Ambulatory venous pressure revisited

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Purpose: The purpose of this study was to describe a method for measuring the deep venous pressure changes in the lower extremity and compare it with those obtained in the dorsal foot vein.

Methods: After cannulation of the posterior tibial vein, a catheter with a pressure transducer in its tip was inserted and placed at the knee joint level. The dorsal foot vein was also cannulated. Pressures were recorded simultaneously at both sites during toe stands and repeated with the probe in the upper, middle, and lower calf.

Results: The study was performed in 45 patients with signs and symptoms of chronic venous insufficiency. Duplex Doppler scanning and ascending and descending venography performed before pressure measurements revealed saphenous vein incompetence in 11 lower extremities, incompetent perforators in 11 extremities (eight were combined with saphenous incompetence), and marked compression of popliteal vein with plantar flexion in 28 extremities. No significant deep axial reflux was observed on duplex Doppler examination or descending venography. No morphologic outflow obstruction was detected. The mean deep pressure at the knee joint level fell during toe stands, –15% ± 27 (SD), and the mean dorsal foot vein pressure drop was even more marked, –75% ± 22 (SD). Although the exercise pressure in the dorsal foot vein decreased in all patients (range, 13-90% drop), the popliteal vein pressure increased (4-72%) in nine limbs, decreased only marginally if at all in 15 limbs (0-15%), and fell more markedly in 21 extremities (22-65%). Deep vein recovery time was considerably shorter overall as compared with the findings by the dorsal vein measurement. In the comparison of limbs with and without superficial reflux, the recovery times in the deep system were significantly shorter in limbs with superficial incompetence.

Conclusion: Ambulatory dorsal foot venous pressure is not always accurate in detecting changes in the pressure of the tibial and popliteal veins. Although dorsal foot venous pressure may be normal, deep venous pressure may decrease to a lesser degree or even increase. (J Vasc Surg 2000;31:1206-13.)

The dorsal foot vein pressure is considered the "gold standard" of hemodynamic measurement of venous circulation of the lower extremity.[1] Ambulatory venous pressure is believed to reflect accurately the global hemodynamic impact of any alteration of any part of the venous function. Despite normal dorsal foot venous pressures, limbs have been observed to display severe symptoms of obvious venous stasis including ulcer.[2,3] Patients may also have signs and symptoms of venous outflow obstruction of the limb with normal results from standard morphologic studies. Although good clinical results have been observed after deep vein valve repair, the ambulatory dorsal foot venous pressure is recognized as a poor detector of hemodynamic improvement.[4] Therefore, it appears that regional hemodynamic changes can occur in the deep or superficial system that are not necessarily detected by the ambulatory dorsal venous pressure and may, in part, explain the above discrepancies. This study describes a method for simultaneous measurement of pressure in the deep venous system and dorsal vein pressure during toe stands and attempts to analyze their relationship.

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Competition of interest: nil.

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0741-5214/2000/$12.00 + 0 24/1/105669
doi:10.1067/mva.2000.105669

MATERIAL AND METHOD

Air plethysmography (APG-1000; ACI Medical Inc, Sun Valley, Calif); duplex Doppler study with standardized compression; ascending and descending venography; arm/foot pressure differential; dorsal foot venous hyperemia pressure; and ambulatory dorsal foot venous pressure measurements were per-

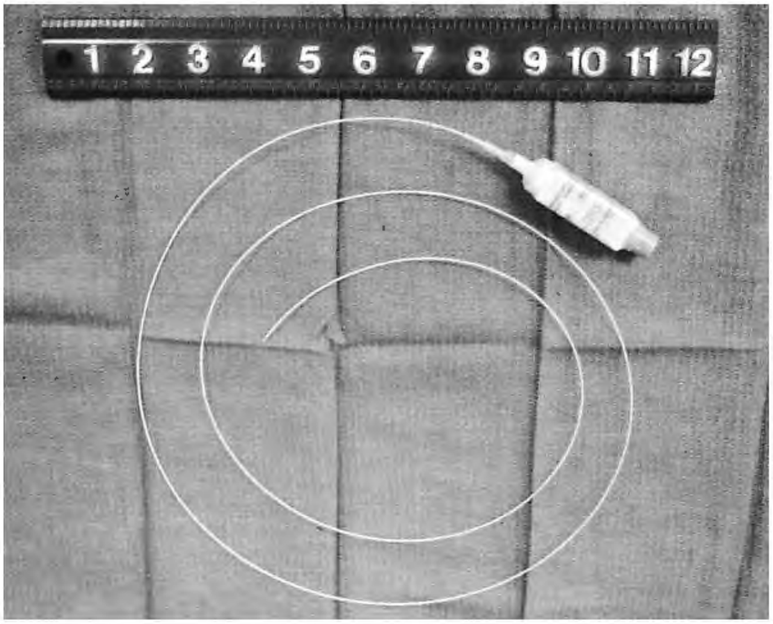

Fig 1. The Millar probe.

formed in 45 patients. The female to male ratio was 27:18, the left leg to right leg ratio was 28:17, and the median age of the patient was 50 years (range, 20-83 years). The techniques are described elsewhere.[5,6] The primary complaint was severe leg swelling in 24 patients, marked pain in 18 patients, and ulcer in three patients. There was an 80% prevalence of swelling and a 69% prevalence of pain. In addition to the ulcers, varicose veins were observed in 11 patients, and pigmentation, lipodermatosclerosis, or both were seen in four patients. Only nine patients had a history or findings on investigations suggesting a postthrombotic disease.

The patients underwent the deep venous pressure measurement because the results of the venous invasive and noninvasive tests, described above, were essentially normal or the results could not satisfactorily explain the clinical condition. The procedure was approved by the Internal Review Board at River Oaks Hospital, and informed consent was obtained.

With the patient in a semierect position, the posterior tibial vein, behind or slightly above the medial malleolus, was cannulated under sterile conditions with an 18-gauge Angiocath needle guided by ultrasound scan (Site-Rite Mark II 21000 Series; Dymax Corp, Pittsburgh, Pa). If this maneuver was unsuccessful, the Angiocath was inserted directly into the exposed vein through a small incision using local infiltration analgesia. A Millar probe (MICRO-TIP catheter transducer, Model SPC-320, #2 French outer diameter, 140-cm length; Millar Instruments, Inc, Houston, Tex) was used to measure the deep pressure (Fig 1). This probe is approved for diagnostic pressure measurement in the cardiovascular system. After calibration, it was inserted through the Angiocath and advanced to the popliteal vein. Its tip was placed at the level of the tibial plateau. The correct position was affirmed by fluoroscopy (Fig 2). If an incision had been made, it was closed with a resorbable stitch subcuticular at this point and a small 1 × 1-in dressing as affixed with tape. The patient was helped to a sitting position, a dorsal foot vein was cannulated with a scalp needle (14-gauge), and the needle was fixed in its position. The patient then assumed a standing position. The transducer (Transpac IV Monitoring Kit; Abbott Critical Care Systems, North Chicago, Ill) was calibrated and kept at the same level as the Millar probe as marked on the outside of the limb. Pressures were simultaneously recorded from the deep vein and the dorsal vein while the patient performed 15 toe stands (Fig 3). After the pressures had returned to baseline, the exercise was repeated with the tip of the Millar probe in the upper, middle, and lower third of the calf while the other transducer remained in the same position.

The Millar probe and the transducer used to measure dorsal venous pressure were connected to a chamber filled with normal saline to ensure that comparable pressures were recorded in both sys-

Fig 2. Fluoroscopy image showing the Millar probe (*arrow*).

Fig 3. Foot of patient with a Millar probe inserted into the posterior tibial vein behind the medial malleolus with a cannula placed in the dorsal foot vein for simultaneous pressure measurements.

tems. The pressure in the chamber was increased from 0 to 120 mm Hg in increments of 10 mm Hg as measured by a mercury manometer. The two techniques of pressure measurement corresponded completely.

RESULTS

Only 18 (40%) of the 45 Millar catheters could be inserted percutaneously; thus, open surgery was necessary in 27 limbs. Two instances of wound infection occurred, both of which were successfully treated conservatively.

During toe stands the mean deep pressure at the joint level fell (–15% ± 27 [SD]), and the mean dorsal foot vein pressure drop was even more marked (–75% ± 22 [SD]) (Table I). Although the exercise pressure in the dorsal foot vein decreased in all patients (range, 13-90% drop), the deep pressure reacted differently. In fact, the popliteal vein pressure increased (4-72%) in nine limbs (group C). It decreased only marginally, if at all, in 15 limbs (0-15%, group B) and fell more markedly in 21 extremities (22-65%, group A) (Fig 4). Therefore, the overall results are shown together with groups of limbs stratified according to the pressure change in the deep system and also according to the presence of superficial reflux.

Air plethysmography and ambulatory pressure results performed before the deep venous pressure measurements are shown in Table II. There is no significant difference in ambulatory dorsal foot venous pressures in the different groups, even among limbs with and without reflux. In a comparison of the latter two groups, significantly shorter venous recovery time ($P < .001$), higher venous filling index ($P < .01$), higher venous volume ($P < .05$) and larger residual volume fraction ($P < .05$) were observed in the group of patients with reflux. This was to be expected because they are plethysmographic indicators of reflux. Ultrasound scan showed this reflux to be only superficial.

Duplex Doppler scanning revealed long or short saphenous vein incompetence in 11 lower extremities. Incompetent perforators were observed in two limbs on ascending venogram and by ultrasound scan. Perforator insufficiency was observed only on venogram in an additional nine limbs. The incompetent perforators were observed in combination with long saphenous venous incompetence in eight of 11 lower limbs. No significant deep axial reflux was observed on erect duplex Doppler examination with standardized compression or on descending venography. Ascending venography showed marked compression of the popliteal vein with plantar flexion in 28 legs, minimal compression in seven legs and none in seven legs (foot movement was not performed in three limbs) (Fig 5, Table III). No other morphologic outflow obstruction was observed.

Seven of the 11 limbs with superficial reflux were found in group A and four in group B. No refluxive limb was seen in group C limbs with increased deep

Table I. The ambulatory pressure and recovery time recorded simultaneously in the dorsal foot vein and in the popliteal or tibial veins*

	Total material (n = 45)	*Patients with no reflux (n = 34)*	*Patients with reflux (n = 11)*	*Group A (n = 21)*	*Group B (n = 15)*	*Group C (n = 9)*
Dorsal foot vein						
Exercise pressure change (%)	–75 ± 22	–75 ± 20	–75 ± 27	–81 ± 16	–76 ± 15	–60 ± 23
Venous recovery time (s)	44 ± 46	45 ± 42	39 ± 60	36 ± 40	68 ± 58	21 ± 12†
Deep vein						
Exercise pressure change, at the knee joint (%)	–15 ± 27	–12 ± 28	–27 ± 19ns	–38 ± 1	–8 ± 5†	+24 ± 23†
Exercise pressure change, upper third of calf (%)	–23 ± 29	–20 ± 32	–31 ± 18ns	–40 ± 17	–17 ± 13†	+23 ± 26†
Exercise pressure change, middle third of calf (%)	–22 ± 36	–16 ± 16	–35 ± 20ns	–42 ± 18	–23 ± 11†	+45 ± 25†
Exercise pressure change, lower third of calf (%)	–21 ± 34	–16 ± 37	–33 ± 22ns	–37 ± 21	–27 ± 12†	+40 ± 23†
Venous recovery time, at the knee joint (s)	12 ± 17	13 ± 19	9 ± 5†	6 ± 4	7 ± 5	32 ± 31†
Venous recovery time, upper third of calf (s)	10 ± 17	13 ± 20	5 ± 5†	5 ± 3	9 ± 5	31 ± 37†
Venous recovery time, middle third of calf (s)	13 ± 17	16 ± 19	6 ± 6†	5 ± 3	11 ± 8	41 ± 28†
Venous recovery time, lower third of calf (s)	16 ± 22	20 ± 26	8 ± 7†	6 ± 5	13 ± 9	53 ± 36†

*The results are given in the total material and are stratified in groups with / without superficial reflux, according to the deep venous pressure change in group A (22%-65% drop), group B (0%-15% drop), and group C (4%-72% *increase*). Mean dorsal foot venous pressures were the same in all groups (mean ± SD).
†$P < .05$.
ns, No significant difference between group with reflux and group with no reflux.

pressure (Table III). This could well explain the significantly higher venous volume ($P < .05$) and residual volume fraction ($P < .05$) observed in group A compared with groups B and C (Table II). The reactive hyperemia pressure elevation was significantly greater in group C ($P < .05$), but other air plethysmography parameters were essentially the same in all groups.

The dorsal foot vein and deep venous pressures with corresponding venous recovery times are shown in Table I. The deep venous pressure values and venous recovery times are statistically significant within groups A through C, as expected because of the arbitrary grouping by pressures. The dorsal foot vein pressure is significantly lower than the pressures measured in the deep system. The dorsal foot vein recovery times are also longer in groups A and B, as compared with group C. The latter has a longer venous recovery time in the deep system; however, note that the recovery time in groups A and B reflects a return from a lower pressure (ie, mainly filling), whereas recovery in group C is from a higher pressure (ie, mainly drainage). In a comparison of limbs with and without reflux, the recovery times in the deep system are significantly shorter in limbs with reflux. There is, however, no statistical difference within the two groups in dorsal foot venous pressures and recovery times or in deep venous pressures at different levels.

Comparison among limbs with and without radiologic popliteal vein entrapment was not fruitful, mainly because of the small number of limbs without venous compression (seven of 45 limbs). When the patients with concomitant superficial reflux were excluded, however, a strong tendency toward higher arm / foot differential pressure, larger dorsal vein reactive hyperemia pressure elevation, and less deep venous pressure drop was noted in the entrapment group. The differences were not statistically significant.

DISCUSSION

The Millar transducer-tip probe proved to be a reliable tool for pressure measurement in the deep system. Infection occurred in two of 27 patients after open cannulation. An improved percutaneous insertion technique would decrease the number of open insertions and decrease the risk of infection. It would also facilitate repeat investigations.

Most patients in this study had the deep venous pressure measured because extensive evaluation,

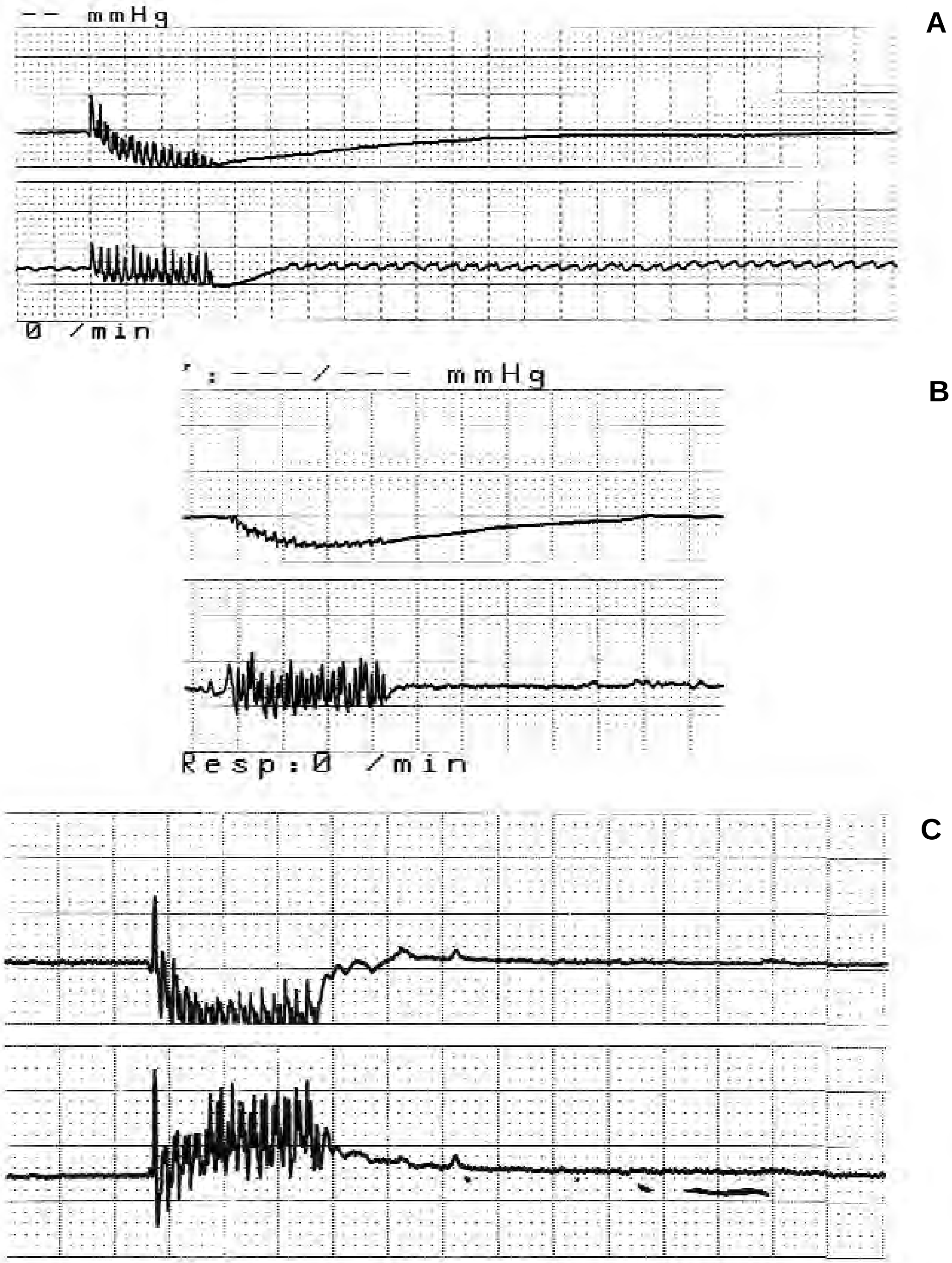

Fig 4. Typical pressure curves during and after exercise obtained from the dorsal foot vein (*top curve*) and the distal popliteal vein (*bottom curve*) in a limb from group A (A), group B (B), and group C (C).

including ambulatory foot venous pressure, had revealed no substantial hemodynamic disturbances to explain the patients' symptoms of venous stasis. Surprisingly, radically different pressure events were found in the deep system compared with the findings in the dorsal vein. The deep pressure could actually increase in the deep system and remain completely undetected by the ambulatory foot venous pressure. Referring to studies available at that time, Nicolaides and Zukowski[1] stated in 1986 that "pres-

Table II. Preoperative air plethysmography and pressure measurement results*

	Total material (n = 45)	*Patients with no reflux (n = 34)*	*Patients with reflux (n = 11)*	*Group A (n = 21)*	*Group B (n = 15)*	*Group C (n = 9)*
Venous pressure						
Dorsal foot vein pressure drop (%)	–60 ± 16	–62 ± 17	–57 ± 12	–64 ± 12	–57 ± 17	–57 ± 22
Venous recovery time (s)	50 ± 46	60 ± 49	24 ± 15†	47 ± 48	60 ± 46	44 ± 42
Hand/foot pressure differential (mm Hg)	1.1 ± 1.0	1.1 ± 1.0	1.0 ± 2.9	0.9 ± 0.9	1.2 ± 0.9	1.3 ± 1.2
Reactive hyperemia pressure elevation (mm Hg)	5.6 ± 5.1	6.4 ± 5.6	3.6 ± 2.9	5.4 ± 4.2	4.0 ± 4.1	8.6 ± 7.3‡
Air plethysmography						
Venous filling index$_{90}$ (mL/s)	2.0 ± 2.1	1.2 ± 1.0	4.2 ± 2.7§	2.4 ± 2.6	1.6 ± 1.8	1.6 ± 1.1
Ejection fraction (%)	65 ± 21	67 ± 22	57 ± 13	62 ± 22	72 ± 19	59 ± 17
Venous volume (mL)	98 ± 62	82 ± 48	140 ± 78‖	119 ± 81‡	77 ± 34	86 ± 26
Residual volume fraction (%)	39 ± 26	35 ± 27	51 ± 17‖	48 ± 27‡	36 ± 22	25 ± 24

*Results are given in the total material and are stratified according to the presence or absence of superficial reflux and to the deep venous pressure change in group A (22%-65% drop), group B (0%-15% drop), and group C (4%-72% *increase*) (mean ± SD).
†$P < .001$, comparing patients with reflux to those with no reflux.
‡Significantly different from other groups, $P < .05$.
§$P < .01$, comparing patients with reflux to those with no reflux.
‖$P < .05$, comparing patients with reflux to those with no reflux.

sure changes occurring in the deep system were almost identical to those in the superficial system, indicating that the pressure changes measured in the superficial veins represent those occurring in the deep veins." This erroneous concept has prevailed. This study clearly shows that superficial pressure does not accurately reflect pressure changes in the deep system.

Historically, it was realized by the late 1880s that venous hypertension was the major pathophysiologic factor in limbs with chronic venous insufficiency.[7] Pollack and Wood[8] measured the venous pressure at the foot and showed that the pressure dropped during exercise, probably because of the emptying of the leg veins by the calf muscle pump. Although pressure has been repeatedly measured in the superficial system, few studies compare these with pressures obtained in the deep veins.[8-10] The studies of Höjensgård and Sturup (1952)[9] and Arnoldi (1966)[10] are largely the basis for the erroneous conclusion described above. The former study included only three limbs with pressure measured simultaneously in the long saphenous and posterior tibial (two limbs) or popliteal veins (one limb). The pressure did not change at all in the popliteal vein and declined less in the posterior tibial than the superficial vein. Arnoldi intentionally studied only limbs with obvious saphenous varicosities and documented incompetent leg perforators. Alimi et al (1994)[11] studied compartment pressures combined with long saphenous and popliteal vein pressures in a group of healthy limbs. With foot action, the compartment pressure increased and naturally affected, in part, the venous pressure, but on cessation of contractions, the compartment pressure immediately returned to base levels and could not explain any prolonged, increased venous pressure. The pressure gradient with foot action was consistently higher in the saphenous vein as compared with the popliteal vein. None of these studies showed an increase in the postexercise popliteal vein pressure. Deep venous pressures were most frequently unchanged after exercise; in a few limbs, the pressure dropped. The conflicting result in this study may be explained, in part, by the improved technique of pressure measurement with the transducer tip catheter, which is vastly superior to the long, stiffer polyethylene tubes previously used. More important, most catheters in other studies were introduced into the deep vein through the short saphenous vein. This technique usually placed the catheter tip in the proximal popliteal vein, above the joint line, at the level of the upper edge of the patella. The popliteal pressures measured with these catheters were at the level of or above the insertion of the gastrocnemius and soleus muscles and thus would probably not accurately reflect the popliteal or tibial pressure within the muscle pump. Certainly a popliteal vein entrapment would not be detected.

Intuitively, an increased pressure in the popliteal vein on exercise would indicate an obstruction to venous outflow. Radiographic narrowing of the popliteal vein during plantar foot flexion was seen in 28 (62%) of the 45 limbs in this study. This extrinsic

Fig 5. Fluoroscopy images during popliteal venogram with the foot in neutral position (*left*) and during plantar flexion of the foot (*right*).

Table III. Distribution of limbs with and without radiologically demonstrated popliteal vein entrapment in groups A, B, and C

	Popliteal vein entrapment			
	Definite	*Minimal*	*None*	*Unknown*
Group A (n = 21)	12 (5)	4 (2)	4	1
Group B (n = 15)	10 (2)	3 (1)	1 (1)	1
Group C (n = 9)	6	0	2	1

The numbers within parentheses represent the limbs with superficial reflux.

compression may influence the hemodynamic result. However, there was deep venous pressure elevation in six (21%) of the 28 limbs with popliteal vein compression compared with two (29%) of the seven limbs without compression. Thus, popliteal compression was not a prerequisite for deep venous pressure increase. The situation in healthy limbs and the influence of isolated or combined superficial and deep reflux on popliteal postexercise pressure warrant further studies.

The concept that the dorsal foot venous pressure can reflect all other portions of a closed vessel system with valves is not hydraulically logical. Certainly pressures at the same level will be similar when valves are open, but pressures and recovery times of different portions of the system will differ when the valves are closed.[12] In this study, none of the patients with superficial disease (mainly long saphenous venous incompetence with perforator incompetence [8/11]) had a pressure rise in the popliteal vein. Instead, most of these limbs had a deep pressure decrease mimicking the dorsal foot vein drop, albeit not so markedly. The recovery time was significantly shorter, however, in the deep system compared with that in the dorsal foot vein in these limbs. Moreover, the recovery time in the deep system was shorter in the limbs with superficial incompetence as compared with the findings in the limbs with no incompetence. Probably the presence of perforators plays a role. The increased superficial reflux of the saphenous system appeared to fill the deep system more quickly by retrograde flow through the communicating perforators. Available diagnostic tools are incapable of quantifying flow through incompetent perforators and can only detect their presence to some degree. Further studies in which simultaneous pressures in the saphenous, dorsal foot, and deep veins are measured may elucidate this complex issue. Depending on local variations of arterial inflow, compliance, valve status, and ejection fraction of the venous segment, the pressures and recovery times will obviously be different in different regions of the venous vasculature of the limb.

In conclusion, this study found that ambulatory dorsal foot venous pressure does not always accurately reflect the pressure event in the tibial and popliteal veins. Direct popliteal venous pressure measurement may be indicated in select limbs with significant signs and symptoms of chronic venous insufficiency when the results of other venous studies, including dorsal foot venous pressure, are normal. Deep venous pressure may increase and thus detect functional lesions not shown by conventional methods (eg, popliteal vein entrapment and significant localized vein stenosis). Further studies in which this method is used may enhance our understanding of the complex calf muscle pump and the poorly understood pathophysiology of venous disease.

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Submitted Aug 27, 1999; accepted Dec 10, 1999.