INVESTIGATION OF THE VELOCITY OF SPREAD OF THE PULSE WAVE IN THE HUMAN AORTA

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The modern technique of investigation of the velocity of spread of the pulse wave in the human aorta is based on Weber's principle, first applied more than a century ago. Sphygmograms of the carotid and femoral arteries are recorded simultaneously, and the time taken for the pulse wave to spread is determined (t_1); after measurement of the appropriate distances on the anterior surface of the body (Fig. 1), the velocity of spread of the pulse wave (V) is determined from the following equation:

$$V = \frac{S_2 + S_3 - S_1}{t_1}. \qquad (1)$$

Although this method of determining the velocity of spread of the pulse wave in the human aorta has obvious advantages, it also possesses disadvantages. First, it must be pointed out that, as N. N. Savitskii pointed out [2], the value of V obtained from Eq. (1) characterizes the velocity of spread of the pulse wave only in the descending aorta (more precisely, in the thoracic and abdominal aorta and the iliac arteries). The information thus obtained is insufficient for judging the elastic properties of the aorta as a whole, especially in cases in which atherosclerosis affects mainly the ascending aorta, or in which the hydrodynamic conditions are different in the ascending and descending parts of the aorta (patent ductus arteriosus, coarctation of the aorta, etc.). Moreover, in the method under review, it is assumed that the velocity of spread of the pulse wave is the same in the carotid artery and the aorta,which is not strictly true.

Velocity of Spread of the Pulse Wave in the Aorta and in Its Parts (mean values in m/sec)

Group of subjects	Aorta as a whole	Descending part of aorta	First part of aorta
Patients with hypertension	9.42	10.13	7.72
Patients with hypertension and atherosclerosis of the aorta	11.65	10.21	13.26

We have therefore attempted to develop a more accurate method of determining the velocity of spread of the pulse wave in the human aorta.

In order to determine this index in the whole aorta, we must know its length from the semilunar valves to Poupart's ligament. As Wezler and Böger [7] showed, the length of the aorta can be determined without significant error by measuring the distance corresponding to the projection of this vessel on the anterior surface of the human body (see Fig. 1).

Since, in topographical anatomy, the surface marking of the semilunar valves of the aorta is taken to be on the anterior surface of the chest slightly below the point of attachment of the third rib to the sternum, the length of the ascending aorta can be calculated from the distance from the lower edge of the third left rib to the left of the sternum to the fossa above the manubrium, and the length of the descending part of the aorta from the distance from the sternum, through the umbilicus to Poupart's ligament. The total length of the aorta (ΣS) is then given by (Fig. 1):

$$\Sigma_S = S_0 + S_2 + S_3. \qquad (2)$$

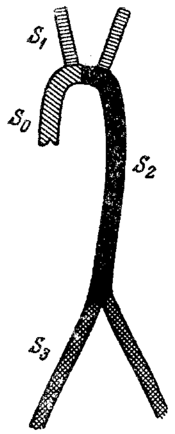

Fig. 1. Diagram of the aorta. S_0) Ascending aorta; S_1) carotid artery; S_2) descending aorta; S_3) iliac artery.

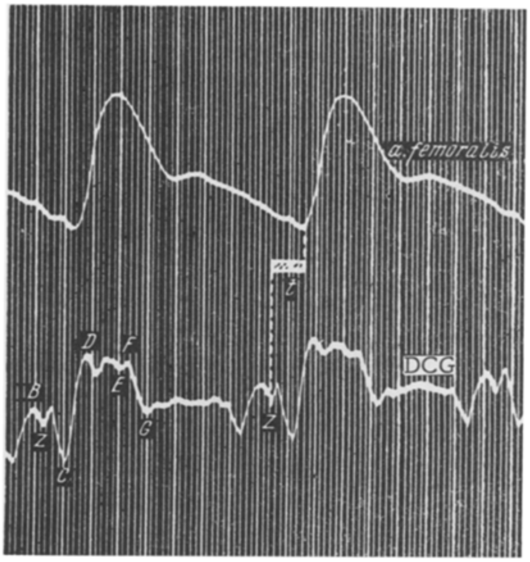

Fig. 2. Determination of the time of spread ot the pulse wave (t) in the aorta by synchronous recordings of the dynamocardiogram (DCG) and the sphygmogram of the femoral artery.

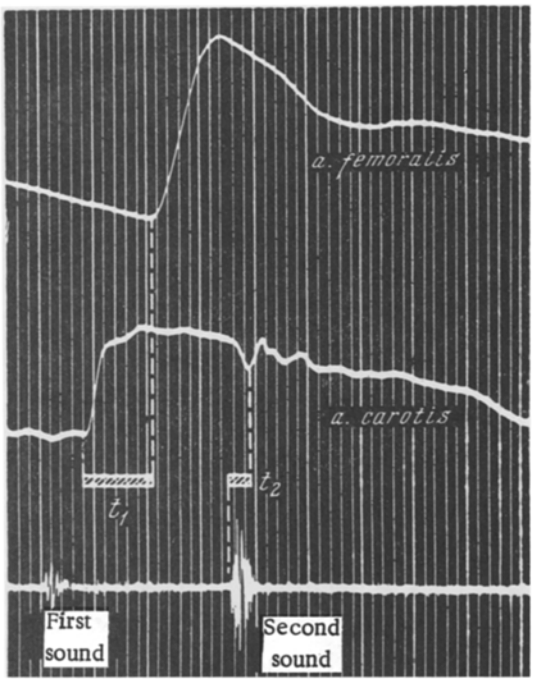

Fig. 3. Determination of the time of spread of the pulse wave in the aorta ($t = t_1 + t_2$) by means of synchronously recorded sphygmograms of the carotid and femoral arteries and the phonocardiogram.

To determine the time of spread of the pulse wave along the whole aorta (t), the moment of opening of the semilunar valves (the beginning of expulsion of blood from the ventricles) and the moment of appearance of the pulse wave in the femoral artery must be recorded objectively. We suggest the following two methods of determination of this time.

The first method consists of making synchronous recordings of the pulse in the femoral artery and of some form of curve indicating the moment of opening of the semilunar valves. Such curves include the dynamocardiogram, the electrokymogram, and, in some case, the rheocardiogram and cardiogram. In this method, t corresponds to the time interval between the beginning of the expulsion of blood from the left ventricle and the beginning of the anacrotic portion of the pulse wave in the femoral artery. Knowing the value of t, and measuring the path taken by the pulse wave by the method described above [ΣS in Eq. (2)], the value of the velocity of spread of the pulse wave along the whole aorta can easily be calculated:

$$V_a = \frac{\Sigma S}{t}. \tag{3}$$

We first began to use this method in 1958 [1]. We used dynamocardiography to determine the moment of opening of the aortic valves; the Z wave of the dynamocardiogram corresponds to the beginning of the phase of expulsion of blood from the ventricles (Fig. 2).

The second method of determining the time of spread of the pulse wave along the aorta is by simultaneously recording the phonocardiogram and the sphygmograms of the carotid and femoral arteries (Fig. 3). In this case, the phonocardiogram and carotid pulse are used to determine the moment of opening of the aortic valves.

The pulse wave reaches the carotid artery after a slight delay in relation to the moment of its appearance in the first part of the aorta (opening of the aortic valves). The magnitude of this "time lag" can easily be calculated from the interval between the beginning of the second sound on the phonocardiogram and the lowest point of the incisura on the carotid pulse curve [5]. Consequently, knowing the moment of appearance of the pulse wave in the carotid artery and its "time lag" in relation to the beginning of the expulsion of blood from the ventricle, we can accurately determine the moment of opening of the aortic valves. When working on this principle, we can assume that the time of spread of the pulse wave along the whole length of the aorta ($\underline{t}$) will be equal to the sum $t_1 + t_2$ (see Fig. 3), and the velocity of spread of the pulse wave along the whole aorta will be found from Eq. (3).

In most healthy persons, the velocity of spread of the pulse wave, determined by the methods we suggest (V_a), was either less than the velocity determined in accordance with Weber's principle (V) or practically equal to it. The average value of V_a was 5.41 m/sec and of V, 5.79 m/sec. In pathological conditions the velocity of spread of the pulse wave along the whole aorta was often higher than the velocity in the descending part. This relationship between V_a and V is most commonly found where there are marked atherosclerotic changes in the aorta (see table).

The fact that there is a difference between the velocity of spread of the pulse wave in the aorta as a whole and in its parts (in the descending part) may be explained from the physical point of view by the variable velocity of spread, as was demonstrated by Gauer [3].

In the table we compare the figures showing the velocity of spread of the pulse wave in the aorta as a whole (by our suggested method), in the descending part (Weber's principle), and in the first part of the aorta. The last value is determined by Jordan's method from the expression $(S_0 + S_1)/t_2$.

It will be clear from the table that the suggested method of investigation of the velocity of spread of the pulse wave gives more valuable information about the elastic properties of the aorta than the method based on Weber's principle.

SUMMARY

It is suggested that the time of the pulse wave spread in the aorta may be determined by the interval between the beginning of the phase of ejection and the pulse appearance on the a. femoris; on this basis, the rate of the pulse wave spread along the whole of the aorta may be determined.

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