ROLE OF RHEOPLETHYSMOGRAPHY IN COMBINED INVESTIGATION OF THE CEREBRAL AND PERIPHERAL CIRCULATION

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An investigation of fluctuations in the blood volume of the brain and finger by means of rheoplethysmography accompanied by parallel recording of fluctuations in their pulse volume (the ordinary rheogram) was carried out on human subjects. The authors illustrate some interesting possible applications of the method by examples showing differences in the direction and degree of fluctuations in blood volume in the cerebral and peripheral circulation. Comparison of the rheoplethysmogram and rheogram of an organ enables the role of the arterial inflow and venous outflow in the genesis of changes in blood volume to be assessed.

The investigation of the mechanism of vasomotor responses to external stimulation and of the nature of endogenous hemodynamic changes ("spontaneous vascular fluctuations") calls for a comparative analysis of the form and direction of the vascular effect in different parts of the body. In particular, for the analysis of certain theoretical and clinical problems it is important to be able to do this with respect to the blood vessels of the brain, on the one hand, and those of the limb, which have received adequate study as a model of the "peripheral circulation," on the other.

In the present investigation this problem was investigated by a rheoplethysmographic method based on the principle of rheography (with preservation of the slow component), enabling the dynamics of the blood volume of an organ to be studied regardless of whether it is isolated from the external environment by a covering of bone (as the brain, for example), or not.

Despite extensive use of rheography as a method of analysis of the form and amplitude of pulse waves of the brain (the rheoencephalogram), this method has only occasionally been used to record the total blood volume of the brain (its plethysmogram), yet all workers who have used it emphasize the promising character of this method [1-4, 6, 10, 13].

The use of rheoplethysmography for the comparison and comparative analysis of vasomotor responses of different organs has received still less attention in the literature.

Methodologic studies have shown that the rheographic curve closely reproduces the dynamics of fluctuations in blood volume and is parallel in character to that obtained by the method of direct mechanoplethysmography [4, 5, 7-9, 11, 12].

EXPERIMENTAL

The adequacy of the method was verified in this investigation by recording the ordinary digital plethysmogram (with a mechanoplethysmograph) and comparing it with the electroplethysmogram of the finger recorded by means of a rheographic attachment, with working frequency of 110 kHz, through a dc amplifier on

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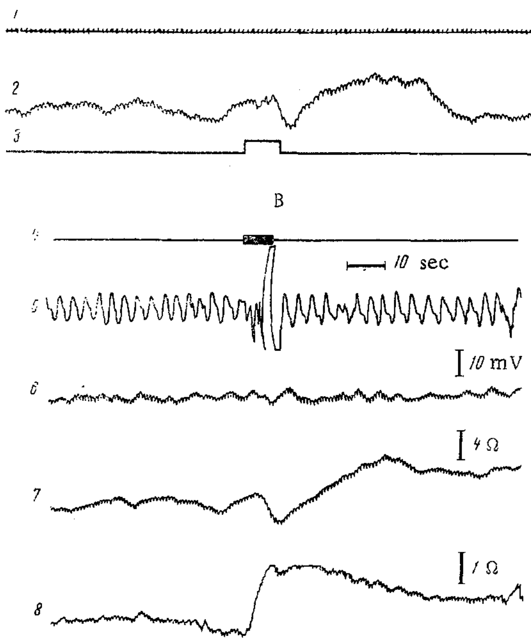

Fig. 1. Similarity of slow waves of blood volume in mechanoplethysmogram and rheoplethysmogram. Differences in direction of changes in blood volume of brain and finger during respiratory-vascular reflex. A) Recording on mechanoplethysmograph: 1) time marker (in sec); 2) mechanoplethysmogram of index finger; 3) marker of deep inspiration – expiration by command; B) recording on polygraph: 4) marker of deep inspiration – expiration; 5) respiration; 6) photoplethymosgram of ring finger of same hand; 7) rheoplethysmogram of middle finger of same hand; 8) rheoplethysmogram of brain (FM).

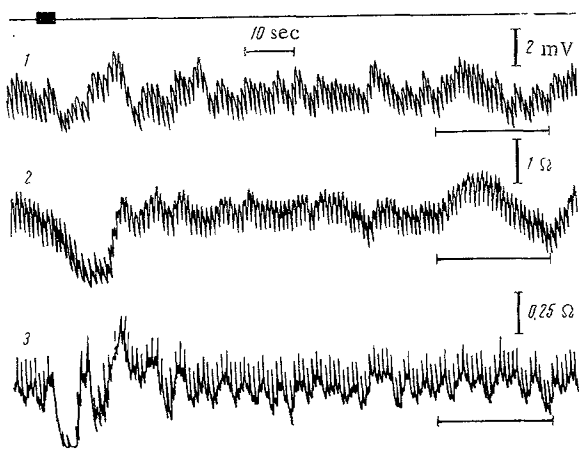

Fig. 2. Differences in direction of responses of cerebral and peripheral vessels in the respiratory-vascular reflex. "Spontaneous" waves recorded on digital photoplethysmogram and rheoplethysmogram are almost absent on the rheoplethysmogram of the brain. Marker of deep inspiration – expiration. 1) Photoplethysmogram of ring finger; 2) rheoplethysmogram of middle finger of same hand; 3) rheoplethysmogram of brain (FM).

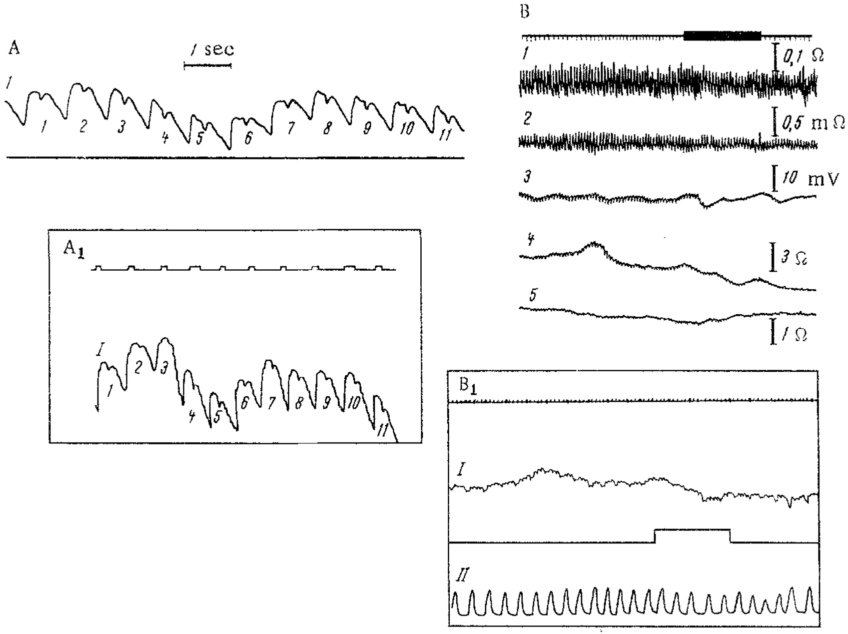

Fig. 3. Similarity between digital mechanoplethysmogram and rheoplethysmogram (A and A_1, see pulse waves; B and B_1 – another subject – see slow waves). Arousal reaction: decrease in blood volume in digital rheoplethysmogram and increase in blood volume in cerebral rheoplethysmogram. A_1) Mechanoplethysmogram of index finger; A) rheoplethysmogram of middle finger of same hand; B) recording on polygraph: 1) rheoencephalogram (FM); 2) rheogram of middle finger; 3) photoplethysmogram of index finger of same hand; 4) rheoplethysmogram of middle finger; 5) rheoplethysmogram of brain (FM); B_1: I) mechanoplethysmogram of ring finger of same hand; II) respiration.

the RDH-2 unit of a Japanese RM-150 polygraph. The rheoplethysmogram of the brain (frontomastoid lead) was recorded on another unit of this instrument in the same way.

One rheographic electrode was applied to the palmar surface of the finger in the region of the terminal phalanx, and the other electrode on the dorsal aspect at the base of the finger. The digital mechanoplethysmogram was recorded from the next finger of the same hand on a ZP4-1 ink-writing plethysmograph equipped with pneumoelectrical converters and an amplifier which ensured the total reproduction of all slow waves. Finally, the photoplethysmogram, largely reflecting fluctuations in the blood volume of a small area of skin in the neighborhood of the photodetector, was recorded from the middle finger of the same hand on the polygraph through a dc amplifier. In addition, in some tests, the ordinary rheoencephalogram and the digital rheogram were recorded simultaneously on two other channels through an amplifier. For special purposes, a parallel recording was made of respiration.

Besides waves (of the first, second, and third orders) characterizing the vascular curve in a resting state, vasomotor responses to various external stimuli also were examined.

EXPERIMENTAL RESULTS

Parallel recordings of the mechanoplethysmogram and rheoplethysmogram from two fingers of the same hand showed that the curves are similar but not completely identical. This is clear from Figs. 1 and 3. Some differences are observed in the steepness of the rise and in the duration of the slowest waves. In addition, whereas respiratory waves (waves of the second order) were clearly visible on the digital mechanoplethysmogram, as a regular feature they were much less clearly defined on the rheoplethysmogram.

Differences between the patterns of the mechanoplethysmogram and rheoplethysmogram may perhaps be partly due to the fact that the fluctuations in volume reaching the mechanoplethysmograph from the glass sensor element reflect changes in the blood volume of the entire finger, while the curves recorded through rheographic electrodes reflect changes in volume of that part of the finger to which the electric field created between the electrodes extends. Probably, however, this is not the only reason for the differences, but there may be some difference also in the actual processes recorded: in one case (mechanoplethysmogram), fluctuations in volume reflecting exclusively changes in the blood volume of the organ are recorded, while in the other case (rheoplethysmogram) it is changes in impedance which are recorded. These latter are principally due to the changes in volume, but not entirely, and certain other nonhemodynamic factors may be concerned (tissue metabolism, changes in the composition of the blood, etc.).

Despite these facts, the general results of comparison of the rheoplethysmogram and mechanoplethysmogram recorded from the fingers suggest that rheoplethysmography is a sufficiently adequate method of making observations on fluctuations in the total blood volume of an organ and, consequently, that it can be used to record the cerebral blood volume. The adequacy of the method for investigation of the cerebral hemodynamics was confirmed by control recordings during the application of factors evoking typical and well-studied changes in the blood volume of the brain (the amyl nitrite test, for example).

It may be supposed that the photoplethysmogram, in conjunction with the digital rheoplethysmogram, would be of interest as a method of estimating separately the characteristics of vasomotor function of the cutaneous and muscular vessels. However, it is quite clear that slow waves are not fully reproduced on the photoplethysmogram, despite the use of a dc amplifier. This may be connected with the specific features of the type of photoelectric detector used.

The results of observations with parallel recordings of the rheoplethysmogram of the brain and finger revealed a number of new facts illustrating the possible role of the method. It was shown, for example, that the slowest spontaneous waves (of the third order), which are clearly visible on the peripheral rheoplethysmogram (of the finger), are as a rule comparatively inconspicuous on the cerebral rheoplethysmogram (see the rheoplethysmogram of brain and finger in Fig. 2, and also the photoplethysmogram).

This fact must evidently be regarded as evidence of the greater stability of the cerebral blood volume than that of the skin and muscles, and of the existence of mechanisms maintaining this stability. Yet another highly typical phenomenon can be seen in Fig. 2: the "respiratory waves" are much sharper on the curve of cerebral blood volume than on the digital curve.

Although the background slow waves on the cerebral rheoplethysmogram are very small, some external procedures such as, for example, a voluntary inspiration of rather deeper extent than normal, evoke slow response waves in both the digital and the cerebral rheoplethysmogram, but the direction and shape of the waves are different. This is particularly clear in Fig. 1: the reaction of deep inspiration and subsequent expiration. These differences undoubtedly reflect regional specificity in the vascular response.

Another example illustrating differences between the responses of the cerebral and digital vessels of an external stimulus is given in Fig. 3. In this case, this is a reaction of orienting type in response to speaking to a sleeping subject. The subject did not awaken, but the vasomotor response is perfectly clear: a decrease in blood volume (the usual form of orienting reaction at the periphery) is visible on the digital rheoplethysmogram (and also mechanoplethysmogram), while the opposite effect – an increase in blood volume – is observed on the cerebral rheoplethysmogram. The regularity of this response and the nature of its physiological mechanisms are problems which arise out of this investigation.

Parallel recordings (see Fig. 3) of pulse waves from a rheographic detector through an ac amplifier can also be used to judge the relative importance of the arterial inflow and the venous outflow in the genesis of fluctuation in blood volume.

The examples given above thus illustrate some interesting prospects for research utilizing the method of combined rheoplethysmography.

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