Acta Physiol. Scand. 27: 49-67, 1952

From Medical Department B, Rigshospitalet, Copenhagen, Denmark.

Static and Dynamic Pressures in Superficial and Deep Veins of the Lower Extremity in Man.

By

I. C. HÖJENSGÅRD and H. STÜRUP.

Received 27 March, 1952.

In recent years great interest has been displayed in the pathophysiology of the chronic venous disorders of the lower extremities, and studies with modern pressure registration methods have added to the knowledge concerning these diseases. This has made it evident that it is desirable, and also possible, to extend the knowledge of the statics and dynamics of the normal venous system. In the present study we endeavoured to do so by measuring the pressure in the superficial and deep veins of the normal lower extremity in the erect position, during standing, during walking, and during straining. By simultaneous measurements in the superficial and deep venous systems we have tried to elucidate certain aspects of the interplay between them.

v. RECKLINGHAUSEN (1906) and HOOKER (1911) reported a very low pressure in normal *superficial veins* in the motionless erect position. In 1923, CARRIER and REHBERG found the pressure to depend entirely on hydrostatic factors, but to be somewhat lower than the calculated pressure. Nearly all subsequent workers (RUNGE 1924, BARBER and SHATARA 1925, VILLARET et al. 1930, SMIRK 1935, BEECHER, FIELD and KROGH 1936, SEIRO 1938, ADAMS 1939, RUTLEDGE 1941, MAYERSON, LONG and GILES 1943, HENRY 1948, HICKAM et al. 1949, POLLACK and WOOD 1949, WARREN et al. 1949, and WALKER and LONGLAND 1950) have reported that in the standing position the pressure corresponds approximately to the distance from the point of measurement to the heart; in the completely passive erect position (*e. g.* on a table tilted into a steep position) it may be slightly higher (MCINTIRE and TURNER 1935, MAYERSON and BURCH 1939).

HOOKER (1911), CARRIER and REHBERG (1923), and RUNGE (1924) discovered that muscular exercise produces a decrease in the pressure. The decrease in pressure during walking was measured first by SMIRK (1935), BEECHER, FIELD and KROGH (1936), and SEIRO (1938), and during recent years with varying techniques by a number of workers (HENRY 1948, HICKAM et al. 1949, POLLACK and WOOD 1949, WARREN et al. 1949, WALKER and LONGLAND 1950, and DE CAMP et al. 1951). The pressure variations during the phases of a single step have been discussed by BEECHER, FIELD and KROGH 1936, and thoroughly investigated by POLLACK and WOOD 1949.

Increase in pressure during straining has been observed by LEDDERHOSE (1906) and measured by several others (RUNGE 1924, VILLARET et al. 1930, SMIRK 1935, ADAMS 1939, CHAPMAN and LINTON 1945, and WHITE and WARREN 1949). ADAMS observed a less marked and slower increase in pressure on straining in normal than in incompetent veins, whereas WHITE and WARREN consider the increase in pressure to depend more closely on the effort made than on the state of the valves.

Little is known about the pressure in the *deep veins* of normal lower limbs. VEAL and HUSSEY (1940 and 1941) reported that the pressure in the popliteal vein in the erect position was as low as 30—60 mm of mercury. BAUER (1948), on the other hand, found the pressure in the popliteal vein on a steep tilt table to correspond to the estimated hydrostatic pressure. Judging by the diagrams published by VEAL and HUSSEY, walking has but little influence on the pressure in the popliteal vein; they reported slight fluctuations, but no increase. The pressure in the deep veins during straining does not appear to have been studied in the standing subject, and simultaneous recording of the pressure in normal superficial and deep veins does not seem to have been made previously.

Technique.

The technique is that used in our previous studies of the venous pressure in patients with varicosities and postthrombotic syndrome (1949, 1950): The pressure is measured either through a needle, usually with a bore of 0.6—0.7 mm, introduced into the veins by the percutaneous route, or through a catheter (a plastic ureteric catheter No. 5), introduced into the vein through a coarse needle or directly after exposure of the vein. The measurements of the pressure in *the long saphenous vein* were in 9 cases made through a needle, in 3 cases through a catheter at the ankle. The measurements in *the popliteal vein* were in 5 cases made by the procedure of introducing a catheter into the short saphenous vein on the middle of the calf and passing it so far up that the tip entered the popliteal vein, — in 2 cases by direct venipuncture. Measurements of pressure in *the posterior tibial vein* were carried out in 2 subjects with a catheter introduced into the exposed vein behind the medial malleolus.

The pressure was recorded by means of the TYBJÆRG HANSEN manometer with electrical transmission. The properties of this mano-

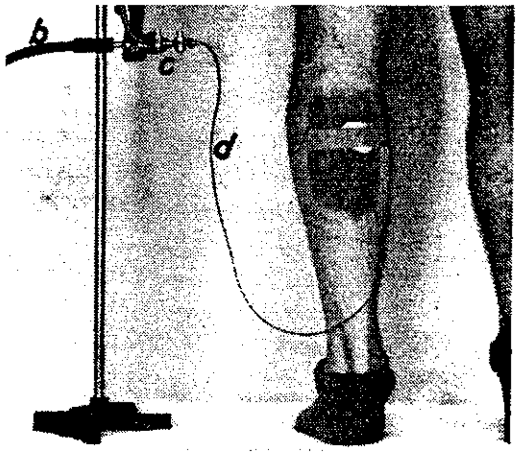


Fig. 1. Measurement of the pressure in the popliteal vein. The catheter has been introduced a few cm up the short saphenous vein; observing sterile precautions it is pushed upwards, until the tip rests in the popliteal vein.
a: Rubber tubing to saline container. *b:* Cable to amplifier. *c:* Manometer, fixed on stand. *d:* Venous catheter.

meter (modulus of volume elasticity, natural frequency, degree of damping[1] and linearity) are such that the pressure variations of importance to our venous pressure measurements are recorded without distortion (Tybjærg Hansen 1948 and 1949). When venous catheter was used, it was connected directly to the manometer; the needle was connected by way of a flexible, but relatively unyielding tube of a larger bore than the needle (a piece of a ureteric catheter). The manometer was mounted on a stand beside the subject (cf. figure 1).

By a cable, 1.25 m long, the manometer was connected with a high-frequency device and an amplifier. The pressure variations were traced on an Elmquist electrocardiograph, in which the oscillographs and the camera, but not the amplifiers were used.

The experimental procedure limits the movements of the subject somewhat, and walking was therefore carried out in the form of marking-time (standing-walking).

Between the recordings the catheter or needle were rinsed with heparinized normal saline, running into the system from a container elevated up to a known level, used at the same time to adjust the pressure. During the experiments numerous adjustment pressures were recorded, since the sensitivity of the manometer sometimes changed slightly.

The sensitivity of the system was regulated so that 1 cm on the film strip (the distance between the thick horizontal lines is 0.5 cm) was taken to correspond to 25—26 cm of water.

[1] In our measurements we did not employ oil damping. The damping of the manometer with air between the plates is so slight that momentary alterations of the pressure are recorded with their full value in less than 0.02 seconds.

In some instances the manometer was placed on a level with the *point of measurement* (which in this paper means the site of the opening of the tip of the needle or the catheter in the vein); in other instances another arbitrary level was selected for practical reasons. The magnitude of the *recorded pressure* depends in all cases on the zero-point of the manometer, *i. e.* the level at which the manometer is placed. The *actual pressure* at the point of measurement is then calculated on the basis of the recorded pressure as follows: Recorded pressure ± the distance between the levels of the site of measurement and the manometer.[1] *Relative pressures* (alterations in pressure) may of course be read directly from the curves and are independent of the level of the manometer.

Sources of Error.

In the standing posture the slight muscular movements of the legs inevitable in individuals standing without support, will lower the venous pressure; for this reason we tabulated the highest pressure in each subject, this pressure presumably being the most correct one. The lowest pressure was, however, seldom more than 10 cm of water below the highest.

During walking some artificial fluctuations are recorded owing to the movements of the catheter or the flexible tube between the vein and the manometer. This means that the pressure curve cannot in every detail be taken to represent the real fluctuations of pressure inside the vein; no major systematic distortion of the real pressure curve was observed, and the artificial fluctuations do not influence the alterations (decrease or increase) of the *mean* pressure.

Hydrostatic variations in the venous pressure, caused by the movements of the leg during walking, are not recorded because the manometer is fixed beside the subject. For the same reason there is no vibration of the manometer or the cable during movements of the leg; this might cause artificial oscillations.

Results.

We have measured the pressure in *superficial veins of the leg* at different levels in 12 subjects (chiefly in the main trunks of the long and short saphenous veins), in the *popliteal vein* (or lower end of the femoral vein) in 7, and in the *posterior tibial vein* at various levels in 2 subjects. In all cases the pressure was recorded *in the motionless standing position, during walking,* and *during straining.* All the subjects were young, healthy men, aged 20—36 years (cf. the tables), without a history of or clinical signs of lower extremity disease.

---

[1] This conversion is not given in the tables accompanying our previous papers, as the level of the manometer was the same in all experiments (50 cm above the floor) and the values were therefore directly comparable.

Venous Pressure in the Standing Position.

The maximum values obtained are given in Table 1 which shows also the distance from the point of measurement to the upper edge of the fourth rib at the sternum (the projection of the

Table 1.

Venous pressure in the standing position and during walking.

Subject No.	Subject Age	Distance from manometer level to 4th rib in cm	Venous pressure at manometer level in the standing position in cm H_2O	Fall in venous pressure during walking cm H_2O	Fall in venous pressure during running cm H_2O	Level of measurement (cm above floor)
			Superficial veins:			
14	33	82	82	50.5	—	34
16	30	80	81.5	76.5	—	23
32	35	88	89.5	76	—	11
64	27	116.5	119.5	63.5	—	44
				80	—	24
78	36	108	106	40	62.5	31
99	36	115	116	58	—	38
100	24	85.5	87.5	67.5	—	38
				73	—	12
101	24	97.5	99.5	58.5	—	29
102	23	88.5	85	67	—	32
103	23	113.5	112	62.5	—	15
104	25	86	88.5	41.5	—	41
105	34	104	103	38	51.5	61
				51.5	—	41
Mean values		97	97.5	60		
			Popliteal vein:			
26	25	84	84	0[1]	—	48
27	21	77	84.5	0[1]	—	46
75	36	88	89.5	0	0	65
100	24	70.5	74	0[2]	0[2]	53
101	24	73.5	73	39[3]	60[3]	53
104	25	77	78	0	0[2]	60
105	34	106	103	0	23.5	60
				0	—	52
Mean values		82	83.5			
			Posterior tibial vein:			
64	27	116.5	122	30	—	44
				65	—	24
78	36	108	107	34.5	59.5	30
				34.5	—	20
Mean values		112	114			

[1] During rhythmical elevations of the heel.
[2] Tendency of pressure to rise.
[3] Pressure probably not determined in the popliteal vein, but in a superficial one (see text).

right atrium on the anterior surface of the body) for each subject. The mean value of the recordings for *all* the subjects was 93.4 cm of water, corresponding to 88.5 cm of blood (specific gravity of the blood: 1.055). The mean value of the calculated hydrostatic pressures for all the subjects was 94.4 cm.

In the three subjects submitted to simultaneous measurements of the pressure in a deep and superficial vein at the same level (Nos. 64, 78, and 105) the two pressures proved exactly identical each time in the resting erect position.

Venous Pressure during Walking.

The venous pressure was recorded during standing-walking (rate 40 "steps" with the leg concerned per minute), the toes being lifted about 10 cm off the floor and the heel correspondingly higher. In those cases where the pressure in the popliteal vein was measured by direct needle puncture, standing-walking was impracticable, since the needle was apt to slip out. These subjects were instead told to carry out rhythmical elevations of the heel — 40 per minute — with extended knees. This form of exercise means quite a considerable activity of the leg muscles, so that from a functional point of view it may to some extent be compared to walking.

It will be seen from fig. 2 that during walking the pressure in *the superficial veins* showed great fluctuations with each step,

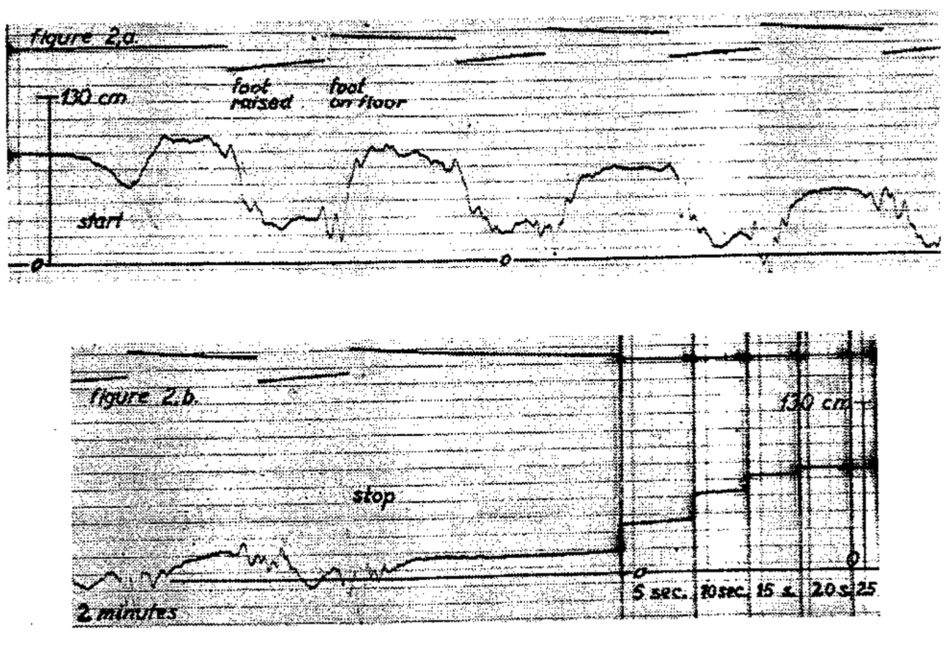


Fig. 2. Pressure in a normal long saphenous vein during walking, measured 11 cm above the floor (Subject 32). *2a:* Start of walking. *2b:* Cessation of walking. Time-marking: 0.1 and 0.02 sec.

but upon the whole decreased. The decrease occurred early, mainly within the first few steps. At the end of 30 seconds no further decrease in pressure was recorded in any case. After cessation of walking, the pressure rose to resting level in the course of 10—65 seconds (averaging 30 sec.) (Fig. 2 b). The decrease in pressure is calculated as the difference between the venous pressure on motionless standing, before walking was started, and the pressure immediately after walking was stopped (*cf.* also the discussion). Table 1 gives the maximum decreases in pressure for each subject obtained by the same procedure in several experiments. The pressure fell 38—80 cm of water (averaging 60 cm).

The nature of walking proved of great significance to the magnitude of this decrease. In addition to standing-walking, other forms of muscular exercise with the lower limbs were tried in a few cases. In No. 32 ordinary standing-walking caused a decrease of 76 cm, standing-walking with elevation of the heel during the weight carrying phase of the step a decrease of 78.5 cm, rhythmical elevation of the heel with extended knees a decrease of 40.5 cm, and walking movements of the freely hanging leg a decrease of 43.5 cm. Subjects 78 and 105, who had shown a decline of 40 and 46.5 cm respectively while standing-walking at the rate of 40 steps per minute, showed a decrease of 62.5 and 51.5 cm respectively during "standing-running" (rate: 80 steps per minute).

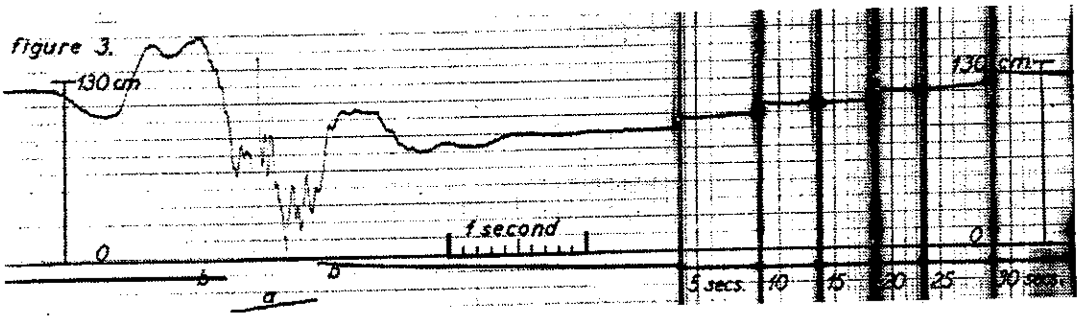
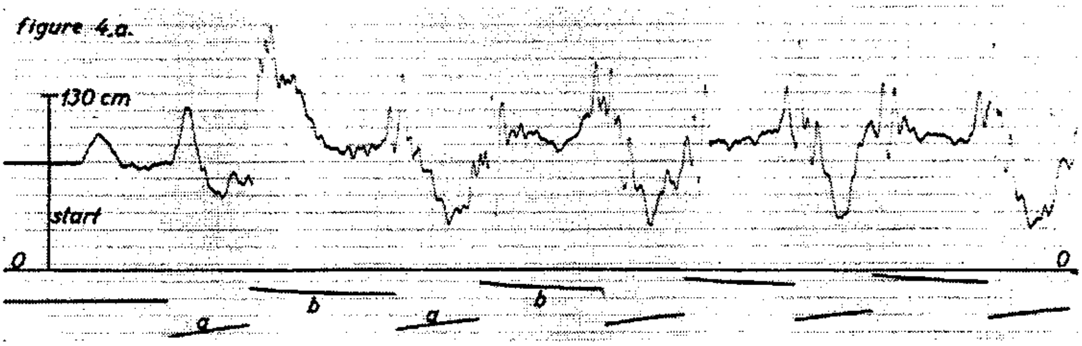


Fig. 3. Effect of a single step on the venous pressure in a normal superficial leg vein, measured 12 cm from the floor. (Subject 100.)
Step-marking: *a*: Foot raised. *b*: Foot on floor. Time marking: 0.1 and 0.02 sec.

The pressure variations in the superficial veins during a single step were recorded for 4 subjects. Fig. 3 gives a typical pressure curve during a single step carried out as follows: Starting with feet joined, the subject takes half a step with the "free" leg, then a whole step forward with the leg in which the pressure is measured, and at last brings the free leg forward to the joined position. The curves are very much alike for all four subjects. While the free leg is being swung forward, there is an average increase in pressure of about 30 cm (sometimes after an initial, negligible decrease in pressure); while the leg examined is being lifted, there is a marked fall in pressure which continues while the leg is being swung forward until it meets the floor again. At this moment the pressure is about 75 cm below the initial resting value. As soon as the examined leg again carries the whole weight of the body, there is a quick moderate increase in pressure; when the legs have again resumed the resting position a quite slow, but marked increase is seen, so that 5—30 seconds after the step has been completed the resting pressure has been re-established. In 8 experiments the 4 subjects exhibited a decrease in pressure (calculated as the difference between the resting pressure and the venous pressure immediately after the completion of the step) of 15—50 cm, averaging 30 cm. The duration of the individual pressure phases is seen from Fig. 3. — A muscular activity of no more than an up-and-down movement of the foot hanging freely down also caused a marked decrease in pressure, *viz.* about 40 cm of water (in one experiment).



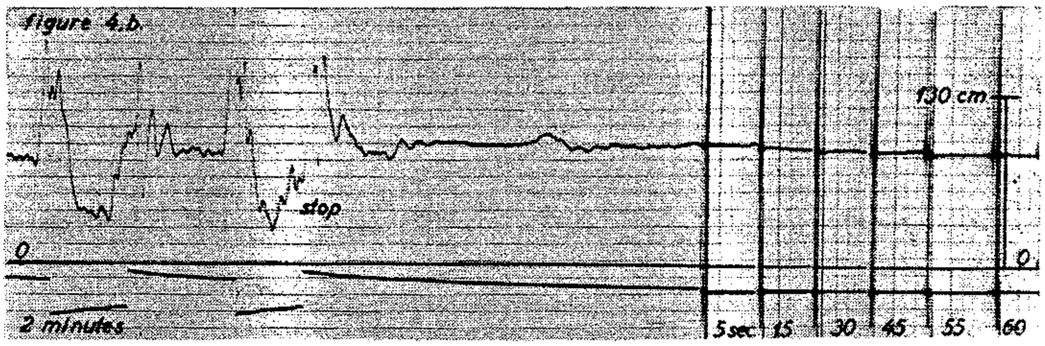


Fig. 4. Pressure in popliteal vein of a normal subject during walking (Subject 100). *4a:* Start of walking. *4b:* Cessation of walking. Step-marking: *a:* Foot raised. *b:* Foot on floor. Time-marking: 0.1 and 0.02 sec.

The results of pressure measurements in the *popliteal vein* during walking may also be read from Table 1. Apart from Subject 101, no decrease in the pressure was observed in any case. The pressure fluctuated (*cf.* Fig. 4) about a mean value approximately equal to the venous pressure in the erect position (during rhythmical elevations of the heel as well as during standing-walking). Immediately after walking was stopped, the venous pressure was almost equal to the resting pressure (*cf.* Fig. 4 b). Standing-running resulted in a slight increase in the mean pressure in two subjects (Nos. 100 and 104), whereas in one (No. 105) an unmistakable decrease (of 23.5 cm of water) was seen.

Subject 101 exhibited a rather marked decrease in pressure during walking. In this case, however, we have reason to presume that the catheter, which was introduced through the short saphenous vein exposed in the middle of the calf, did not reach the popliteal vein, but passed into the subcutaneous femoro-popliteal vein. This presumption is supported on the fact that the introduction of the catheter had proved very difficult and that its tip appeared to be palpable under the skin which it was not in the other cases. Subsequent phlebography of this limb showed that a few cm from its junction with the popliteal vein, the short saphenous vein showed a kink forming almost a right angle (presumably at the entrance of the femoro-popliteal vein from above).

For 2 subjects the pressure variations in the popliteal vein were recorded during a single step. As might be expected the pressure fluctuated, but no final decrease resulted (Fig. 5). The fluctuations are on the whole less marked than those in the superficial veins (an initial increase of about 25 cm of water, followed by a decrease to about 25 cm of water below the resting level, then a rapid increase up to about 50 cm of water above the resting level, and at last a rapid decrease of about 50 cm of water). The increases and decreases are approximately equal, so that immediately after completion of the step, the venous pressure is equal to that prior to its commencement. When the pressure is at the resting level at the completion of the step, before the action of the next step sets in, it is logical that no decrease in pressure can take place during successive steps (*i. e.* walking).

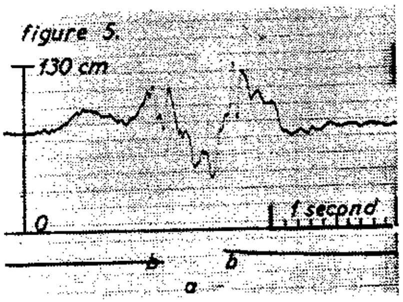


Fig. 5. Pressure in popliteal vein of a normal subject during a single step (Subject 100).
Step-marking: *a:* Foot raised. *b:* Foot on floor. Time-marking: 0.1 and 0.02 sec.

Table 1 also gives the results of measurements in the *deep leg veins* (posterior tibial vein). During walking a decrease in pressure was recorded in each of the 12 experiments on two subjects, performed at different levels of measurement. The decrease in pressure ranged from 25 to 65 cm of water. In one experiment of standing-running, the decrease was 59.5 cm (measured 31 cm above the floor).

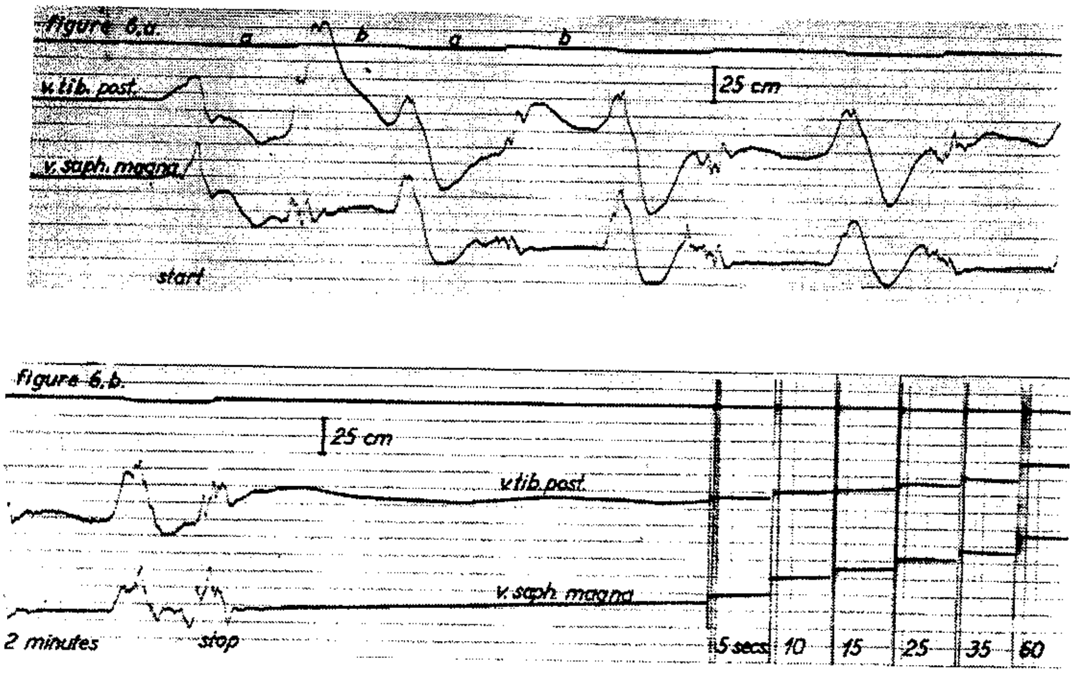


Fig. 6. Pressure in posterior tibial vein and long saphenous vein of a normal subject during walking, measured simultaneously at the same level, 24 cm above the floor (Subject 64). The zero-point lines of the two veins are placed at different levels on the film strip for practical reasons. The venous pressure in the motionless standing position was the same in both veins. *6a:* Start of walking. *6b:* Cessation of walking.
Step-marking: *a:* Foot raised. *b:* Foot on floor. Time-marking: 0.1 and 0.02 sec.

The decrease in pressure during walking takes place in the posterior tibial vein as it does in the superficial veins during the first few steps (Fig. 6 a). The increase in pressure after cessation of walking also seems to occur at approximately the same rate as reported for the superficial veins: in Subject 78 the resting pressure was reached in 10—20 sec., in Subject 64 in a somewhat longer time (Fig. 6 b).

Simultaneous recording of the pressure at the same level in a deep and a superficial vein during walking was carried out for 3 subjects (Nos. 64, 78, and 105; Table 1). In two subjects the veins examined were the posterior tibial vein and the long saphenous vein, and in one the popliteal vein and the long saphenous vein. Fig. 6 illustrates the pressure variations 24 cm above the floor in Subject 64 at the commencement and termination of walking. The mean pressure in both veins decreases. When due regard is paid to the fact that the pressures of the two veins were recorded with a different zero-point line to make them distinguishable on the film, the pressure in the posterior tibial vein is seen to be higher than that in the long saphenous vein during the greater part of each step. At a certain phase (*viz.* immediately after the leg has been lifted off the floor) the pressures in the two veins appear to be approximately equal, or perhaps the pressure in the superficial vein is slightly higher than that in the deep vein. At the 34 cm level the findings were similar. In principle, the curves obtained in Subject 105 showed the same relation between the pressures in the deep and superficial vein, but the pressure in the popliteal vein did not fall during walking. In Subject 78, on the other hand, the pressure curve for the posterior tibial vein and that for the long saphenous vein were almost identical during all phases, both at the 20 and 30 cm levels. In this subject, therefore, the decrease in pressure was equal in the deep and the superficial vein

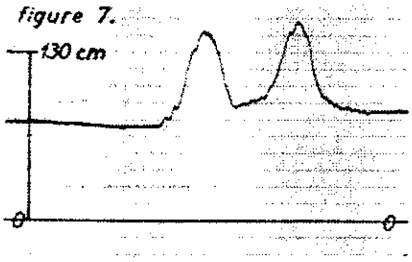


Fig. 7. Effect of increased intraabdominal pressure (coughing) on the pressure in the popliteal vein of a normal subject (Subject 100), measured 53 cm above the floor.
Time-marking: 0.1 and 0.02 sec.

Effect of Increased Intraabdominal Pressure on Venous Pressure in the Lower Limb.

Intraabdominal pressure was increased by vigorous coughing and brief, forcible straining. It is the instantaneous, abrupt increase which is of interest in this respect, not the slow increase in pressure which occurs, when straining has been continued for some time. The pressure alterations in *the superficial veins* are recorded in Table 2. The increases in pressure are slight; such low figures are uncertain, since coughing or sudden straining may entail muscular movements which will affect the venous pressure in the lower limbs. And indeed, the curves are irregular. Even though the maximum rises in pressure from several experiments are taken for each subject, most of them could be called only "slightly positive" ($<$ 10 cm of water).

In the *popliteal vein*, on the other hand, coughing and straining produced marked increases in pressure (Table 2 and Fig. 7), averaging 55 cm of water, or in other words, an increase amounting to about 65 % of the resting venous pressure. The magnitude of the fluctuations depended to a large extent on the technique of straining. The subjects had to try several times, before the maximum increase in pressure was obtained. The highest values were attained by Subject 75 (one of the authors).

Table 2.

Venous pressure during coughing and straining.

Subject No.	Level of measurement (cm above floor)	Increase of venous pressure on coughing cm H_2O	Increase of venous pressure on straining cm H_2O
Superficial veins:			
14	34	—	0
16	23	—	18
32	11	< 10	14
64	44	14	—
	24	< 10	10
78	31	15	19
100	12	< 10	< 10
	38	< 10	< 10
101	32[1]	—	< 10
	29	< 10	< 10
102	32	10	< 10
103	15	23	—
104	36[1]	< 10	< 10
105	61	< 10	13
	41	15	18
Mean values		< 10	< 10
Popliteal vein:			
26	48	18	27
27	46	37	55
75	65	93	39
	55	66	37
100	53	72	40
101	53	34	57
104	60	104	49
105	60	51	abt. 75[2]
	52	52	70
Mean values		59	abt. 50
Posterior tibial vein:			
64	44	33	—
	24	32	28
78	31	15	19
	19	< 10	15
Mean values		abt. 23	21

[1] Short saphenous vein.
[2] In this case the increase in pressure was so marked that the peak of the fluctuation was projected outside the film.

In the *deep leg veins* (posterior tibial vein) the two subjects examined exhibited an increase in pressure upon increased intra-abdominal pressure, but this increase was considerably less marked than that in the popliteal vein, although it was unmistakable (Table 2).

Simultaneous recording of pressure alterations in a superficial and a deep vein at the same level during coughing and straining

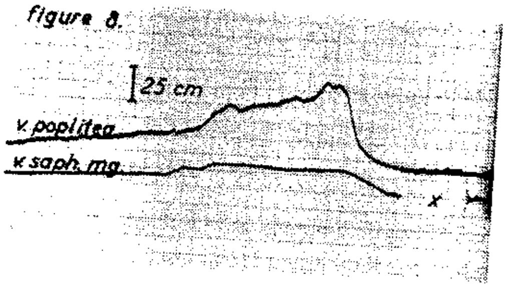


Fig. 8. Effect of increased intraabdominal pressure (straining) on the pressure in a normal long saphenous vein 41 cm above the floor, and in the popliteal vein 53 cm above the floor, recorded simultaneously (Subject 105). (x = test-marking.) Time-marking: 0.1 and 0.02 sec.

was carried out for 3 subjects: The increase in pressure in the popliteal vein was considerably in excess of that in the superficial vein (Subj. 105, Fig. 8). The increase in pressure in the posterior tibial vein was also distinctly greater than that in the superficial vein in Subject 64 (Fig. 9), less marked in Subject 78.

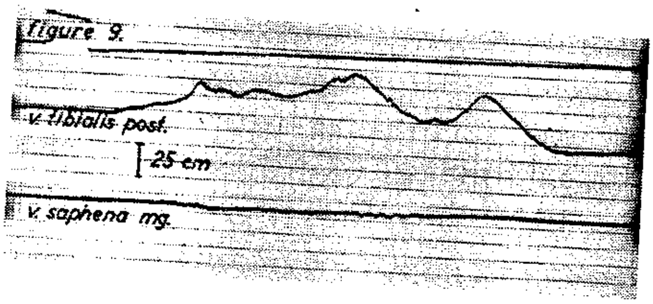


Fig. 9. Effect of increased intraabdominal pressure (straining) on the pressure in the long saphenous and posterior tibial veins of a normal subject, measured simultaneously and at the same level: 24 cm above the floor (Subject 64). Time-marking: 0.1 and 0.02 sec.

In one experiment the pressure alterations during coughing and straining were recorded in the *recumbent position* (Subject 105, popliteal vein and long saphenous vein at the same level). No sudden increase was observed in the pressure of either vein.

Not until the Valsalva manoeuvre had been continued for some time did a slow increase occur in the deep vein, but none in the superficial vein.

Discussion.

Simultaneous measurement of the venous pressure in the superficial and deep veins of the lower limbs revealed that in normal subjects in the *motionless standing position*, the pressure is identical at the same level. In the long saphenous vein, the popliteal vein, and the posterior tibial vein the pressures measured were almost equal to the hydrostatic pressure calculated. Thus, in the upright position at ease, the valves do not influence the pressure in the deep or superficial veins.

During walking (standing-walking) the mean pressure fell in the *superficial veins*. As mentioned above, the magnitude of the decrease was estimated by comparing the pressure before commencement of walking (resting pressure) and the pressure immediately after cessation of walking. In actual fact, the latter pressure is of less physiological interest than the mean venous pressure *during* walking, and the two pressures need not be identical. But it is difficult to estimate the mean pressure; sufficient electric damping of the fluctuations (TYBJÆRG HANSEN) proved impossible with such large and slow fluctuations as those caused by the phases of walking, and planimetric calculation was impracticable owing to the irregular character of the periods. However, it is clear from the curves that the mean venous pressure during walking — after the decrease during the first few steps — is approximately equal to the pressure immediately after cessation of walking.

The magnitude of the decrease in pressure, averaging 60 cm of water, was almost equal to the decrease which we have previously observed in patients with primary varicosities during walking with proximal compression of the saphenous veins. This finding corroborates that such limbs (at least as regards the venous pressure) are quite normal, when the incompetent saphenous vein is compressed, and especially it indicates that the function of the deep veins is normal in such extremities.

The fall in pressure during walking observed by us is not directly comparable with that reported by other workers (*cf.* the introduction). The techniques differ, and the influence of these differences on the decrease is partially unknown. The efforts made in walking will play a rôle (in some instances we observed a more marked decrease during running than during walking), and the magnitude of the decrease presumably also depends on the level of the point of measurement (SEIRO 1938, WARREN et al. 1949). In our experiments the latter ranged from 11 to 61 cm above the floor. We tried to find out whether our results showed a relation between the level of measurement and the magnitude of the decrease in pressure, but the scatter of the values was too marked. We are, therefore, unable to state whether the absolute decrease in pressure during walking is the same at any level on the leg, whether it increases the more distal the level, or whether any proportionality exists at all.

The environmental temperature also appears to influence the magnitude of the decrease in pressure (HENRY 1948, HICKAM et al. 1949). We did not measure the temperature in our experiments; they were carried out at ordinary room temperature (about 20°C.).

In those experiments in which we know for certain that the measurements were made in *the popliteal vein*, no fall occurred during walking, and during running in only one case. Accordingly, it must be considered a fact that the mean venous pressure during walking corresponds to the pressure in the motionless standing position.

In the *posterior tibial vein*, on the other hand, the pressure was observed to fall in each of a number of experiments on two subjects. The number of persons investigated is too small to allow of conclusions as to the magnitude of this decrease at a given level — whether it is the same at every level or whether it may depend on the distance of the level of measurement from the floor.

The fact that mean pressure is constantly high in the popliteal and femoral veins, even during walking, while this action makes the mean pressure in the saphenous veins fall considerably, makes any flow of blood from the superficial to the deep veins above knee level seem impossible. In the lower leg the pressure difference between the deep and the superficial system is less marked, if at all always present, and a flow of blood from the superficial to the deep veins seems more likely here. Our simultaneous pressure registrations in superficial and deep veins, however, show that even above knee level there is, in a certain phase of each step, not a higher and probably a somewhat lower pressure in the deep than in the superficial vein; thus, a flow of blood from superficial to deep veins even above knee level cannot be ruled out. (For further details, and for general conclusions concerning the venous return from the lower limb and the function of the venous pump: see HÖJENSGÅRD and STÜRUP 1952.)

Pressure variations *during a single step* have been described above. The variations recorded by us cannot be explained by the variations in the hydrostatic pressure caused by the movements of the leg, as our method does not record such variations. It is apparent also from unpublished experiments with *active* movements of walking with the freely hanging leg that the decrease in pressure is caused by muscular activity, as this form of exercise produced a considerable decrease in pressure, while *passive* movements of walking with relaxed, hanging leg produced only slight pressure variations and no decrease worth mentioning.

The pressure curve recorded in the superficial veins during a single step (example in Fig. 3) corresponds on the whole to that recorded by POLLACK and WOOD (1949), when regard is paid to the fact that our single step begins with the "free" leg, while POLLACK and WOOD begin with the leg to be examined. We are in a position also to confirm their interpretation of the cause of the individual phases in broad features. The pressure variations in the *deep* veins during a single step (Fig. 5) may be explained in a similar way.

Since the pressure in the deep veins of the lower leg decreases during walking, the valves in these veins are presumably essential to prevent a retrograde flow of blood from the popliteal vein in which the pressure remains high. Since no decrease in pressure occurs in the popliteal vein, there is no tendency to retrograde flow in the femoral vein. Consequently, absence of valves in the femoral vein can hardly be expected to be of anywhere near the same pathological significance as absence of valves in the deep lower leg veins (if the assumption holds true that a sustained high pressure in the lower leg veins is the essential factor in the production of the oedema which causes the symptoms and signs in extremities with venous diseases). The fact that normally the femoral vein is provided with only a few valves, while the deep lower leg veins possess numerous densely arranged valves, supported on clinical and phlebographic findings (HÖJENSGÅRD 1951), points in the same direction.

It is clear from the coughing and straining experiments that increased intraabdominal pressure results in but slight or no acute increase in the pressure in a normal superficial vein of the lower leg (and at any rate of the lower end of the thigh). (This test may acquire diagnostic importance in cases where clinical signs cannot decide whether or not a saphenous trunk is competent, since we have shown previously (1949) that an unmistakable increase in the pressure occurs in an incompetent saphenous trunk.) In the popliteal vein, on the other hand, an increased intraabdominal pressure causes a marked, sudden increase in pressure. This means either that the valves proximal to the site of measurement do not close during the experiment or that the pressure may propagate through the closed valves, *i. e.* they form an elastic membrane. The latter possibility seems the more likely of the two.

In the erect position the popliteal vein is highly distended by blood, and this is probably a factor of the utmost significance to the propagation of the intraabdominal increase in pressure (DOHN). As mentioned above, one of our experiments showed that straining in the horizontal position did not result in an acute increase in the pressure in the popliteal vein. In the horizontal position the deep veins probably hold less blood and therefore have more capacity of dilating than in the upright position. Thus, the increase in pressure is lost before it reaches the popliteal vein. (During *prolonged* straining a slow, even increase in pressure in the popliteal vein occurred in the horizontal as well as in the upright position; this is due, in our opinion, to the obstruction to the venous return caused by the increased abdominal pressure.)

Straining causes an increase in the pressure, also in the posterior tibial vein. The increase appears to be less marked in the latter than in the popliteal vein, but undoubtedly higher than in the superficial vein (Figs. 8 and 9). It was impossible to decide, whether the increase in pressure diminished towards the distal aspect, but it seems likely.

Summary.

The venous pressure in superficial leg veins, in the popliteal vein, and in the posterior tibial vein were measured in 12, 7, and 2 normal persons respectively, during motionless standing, during walking, and during straining. Some of the measurements were made simultaneously and at the same level in superficial and deep veins. In the upright position the pressure at rest was the same in

all veins, deep as well as superficial, at the same level and almost equal to the calculated hydrostatic pressure. During walking there was a rapid fall in the pressure in the superficial veins, but none in the popliteal vein. In the posterior tibial vein there was a definite decrease. Pressure curves representing the superficial and deep veins during a single step were analysed. During straining and coughing the pressure showed but slight or no increase in the superficial veins, whereas a marked, sudden increase occurs in the popliteal vein; in the posterior tibial vein there was a definite, but apparently less marked increase in pressure.

References.

ADAMS, J. C., Surg. Gynec. Obstet. 1939, *69*, 717.

BARBER, R. F., & F. I. SHATARA, N. Y. State J. Med. 1925, *25*, 262.

BAUER, G., J. int. Chir. 1948, *8*, 937.

BEECHER, H. K., M. E. FIELD & A. KROGH, Skand. Arch. Physiol. 1936, *73*, 133.

CARRIER, E. B., & P. B. REHBERG, Ibidem 1923, *44*, 20.

CHAPMAN, E. M., & R. R. LINTON, J. A. M. A. 1945, *129*, 196.

DECAMP, P. T., R. J. SCHRAMEL, C. J. RAY, N. D. FEIBLEMAN, J. A. WARD & A. OCHSNER, Surgery 1951, *29*, 44.

DOHN, K., Personal communication.

HENRY, J. P., Amer. J. Med. 1948, *4*, 619.

HICKAM, J. B., R. P. MCCULLOCH & R. J. REEVES, Amer. Heart J. 1949, *37*, 1017.

HOOKER, D. R., Amer. J. Physiol. 1911, *28*, 235.

HÖJENSGÅRD, I. C., Chronic venous insufficiency of the lower limbs.— Thesis, Copenhagen 1951.

HÖJENSGÅRD, I. C. & H. STÜRUP. Acta chir. Scand. 1949, *99*, 133.

HÖJENSGÅRD, I. C., & H. STÜRUP, Acta derm.-ven. 1952, suppl. *29*, 169.

LEDDERHOSE, G., Mitt. Grenzgeb. Med. Chir. 1906, *15*, 355.

MAYERSON, H. S., & G. E. BURCH. Amer. J. Physiol. 1939—40, *128*, 258.

MAYERSON, H. S., C. H. LONG & E. J. GILES, Surgery 1943, *14*, 519.

MCINTIRE, J. M., & A. H. TURNER. J. Clin. Invest. 1935, *14*, 16.

MCPHEETERS, H. O., C. E. MERKERT & R. A. LUNDBLAD, Surg. Gynec. Obstet. 1932, *55*, 298.

POLLACK, A. A., & E. H. WOOD, J. Appl. Physiol. 1949, *9*, 649.

RECKLINGHAUSEN, H. VON, Arch. exp. Path. Pharmak. 1906, *55*, 463.

RUNGE, H., Arch. Gynäk. 1924, *122*, 142.

RUTLEDGE, D. I., Studies on venous pressure. — Thesis, University of Minnesota 1941.

SEIRO, V., Acta chir. Scand. 1938, *80*, 41.

SMIRK, F. H., Clin. Sci. 1935—36, *2*, 317.

STÜRUP, H., Ulcer of the leg. With a survey of the postthrombotic syndrome. — Thesis, Copenhagen 1950.

Stürup, H., & I. C. Höjensgård, Acta chir. Scand. 1950, *99*, 518.
Stürup, H., & I. C. Höjensgård, Ibidem 1950, *99*, 526.
Tybjærg Hansen, A., Pressure measurement in the human organism. — Thesis, Copenhagen 1949.
Tybjærg Hansen, A., & E. Warburg, Mem. del sec. congr. inter-amer. de cardiologia, Mexico 1948. Vol. III, p. 1558.
Walker, A. J., & C. J. Longland, Clin. Sci. 1950, *9*, 101.
Warren, R., E. A. White & C. D. Belcher, Surgery 1949, *26*, 435.
Veal, J. R., & H. H. Hussey, Amer. Heart J. 1940, *20*, 308.
Veal, J. R., & H. H. Hussey, Surg. Gynec. Obstet. 1941, *72*, 841.
White, E. A., & R. Warren, Surgery 1949, *26*, 987.
Villaret, M., F. Saint-Girons & L. Justin-Besançon, La pression veineuse périphérique. — Paris 1930.