TWO TYPES OF DYNAMICS OF LIMB VEIN FILLING AFTER VENOUS OCCLUSION

L. F. Borisova

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In the investigation described below the dynamics of the venous blood volume was studied not only during the first moments of venous occlusion (as is usually done when determining the volume velocity of the blood flow), but also throughout the period of filling of these vessels. The dynamics of the venous blood volume was examined in normal subjects and in patients with diseases of the venous systems (DVS), both at rest and during various function tests.

EXPERIMENTAL METHOD

An improved apparatus for venous occlusion plethysmography (VOP), by which the change in limb volume arising as a result of occlusion, the first derivative of this value, and its logarithm could be recorded [1], was used. Whitney's technique, with mercury–rubber transducers, was adopted. The transducer was placed on the junction between the middle and upper thirds of the leg of the recumbent subject. The occlusion cuff (OC) was applied above the knee. The occlusion pressure (OP) was 60 mm Hg.

The volume velocity of the blood flow (Q) after occlusion, the rate of venous outflow (r) after the rapid fall of OP to zero, the increase in venous capacity (D), the time at which the plethysmogram (P) flattened out on a plateau (t_p), and the time for P to return to its original zero value were determined. These parameters were calculated by the equations:

$$Q=\frac{k\cdot h\cdot n\cdot 60}{a}\ \text{ml/min/100 cm}^3\ \text{tissue},$$

where n = 1 mm/sec is the tape winding speed of the automatic writer, a, the amplitude of the calibration signal (in mm), k = 0.214 is an experimentally obtained coefficient for amplifications of 1, 2, and 2 V/cm, respectively, in the first, second, and third channels of the automatic writer, and h is explained in Fig. 1;

$$r=\frac{k\cdot 10h^{*}\cdot n\cdot 60}{a}\ \text{ml/min/100 cm}^3\ \text{tissue (}h^{*}\text{ is explained in Fig. 1.);}$$

$D = d/a$ ml/100 cm^3 tissue, where D is the amplitude of the curve of change in volume on reaching the plateau.

Changes in the "volume" of the test region, recorded by the plethysmograph, reflect responses of capacitive vessels [8]. According to data in [5], during occlusion under an OP of

TABLE 1. Mean Values of Parameters Studied in Healthy Subjects (M ± m)

Type of response	Q	D	t_p	r	t_s	$\frac{\Delta V}{V}/a$ at $t=t_s=47$	t_1	τ	t_r	$\frac{\Delta V}{V}/a$ at $t=t_1$	$\frac{\Delta V}{V}/a$ at $t=t_1+\tau$	t_2
I (39 LL.)	3,7± 0,18	2,5± 0,07	147,4± 5,92	33,7± 1,2	—	1,6± 0,05	3,9± 0,12	3,0± 0,24	54,9± 3,75	1,0± 0,05	0,8± 0,04	48,0± 3,8
II (12 LL.)	3,1± 0,3	2,0± 0,14	120,0± 12,64	27,5± 1,25	46,8± 9,14	1,3± 0,07	3,4± 0,23	3,1± 0,49	47,3± 6,09	0,9± 0,1	0,6± 0,09	40,8± 6,04
P	<0,05	<0,002	<0,05	<0,001	—	<0,001	>0,05	>0,1	>0,1	>0,1	>0,1	>0,1

Legend. Differences between parameters Q, D, t_p, and r obtained in healthy men (14) and women (21), in both type I and type II, were not statistically significant (except in the case of r in type II).

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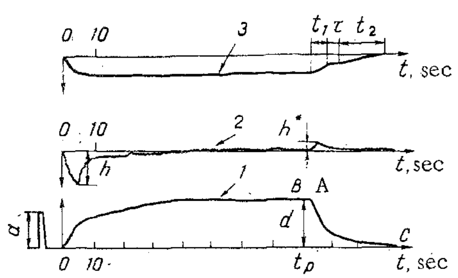

Fig. 1

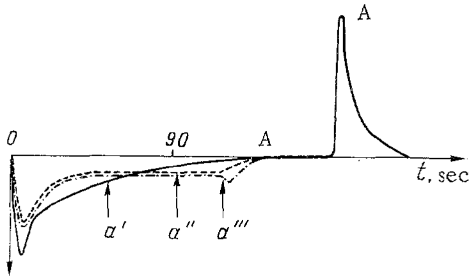

Fig. 2

Fig. 1. Synchronous recording of signals from plethysmograph and of amplifiers differentiating and taking logarithms. 1) Change in volume; 2) rate of change of volume; 3) logarithm of change of volume. In curve 2, after reaching zero level, which corresponds to flattening out of P on plateau, amplitude of recorded signals is reduced by 10 times. Explanation of letters given in text.

Fig. 2. Rate of change of volume of limb segments (A) corresponding to types I (a') and II (a'', a''') of FC.

30 mm Hg, the increase in volume of the tested limb segment **(V)**, measured by VOP in man, is due to an increase in the intravascular volume of the limb (filtration is negligible under these circumstances). However, since experiments by a gravimetric method on dogs' limbs [9] showed that with an increase in venous pressure the slow component of the change in mass is purely the result of transcapillary movement of fluid and, since also in the investigation cited the experiments were conducted at OP of 60 mm Hg, it seems proper to assess the contribution of filtration to the recorded increase in volume (ΔV). According to data in the literature [11], the volume velocity of filtration in the human forearm is 0.0005 ml/sec/100 ml tissue. Data in the literature on the effect of venous hydrostatic loads on the spatial surface in the muscles are few in number and contradictory in nature [2]: Both an increase or no change in the coefficient of capillary filtration have been recorded during a rise of pressure in the collector vein of the leg or forearm muscles. The rate of filtration of 0.005 ml/sec/100 cm^3 tissue will therefore be regarded as approximately unchanged after occlusion also. Consequently, during 120-147 sec of occlusion (Table 1) the contribution of filtration to the increase in limb volume is 0.06-0.074 ml/100 cm^3 tissue, i.e., not more than 3% of D (Table 1). The parameter D can thus in fact be interpreted as the increase in venous capacity. t_p (in sec), the time taken for P to flatten out on a plateau, is equal to the segment $0-t_p$ on the time axis (Fig. 1).

The venous outflow (VO) curve, i.e., the curve AC in Fig. 1, in normal subjects, is a combination of two successive exponential curves, which are recorded in the third channel of the automatic writer as segments of straight lines (signals from the plethysmograph are led to the third channel after passage through the amplifier taking logarithms). The following parameters were determined: t_1) the time of VO "according to the first exponent"; t_2) the time of VO "according to the second exponent"; τ) the time of transition from one exponential curve to the other (Fig. 1), and $t_r = t_1 + \tau + t_2$ (in sec) — the time taken for P to return to its original zero value.

EXPERIMENTAL RESULTS

The region of rise of P to the plateau level (Fig. 1, region OB), when the external pressures are balanced by the internal venous pressure (the filling curve — FC), is individual, but nevertheless, in this investigation, two characteristic types of FC were distinguished. In type I, the rate of arrival of blood in the test segment of the limb decreases with the course of time (Fig. 2, a'). In type II, it decreases at first, but then remains practically constant for a long time interval (Fig. 2, a''). On some curves, it sometimes increased for a few seconds until P flattened out on the plateau (Fig. 2, a'''), but FC of this type were also classed in type II.

Type I is physiologically clear: During filling of the veins the gradient between the arterial pressure and pressure in the veins falls; in addition, when the intravascular pressure rises, the rigidity of the veins increases [6], and this leads to a gradual decrease in the rate of filling of the veins with blood.

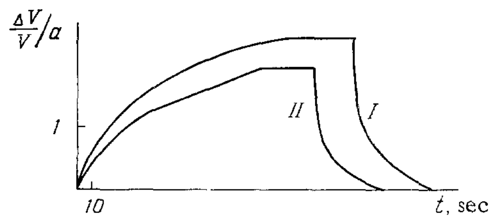

Fig. 3. Changes in volume of limb segment corresponding to types I and II of dynamics of vein filling. Curves plotted from mean values of parameters of circulation in healthy human LL. Besides parameters mentioned in text, the following also were determined on LL of type II: t_S) time of flattening out of the rate of change of volume curve on a plateau (see Fig. 2, a"), its mean value, namely 46.8 ± 9.14 sec, and at t = 47 sec, $(\Delta V/V)/a$ was determined on the change in volume curve. On all curves of VO (Fig. 1, curve AC), $(\Delta V/V)/a$ was determined by means of t_1 (in sec) and $t_1 + \tau$ (in sec) after removal of occlusion was determined (Fig. 1, 3).

Altogether 35 clinically healthy subjects and 115 patients with DVS of the lower limbs (LL) were studied. In 39 LL (over 76%) of 51 studied in normal subjects type I of FC was recorded, and type II in 12; in 30 LL of 115 studied in the patients type I of FC was recorded, and type II in 85 (74%).

Curves of change in volume of the limb segment corresponding to types I and II for healthy subjects, plotted with mean values of the parameters, are shown in Fig. 3. In the curves of types I and II not only did the character of the dynamics of filling of the veins with blood differ, but the parameters Q, D, t_p, $(\Delta V/V)/a$ at 47 sec, and r of types I and II also differed statistically significantly (Table 1).

It must be noted that D in healthy subjects with type II of FC was statistically significantly lower than in type I ($P < 0.002$). In thrombophlebitis and chronic postthrombotic **venous insufficiency, D** in type II also was significantly lowered (for 17 LL with type I, D = 1.5 ± 0.13, for 23 LL with type II, D = 1.2 ± 0.07; $P < 0.05$). The more rapid rise in rigidity of the venous wall with an increase in intramural pressure, in the diseases mentioned above, is emphasized in [4]. All this suggests that the smaller D in subjects with type II FC is connected with the greater rigidity (the lower elasticity) of the veins, and for that reason the dynamics of their filling may be less dependent on the gradients between the arterial and venous pressure and more dependent on the resistance exerted by stretching of the wall, which may be constant over a certain range of pressures. This may account for the constant rate of venous filling in the second part of the filling period that is characteristic of type II (Fig. 2, a").

Histological investigations in varicose veins (VV) showed evidence of increased shunting of arterial blood into the venous system [3]. In fact, in patients with VV and with type II of FC, with the increase in velocity before P flattened out on the plateau, mentioned above (Fig. 2, a'''), the skin temperature of the affected limb was raised, indicating the presence of functioning arteriovenous shunts. It can therefore be tentatively suggested that in these patients arteriovenous anastomoses open for a few seconds before P flattens out on a plateau.

Reproducibility of the parameters mentioned above was tested in five healthy subjects and five patients with DVS. In each of these ten subjects, tests were carried out on three successive days at the same time. In the group of healthy subjects the mean fluctuations of Q amounted to 10.3%, of D to 4.4%, and of r to 2.7%, whereas the corresponding values in the group of patients were 12.3, 9.2, and 8.1%. In the overwhelming majority of subjects tested (except in one patient) the type of FC was unchanged.

According to data in the literature [10], to create a total block of VO, and also to stop the inflow of blood from distal portions of the limb, an OP of about 50-70 mm Hg must be created simultaneously in the proximal OC, located immediately above the knee, and in the distal OC, in the ankle region. To answer the question whether stopping the inflow of blood from the distal parts of the limb affects the parameters studied, 10 LL of healthy subjects and patients with DVS in the early stages of the disease were studied, initially with only one (proximal) OC, and later (after 3-4 min) with two OC (in both cases, OP = 60 mm Hg). Combining these subjects into one group was legitimate in this case, because in the horizontal position, the main factors of VO are the residual force of cardiac ejection and the pressure of the tissues surrounding the veins [3]. The following data were obtained: with one OC: Q = 3.4 ± 0.34 ml/min/100 cm^3 tissue, D = 1.9 ± 0.53 ml/100 cm^3 tissue, r = 35.1 ± 4.54 ml/

min/100 cm^3 tissue; with two OC: Q = 3.9 ± 0.55 ml/min/100 cm^3 tissue, D = 2.6 ± 0.25 ml/100 cm^3 tissue, and r = 34.3 ± 4.64 ml/min/100 cm^3 tissue. According to Student's test these values do not differ statistically significantly. No change in the type of FC likewise was recorded. In these investigations, it was therefore perfectly acceptable to use only the proximal OC, thus causing much less discomfort to the subjects during the investigation.

Since, on the one hand, during DVS initial venous hypertension often arises [4, 7, 12] and, on the other hand, a type-II FC was recorded in precisely these patients, it was considered important to determine how preliminary "removal" of the excess blood volume affects the type of FC. For this purpose, curves were recorded in the subjects first in recumbency in the supine position, when the vessels of the test LL were at the level of the heart, and again after raising LL by 18 cm for 5 min (a support was placed beneath the ankle). As a result of this investigation of 14 LL of healthy subjects and 18 LL of patients, it was found that the type of FC was unchanged after elevation of the limb. There were two exceptions among these 32 cases.

In patients with VV the circulation in LL is known to be improved by the application of external pressure [12]. For this purpose, elastic bandages were applied to 25 LL with VV. Curves were recorded at rest and 2-3 min after application of the bandages. In the control, similar tests were carried out on 29 LL of healthy subjects. In only two of the 51 cases were very slight changes in the type of FC observed after application of external pressure.

Two types of P, differing in the dynamics of filling of the veins with blood, were thus recorded: In type I volume increases as velocity decreases until the curve flattens out on a plateau; in type II the rate of filling falls at first, then remains practically constant until flattening out on the plateau. Under these circumstances, a type-I FC is characteristic for healthy subjects of both sexes, whereas type II is characteristic of the majority of patients with DVS of LL. There is no change in either type of FC with the use of function tests, or in tests carried out on different days. It can be postulated that type II of filling is determined by the greater rigidity of the vein wall.

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