PLETHYSMOGRAPHIC AND RHEOGRAPHIC INVESTIGATION OF THE EFFECTOR STRUCTURE OF VASCULAR REFLEXES

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Peripheral vascular responses in the orienting reflex were studied by comparing changes in the digital plethysmogram and in the rheographic inflow index (RII), the value of which was obtained by summation of the amplitudes of the rheographic waves (of neighboring digits) over a certain period of time (measured in minutes). The decrease in blood filling in the orienting reflex may take place through the participation of at least two predominant mechanisms: a decrease in the inflow of arterial blood and an increase in the venous outflow. This can be observed in the same individual during the same investigation. Facts characterizing the behavior of the cerebral vessels (as shown by rheoencephalography) involved in the orienting reflex are also described. These demonstrate that it has certain features in common with the peripheral circulation, but also features of independence.

The comparative study of variations in the volume of blood contained in an organ and changes in the shape and amplitude of fluctuations in its pulse volume (parallel recording of the digital plethysmogram and rheogram) have revealed no regular correlations between these indices. Meanwhile, investigation of the vascular component of the orienting reflex in man has demonstrated the possibility of divergent changes in both the shape and the amplitude of the rheographic waves, while the general plethysmographic response is consistently a decrease in the blood volume in the organ. Analysis of the shape of the rheographic curve, when interpreted in the traditional manner as an indication of changes in "vascular tone" leads to no definite conclusions regarding the mechanism of the vascular response [3].

To obtain an alternative solution to this problem, using the same observations, the integral amplitude characteristic of the digital rheogram was determined and compared with the plethysmogram of the neighboring finger. The same characteristic was also obtained for the rheoencephelogram (REG), but this was not compared with the curve of total blood filling. An analysis of the data is described below.

EXPERIMENTAL METHOD

The observations were made and described previously [3]. The amplitude characteristic mentioned, the rheographic inflow index (RII), was obtained by summation of the height of the anacrotic phase of the rheographic waves over a certain time interval (calculated in minutes) and it was expressed in ohms by reference to the rheographic calibration signal. A similar method of analysis was proposed by Nyboer [4] and the method used in the present investigation was similar to that used by Lur'e [2], although he estimated this index as an index of the blood flow. However, since this index reflects, in an integrated form, the increase in volume during systole, when the inflow is maximal and when its excess over the venous outflow is also maximal, it is primarily an index of the arterial inflow.

The total blood filling of the brain was not recorded in Lur'e's investigation but only the REG. However, by comparing fluctuations in the RII and changes in the total volume of the organ, the extent to which

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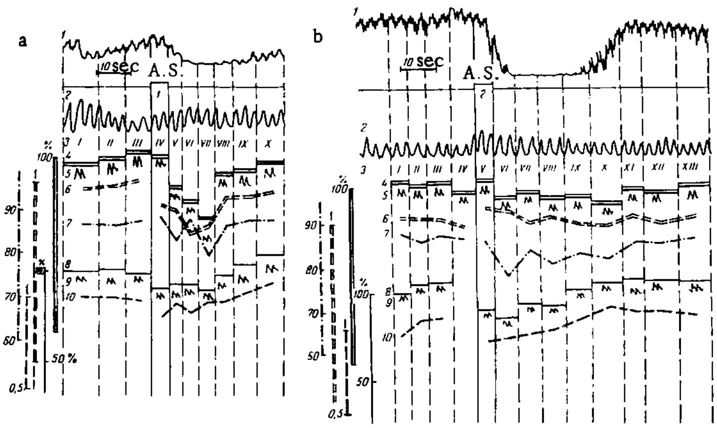

Fig. 1. Comparison of results of plethysmographic investigation and graph of digital rheogram (above) and REG (below) for a healthy woman aged 25 years: a) response to first presentation of stimulus; b) response to second presentation of stimulus. 1) Digital plethysmogram; 2) respiration; 3) periods of plethysmogram (I-X and I-XIII), each corresponding to data on the graph; 4) values of RII (in percent of initial) based on digital rheogram; 6) mean amplitude of anacrotic phase of digital rheogram; 7) pulse; 8) values of RII (percentages of initial level) from REG; 5,9) characteristic shape of pulse waves for particular period; 10) mean amplitude of anacrotic phase of REG. Scale shown on left. A.S.) Acoustic stimulation.

dynamic changes in the total blood filling are determined by changes in inflow can be estimated. The latter is a function, not only of the amplitude of the pulse waves, but also of their frequency, as reflected in the corresponding graph which shows the dynamics of changes in the heart rate, in the mean amplitude of the pulse waves, and in the RII. The averaged amplitude calculated from the basic rheogram, taken before application of the stimulus, was used as the unit of amplitude; changes in RII are given as percentages of the original values, also calculated from the basic rheogram. The shape of the rheographic waves characteristic for the corresponding period is shown schematically above the graph.

EXPERIMENTAL RESULTS AND DISCUSSION

Comparison of these graphs with the plethysmogram explains some aspects of the mechanism of changes in the blood filling of an organ and provides a more definite index of the types of vascular response to a given stimulus. This is clear from a comparison of the graphs (Fig. 1a, b) of two responses to acoustic stimulation observed in a healthy woman in the course of one investigation. Analysis of the results of this observation, with comparison to morphology of the rheographic waves, was published previously [3].

If the "digital" graphs are compared with the corresponding plethysmograms, certain general factors in the responses to the first and second presentations of the acoustic stimulus will be observed: the original background in both cases is not completely "quiet." In response to the acoustic stimulus, in both cases the total blood filling of the finger is reduced; during acoustic stimulation the pulse rate changes slightly and definite changes occur in the mean amplitude of the rheographic waves, the factor determining the direction of the change in inflow during this period; in the first few seconds after application of the stimulus, there was a marked decrease in the pulse rate and some decrease in the rheographic inflow index. During this period the total blood filling fell sharply, and at the lowest point of the plethysmographic response the pulse rate varied in a zigzag manner. Finally, there was a definite similarity with the dynamics of the mean amplitude of the REG, especially in the late stage of the response.

A clear difference between responses to the first and second applications of the acoustic stimulus can be seen from the "digital" graphs so far as fluctuations in the RII are concerned: it fell sharply in the first case (with a corresponding decrease in the total blood filling in the plethysmogram), while in the

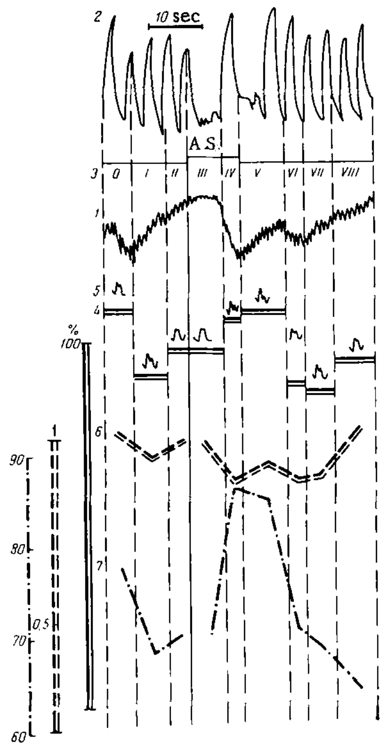

Fig. 2. Comparison of graph based on rheogram with digital plethysmogram of right hand in patient aged 19 years after operation for injury to left brachial plexus. Legend as Fig. 1.

second it rose slightly and then fell slightly. This difference between the RII dynamics is due to a difference in character of the changes in amplitude. The amplitude fell sharply during and after the action of the first stimulus, while in response to the second stimulus it increased slightly and then fluctuated around its initial values.

Probably, the dynamics of changes in amplitude in the cases considered reflects primarily a change in the state of the blood vessesl. This explanation is supported by the fact that amplitude curves in the "digital" and "cerebral" graph diverged in places in the first case, and were completely different in the second. At the same time, the possibility cannot be ruled out that changes in the height of the pulse waves could also be associated with fluctuations in the systolic output of the heart, but the results of the present investigation do not allow more definite conclusions to be drawn.

Under all conditions there was no doubt that the decrease in arterial inflow differed in the two responses evoked by acoustic stimulation. To judge from the shape of the rheographic waves (disregarding their amplitude), in response to the first stimulus it was combined with a decrease in "arterial tone" (sharpening of the systolic wave, deepening of the dicrotic wave), while in response to the second stimulus it was combined with an increase in tone (appearance of a plateau at the apex of the anacrotic phase, a decrease in the dicrotic wave and its displacement upward), although in the last case the decrease in arterial inflow was smaller.

The most striking feature revealed by comparison of these two manifestations of the vascular response to acoustic stimulation is that although the arterial inflow fell much lower in the first response, nevertheless in the second the integral plethysmographic effect was much more marked: the decrease in blood filling was much deeper and developed more rapidly than in the response to the first stimulus. It follows that different mechanisms play the leading role in the formation of a response of a decrease in digital blood filling to the first and second presentations of the acoustic stimulus. In the first response this evidently took place principally through a decrease in the inflow of arterial blood, while in the second case it was mainly due to an increase in the venous outflow (this is the only possible explanation of the great depth of decrease of the total blood filling with a comparatively small decrease in the blood inflow). Changes in the venous outflow also clearly play an important role at the beginning of the second response, when the total blood filling fell despite the high RII, and also at its end, when the plethysmogram moved upward although the arterial inflow was reduced (Fig. 1b, period X).

The effector structure of the peripheral vascular response as a component of the orienting reflex thus differed clearly in the two examples analyzed.

It must be noted that graphs plotted from the REG showed a much closer resemblance to each other than the "digital" graphs. The impression was obtained that the response of the cerebral vessels throughout this investigation was more stable. The dynamics of the changes in mean amplitude of the pulse waves of the REG differed from the corresponding dynamics of the amplitude of the digital pulse volume, especially in response to the second stimulus. This indicates some degree of autonomy in the regulation of the cerebral circulation. At the same time, the response of the cerebral vessels to acoustic stimulation in both cases was no less prolonged than the response at the periphery. When the graph of the REG in this investigation is analyzed it cannot be compared with the curve of total blood filling (as is possible in the case of rheoplethysmography [1], which was not used on this occasion).

The methods used to analyze the rheogram in connection with the plethysmogram thus considerably extend the possibility of assessing the nature of the vascular effect, but they do not overcome the problem of the functional role of shape of the pulse waves, which was emphasized previously [3].

The "digital" graph was obtained by investigation of a patient (after an operation on the brachial plexus) with well-marked cardiovascular lability: it reveals sharp fluctuations in the frequency, volume, and shape of the pulse waves, while the plethysmogram is characterized by large third-order waves. Even against the original background, the dynamics of changes in the arterial inflow (judged from the RII) cannot explain the direction of the spontaneous fluctuations in the plethysmogram (Fig. 2, period I), and the possibility of considerable fluctuations in the venous outflow is suggested. The response of a decrease in blood filling to acoustic stimulation is delayed and it develops at the time of elevation of the RII as a result of a sharp increase in the pulse rate (Fig. 2, period IV). The total decrease in volume of the organ is unquestionably due to the increase in venous outflow which, in this particular case, may be associated with the stronger inspiration at the end of action of the acoustic stimulus. The "behavior" of the respiratory component of the response probably plays an important role as a controlling factor in the mechanism whereby the body as a whole can regulate the volume of blood filling the tissues. At the time of a decrease in blood filling, the shape of the rheographic waves shows signs of "a lowering of arterial tone" (sharpening of the anacrotic phase and downward displacement of the dicrotic wave), although these are combined with a decrease in height of the anacrotic wave. Nevertheless, the slight elevations of the plethysmogram coinciding with a decrease in RII (Fig. 2, periods I and VII) and evidently reflecting some embarrassment of the venous outflow, are not combined with the appearance of Wick's waves, which would be expected on the basis of the general principles of rheography.

These examples show that the methods of analysis of experimental data used in this investigation can bring to light the complexity and variety of the functional structure of vascular reflexes.

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