A Simple Blood Flow Meter.*† (19720)

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While assembling equipment for the Starling heart-lung preparation, the problem of constructing an adequate blood flow meter became apparent. We arbitrarily established the following requirements: 1) accuracy of about 5%, 2) direct recording of flow against time, 3) linear response or a simple algebraic function thereof, 4) relative independence from viscosity changes, 5) immediate response to changes in flow, 6) simplicity of construction.

A recording meter was ultimately devised to meet these criteria using a test tube, a spring, a heart lever, a funnel and a suitable chassis to hold the components together as shown in Fig. 1. It was constructed as follows: A hole approximately 3 mm in diameter was blown in a pyrex test tube (22 x 175 mm). The test tube was suspended by a wire ring attached to an open coil stainless steel spring (wire diam. 0.009 in., O.D. 0.078 in., length 2.5 in.). One end of a fine lever was coupled to the lower end of the spring, the other traced a record on a kymograph. The lever arm ratio was approximately 10:1. The inflow was delivered through a tube running the length of the vessel. The outflow was collected in a funnel supported directly beneath the orifice. All glass parts were siliconed.

The theory upon which this meter is based depends on a consideration of the conservation of energy. By equating the potential energy of a unit volume of fluid at the top of a vessel to the potential energy of a unit volume at an orifice in the bottom of this vessel, it becomes obvious that the height of the fluid column is proportional to the square of the outflow velocity.‡ Since the effective orifice is essentially constant, the rate of outflow is directly proportional to the velocity; thus height is directly proportional to the square of the flow. For any given inflow rate, the fluid height will increase until the outflow rate becomes equivalent. At equilibrium, the fluid height remains constant. Range is determined by the vessel height and the diameter of the orifice. Thus, to measure flow, one need only measure fluid height in such a vessel. Since the vessel is of uniform diameter, height is a linear function of weight. Therefore by suspending the vessel on a spring, one may measure the deflection of an appropriately coupled lever and find it proportional to the square of the rate of flow. For electronic recorders, a strain gauge may be used instead of a spring.

Deviations from theory, due to the physical

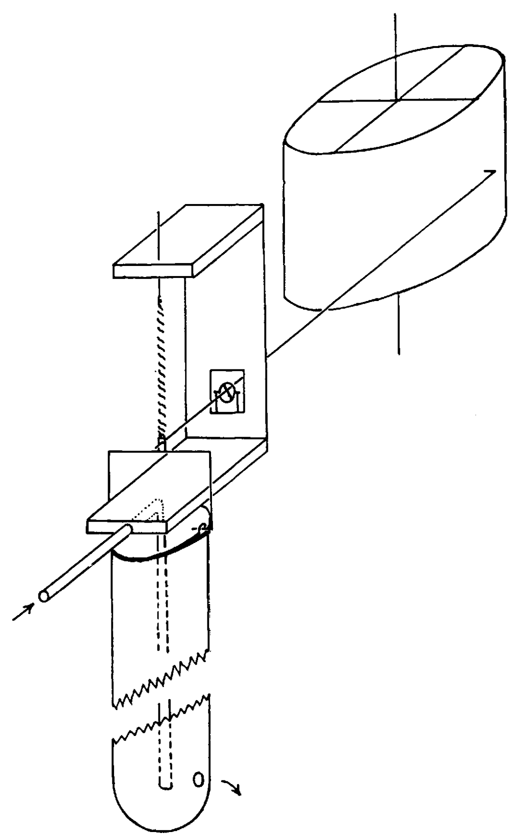

FIG. 1. Diagram of flow meter construction. The orifice is placed at one side of the bottom, in order to avoid the jet of incoming fluid. The funnel below the orifice is not shown.

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‡ $mgh = \frac{1}{2} mv^2$; $kh = v^2$.

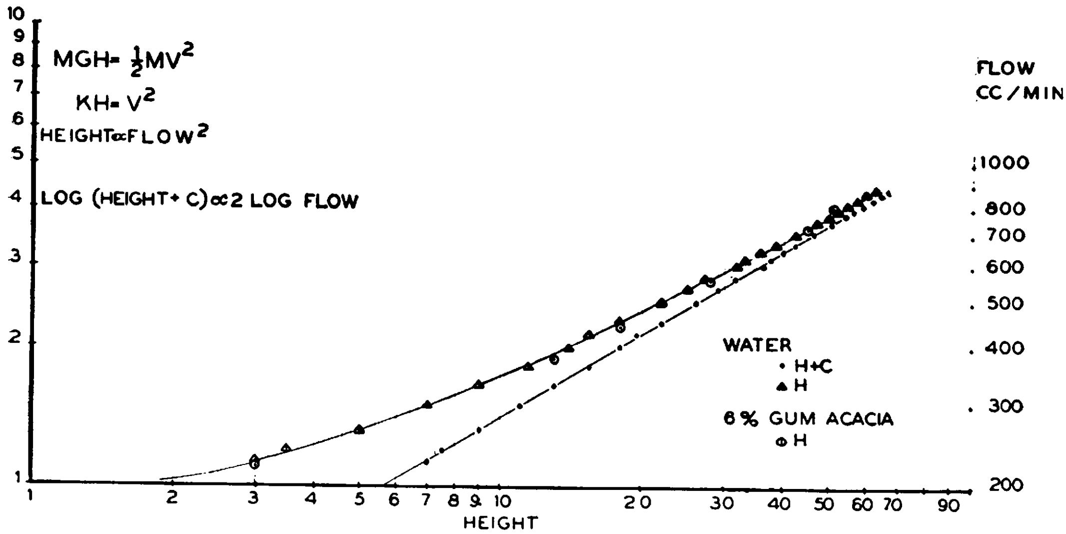

FIG. 2. Example calibration curve. In this case C = 4.

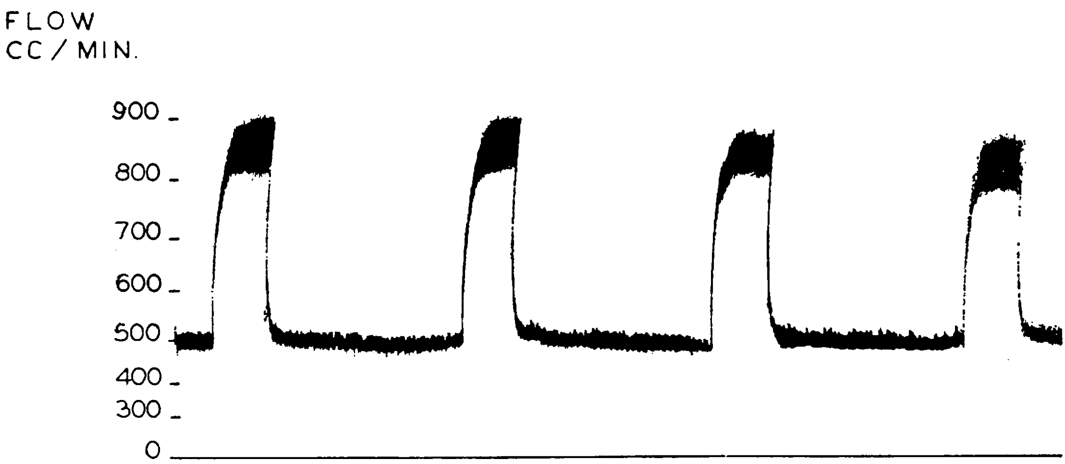

FIG. 3. Flow meter tracing showing response of cardiac output, in the Starling heart-lung preparation, to suddenly raising the venous reservoir 25 mm for 2 minute intervals every 10 min. The initial flow of 510 cc per min increased to 870 cc per min on the first test. Thirty min later, the response was from 505 cc per min to 830 cc per min indicating the amount of spontaneous failure.

properties of fluids, may be minimized by keeping the diameter of the vessel as large as possible and the orifice as short (that is to say the thickness of the vessel wall as thin) as possible. The meter is totally inaccurate when the fluid height falls to within several millimeters of the orifice.

Calibration was accomplished by allowing water to flow through the meter at various constant rates and measuring the volume collected in one- or 2-minute intervals. A linear calibration curve was constructed by plotting the vertical pointer height against the square of the flow. For convenience in reading the calibration curve the log height was plotted against 2 log flow, using several points to draw a line on log-log graph paper as illustrated in Fig. 2. This plot was linear only if it passed through the origin. Therefore, in order to obtain a linear calibration it was necessary to find the intercept, C, and plot 2 log flow against log (height + C). C was then added to the observed height before reading flow from the graph. In all cases, the calibrated points were within about 5% of the best fitting line. When calibration lines using water were compared with calibration lines using 6% gum acacia (relative viscosity 7.5), the difference was never greater than 3%.

In a somewhat similar manner, Stephenson (1) has constructed a flow meter in which the height of a fluid column was related to the rate of discharge through a capillary. Due to pneumatic coupling to the recording device, this meter would seem to be sensitive to temperature and barometric pressure changes. The meter would also seem very sensitive to changes in viscosity and surface tension because of its dependence on capillary flow and the presence of drop formation at the orifice. Due to these factors, and to the presence of turbulent flow, there is no simple mathematical expression for its performance.

In our arrangement of the heart-lung apparatus, the meter was placed at the end of the arterial system, the outflow from the funnel going directly to the venous reservoir. A sample blood flow recording is shown in Fig. 3.

Since small changes in flow may be obscured due to frictional resistance of the writing stylus on the paper, it is suggested that a small electric vibrator be placed on the flow meter support. When the flow is pulsatile, as in the heart-lung preparation, the vibrator is unnecessary.

When the vessel diameter is increased, a larger volume increment is required in order to reach equilibrium and the response time is therefore lengthened. This results in a reduction in the oscillations due to transient changes and the meter approximates, to a finer degree, mean flow.

Summary. An inexpensive direct recording flow meter, relatively independent of viscosity changes and with an accuracy of about 5% was constructed. Its chief advantage lies in its extreme simplicity. The calibration curve, closely approximating a parabolic function, was reduced to a straight line by plotting log height against 2 log flow on log-log graph paper.

1. Stephenson, R. P., *J. Physiol.*, 1948, v107, 162.

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Transport of Radioactive Sodium Across the Synovial Membrane of Normal Human Subjects.* (19721)

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(Introduced by William S. McCann.)

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Any investigation of physiological function of the synovial membrane of joints is limited by suitable technics for the study of this relatively inaccessible structure. The availability of a variety of isotopes obviates some of these difficulties. The present investigation was designed to study the sodium clearance of the synovial membrane by means of radioactive sodium.

A group of 35 healthy adults were injected in the knee synovial space with Na^{24} and the clearance rate determined. The results of this study of normal subjects reveal that significant differences are encountered between normal men and women. The present report describes these variations.

Method. Radioactive sodium (Na^{24}) was obtained from the Oak Ridge National Laboratories as $Na^{24}{}_2CO_3$. It was converted to $Na^{24}Cl$ and suitably diluted to produce an 0.85% sodium chloride solution with an adjusted pH of 7.3. The concentration of Na^{24} was 30-40 μc in each milliliter. After local novocaine anesthesia a 20-gauge needle was inserted under the lateral inferior border of the patella into the synovial space of the knee. Two milliliters of the sterile radioactive

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