A SELF-CALIBRATING BLOOD-PRESSURE MONITORING SYSTEM

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MONITORING during surgical procedures has become standard practice, particularly during operations on the heart and the vascular system. Initially, the electrocardiogram alone was monitored; it gave useful information relative to the development of arrhythmias but few other data of clinical value. Monitoring the electroencephalogram may be helpful in determining at any particular moment the level of anesthesia and the adequacy of cerebral blood flow.

A notable decrease in arterial blood pressure may occur during anesthesia, without the development of clinical signs of hypotension or abnormality in the electrocardiogram or in the electroencephalogram. Although the anesthesiologist periodically records the arterial pressure indirectly, a continuous record is highly advantageous because changes in pressure may be sudden and critical. Under some circumstances, induced hypotension may be utilized to facilitate surgical procedures; during the hypotensive phase the arterial blood pressure may be difficult or impossible to determine by the indirect method. Strain gauges and other transducers have been used to record the arterial pressure directly. The level of pressure must be determined by reference to a calibration, and recording must be done on paper. This method of recording requires the presence of trained personnel. A need for a method of recording the arterial blood pressure continuously and displaying it instantaneously without reference to previous calibration has become apparent. It should be possible to display the record on the screen of a cathode-ray oscillograph.

We are reporting the development of a measuring and monitoring system in which a number of pressures are sequentially sampled by valving these pressures to a common chamber that is covered by a diaphragm coupled mechanically to a simple linear transducer *(Fig. 1)*. The blood pressure and calibration information are reproduced on a cathode-ray tube or on a suitable paper recorder.

In its simplest form, three pressures are used. Two of these are accurately known static pressures that are continuously adjustable and measurable by means of mercury manometers. The third is the direct arterial pressure communicated to the valve-transducer system by means of a nylon tube or catheter. By sequentially sampling the accurately known pressures and the arterial blood pressure, the system is continuously calibrating itself ten times per second at two pressure levels *(Fig. 2)*. The arterial pressure is effectively superimposed on these calibration points, permitting accurate measurement or observation of the complete arterial pressure curve and measurement of systolic and diastolic pressures. Venous pressure also may be measured by this method.

The basic element of the pressure scanner is the stainless-steel, high-precision,

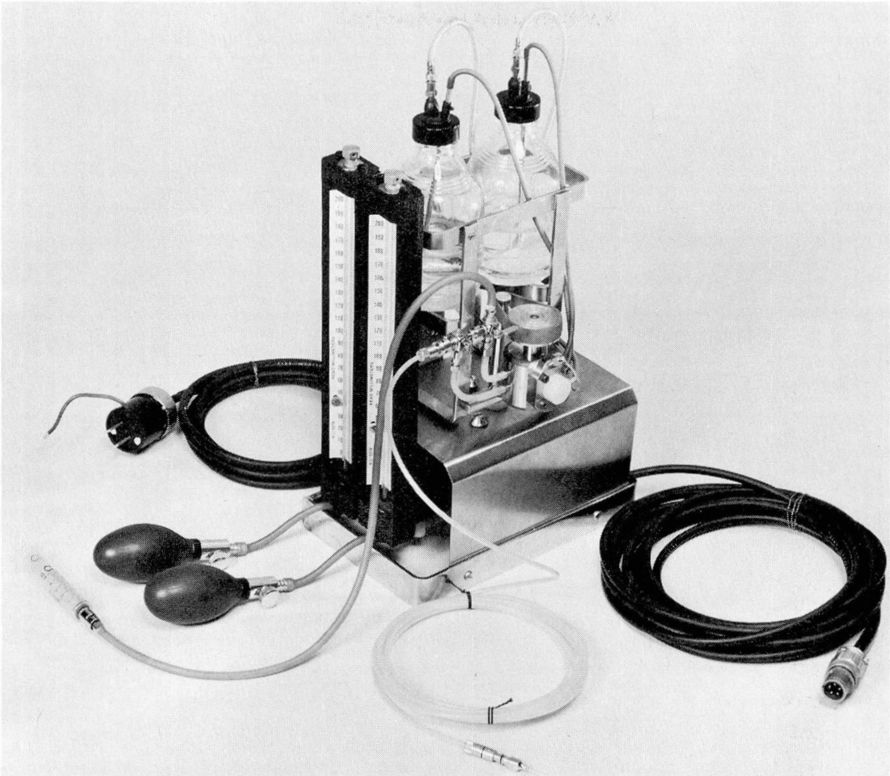

Fig. 1. Photograph of blood-pressure monitoring equipment.

all-metal, motor-driven valve that opens in sequence between the transducer pressure chamber and four pressure sources *(Figs. 3 and 4).* The timing is so arranged that the previously sampled pressure is completely turned off an instant before the succeeding pressure to be sampled is turned on. Each sampling of pressure in its proper turn therefore actuates the ceramic piezoelectric transducer. The transducer chamber with its heavy, stainless-steel diaphragm is bolted directly to the valve body, forming a gasketless seal between precision-honed metal surfaces. The transducer element is cemented directly to the diaphragm. This element is lead zirconium titanate (PZT), a high-sensitivity piezoelectric ceramic material that is unaffected by temperatures up to 300 C.

The necessary operations of filling the valve and tubing with sterile liquid and of removing air are performed with the aid of three, standard, four-way stopcocks. The static calibrating pressures and a standard syringe provide the means of forcing the sterile liquid through any part of the system selected by the positions of the stopcocks. All air is released from the valve through the air-release

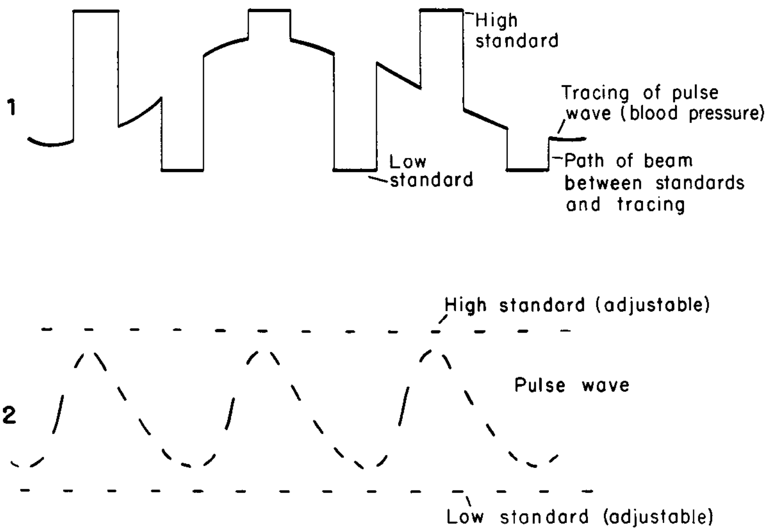

Fig. 2. Diagram of transducer output. The straight lines represent static pressures, and the curved lines represent intravascular pressures.

port, which is capped by a standard Luer slip plug. The static-pressure ports are each kept open one fourth of a valve revolution *(Fig. 5).* In the simplest form, this allows one half of a revolution in which the arterial pressure is in communication with the transducer.

Since actuation of the transducer depends on deflecting a small, extremely stiff, stainless-steel diaphragm one-eighth inch in thickness, the frequency response depends entirely on the size of the inside diameters and the expansion rigidity of the catheter system. In actual operation, as the scanning valves open and close, the pressure in the transducer chamber is changed and precisely measured in less than one thousandth of a second, forty such changes occurring each second. These pressure changes and measurements take place entirely independently of the external catheter system and represent a maximum attainable frequency response of several thousand cycles per second.

This system eliminates the need for direct-current amplifiers and centering controls. The read-out automatically returns to center on the cathode-ray screen. It is independent of transducer or amplifier calibration, and does not require extremely high-gain amplifiers. The system is simple to operate. It can be sterilized by autoclaving or with chemicals.

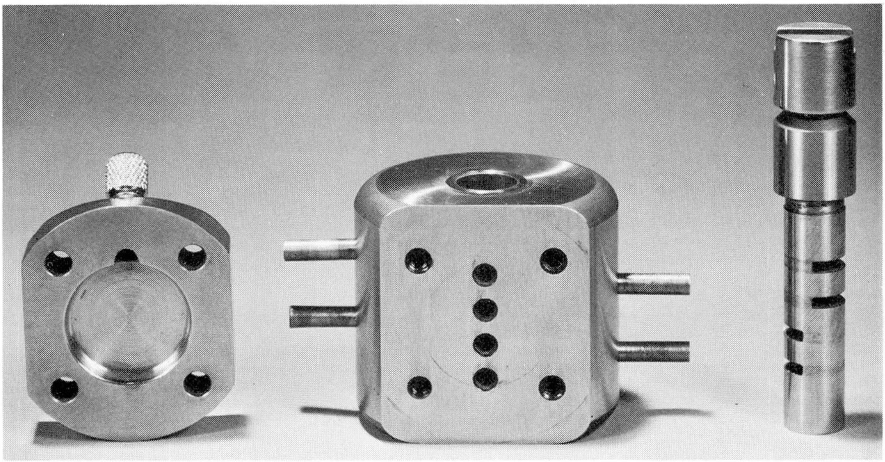

Fig. 3. Photograph of valve.

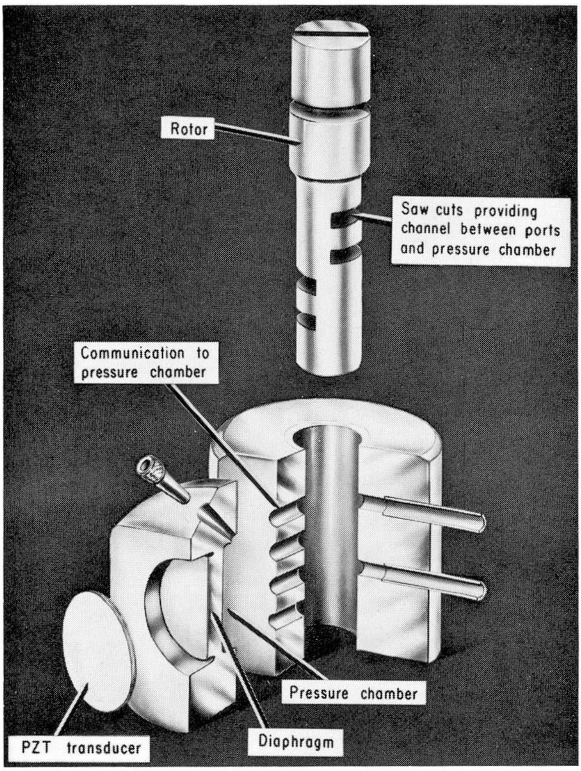

Fig. 4. Diagram of valve.

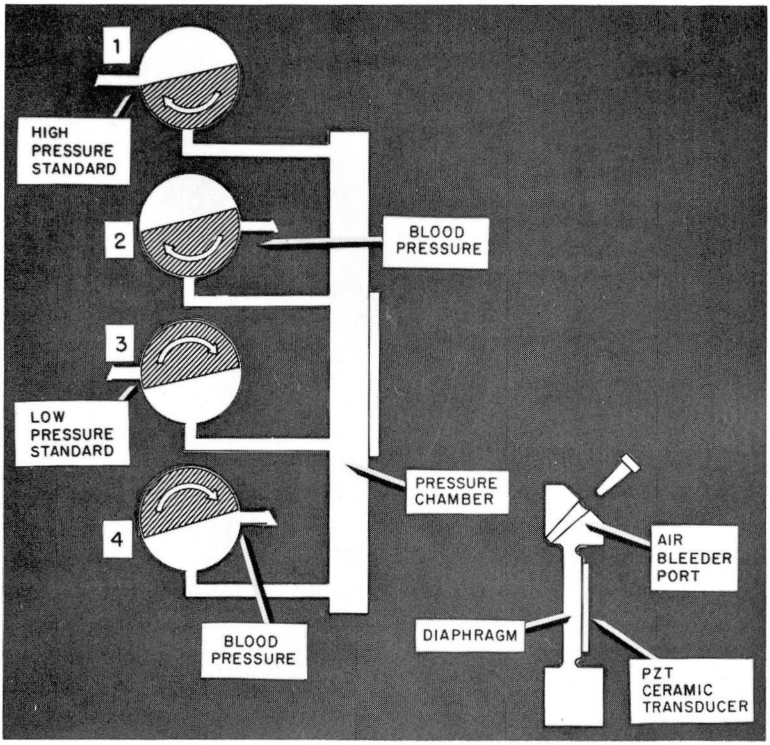

Fig. 5. Diagram of transducer. The circles represent cross sections of the stator, showing: 1—high pressure standard closed, to open in one-half turn; 2—blood pressure closed, to open in one-quarter turn; 3—low pressure standard, about to register; 4—blood pressure registering at end of dwell.

To facilitate autoclaving, to avoid special parts, and to provide hydraulic shock absorption, standard latex heavy-wall rubber tubing is used to connect the system of standard stopcocks to the scanning valve. With this unsupported rubber tubing, reliable frequency response of more than 10 cycles per second is available with a catheter consisting of six feet of nylon tubing, with a 0.078-inch inside diameter, terminating in a No. 18 needle. This response is adequate for accurately recording the arterial blood pressure.[1] With a larger diameter and more rigid catheter system, much higher frequencies can be obtained.

The noise level of the complete scanner system is less than the equivalent of a pressure at 1 mm. of Hg. Therefore, pressures of less than 10 mm. of Hg can be satisfactorily monitored and measured.

An excellent paper record of the pressures can be made with any photographic recorder having a frequency response of 300 cycles per second or more *(Fig. 6)*. Most of the standard direct-writer recorders will also produce an accurate and satisfactory record. A recording can also be made by removing the green or amber

A

B

Fig. 6. Human arterial blood-pressure curves. A, Photographic record (Sanborn Model 62). B, Direct writer record.

filter of an oscilloscope and photographing the screen with an ordinary camera by holding the camera open for the duration of one sweep.

Summary

A new transducer system for recording the direct arterial blood pressure has been developed, by means of which it is possible to display continuously known pressures and the arterial pulse curve on the screen of a cathode-ray oscilloscope, and to record the curves by means of a suitable galvanometer.

Acknowledgment

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Reference

1. Warren, J. V., and Leonard, J.: Intravascular Pressure Recording. *In* Methods in Medical Research, vol. 7, p. 80, edited by J. V. Warren and others. Chicago: The Year Book Publishers, Inc., 1958, 237 pp.