has been provided by one of us[8] in studies on the sensitivity of smooth musculature to exogenous epinephrine in cats as altered by hypophysectomy. It was found that the smooth musculature of such animals shows a definitely hyperdynamic contractibility (30-40%) on contact with epinephrine. This would result in an accentuated contraction of the blood vessels at the site of subcutaneous injection with a corresponding slowing of the rate of absorption. Such a factor would not be active on intravenous or on intraperitoneal injection where absorption would occur largely through the lymphatics.

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Photoelectric Plethysmography of the Fingers and Toes in Man.

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The detection of changes in the blood content of tissues with the aid of the photoelectric cell has been reported by several observers.[1] This paper reports the development of photoelectric plethysmographs which lend themselves to clinical use in dynamic analysis of the peripheral circulation and which may be "plugged in" in place of the patient's lead on the electrocardiograph. A summary of some observations thus recorded on the finger is reported elsewhere.[2]

A beam of light is directed from an ordinary automobile headlight bulb (direct current) on the finger or toe placed above a shielded photoelectric cell of the photo-emissive type, purchased in the radio trade, (cell current generated is approximately equal to 5×10^{-10} ampere—this may be increased by impressing 45-90 volts across the cell). The photoelectric oscillations with variations in the blood content of the digit are recorded by a string galvanometer or suitable oscillograph after amplification.

Adaptation of the principle of the method to the finger is shown in Fig. 1. A comfortable saddle or sling for the arm is necessary to

[8] Heinbecker, P., *Am. J. Physiol.*, 1937, **120**, 401.

[1] Bonsmann, M. R., *Arch. f. exp. Path. u. Pharmakol.*, 1934, **176**, 460; Matthes, K., *Ibid.*, 1935, **179**, 698; Hanzlik, P. J., DeEds, F., and Terada, B., *J. Pharm. and Exp. Therap.*, 1936, **56**, 194; Molitor, H., and Kniazuk, M., *Ibid.*, 1936, **56**, 1.

[2] Hertzman, A. B., and Spealman, C. R., *Am. J. Physiol.*, 1937, **119**, 334.

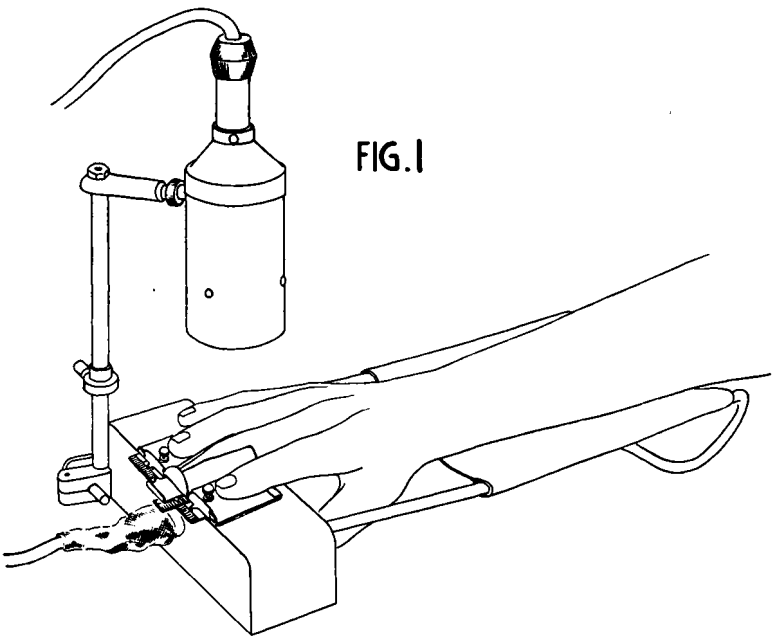

FIG. 1.
Finger photoelectric plethysmograph.

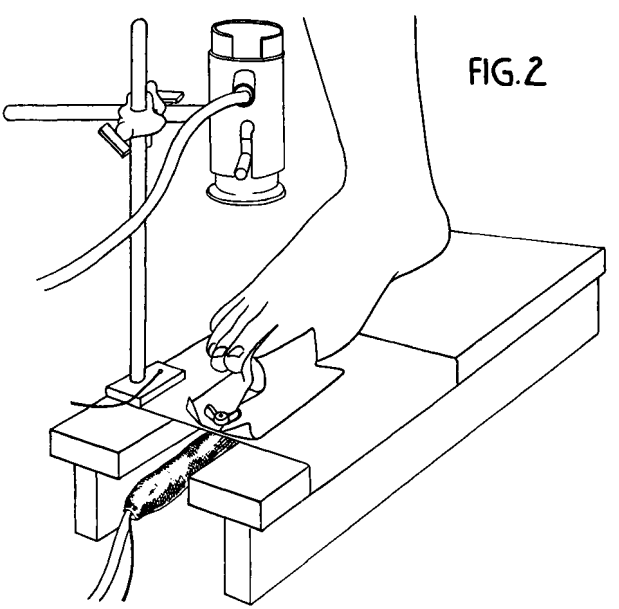

FIG. 2.
Toe photoelectric plethysmograph.

secure the desired muscular relaxation which greatly affects finger volume. Movements of the arm must not be transmitted to the finger. A pillow may be substituted for the saddle and the method used on the subject in bed. The light and photoelectric cell may be placed in any plane desired.

In the arrangement for the toe (Fig. 2), a heel plate (not illustrated) prevents movement of the foot. The method may be used on the subject when standing, sitting, or reclining. If the light, toe mask and photoelectric cell are mounted on a sliding base, fitting the plethysmograph to feet varying in length and to individual toes of the same foot is quickly and conveniently accomplished. It is convenient to have a battery of toe masks of various sizes and shapes to take care of the great variations in toes.

The finger volume pulse, thus recorded, is illustrated in a previous paper[3] in comparison with the volume pulse of the nasal septum, similarly recorded. The amplitude of the digit volume pulse, the form of the wave, the position and size of the dicrotic wave, alter with circulatory dynamics the study of which is thus conveniently and profitably aided by the photoelectric technique (Fig. 3).

The photoelectric technique may be readily used as an electric

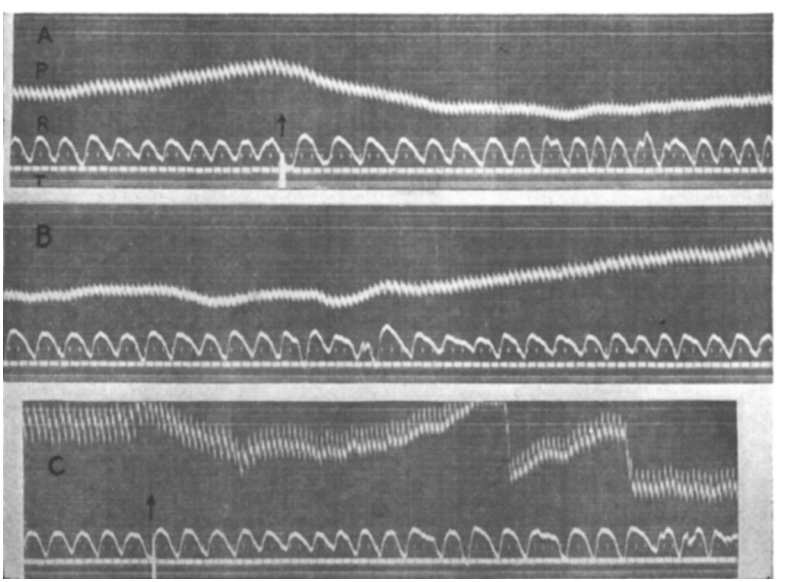

FIG. 3.

P—finger photoelectric plethysmogram. R—respiration. Time—1 second. Amyl nitrite at arrow in records A and C. Record B continuation of A.

[3] Hertzman, A. B., PROC. SOC. EXP. BIOL. AND MED., 1937, **37**, 290.

plethysmograph to study simultaneously the effects of various procedures on digit blood volume as well as on the form and amplitude of the digit volume pulse. Illustration is provided in Fig. 3 showing the effects of amyl nitrite on finger blood volume and finger volume pulse.

Validity of the Method. This has been examined through the execution of experiments along two general lines: (1) comparison of the photoelectrically recorded changes in finger blood volume with the changes in finger volume simultaneously recorded (on the same finger) by the transmission type of plethysmograph. The sensitivity of the photoelectric recorder in the several trials was measured in arbitrary units by the insertion of a suitable absorption filter between light and finger. (Although the *in vitro* whole blood and hemoglobin equivalents of the filter were readily determined, it was found that these values were irrelevant for the purpose.) The blood equivalents of these arbitrary units were calculated from the data supplied by the transmission plethysmograph. The photoelectric recorded pulse volume could then be calculated and compared with the pulse volume recorded by the transmission plethysmograph and with normal pulse volumes recorded in the literature. It is apparent from Table I that the photoelectric recorder is semiquantitative. The indeterminate character of the finger geometry involved in the transmission of light to the photoelectric cell precludes expectation of precise quantitation and prohibits the transfer of the plethysmographically determined blood equivalent of the filter from one individual to another. One is, therefore, compelled either to assign an arbitrary value to the filter used in determining recorder sensitivity or, when blood equivalents are desired, to actually determine these by means of transmission plethysmographs, in each individual digit studied. The former procedure is apparently compatible with quantitatively equivalent studies and readily permits a study of peripheral circulatory mechanics, so that actual blood equivalents become desirable only in rare instances. This is important not only for simplicity and convenience in the use of a photoelectric plethysmograph but also for application to regions such as the nasal mucosa which cannot be satisfactorily studied with transmission plethysmographs. Unfortunately, in such cases, the question as to what is the tissue blood equivalent of the filter becomes extremely complex. Space limitations preclude the consideration of the effects of variations in red blood cell form and number, of changes in the oxygen saturation of hemoglobin, of the axial stream effect in small vessels. These factors bear on the quantitation of

TABLE I.
Summary of Calibration Data.

Exper.	Increase in Finger Volume (Plethysmograph), cc.	String Deflection mm.	String Deflection to Red Filter, mm.	Blood Vol. Equivalent to String Deflection, cc./mm.	Blood Equivalent to Red Filter cc.	Pulse Vol. Plethysmograph cc.	Pulse Vol.—Photoelectric (Calculated) cc.
$(1)_1$	0.21	28	24	.0075	.18	.012	.015
$(1)_2$	0.29	40	24	.0072	.173	.0102	.0144
$(2)_1$	0.30	19	9	.0158	.142	.0126	.0125
$(2)_2$	0.48	24	7.5	.02	.15	.0133	.016
$(2)_3$	0.31	20	13.5	.0155	.209	.0077	.0108
$(2)_4$	0.28	27.5	31	.0102	.316	.0140	.0275

the photoelectric recorder but apparently do not significantly influence the qualitative value of its records.

(2) The essential validity of the photoelectric method is further supported by comparison of the photoelectric records with instances in which independent confirmation by other methods is available in the literature. Thus: 1. A pulse volume (photoelectric) of .01-.02 cc. compares favorably with the values of Johnson[4] and of Goetz[5] obtained with optically recording plethysmographs. 2. Quiet breathing has only negligible effects on finger volume and on the volume pulse. Compare Goetz.[5] 3. A marked vasoconstriction in the finger is observed at the time of a deep respiration in a quietly resting individual. One is reminded of the demonstration[6] that the phenomenon is a vasoconstrictor reflex not obtained in denervated and sympathectomized limbs. 4. The changes in amplitude and form of the volume pulse recorded in the valsalva experiment were identical with those obtained by Goetz[2] using transmission plethysmograph. 5. Amyl nitrite (Fig. 3) is followed by decreasing finger blood volume, decreased pulse amplitude and a collapsing type of wave indicating arterial relaxation in the finger with drainage of blood to other areas. Johnson[7] obtained similar results. Additional instances have simply illustrative value in establishing confidence in the validity of the records taken with the photoelectric plethysmograph.

Summary. Photoelectric plethysmographs for the fingers and toes are described which use electrocardiographs for the recording and which have definite advantages in routine clinical observations on the circulation. The validity of the technique is established (1) by comparison of the photoelectric records with simultaneous records obtained with transmission plethysmographs, (2) by comparison of the photoelectric records in instances of circulatory disturbances with independent directional confirmation by other methods in the literature.

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4 Johnson, C. A., *Surg. Gynec. and Obst.*, 1932, **55**, 731.

5 Goetz, R. H., *Pfluger's Arch. f. d. ges. Physiol.*, 1935, **235**, 271.

6 Bolton, B., Carmichael, A. E., and Stürup, G., *J. Physiol.*, 1936, **86**, 83.

7 Johnson, C. A., *J. Lab. and Clin. Med.*, 1932, **17**, 59.