involves use of flapper valves which can be pressurized using canned Freon: the flapper valves work in pairs as a push-pull or pressure differential means. This report might be considered a preliminary report because the gage has not been clinically tested. It rather shows the concept, and the physical dimensions that are possible for building a shear force gage.

Notation

\[ A_{12}, \quad \text{actual orifice area, in}^2 \]
\[ C_{D_{12}}, C_{D_{23}}, \quad \text{orifice and nozzle discharge coefficients, respectively.} \]
\[ D_{12}, D_{23}, \quad \text{orifice and nozzle diameters, respectively, inches.} \]
\[ g = 386 \text{ in./sec}^2 \]
\[ K = \left[ \frac{\gamma g}{R} \frac{2}{\gamma + 1} \left( \frac{\gamma + 1}{\gamma - 1} \right) \right]^{1/2} \quad \text{= unique factor for each gas.} \]
\[ N_{12}, \quad \text{ratio of actual weight flow to critical or sonic flow.} \]
\[ P_1, P_2, \quad \text{absolute supply pressure and chamber pressure, respectively, psia.} \]
\[ T_1, \quad \text{absolute supply temperature, deg K.} \]
\[ X, \quad \text{flapper displacement, inches.} \]
\[ \gamma, \quad \text{ratio of specific heats for fluid used (air or Freon 12).} \]

**DESIGN CONCEPTS**

A very simple gage proposed by D. W. Lewis and reported in detail by A. McCombs (2) is shown schematically in Figure 1. In this case the main body of the gage would rest on the sheet of the bed and the skin of the person would be pressed against the flexible membrane. A shear force was applied to the gage, the flexible membrane would move with the skin, causing the sliding disk to uncover the
disk made of a porous medium. In so doing, the flow rate through the porous medium would change as well as the pressure differential across the medium, either one of which could be sensed and used as an indicator for the shear. In short, a flexible membrane acts as a spring and the sliding disk acts as a valve, so that by proper calibration the shear force can be related directly to the pressure differential or flow rate across the porous medium.

**FIGURE 1.**—Shear gage schematic (2).

Variations of this design format have been built and are reported by McCombs (2), with the associated problems that were characteristic of this design. Although very simple in concept, the execution of this design did not prove to be satisfactory from a practical point of view. Certain unexplained leakages occurred and could not be remedied, producing some non-repeatable measurements. The porous medium used in this case was a special plastic that did deform, which action possibly accounts for the non-repeatability of the system. Perhaps if the porous medium had been a more rigid material such as a glass or a rigid silicone, this design concept might have been successful.

**FLAPPER VALVE DESIGN**

A simple schematic representation of a flapper valve is shown in Figure 2. By changing the position of the flapper relative to the nozzle, the ratio of the pressures in chambers 1 and 2 change. A
description of this is given by:

\[ P_2 = P_1 \left( \frac{N_{12}}{N_{23}} \right) \left( \frac{1}{4} \right) \left( \frac{D_{23}}{D_{12}} \right)^{-2} \left( \frac{C_{D_{23}} X}{C_{D_{12}} D_{23}} \right) \]  \[1\]

**Figure 2.**—Flapper valve schematic, \( P_1 \) supply pressure, \( P_2 \) chamber pressure, \( P_3 \) atmospheric pressure.

In this equation \( N_{12} \) is the ratio of the actual weight-flow to the critical or sonic flow and may be computed by the following equation:

\[
N_{12} = \left[ \frac{\left( \frac{P_2}{P_1} \right)^2 \frac{\left( \frac{P_2}{P_1} \right)^{\frac{\gamma+1}{\gamma}}}{\frac{2}{\gamma} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{\gamma-1}}} \right]^{1/2}
\]  \[2\]

A value for \( N_{23} \) would be given by the same equation above except that for each subscript 12 would appear the subscript 23. Finally, gamma (\( \gamma \)) is a ratio of specific heats for the fluid used in the device. The \( C_D \) type terms represent discharge coefficients for the upstream orifice and the downstream nozzle. And \( D_{12} \) and \( D_{23} \) represent the diameters of the upstream orifice and the diameter of the downstream nozzle, respectively. For the case of supply pressures of 15 psig or less and venting to atmospheric pressures, sonic flows will not occur at either the orifice or the nozzle.

Figure 3 shows a plot of chamber pressure vs. a dimensionless displacement for various values of the diameter ratio, \( D_{23} / D_{12} \). This was taken from (1).
To provide a portable gage, the working gas selected was Freon-12 because it is readily available in sealed pint cans. It is desirable to know the effect of the specific heat ratio for differing gases in the static response of a flapper valve. Figure 4 shows the dimensional plot of pressure vs. displacement for both air and Freon-12 at a supply pressure of 5 psig (259 mm Hg). To show the influence of pressure, on this same figure is plotted the curve for air at 20 psig (1,034 mm Hg).

From Figure 4, one can see that the basic static response is only slightly altered by changes in supply gases. This means that the design which works with air should also work satisfactorily with Freon-12. Of course, these conclusions apply only to the case where subsonic flow exists at both orifices. Note also that Figure 4 is valid for a diameter ratio equal to 1; i.e., the diameter of the upstream orifice is the same as the diameter of the nozzle.
FIGURE 4.—Pressure ratio versus displacement for air and for Freon.

FLAPPER VALVE PHYSICAL MODEL

The flapper valve used in this shear gage is not a flat plate but rather a cylinder (Fig. 5). The cylindric disk is supported by a single wire that acts as a spring to return the disk to a central position. The disk is also supported on Teflon riders to reduce the friction of the system. In operation, the exposed surface of the disk will be up against the skin, the shear of which is to be measured, and the main body will be against the sheet of the bed, for example, and will remain essentially motionless. As the skin shear force increases, the disk will move, causing a restraining force, oppositely directed, to be generated in the wire.
The flapper valve arrangement using this disk is shown in Figure 6. In this case, a flapper valve is really a pair of valves in which the motion is toward one nozzle while simultaneously being away from a second nozzle. This produces a pressure differential between the chambers, (see chamber 2, Figure 2) that can be indicated on a manometer (Fig. 6) or otherwise detected. This change of pressure vs. change of position then can be plotted as indicated on Figure 7.
This pair of flapper valves will, in general, measure shear force in only a single direction. By using two such pairs of flapper valves arranged in a mutually perpendicular manner (Fig. 8), two pressure differentials can be ascertained and theoretically could be plotted as shown in Figure 9. In that figure, A would represent a displacement; 2A, twice that displacement; and 3A, three times that displacement. By knowing the $\Delta P_x$ and the $\Delta P_y$, one could then go to Figure 9 and discern the actual shear force that corresponds to a particular displacement (A, 2A or any particular amount). These same differential pressures could be treated vectorially through pneumatic logic to yield the same result.

**FIGURE 7.**—Pressure difference versus displacement.

**FIGURE 8.**—Flapper valve configuration around disk.

**FIGURE 9.**—Pressure difference versus pressure difference.
THE PHYSICAL SHEAR GAGE

The overall description of the physical gage that has been constructed and tested is shown in Figure 10. One can see the essential dimensions of this as a rather flat plate-like structure approximately 0.080 in. thick with a central detecting disk that is 0.25 in. (6.3 mm) in diameter. The supply and pressure connections to the individual
chambers was obtained by chemically etching a thin brass plate (Fig. 11). This plate was 0.010 in. (0.25 mm) thick.

Other physical dimensions for this gage include a spring wire of 0.005 in. diameter (0.13 mm) stainless steel with a length of 0.060 in. (1.52 mm). The channel plate is 0.010 in. (0.25 mm) brass shim-stock. The orifice diameters were chosen to be all the same 0.040 in. (1.02 mm), making a diameter ratio equal to 1. With a disk diameter of 0.25 in. and with the disk centrally located, the flapper valve is 0.008 in. (0.20 mm) away from each nozzle. Supply pressure chosen was 5.0 psig, primarily to minimize the total flow rate from a small supply can that is readily available at airconditioning and refrigeration supply houses.

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REFERENCES