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High-Sensitivity Optical Lymph Flow-Meter

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Summary

An optical flow-meter is described which allows precise and continuous registration of the flow of lymph from cannulated human lymph vessels. The cannula from the lymph vessel is connected to the measurement tubing of the instrument where the flow is measured by automatically monitoring the movement of an air bubble introduced into the flow at the beginning of the measurement. The limit of sensitivity of the instrument is about 0.1 µl, allowing reliable registration of stroke volumes of about 1 µl which typically occur in human leg lymphatics. The size and capacity of the instrument were chosen to be suitable for clinical use. A technical description of the instrument is given. Application of the instrument is illustrated with recording of lymph flow and lateral intralymphatic pressure in a prenodal lymph vessel of the human leg.

Introduction

Simultaneous measurements of intralymphatic pressure and lymph flow have shown that the pressure generated by rhythmic intrinsic contractions of the collecting lymphatics is the main factor responsible for lymph flow during the relaxation of limb muscles (1, 2). The measurement of lymph flow calls for methods of high sensitivity and precision since the flow pattern consists of pulses with stroke volumes of about 1 µl or less, occurring only a few times per minute. We calculated flows by measuring the distance passed by a minute air bubble introduced into tubing inserted into both ends of a leg lymph vessel (2). The lymph flow measurements have now been improved by using a newly constructed lymph flow-meter described in the present report.

An accumulated flow of up to 150–200 µl can be continuously measured by the instrument, corresponding to a typical registration time of up to 1 hour for resting individuals (2). For particular investigations in the laboratory, an instrument with higher volume capacity might be desirable, and several possibilities exist for such modifications of the instrument.

Principle of Operation of Lymph Flow-Meter

The function of the instrument is based on the principle of measuring volume flow in a transparent tubing by monitoring the position of an air bubble introduced into the lumen at the inlet end of the tubing. By fixing the tube in a circular track (Fig. 1), the movement of

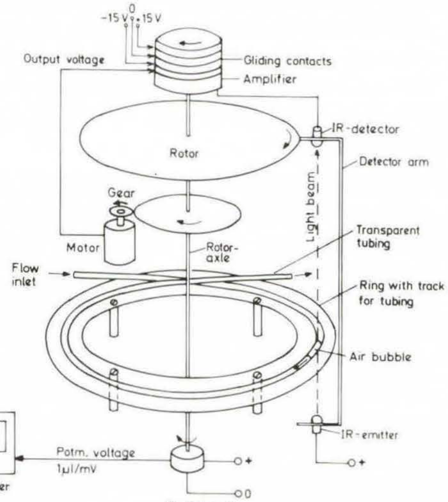

Fig. 1 Schematic view of lymph flow-meter

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the detector which senses the position of the air bubble, can be guided by a rotating horizontal arm. The angular motion of this arm is controlled in such a way that it always will be "locked" to the position of the liquid/air interface within the tube. The angular position of the detector arm is monitored by recording the voltage of a potentiometer mechanically coupled to the axis of rotation. This permits flow measurements to be continuously recorded, e.g. at a calibration of 1 mV/μl.

Instrument Description

The polyethylene tube (Intramedic PE 60, Clay Adams) has an outer diameter of 1.22 mm, an inner diameter of 0.76 mm, corresponding to a linear distance along the tube of 2.2 mm per μl of lymph flow. The tube is held in a circle of 14 cm diameter by means of an inner and an outer tracking ring mounted on a transparent perspex support (see Fig. 1). The sensor which detects the position of the interface between the liquid and the air bubble consists of an infrared emitter (Spectronic SE 5455-4) positioned below the track and an infrared detector (Spectronic SD 5443-2) above the track. Since the detector is sensitive only to infrared radiation, operation of the instrument is independent of ambient light levels. A front lens is an integral part of both emitter and detector, and both elements are placed in such a distance from the track that the width of the track corresponds to the field of view of detector and emitter (20°).

Over a liquid filled region of the tube the detector will receive more of the radiation from the emitter. Thus, the current from the detector will be high when the detector is positioned over a liquid filled tube, and low if the tube is filled with air. An amplifier converts this current into a voltage which is amplified and compared with an adjustable reference voltage. The difference voltage is used to drive a DC motor which by a reduction gear rotates the detector arm. The direction of motion is determined by the polarity of the driving voltage. The amplifier is adjusted such that +5 V will be applied to the motor if the tube is filled with liquid, −5 V will be applied if the tube is filled with air. By letting a positive voltage to the motor correspond to angular movement in the direction of flow, this servo-system will make the detector arm follow the movement of the air-bubble along the circular path of the tube.

In order to eliminate possible sources of contact noise in the signal leads, the amplifier circuitry is mounted on the detector arm, and the output voltage for the DC motor is picked up by gliding contacts on the axis of the instrument. Suitable time constants have been chosen for the pulse response of the electronics, such that the detector arm is held in position without oscillation at the liquid/air interface, but is also able to respond quickly to changes of volume flow.

Since the response of the infrared detector varies slightly with ambient temperature, it was found necessary to include temperature compensation in the amplifier circuit. Thus, the instrument is independent of operating temperature, and therefore no warm-up perioc is necessary prior to use.

A potentiometer without mechanical stop is directly coupled to the axis of the detector arm, such that rotation of the arm in the direction of flow increases the voltage measured across the potentiometer. This output voltage is directly calibrated as 1 mV/μl, and by connecting it to a recorder, a continuous registration of lymph flow as a function of time is obtained.

Application

Fig. 2 shows a simultaneous recording of lymph flow and lateral intralymphatic pressure Both the distal and the proximal ends of the lymph vessels were cannulated. The other ends of the cannulas were connected to the flowmeter tubing so that a closed circuit was created. A T-piece was placed in the circuit and connected to the pressure transducer. The amplified signals of lymph pressure and flow were simultaneously registered on a two-pen direct writing recorder.

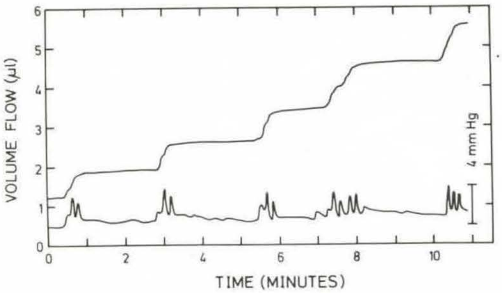

Fig. 2 Simultaneous recording of lymph flow (upper trace) and lateral intralymphatic pressure (lower trace) from cannulated prenodal lymph vessel in the human leg. The time axis common to the two measurements is shown on the abscissa. Accumulated lymph volumes is shown on the left ordinate, whereas the pessure is indicated to the right in the figure

The tracings presented in Fig. 2 indicate that each pressure wave was reflected in the flow measurement. Each wave caused a flow of about 1 µl of lymph. The sensitivity of the instrument is demonstrated by the fine structure of the flow-meter recording, which reveals the flow caused by each individual pressure pulse within a wave of spontaneous contractions.

References

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