Discussion and conclusions. Beeson(2) has shown that in animals made tolerant to the pyrogenic effect of typhoid vaccine, there is an increased disappearance of the pyrogenic material from the blood stream. The increase in disappearance rate is blocked by the administration of thorotrast. He interpreted this as an indication that the reticulo-endothelial system removes the pyrogenic material from the blood stream and that it does so with increased efficiency on repeated contact with the pyrogen, thus leaving less and less pyrogen in the blood stream to damage other susceptible tissues. More recent studies by Bennett and Cluff(1) have shown that rabbits made tolerant to pyrogens become non-reactive also to the Shwartzman phenomenon. Both of these effects are blocked by the injection of thorotrast(2,3), as is the removal of bacteria from the blood stream(4). However, although there seem to be some similarities between the characteristics of resistance to the Shwartzman phenomenon and resistance to pyrogen effect, the third effect (*i.e.* removal of bacteria from the blood) does not show a cross-relationship, at least insofar as alteration of bacterial removal by pyrogen-tolerance is concerned. The extent of splanchnic removal of bacteria from the blood stream of pyrogen-tolerant animals is not significantly different from the removal rate observed in the control groups.

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Simultaneous Recording of Pulse Contours on Central and Peripheral Arteries with Mechano-Electronic Transducers. (18969)

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With each heart beat the sharp systolic rise in blood pressure expands the elastic walls of the adjacent aorta. This expansion travels rapidly along the walls of the arteries as an elastic wave of decreasing amplitude and can be felt as the pulse.

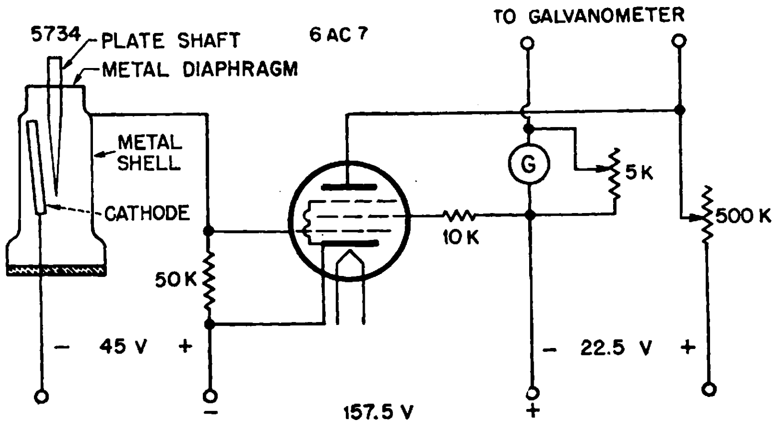
Regarding the relationship between the pulse wave and other factors in hemodynamics it must be kept in mind that the contour and velocity of any wave are determined by the energy generating it and the elastic qualities of the medium through which it travels. The energy in this case amounts to the product of stroke volume $\times$ blood pressure. Hence, these factors determine the pulse wave in principle. The medium transmitting the pulse wave is the wall of the blood filled vessels. The elastic properties of the arterial wall are based upon two components: The elastic fibers which are of passive nature and the muscular elements capable of active contraction. The tone of the muscle fibers in the arterial wall exerts a decisive influence on the velocity and contour of the pulse wave.

An evaluation of the pulse wave therefore offers a means of estimating not only peripheral vascular resistance, but also vasomotor activity as governed by the autonomic nervous system. Despite the importance of these factors in physiological research and particularly in clinical medicine, comparatively few efforts have been made to render the principle more widely applicable.

The principal functions involved are: 1. Systolic and diastolic blood pressure; 2. Diameter of the aorta; 3. Pulse wave velocity measured by simultaneous recording of the pulse contours on at least 2 different sections of the arterial system. The method described here pertains to the last item.

The air transmission sphygmograph as first developed by Frank(1), Wiggers(2), and others has been most frequently used to record pulse contours. This method, although offer-

1. Frank, O., *Z. f. Biol.*, 1930, v89, 274.
2. Wiggers, C. J., Modern aspects of the circulation in health and disease, 1923, Lea and Febiger, Philadelphia.



TRANSDUCER TUBE AND AMPLIFIER
FIG. 1.

ing reliable results in the hands of experienced investigators, has certain limitations.

For proper damping and adequate frequency the length of the tubes must not exceed 2 feet(1). This is a disadvantage since movements of the patient or test subject, as on a tilt table, are limited. Furthermore, the sensitivity of the capsules depends upon the air pressure, which makes the system unsuitable for studies at low barometric pressure and at extreme temperatures.

It seemed likely that a decided improvement in the recording system could be effected by transducing the arterial pulsation into changes of an electrical current. The pickup, which would be called a mechano-electric or mechano-electronic transducer, must be highly sensitive, as only very small forces are available. Moreover, the pressure exerted by the pickup on the artery must not exceed the diastolic pressure, in order to avoid distortion of the pulse wave(1). Good results were obtained when piezo-quartz was used as transducer in combination with the recording cathode-ray oscillograph(3). But this device calls for extremely high amplification, and the amplifier must have a long time constant unless D.C. amplification is employed. Furthermore, it is not easy to adjust.

In recent years several reliable types of mechano-electric transducers have become available for biological purposes. In view of the exceedingly small forces operating on such a pickup from the pulse through the skin a mechano-electronic transducer in the shape of a subminiature tube was used in the present investigation. This transducer (RCA-5734), originally designed for application in phonograph pickups and microphones(4) has a natural frequency of 13,000 cycles per second and is specially matched for further D.C. amplification. Superficially the tube resembles a common subminiature radio tube. The difference lies in the shape of the plate. This consists of a conically shaped bar which coincides with the axis of the tube (Fig. 1). The plate shaft, fixed in a small metal diaphragm, protrudes as a small pin out of the tube. The indirectly heated cathode runs parallel to the conical side of the plate shaft. Movements of the projecting pin alter the distance between plate shaft and cathode, thus the inner resistance of the tube is changed in proportion to the deflection. This in turn effects the plate current. Therefore, proportional voltage variations will occur in a resistor on the plate circuit and can be picked up by an amplifier.

In order to transfer the pulse wave motion from the skin to the tube, a suitable adapter was constructed. This consists of a frame which holds the transducer tube and a flat

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4. Olson, H. F., *J. Acous. Soc. Am.,* 1947, v19, 307.

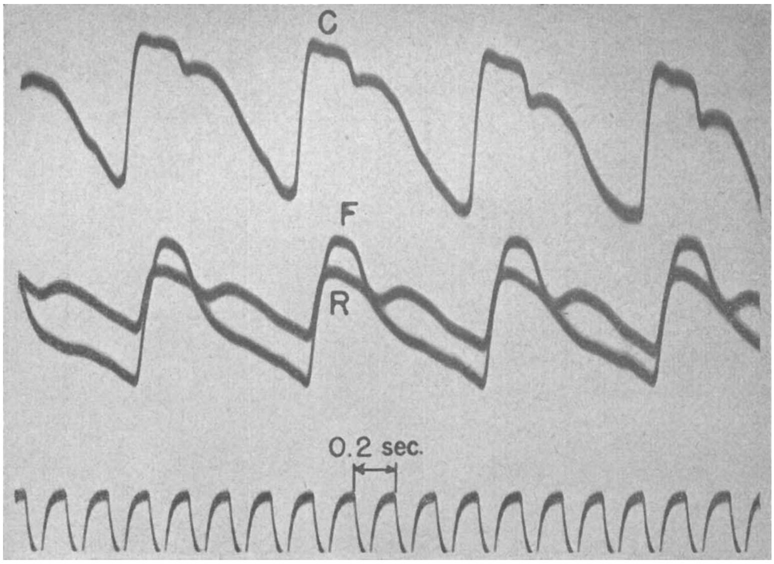

FIG. 2. Optical recordings of pulse curve on carotid (C), radial (R), and femoral (F), arteries.

spring with a small pelotte. Each frame is shaped according to the anatomy of the required location: to the neck for the carotid, to the wrist for the radial, and to the inguinal region for the femoral artery. When the frame is fixed in position with a strap and the pelotte is seen to move over the artery, the pin of the tube is brought into contact with the spring by an adjusting screw. Voltage changes representing the transduced pulse wave are fed into one stage amplifier by direct coupling to the grid circuit, thus avoiding disturbing resonances by using a coupling network. A dial microammeter inserted in the plate circuit, which is equipped with the necessary resistors and is compensated for the basic current, indicates a pulse wave directly. Another galvanometer of the mirror type with an adequate natural frequency records the pulse waves on a photokymograph. The advantages of remote recording are implicit in this arrangement. A combination of 3 complete pickup units has been assembled for simultaneous recording on 3 different arteries. A sample of the recordings obtained is shown in Fig. 2.

From the recordings, the pulse wave velocity can be determined by measuring the time interval between corresponding points on the anacrotic part of the pulse contour on 2 arteries at a measured distance from the heart. The analysis of the pulse contours is carried out in the same manner as in sphygmographic records obtained by the air transmission sphygmograph.

Summary. The application of mechano-electronic transducers is described for the simultaneous recording of arterial pulse contours on central and peripheral arteries in man. The principal advantages of this device over air transmission sphygmographs are remote recording and greater freedom of movement for the subject. The instrument is not affected by changes in environmental temperature or barometric pressure.

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