APPLICABILITY OF IMPLANTABLE TELEMETRY SYSTEMS IN CARDIOVASCULAR RESEARCH*

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Summary This paper briefly describes the results of an experimental program undertaken to develop and apply implanted telemetry to cardiovascular research. Because of the role the kidney may play in essential hypertension, emphasis is placed on telemetry's applicability in the study of renal physiology. Consequently, the relationship between pressure, flow, and hydraulic impedance are stressed. Results of an exercise study are given.

Introduction This paper describes current results from an extended research program designed to correlate dynamic blood pressure, heart rate, and blood flow changes during a variety of psychological and physiological stresses. The advantages of an implantable system for data acquisition will be emphasized. Indeed, an implantable system appears to be the only means by which physiological parameters can be monitored completely free of psychic stimuli from external attachments. Another frequently encountered problem with externally mounted signal conditioners has been the incessant severing of protruding leads by experimental subjects. This results in expensive, time-consuming repairs and recalibration of the system. Infection at the site of the exiting leads is another formidable objection to the use of external systems. There are, of course, more stringent design problems when an internal signal conditioning system is chosen over an externally mounted system. These problems and their solutions will be discussed in the following section.

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* This work was supported by the National Aeronautics and Space Administration under Contract No. NSA-05-018-087.

Aortic blood pressure, heart rate, and renal blood flow data obtained from an unanesthetized dog performing strenuous treadmill exercise will be presented. This is a significant physiological stressor calling forth many homeostatic cardiovascular reflexes. Radiotelemetry methods offer significant advantages over other data acquisition methods when acquiring meaningful dynamic cardiovascular data.

Instrumentation In this application a frequency modulation mode of telemetry is employed; therefore, common to all channels are a carrier oscillator, batteries, and associated power controllers. Each individual channel in addition has a signal conditioner in combination with a frequency modulated subcarrier oscillator. The system utilizes a 9.5 vol mercury cell battery with a voltage regulator. Transmission is initiated by an RF signal and terminates automatically after 10 minutes. A potential of 800 activations is available. By this expedient in concert with the use of low power electronics an experiment with a potential duratior. in excess of a year can be conducted.

The basic concept of the instrumentation being reported upon in this paper has been described previously (1). However, several modifications were found to be necessary before this equipment could be utilized for long-term studies. One of the significant problems encountered was that of body fluids leaking into the transducer plugs and into the blood floi transducers themselves. The problem at the plug was solved by using a polyolefin shrinkable tubing to encase the transducer leads (Fig.1). An effect analogous to that of a telescoping fishing rod was achieved, which reduced the stress at this critical junction of the lead and plug. The original blood flow transducers employed proved to be unsatisfactory because of structural inadequacies. Therefore we have designed and fabricated our own ultrasonic flow probes from cast acrylic. This probe has functioned properly for an extended period of time. The voltage requirements of the signal conditioning system have been reduced in the latest design. The dimensions of the current two-channel system are approximately 2 x 3 x 1/2 inches.

Detection of blood pressure was accomplished by the use of chronically implanted miniature pressure sensors. The sensor body is unalloyed titanium 6.5 mm in diameter and 1 mm thick. This material is highly corrosion resistant allowing long-term direct contact with body fluids. Four semiconductor strain gauges connected in a conventional four-arm bridge are bonded to the inner surface of the small pressure-sensing diaphragm. Positive pressure on the face of the transducer causes resistance changes which are transformed to a voltage change. The sensor is quite sensitive producing approximately 30 mv/300 mm Hg.

Figure 2 is a block diagram of the signal conditioning system for blood pressure. The system is “duty cycled” with a sampling rate determined by the basic frequency of the subcarrier oscillators, i.e. 2300 cps for blood flow and 3900 cps for blood pressure.

Flow detection by an ultrasonic technique was selected because of several advantages. As contrasted with the electromagnetic techniques, the ultrasonic flow-sensing probes are lighter, power requirements are less, and the signal level is higher. The flow concept used is illustrated in Figure 3. Two crystals placed across a flow section are excited in phase opposition by a pulsed 5 mHz signal. The detected signals are either delayed or advanced in time and are therefore modulated in phase proportional to flow. Proper conditioning yields a voltage proportional to flow. The selection of the 180 degree quiescent phase difference between the crystal voltages results in excellent sensitivity. In practice, the flow velocity is quite low producing a maximum phase shift of less than 0.1 radian. Primary output signals typically are on the order of several tens of millivolts.

Applicability and Results A variety of stressors have been utilized in assessing the applicability of this implantable telemetry system for chronic studies. They have included psychosocial stressors, pharmacological agents, and treadmill exercise. An exercise episode will suffice to illustrate the application of the device and to substantiate its utility. Prior to exercise, the dog was held in a stand-stay position on the treadmill for 3 minutes. Exercise consisted of running on a 15-degree incline for 3 minutes each at 2 and 3 miles per hour, and for 5 minutes at 4.5 miles per hour; then back to 2 miles per hour for 3 minutes, followed by 3 minutes of stand-stay on the treadmill. Typical results are illustrated in Figure 4. For this dog, mean pressure fell at the onset of exercise with perhaps a slight increase in mean blood flow. Pressure fell while pulse flow increased. Throughout the course of exercise, mean pressure increased and mean flow decreased, while pulse pressure remained unchanged and pulse flow increased. Since mean flow decreased and mean pressure increased, the absolute value of the resistance to flow increased. Also at the onset of exercise, df/dt increased and dp/dt remained constant while throughout exercise both df/dt and dp/dt increased. It would appear that these results indicate a definite decrease in resistance to renal blood flow at the beginning of exercise. This renal blood flaw pattern would seem to correlate with the recent work of Stinson et al. (2) who have demonstrated cholinergic vasodilatation during the reduction of mean renal arterial pressure. It would further appear that as the severity of the exercise increased and the oxygen consumption of the exercising muscles is concomitantly increased, there is an increased resistance to renal bloodflow, an increased heart rate, a slight increase in mean blood pressure--all of which reflect increased metabolic demands (3). The increase in pulse flaw is probably due to significant vasoconstriction of intrarenal vasculature, and flow results primarily at some point in systole. The flow rate, df/dt, increased at onset of exercise apparently because of a decrease in resistance. The rate of pressure change, dp/dt, is displayed to illustrate that at the onset of exercise df/dt is apparently not a consequence of increasing dp/dt. However, as exercise continues, the increase in pulse flow apparently results from an increased resistance to flow in vascular beds not directly involved in the exercise; this results in an increased dp/dt. The modest rise in mean blood pressure is in accord with previous exercise studies conducted with the dog (3).

Conclusions The implanted miniaturized system used in this study eliminates clouding of the data by emotional responses which occur in animals with other procedures and permits a more valid interpretation of the influence of the manipulated variable on physiological function. The implant method also allows a better definition of normal physiological baseline conditions and eliminates the many problems associated with both hardwire and external telemetry techniques. The equipment described appears to have widespread application in chronic studies. Collection of quantitative and qualitative blood pressure and blood flow data on free-roaming animals with the use of implant telemetry considerably broadens the experimental field in cardiovascular research.

Acknowledgements The assistance of Mr. John Henricksen and Mr. Leo Casados in circuit design and packaging and of Dr. R. A. Stocking in surgery is gratefully acknowledged. Mrs. Patricia Stephens assisted with the art work, Mr. Jack Eppinger with the photography, and Miss Jo Kolsum with the typing.

References (1) Roland D. Rader, "Cardiovascular Telemetry Implants," Telemetry J., 6(3):15-20 (April-May), 1971. (2) J. M. Stinson, A. B. Barnes, R. M. Zakheim, J. E. Chimoskey, F. R. Spinelli, and A. C. Barger, "Reflex Cholinergic Vasodilatation During Renal Artery Constriction in the Unanesthetized dog," Amer. J. Physiol. 217(l):239-246 (July), 1969. (3) William John Sears, Telemetered Blood Pressure and Heart Rate in Dogs During Graded Treadmill Exercise, Natural Activity and Situational Stress, Ph.D. dissertation, University of Southern California, January, 1968.

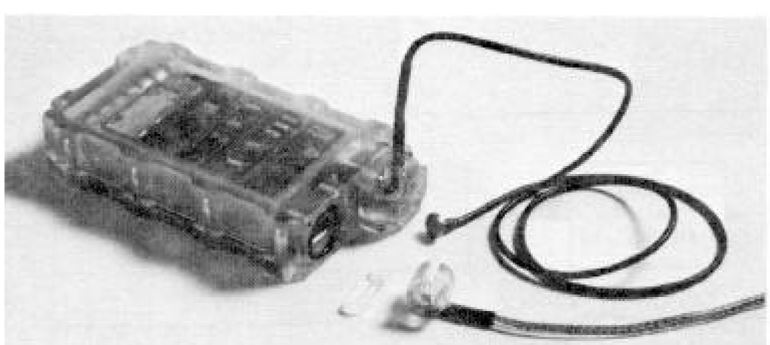

Fig. 1 - Implantable Two-Channel Telemetry System with Attached Pressure and Flow Sensors

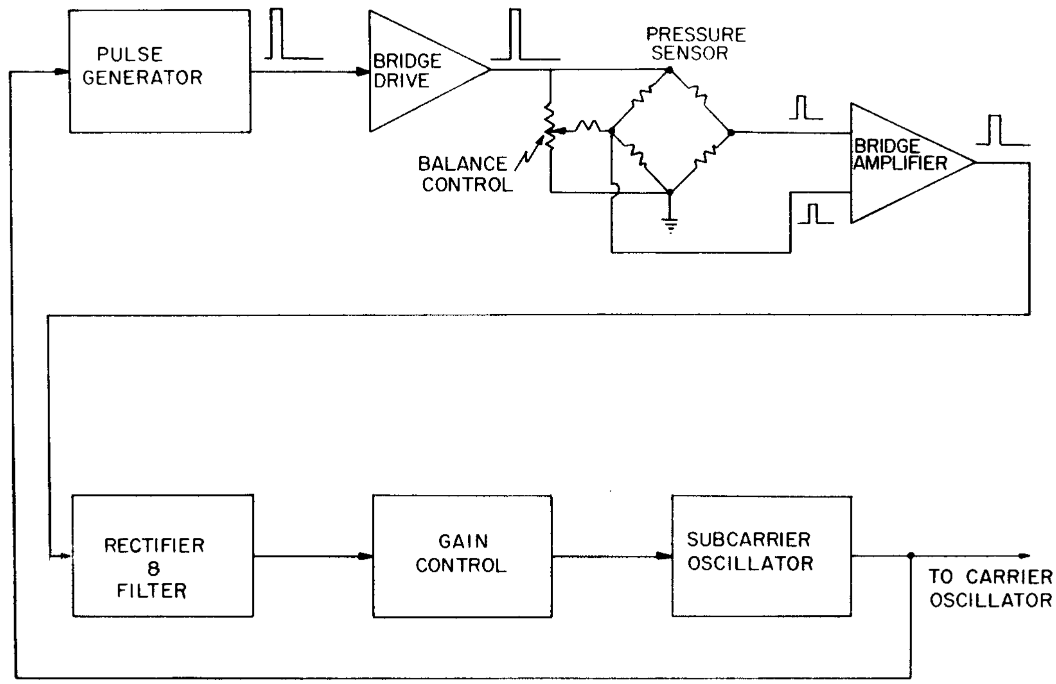

Fig. 2 - Block Diagram of Blood Pressure Signal Conditioning System

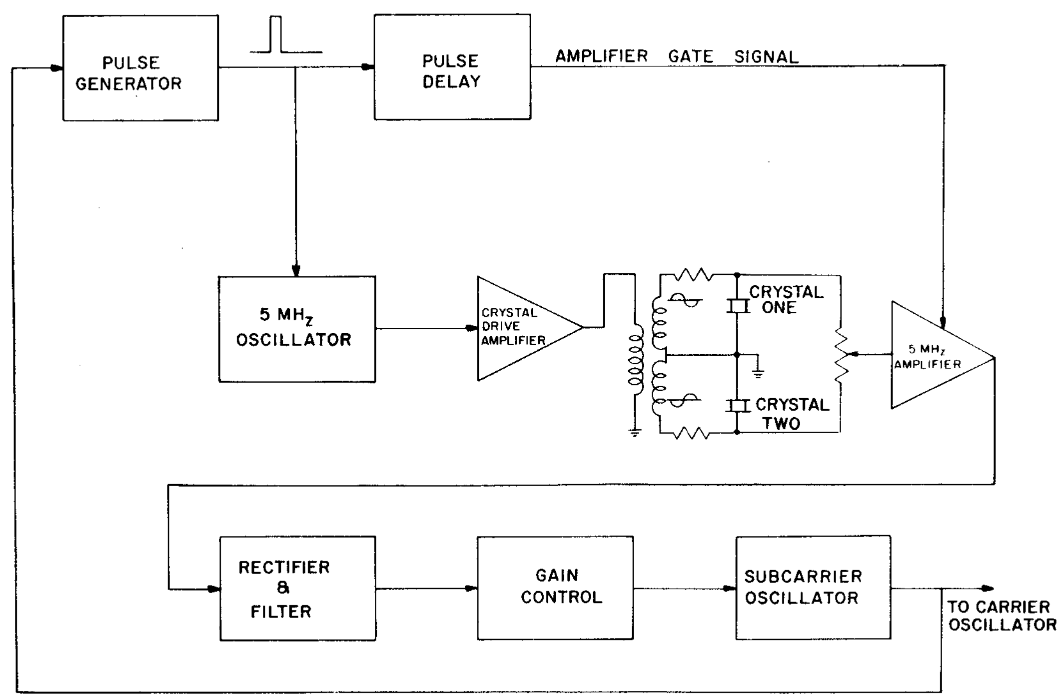

Fig. 3 - Block Diagram Of Blood Flow Signal Conditioning System

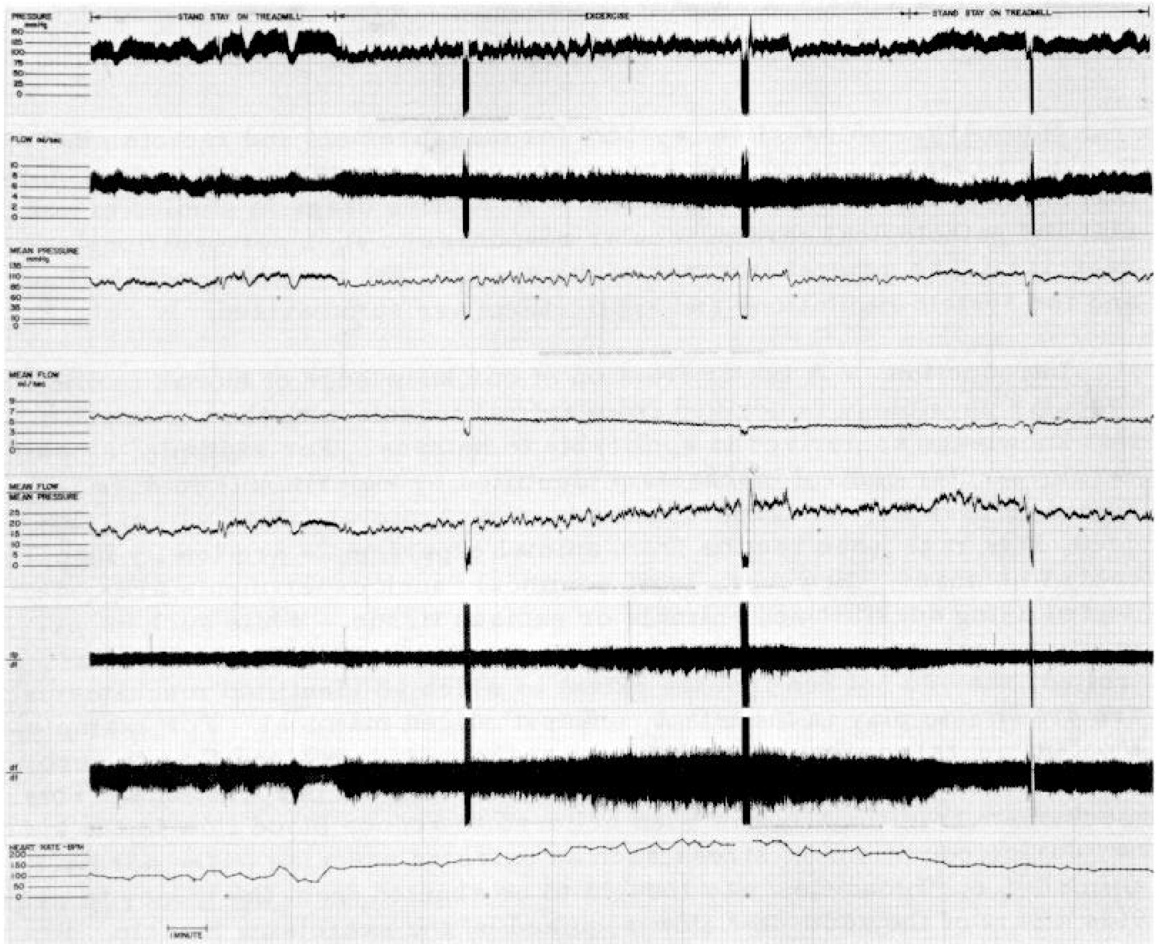

Fig. 4 - Data Resulting from a Typical Exercise Event