AN IMPROVED MERCURY STRAIN GAUGE PLETHYSMOGRAPH

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Mercury strain gauge plethysmography has first been described by Whitney in 1953 (1) in order to assess blood flow in the limbs. It is an attractive method because it is external, simple and can be used on fingers as well as limbs.

This method has been widely used in measurement of flow (1,2,5,9,11), systolic (6,8), diastolic and venous pressure (8). The results seem to be in good agreement with various others methods (6,7,9).

A silastic capillary filled with mercury is attached around the limb. The change in girth of the limb induces a change of the resistance of the mercury column

$$dR/R = 2\ dL/L$$

(R and L being the resistance of the gauge and the girth of the limb)

For isotropic radial dilatations

$$dS = 2\ dL/L = dR/R$$

where S is the local sectional area of the limb.

It is then necessary to measure simultaneously R and dR, in order to compute dL. The girth L can be measured directly.

The mercury strain gauge plethysmographs generally use the Wheatstone bridge technique, either using direct current (1,11) or alternating current (3) and constant voltage. Bridges energetized by constant current, either direct (4), or alternating (9) have been used. Direct reading of voltage when the gauge receives a constant current of known intensity has been proposed (5,10).

Those techniques involve a calibration of the gauge mounted on the limb, by mechanical (10,11) or electrical (1,3,4,9) means. Each way creates specific errors (1,2,5).

In order to avoid those errors we used the following method : the gauge is energetized by a constant current I and a variable calibrated resistor receives a current I' = 1/10. The voltage across the gauge and resistor are then compared by subtraction after demodulation. The result is amplified and applied to a galvanometer. This method gives a direct reading of the resistance of the gauge R = R'/10 (R' being the value of the calibrated resistor for a null signal on the galvanometer). The small changes in resistance near this value are then amplified and filtered. The output signal is applied to a recorder. The calibration depends only on the value of I and the gain of the amplifiers. It is then constant for any initial stretch of the gauge. This is not true with Wheatstone bridge methods.

Fig. 1 gives the block diagram of the plethysmograph. Phase shift oscillator I delivers a sinusoidal voltage (15 kHz) to current generators II and III energetizing the gauge G and the variable calibrated resistor R' of 100 Ω with currents of respectively 30 mA and 3 mA. Demodulation occurs in circuits IV and V. Comparison is made by differential amplifier VI (gain 140). A low-pass filter VII is set in the feed-back loop of this amplifier (elimination of frequencies superior to 15 kHz). The result is applied to galvanometer VIII. Oscillations are amplified by amplifiers X (gain $4\ 10^{-2}$, $8\ 10^{-3}$, $4\ 10^{-3}$ and $4\ 10^{-4}$ Ω/V) and applied to the recorder. Filter IX lessens respiratory effects on arterial signals. This filter can be activated when switch S_1 is in "arterial" position. It is disconnected in "venous" position. Switch S_2 disconnects the galvanometer when on "wait" position, and connects it when on "measure" position.

Output impedance is lower than 2 k Ω. Sensitivity is very high (Max $4\ 10^{-4}$ Ω/V) and allows the use of cheap recorders. Attenuation is 3 dB to 20 Hz ; this allows a good reproduction of arterial pulse.

We used the gauges made by Parks Electronics. The gauge extremities are sewn on small Velcro squares, which allow an easy and quick mounting on the limb. The length of each gauge wire is approximately 5 inches. It is connected to the plethysmograph by a cable of 5 ft. The resistance of cable and wires can be compensated thus : the 5 ft cable is connected to the plethysmograph and to a short circuit made of a wire of same length and nature as the gauge wires. The dial of the calibrated resistor is then set to zero, and the offset voltage of differential amplifier X is adjusted to obtain a null signal on the galvanometer.

This compensation may be realised once and for all, if one uses always the same cable and the same length of wire for the gauges.

This plethysmograph gives an immediate reading of R and dR for any initial stretch of the gauge. Sensitivity is constant and high, allowing the use of almost any recorder. This eliminates the need of performing calibration before each measurement.

Futhermore, the apparatus is light and of small size and can be easily used at the patient bedside.

With this plethysmograph, it is possible to record either arterial volume pulse or changes in venous volume (for instance, after occlusion by a cuff).