BLOOD FLOWMETERS SYMPOSIUM

List of papers and demonstrations for meeting as of February 15, 1959

ABBOTT, E. A. see Herrold

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1. ALBERTAL, George, M. D. Thoracic Service, Peter Bent Brigham Hospital, Boston, Mass.

LABORATORY AND CLINICAL APPLICATION IN EXTRA-CORPOREAL CIRCULATION OF AN ELECTROMAGNETIC FLOWMETER

(abstract not received) Note from letter, "We have been working for the past year with an electromagnetic flowmeter in the laboratory and for clinical application in extra-corporeal circulation. We are very satisfied with it and we think it answers most of the problems encountered. We have some notes and results and would like to present them at your meeting. ---"

DEMONSTRATION

Foxboro Magnetic Flowmeter The Foxboro Co. Foxboro, Mass.

ANDERSON, J. A. see Herrick
ASSALI, N. S. see Herrold
BAY, Emmet B. see Feder

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2. COOPER, Theodore, M. D., Ph.D. and RICHARDSON, Alfred W., Ph.D., Dept. Physiology and Surgery, St. Louis University School of Medicine, St. Louis, Missouri

COMPARATIVE PULSATILE BLOOD FLOW CONTOURS DEMONSTRATING THE IMPORTANCE OF R-C OUTPUT CIRCUIT DESIGN IN ELECTROMAGNETIC BLOOD FLOW METERS

Comparative studies of pulsatile blood flow contours have been made on the arterial vascular system of dogs, and in rigid physical systems employing electromagnetic blood flow meters of different designs, and a differential pressure-analog computer velocity meter. It has been concluded that the major contributing factor in the limitation of response speed is not necessarily the selection of the carrier frequency. The resistance and capacitance that is required in the rectification circuit where ripple must be eliminated creates a compromise condition which actually sets the upper limit of response speed, rather than the carrier frequency per se, although the two factors are related. High speed fidelity can be improved by frequency multiplication at the critical point. Experimental results are presented to support this concept.

DEMONSTRATION

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3. CORDELL, A. Robert, M. D. and SPENCER, Merrill P., M. D.
Dept. Surgery and Physiology, Wake Forest, The Bowman Gray School of Medicine, Winston-Salem, North Carolina

ELECTROMAGNETIC BLOOD FLOW MEASUREMENT IN EXTRACORPOREAL CIRCUITS

The square wave electromagnetic flow meter of Denison and Spencer has been adapted for monitoring of blood flow through extracorporeal circuits. A calibrated voltmeter has been incorporated into the instrument panel which allows direct readout of flow from the monitoring unit. This unit consists primarily of an electromagnet imbedded in plastic which is inserted at any point into the extracorporeal circuit. Blood flows through what amounts to stainless steel connectors with no change in cross sectional area and, therefore, no increase in resistance. The interior of the monitoring unit is streamlined to prevent undue trauma to blood constituents.

Calibration of the monitoring probe has been carried out using blood of a known hematocrit. Changes in hematocrit while monitoring exert a negligible effect since a variation in hematocrit between 30 and 50 volumes percent causes only a 4 percent change in sensitivity. Its calibration is not sensitive to blood viscosity or temperature change. Blood flow may be recorded along with other modalities on a multiple channel recorder during cardiopulmonary by-pass for open heart surgery.

This system of blood flow measurement is linear, indicates positive or negative direction of flow, and can be used to check pulsatile character of the flow from the pump in conjunction with a high frequency recorder. It is easily cold sterilized and has a smooth channel with no moving parts. The magnet detects a wide latitude of flow rate and, by changing the attentuation of the amplifier, is used for total cardiopulmonary by-pass of an adult or infant as well as for perfusion of artificial kidneys or isolated body segments.

DENISON, A. B. see Spencer
ELLIS, R. M. see Franklin

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4. FARRALL, William R. Farrall Instrument Co. Grand Island, Nebr.

DESIGN CONSIDERATIONS FOR ULTRASONIC FLOWMETERS

The ultrasonic flowmeter is an extremely complex electronic-aooustic system. By thorough engineering and careful construction, it is possible to develop satisfactory equipment. In spite of the complicated electronics a flowmeter has been constructed which has operated for three years with little down time. Development of circuits for this instrument requires careful consideration as to wave shape, stability, and physical layout. This attention results in an instrument which will give a stable base line and reproducible data.

DEMONSTRATION

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5. FEDER, Walter, M. D. and BAY, Emmet B., M. D., Dept. Med. The University of Chicago, Chicago 37, Ill.

THE DC ELECTROMAGNETIC FLOWMETER AND ITS APPLICATION TO BLOOD FLOW MEASUREMENT IN UNOPENED VESSELS

The simplest and most direct method for measuring blood flow in unopened vessels is by means of the DC electromagnetic flowmeter. Mathematical and physical considerations directly relate flow to the EMF generated at the electrodes by the moving conductor; namely, the blood in the vessel.

Our studies reveal that the obstacles to its successful utilization revolve about the following problems which can be overcome:

(1) Non-Polarizable electrodes - Ag Ag-Cl chloride electrodes of any desired size can and have been constructed which remain stable for weeks at a time under varying conditions including those of flow in a model. The variation for 15 minute periods is negligible - ± 10 microvolts; where the flow signal will be of the order of 0.1 to 1.0 millivolts.

(2) Magnet design - field strengths of various shapes of magnets with various pole faces have been carefully plotted to achieve the smallest possible weight: field strength ratio. The most efficient type for use in the dog has a field strength in the range of 2000-2500 gauss.

(3) Recording - Commercial DC amplifiers are now available which are stable, linear and have a high input impedance.

Flow models have been constructed and flow has been accurately recorded using both gravity and pulsatile types of flow.

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6. FERGUSON, D. J., M. D. and WELLS, H. S., M. D., Veterans Administration Hospital and University of Minnesota, Minneapolis 17, Minn.

HARMONIC ESTIMATION OF SIGNIFICANT FREQUENCIES IN BLOOD FLOW

Blood flow curves have been obtained from human patients and from dogs in a variety of locations and physiological circumstances, using a magnetic meter known to respond accurately to at least 45 cycles per second. (A description of apparatus and calibration is in press, in Circulation Research). The curves have been analyzed harmonically in order to assess the relative contribution of higher frequencies to the amplitude of peaks in the original curve. The information thus obtained provides an estimate of the frequency to which any flow meter must respond accurately if pulsatile flow under the given circumstances is to be correctly recorded. In all cases studied so far, the needed frequency was less than 50 percent of that provided by the meter we have used.

Foxboro Instrument Co. See Albertal

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7. FRANKLIN, Dean L., ELLIS, R. M., M. D., and RUSHMER, R. F., M. D., Dept. Physiology and Biophysics, University of Washington School of Medicine, Seattle 5, Washington

PULSED ULTRASONIC FLOWMETERS

Instantaneous blood flow through various arteries has been measured continuously in intact dogs during spontaneous activity by means of a new pulsed, ultrasonic flowmeter. The detection of small phase shifts in a continuously transmitted high frequency sound has been a serious obstacle to the development of ultrasonic flowmeters in this and other laboratories. A more promising approach involves the direct measurement of differences in ultrasonic transit times by pulse techniques. Two piece electric crystals were mounted on opposite ends of a plastic cylinder enclosing the thoracic aorta so that a burst of 3 megacycle sound, emitted from one crystal, passed diagonally through the blood to excite the opposite crystal. When the direction of transmission was reversed upstream and downstream, the difference in transit time was an expression of the velocity of blood flow. Bursts of sound were emitted 10,000 times a second and the direction of transmission was alternated 400 times a second. A linear voltage rundown circuit generated sawtooth voltages, the amplitude of which were proportional to transit times. Flow velocities were indicated by recording the differences between the peak amplitudes of upstream and downstream voltages. The frequency response was in excess of 30 c.p.s. Integrated flow per stroke, accumulated flow per unit time and heart rate were simultaneously derived by means of electronic computers.

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8. FRY, Donald L., M. D., National Heart Institute, Bethesda 14, Maryland

THE MEASUREMENT OF PULSATILE BLOOD FLOW BY THE COMPUTED PRESSURE GRADIENT TECHNIQUE

The pressure gradient in a flow is associated with the inertial and frictional properties of the fluid. With certain restrictions the pressure drop between two relatively close points along the aorta is composed of two pressure components, (1) a component associated with the time acceleration of the flow and (2) a component associated with the frictional losses in the flow. This relationship may be expressed mathematically by a linear, first order differential equation. This equation may be instantaneously and continuously solved for velocity by using a simple analog computer that is driven by an electrical signal that is proportional to the instantaneous pressure drop along the aorta. The electrical signal is obtained from a differential pressure transducer attached to a special double lumen catheter.

In pulsatile flow the foregoing technique can be shown to give velocity curves that are very similar to the curves obtained simultaneously from an electromagnetic flowmeter and a direct velocity monitoring technique.

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9. HERRICK, J. F., Ph.D., and ANDERSON, J. A., M. D., Mayo Clinic, Rochester, Minn.

AN ULTRASONIC FLOWMETER

Although problems must be solved before attaining the ultimate goal desired in the development of an ultrasonic method for measuring the flow of blood, the method in its present stage of development is proving to be a useful tool to the physiologists. The physiologists who are using the method in our laboratory have confidence in the performance of the ultrasonic flowmeter when a quantitative understanding of rapid changes in flow is required. A report of these particular investigations will be presented in a separate paper by the physiologists who are using the method presently.

The purpose of this paper is three fold: (1) to demonstrate the performance of the ultrasonic flowmeter at its existing stage of development, (2) to analyze and evaluate the method and (3) to discuss the problems which must be solved in order to attain the desired and ultimate goal of a method for measuring the flow of blood.

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10. HERROLD, G. H., M. D., ABBOTT, E. A., WILK, R. B., WESTERSTEN, A., and ASSALI, N. S., M. D., University of California Medical Center, Los Angeles 24, California

RECENT DEVELOPMENTS IN THE ELECTRO-MAGNETIC FLOWMETER FOR MEASURING REGIONAL BLOOD FLOW

The electromagnetic flowmeter for measuring regional blood flow has been improved in its recording circuitry and made into a versatile instrument suitable for human as well as animal research. Provision has been made for the simultaneous recording of pulsatile and mean flow rates. The accuracy of measurement is within 5 percent.

A ring modulator circuit is used as a phase sensitive detector. The main advantages of this type of detector are excellent linearity and inherent insensitivity to artifacts differing in phase from the desired flow signal.

A differential amplifier is used in the mean flow circuit to integrate directly the output of the phase sensitive detector. The phase relationship is, therefore, preserved. Thus, the mean flow circuit will integrate positive as well as negative flow rates.

The need for a specially constructed low impedance device has been eliminated and a circuit designed to accept the high impedance output of a conventional resistance capacitance network has been devised.

In order to avoid the necessity of recalibration at the site of each measurement, a grounded annular ring is located at each end of the flowmeter sleeve. This establishes an essentially constant impedance reference point to ground to the balanced input of the signal amplifier.

An adjustable sensing unit which permits measurement of blood flow from vessels of varying sizes has been developed, thereby eliminating the need for an excessive number of flowmeter units.

An electromagnetic flowmeter incorporating the above features will be demonstrated.

DEMONSTRATION

JOCHIM, Kenneth E. see Shirer
JOHNSON, P. C. see Sevelius
MARSHALL, R. J. see Shepherd

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11. NASH, Charles W., Ph.D., Dept. Physiology and Pharmacology, University of Alberta, Edmonton, Canada

AN AUTOMATIC, RECORDING BUBBLE FLOW-METER

This meter has the advantages of the conventional bubble flow-meter with respect to accuracy and low resistance with the added advantages of rapidly repeated automatic operation and of allowing the simultaneous recording of both flow rate and blood pressure with a single channel oscillograph. Although the flow determination is an intermittent one it is repeated frequently enough to make the system suitable for following the course of rapid changes in the rate of blood flow in peripheral vessels.

DEMONSTRATION

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12. OLMSTED, Frederick, M. D., Research Division of the Cleveland Clinic Foundation and the Frank E. Bunts Educational Institute, Cleveland Clinic, Cleveland 6, Ohio

RECORDING OF CONTINUOUS PHASIC CARDIAC OUTPUT IN THE ACTIVE DOG; RESULTS WITH THE CHRONICALLY IMPLANTED ELECTROMAGNETIC FLOWMETER

Electrical fields surrounding the magnetic meter implanted in an active animal, both by evidence and theory, form a complex R-C bridge, part of which is unstable. This concept facilitates design of a very simple, stable circuit utilizing two balance points of the bridge; one sensitive to transient artefact, one to flow-signal only.

Phasic cardiac output, blood pressure, and heart rate were recorded from many active dogs during sleep, rest, exercise, emotional disturbance, fright, and responses to vasoactive substances. Accumulated evidence shows that concepts of cardiac control and action based on anesthetized, operated preparations might well be reappraised.

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13. POTTER AERONAUTICAL CORPORATION, Union, New Jersey, SMITH, C. S., Industrial Meter Division

DEMONSTRATION ONLY

RICHARDSON, Alfred W. see Cooper
RUSHMER, Robert F. see Franklin

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14. SEVELIUS, G., M. D. and JOHNSON, P.C., M. D., Radioisotope Service, Veterans Administration Hospital and Department of Medicine, University of Oklahoma, Oklahoma City, Oklahoma

CORONARY BLOOD FLOW DETERMINED BY SURFACE COUNTING TECHNIQUE AND RATIO FORMULA

Prinzmetal and others have shown that an estimate of cardiac output can be obtained by recording the time activity curve of intravenously injected radioiodinated serum albumin through the heart with a scintillation tube placed on the body surface over the heart. By using a high frequency response in our rate meter we have found that an extra peak is present on the downslope of the curve of the left ventricle. This peak appears simultaneously with the peripheral circulation as measured by the appearance of the radioactivity in the carotid artery. When the detector is placed over the base of the heart this peripheral circulation peak is dominated by the coronary blood flow. A formula for calculating blood flow from the peripheral circulation peak was developed in our laboratory in connection with work on renal blood flow. This formula was used for coronary blood flow as follows:

$$\text{coronary blood flow} = \text{cardiac output} \cdot \frac{A^2_h}{A^2_c} \times \frac{T_c}{T_h}$$

where: A = areas of the curve, T = time of first passage of radioactivity, h = heart, c = coronary.

The coronary blood flow in different clinical diseases and age groups will be presented.

The mean $\pm$ standard error of the mean in 19 normal male patients was 306 $\pm$ 18 cc/min. In 9 male patients with coronary insufficiency, the mean coronary blood flow was 162 $\pm$ 9 cc/min. ($P < .001$).

The mean ages of these two groups were 49 $\pm$ 14 and 50 $\pm$ 12 years respectively. The mean weights were 152 $\pm$ 5 and 150 $\pm$ 4 pounds for the coronary group. Coronary blood flow calculated on a weight basis was 2.0 $\pm$ 0.5 and 1.1 $\pm$ 0.2 cc/min. per pound weight. Using this technique, 65 mg. Nitroglycerine increased the coronary blood flow in a normal 65 percent.

SHACKLEFORD, Richard B. see Shirer

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15. SHEPHERD, John T.,M. D., and MARSHALL, R. J.,M. D., Mayo Clinic, Rochester, Minn.

APPLICATIONS OF ULTRASONIC FLOWMETER

(Abstract in preparation. This is to be a report on the application of the ultrasonic flowmeter presented in the paper by Drs. Herrick and Anderson.)

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16. SHIRER, Hampton W., SHACKELFORD, Richard B., JOCHIM, Kenneth E., Dept. Physiology, University of Kansas, Lawrence, Kansas

A MAGNETIC FLOWMETER FOR RECORDING CARDIAC OUTPUT

Instantaneous cardiac output (less coronary flow) can be recorded with a magnetic flowmeter applied to the ascending aorta, provided: (1) the extremely large EKG potentials can be eliminated, (2) the flowmeter is phase sensitive, and (3) the overall response is uniform to at least 100 cps. This has been done by a modification of the square wave method, recently introduced by A. B. Denison, and through the use of a high switching frequency (480 cps), an input high pass filter, and a double balanced demodulator. Calibration is carried out electrically after an initial in vitro calibration for each pickup sleeve. Two outputs provide simultaneously instantaneous and mean flow. Circuit details and design considerations are discussed and sample recordings shown.

DEMONSTRATION

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17. SPENCER, Merrill P., M. D. and DENISON, Adam B., Jr., M. D., Dept. Physiology and Pharmacology, Bowman Gray School of Medicine, Winston-Salem, North Carolina

THE SQUARE-WAVE ELECTROMAGNETIC FLOWMETER: THEORY OF OPERATION AND DESIGN OF MAGNETIC PROBES FOR CLINICAL AND EXPERIMENTAL APPLICATIONS

This system (Medical Physics, Vol.III, and Methods in Medical Research, Vol. 8) consists of a 240 cps 5 volt 3 ampere square-wave magnet supply, condenser-coupled amplifier with blanking circuits and AC to DC converter in suitable housing and connected by means of a 15 foot extension to any of several types of interchangeable electromagnetic probes, records volumetric blood flow through any surgically exposed but unopened blood vessel from the largest down to 1 mm. O.D. Its chief advantage over the D. C. and sine wave systems is in its greater zero stability resulting from elimination of polarization and transformer voltages. Each probe, cast in waterproof, non-irritant plastic, holds the vessel in the magnetic field and against two gold electrodes oriented so that the flowing blood cuts lines of force and generates a square-wave flow voltage

proportional to the volumetric passage of blood along the vessel. The calibration of each probe is constant (± 8 percent) when matched to the vessel circumference within the range of a perfect fit to 20 percent compression. It is insensitive to variations in blood temperature, vessel wall thickness (checked .75 mm to 2.5 mm.), or physiological variations in blood protein or electrolytes. Three useful types of surgical probes, according to the shape of the magnetic core, are "U"-shaped, "C"-core, and "I" or unipolar. The "U"-shaped is most versatile in routine surgical use. The "C"-core is particularly useful as an implanted probe on the ascending aorta and other large vessels of chronic experimental animals and has an extremely stable zero reference. The "I"-type is useful for the coronary arteries and for implantation on small vessels. For extracorporeal blood flow measurements, a "C"-core magnet features a shaped plastic channel of constant cross section passing the magnetic field through a narrow slit and allowing great sensitivity and range with no significant hydraulic resistance.

DEMONSTRATION

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18. THORNTON, Wm. E., Avionics Research Products Corporation, El Segundo, California

PERFORMANCE AND APPLICATIONS OF A COMMERCIAL BLOOD FLOWMETER

Through the use of solid state elements a square wave electromagnetic flowmeter of high stability, sensitivity and frequency response with a complexity and size no greater than a medium sized table radio is now commercially available. Several magnet assemblies with clip-in electrode assemblies provide measurements on a wide range of vessel sizes with flow rates from less than 10 ML/Sec. upward. When used with a companion electronic integrator, volume over fixed periods of time may be determined directly. A trigger circuit actuated by the flow signal or E.K.G. may be used to record volume per cycle. If instantaneous pressure measurements are made at the flowmeter transducer position, a simple electronic analog computer calculates, from pressure and flow rate quantities, mechanical energy content of the blood stream at the point of measurement.

DEMONSTRATION

WESTERSTEN, A. see Herrold
WILK, R. B. see Herrold
YOUNG, W. S. see The Foxboro Company and Albertal
