THE DANGERS OF USING A THREE-WAY VALVE AS A STOPCOCK IN A TRANSDUCER SYSTEM FOR MEASURING VENOUS BLOOD PRESSURE

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THE SYSTEM shown in Figure 1 has been widely used for the measuring and recording of venous blood pressure, and for the calibration of transducer-recorder systems for this purpose. Such a system was in use at the Toronto General Hospital for this purpose for several years prior to January, 1962.

The equipment consists of a hypodermic needle; 3 mm. plastic tubing, a transducer head no. P 23 BC supplied by Statham Instruments, California, a rubber squeeze bulb, tubing and mercury manometer, a two-way valve, and a three-way valve of the same make and catalogue number as those used in the Toronto General Hospital. It was suspected that during calibration of the transducer cell in the course of an operation in January 1962, air was inadvertently injected into the patient's vein. The following discussion suggests that this could have occurred because of the dangerously small margin of safety between a neutral "off" position of the three-way valve and an open position.

FIGURE 1. General view of the test equipment.

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The valve is used to permit purging the 3 mm. plastic tubing and the transducer head with saline solution from a hypodermic syringe. During calibration of the system with air pressure induced by the rubber bulb and measured with a mercury manometer, the valve handle is, by eye, set in a neutral position with the handle at approximately the desired angle of 45° from the axis of the in-line ports of the valve. When blood pressure is being measured, the handle is set in line with the axis of the in-line ports.

METHOD

Under conditions as close as possible to those in the operating room, the various settings have been determined which will permit the flow of saline solution and of air through the system. Six randomly selected and sterile-wrapped valves labelled B-DMSO 2 were tested. A venous blood pressure equal to the 7 mm. Hg recorded for the patient in the Toronto General Hospital catheterization reports was simulated by submerging the outlet of the hypodermic needle under 10 cm. of water in a graduated cylinder. A pressure head of 10 cm. water is equal to a head of about 7.4 mm. Hg. The base of the cylinder was set at the approximate level of the diaphragm at the top of the metal portion of the transducer.

A jig made to permit accurate measurement of the position of the valve handle is shown in Figure 2.

Each valve tested was firmly mounted on the tapered portion of the brass locating shaft and carefully positioned with the valve stem removed by moving the locating shaft. The stem was replaced and the valve handle set by eye at the 45° line as shown in the print. The position of the valve handle can be read accurately from the prints using the protractor or can be taken from the position of the micrometer stem, which was also firmly mounted to the metal base. The micrometer spindle was used to make very fine adjustments to the position of the valve handle in addition to showing the valve position quantitatively. The scale on the prints can be determined from the micrometer stem markings or more crudely from the centimeter scale on the uncovered side of the plate.

All photographs of the jig used for measurements were taken with a camera having a 5.6 lens at $f\ 32$, shutter speed $\frac{1}{2}$ sec., using triX-120 roll film, negative $2\frac{1}{4}'' \times 3\frac{1}{4}''$. The lens was centred directly over the jig, at 90° to it, and about 28'' away.

During the test, a pressure of 40 mm. Hg was applied to the transducer head, as in the actual calibration process, and the micrometer spindle slowly turned so as to move the valve handle from the neutral 45° position until the first slow leak was observed. The leak was detected in runs without saline in the tubing by observing bubbles forming at a slow but steady rate at the outlet of the hypodermic needle. When saline was present, as in a few initial runs, one or two small bubbles of air trapped in the tubing could be observed to move when the valve was leaking. After the position of the valve handle was photographed under conditions of slow leak, the spindle was turned until a fast leak developed, as indicated by vigorous bubbling or rapid flow of saline under 40 mm. pressure. The position of the valve handle was again photographed.

FIGURE 2. Test jig with valve 3 in the neutral, 45° position.

RESULTS

1. Description of Valve

The three-way valve used in these experiments is sketched in Figure 3. It consists of a valve body, a stem and handle, and three ports. The stem is

FIGURE 3. Schematic sketch of the valve, showing dimensions.

machined from a single piece of metal and is tapered to ensure a tight fit in the similarly machined inside of the body. A 1.85 mm. hole is bored through the stem in the direction of the handle, and another hole of the same diameter is bored at 90° to the main hole and through to the main hole. The position of the 90° hole is indicated by a notch stamped in the stem top. The diameter of the stem at the bore holes is 6.5 mm. The handle of over-all length of 2.4 cm. or 1.8 cm. from the centre line of the stem is fixed to the stem by a pin and silver-soldered. The body of the valve is machined to accommodate the stem in such a way that the handle prevents rotation through more than 180° . A male and a female connection have been machined on the body in line. Another female connection which forms the base of the tee appears to have been silver-soldered onto the body. As conventionally operated, the syringe is attached to the female outlet forming the base of the tee. If the operator holds the syringe in his hand with the valve away from him and the handle on top, the circuit may be completed between either syringe and hypodermic needle, syringe and transducer head, or transducer head and hypodermic needle as follows:

- (1) Syringe and needle—handle in line with syringe, pointing away from operator—body stop for position.
- (2) Syringe and transducer head—handle in line with syringe, pointing toward operator—body stop for position.

(3) Needle and transducer head—handle at right angles to syringe—no stop for position.

The valve is designed for no other mode of operation and there is *no* positive position for closing all three circuits; the handle normally being set during calibration of the cell at a neutral 45° position to the axis of the in-line ports, the ports forming the top of the tee. Thus a 45° turn of the handle completely opens the circuit between hypodermic needle and transducer head. The handles on most of the valves tested turned freely and easily, but the fit could not be said to be sloppy.

It is certainly possible that a small force on the handle such as might occur accidentally when the valve is lying on the operating table could move the handle through a small distance, say $10\text{--}15^\circ$. The experimental results given below show that such a small movement is sufficient to move the valve from the neutral 45° position to an open position.

2. Test Measurements

Results shown in Table I are the valve handle position as indicated by micrometer scale in inches and by angle read from the photographic prints (see Figs. 2, 4, 5) under three conditions:

- (1) Valve in neutral 45° position judged by eye (Fig. 2, valve 3).
- (2) Valve in position resulting in a slow but definite leak (Fig. 4, valve 3).
- (3) Valve in position resulting in a fast leak (Fig. 5, valve 3).

The difference in position between a slow leak and a fast leak was observed to be very small, and always less than $1/100$ of an inch, or about 0.025 mm. for this valve. This is equivalent to about $\frac{1}{2}^\circ$.

The error in locating the valves in exactly the same position every time is a maximum of $30/1000$ in. This results in apparent inconsistencies in the micrometer positions, but the error in the angle of the valve handle is no greater than 1° and probably within the $\frac{1}{2}^\circ$ readable. Thus, the maximum and minimum range of angles from the 45° neutral position which will permit the free passage of air or saline solution for the six valves tested lies between 10° and 16° . This corresponds to travel of the end of the handle from the desired position of from $0.1235''$ ($\sim \frac{1}{8}''$) to $0.198''$ ($\sim 3/16''$). These results clearly illustrate that the valve is not precision machined, and that wide differences in the extent of the neutral position can be expected.

The smaller angular difference ($\sim 10^\circ$) between the neutral position and the open position make it very difficult for anyone to tell the difference without some additional basis for comparison, for example, a 45° set square. This fact is illustrated in Figures 6 and 7 in which the 45° reference line has been blanked out. Even under the considerable magnification of the photographs, it is difficult to see any significant difference between the 45° position and the open position.

The small margin of safety is further exemplified in Figure 8, which shows the position of the bore-holes at the 45° position for a typical valve. This sketch shows that the bore-hole and the outlet ports will begin to overlap if the valve stem is displaced 11° from the 45° position. This prediction is confirmed by the experiments. The distance between bore-hole and body-port as represented by this sketch is less than 1 mm.

TABLE I
MICROMETER SETTINGS AND ANGULAR POSITION OF VALVE HANDLE

Valve	Neutral Position		Slow Leak		Fast Leak		Angular displ. from 45° (fast leak)	Travel of spindle (in.)
	Micrometer reading (in.)	Handle angle (°)	Micrometer reading (in.)	Handle angle (°)	Micrometer reading (in.)	Handle angle (°)		
1 (air)	0.500	44.5	0.381	58.0	0.374	58.5	13.5	0.126
(saline)	—	—	0.378	58.0	0.373	58.5	13.5	0.127*
2	0.490	44.0	0.342	60.5	0.338	61.0	16.0	0.152
3	0.500	44.0	0.412	54.5	0.402	55.0	10.0	0.098
4	0.505	44.5	0.394	54.0	0.391	54.5	10.5	0.114
5	0.500	45	0.418	54	0.409	55	10	0.091
6	0.481	45.5	0.377	58.5	0.374	58.0	13.0	0.107

* Assuming same initial position.

FIGURE 4. Valve 3 in slow leak position.

CONCLUSIONS

(1) Detailed examination of valves labelled B-D MSO 2 has shown that these valves have no closed position, as such. The valves are designed to permit the flow of fluid in one of three directions.

FIGURE 5. Valve 3 in fast leak position.

(2) The valves are well made for the purpose described in (1) above, but are not precision machined to permit their reliable use as shut-off valves in the normal 45° position. Thus, as shown in the *Results*, the variation in the angular distance from open to 45° position is only 10 to 16° , which corresponds to a travel of the end of the valve handle of from $0.124''$ to $0.198''$ a difference of over 50 per cent between individual valves.

FIGURE 6. Valve 3 in 45° position—no reference line.

FIGURE 7. Valve 3 in fast leak position—no reference line.

CROSS-SECTIONAL VIEW OF VALVE STEM AT C

FIGURE 8. Diagram showing bore and port dimensions.
Safe travel distance of the stem is about 0.06 cm.

(3) The angular and linear difference between the 45° neutral position and the open position is so small as to be very difficult to detect with the unaided eye. A precise determination of the large relative differences between valves required the use of an accurately made jig.

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