Differences in pressures of the popliteal, long saphenous, and dorsal foot veins

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Purpose: **The purpose of this study was to examine the relationship among pressures obtained simultaneously in the popliteal, long saphenous, and dorsal foot veins.**
Method: **Eight limbs were studied. One limb had an isolated popliteal vein reflux, and two had moderate long saphenous vein incompetence. No perforator or short saphenous vein insufficiency was detected. Pressures and recovery times of the popliteal/tibial and long saphenous veins were obtained with cannulation at the ankle level and insertion of catheters with a pressure transducer tip. The dorsal foot vein pressure was measured with the insertion of a scalp needle (14-gauge) connected to an external transducer. During 10 toe stands, recordings were simultaneously made in the three veins at the level of the knee joint, in the middle third of the calf, and 5 to 7 cm above the ankle with all the transducers at the same level (ie, same reference point).**
Results: **In one limb the popliteal/tibial pressure increased at all calf levels, whereas pressures decreased in both saphenous and dorsal foot veins. The pressures decreased in all three systems in the remaining seven limbs. There was no statistical difference between the pressure drop in the long saphenous vein and the deep vein. However, the decrease of the dorsal foot venous pressure was significantly more marked compared with the other two veins at all levels. The recovery time was significantly increased in the long saphenous vein compared with the deep vein; recovery time was further prolonged in the dorsal foot vein.**
Conclusion: **The dorsal foot, long saphenous, and popliteal/posterior tibial veins clearly exhibit different pressure waveforms in response to calf exercise. The postexercise pressure, the percentage pressure drop, and the recovery times are widely different, which indicates that the three veins behave hydraulically as separate compartments in limbs without significant venous insufficiency. (J Vasc Surg 2000;32:894-901.)**

The classic report by Pollack and Wood in 1949[1] described venous pressure changes in response to calf exercise. The long saphenous vein was cannulated at the ankle to measure pressure in this study. Studies during the 1950s and 1960s by Höjensgård and Stürup[2] and Arnoldi[3] detailed pressures measured simultaneously in the deep and superficial veins during exercise. A rapid equilibration between the deep and superficial systems was observed, and it has since been generally thought that the dorsal foot venous ambulatory pressure drop and recovery time, in particular, correctly reflected pressure changes in the deep system and represented the global venous hemodynamics of the lower limb. In an earlier publication, we proved this assumption to be erroneous.[4] In fact, the pressure changes in the popliteal and tibial veins were quite different from those recorded in the dorsal foot vein in response to calf exercise. In some limbs, the pressure in the deep system actually increased during exercise, whereas the dorsal foot venous pressure markedly decreased. To further elucidate these findings, we examine the relationship among pressures obtained simultaneously in the popliteal/posterior tibial, long saphenous, and dorsal foot veins.

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METHODS AND MATERIALS

Patients. The popliteal/posterior tibial, long saphenous, and dorsal venous pressures were measured simultaneously in the limbs of eight patients. Before pressure measurements all patients underwent air plethysmography (APG-1000; ACI Medical Inc, Sun Valley, Calif); duplex Doppler scan study with standardized compression; ascending and

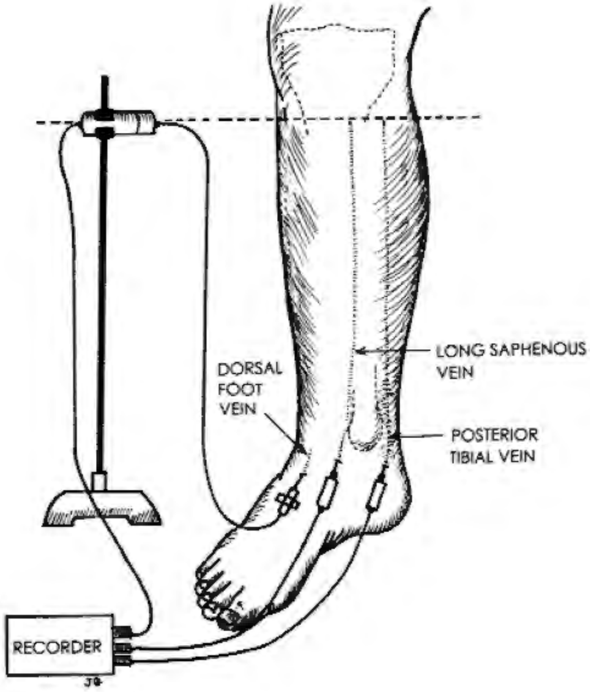

Fig 1. Schematic drawing of the setup of simultaneous pressure measurement. Two Millar probes are inserted into the long saphenous and posterior tibial veins distally and the tips placed close to the knee joint. The external transducer connected to the cannula in the dorsal foot vein is placed at the same level as the tip of the probes. When the Millar probes were pulled down to the middle and lower third of the calf, the external transducer was lowered to the same level as the tip of the probes.

descending venography; and arm/foot pressure differential. Dorsal foot venous hyperemia pressure and ambulatory dorsal foot venous pressure measurements were also performed. The techniques are described elsewhere.[5-7] Patient characteristics are shown in Table I. The stripping of the long saphenous vein in two patients was confined to the above-knee portion only. Only one limb (patient 4) had deep reflux (an isolated popliteal venous incompetence). All limbs had varied narrowing of the popliteal vein on dorsal foot flexion during ascending venography, but arm/foot pressure differential and dorsal foot venous hyperemia pressure were within normal limits in all patients, which indicated an absence of hemodynamic obstruction. No other morphologic obstruction was observed through venography or duplex Doppler scan examinations. Duplex Doppler scan revealed that two limbs had long saphenous vein reflux, which was confined to the above-knee segment only, whereas no perforator

Fig 2. Fluoroscopic image showing initial level of the tips of Millar probes in the long saphenous and popliteal veins.

insufficiency or short saphenous vein incompetence was detected. Some hemodynamic results of the "standard" investigations are listed in Table II. Essentially, all results are within normal limits. The most common primary complaint was pain. These patients participated in the deep venous pressure measurement because the venous invasive and noninvasive test results described above were essentially normal or the results could not satisfactorily explain the patient's clinical condition. The method of pressure measurement was approved by the Internal Review Board at River Oaks Hospital, and informed consent was obtained from each patient.

Method of pressure measurement. The popliteal and long saphenous venous pressures were measured with cannulation at the ankle level and insertion of catheters with a pressure transducer tip. The dorsal foot vein was cannulated with a standard needle connected to an external transducer. During 10 toe stands, pressures were measured simultaneously with all three pressure transducers at the same level (ie, the reference point at the same level in all three veins, Fig 1). The posterior tibial vein behind or slightly above the medial malleolus and the distal long saphenous vein anterior to the medial malleolus were cannulated under sterile conditions with 18-gauge Angiocath needles (BD Medical Systems, Sugar Land, Tex) that were guided by ultrasound scan (Site-Rite Mark II 21000 Series; Dymax Corp, Pittsburgh, Pa); the patient was in a semierect position. If this maneuver proved unsuccessful, the Angiocath was inserted directly into the veins that were exposed through a small incision with local infiltration analgesia. Two Millar probes (Mikro-Tip catheter transducer, model

Table I. Characteristics of eight patients

Patient no.	*Sex*	*Age (y)*	*Right/ left limb*	*Primary complaint*	*Previous surgery*	*LSV vein incompetence*	*Deep reflux*
1	F	43	Right	Swelling	None	None	None
2	M	66	Left	Dermatitis	None	None	None
3	F	62	Left	Leg pain	None	Present	None
4	F	47	Right	Leg pain	None	Present	Present
5	F	35	Right	Leg pain	None	None	None
6	M	50	Left	Swelling/ leg pain	LSV stripping to the knee/stab avulsions	None	None
7	F	54	Left	Leg pain	LSV stripping to the knee/stab avulsions/popliteal vein valvuloplasty	None	None
8	F	53	Left	Leg ulcer	None	None	None

F, Female; *LSV,* long saphenous vein; *M,* male.

Table II. Hemodynamic results of standard investigation in eight limbs

Patient no.	*Ambulatory venous pressure drop (%) (normal > 50)*	*Venous recovery time (s) (normal > 20)*	*Venous filling index (mL/s) (normal < 2.0)*	*Ejection fraction (%) (normal > 40)*	*Volume recovery time (s) (normal > 3)*
1	57	138	0.8	97	4
2	75	24	1.7	68	9
3	93	120	2.2	44	5
4	45	34	1.2	69	6
5	74	120	1.1	65	3
6	92	63	1.1	55	8
7	82	41	0.9	40	8
8*	84	6	—	—	—
Mean ± SD	75 ± 17	68 ± 51	1.3 ± 0.5	63 ± 19	6 ± 2

*Results could not be obtained with air plethysmography because of marked swelling of leg.

SPC-320, #2 French outer diameter, 140-cm length; Millar Instruments, Inc, Houston, Tex) were used to measure the deep and long saphenous venous pressures. The Millar probe is approved for diagnostic pressure measurement in the cardiovascular system. This probe was inserted through the Angiocath and advanced in both the popliteal and long saphenous veins to the level of the tibial plateau. The correct position was affirmed with fluoroscopy (Fig 2). If an incision had been made, it was closed with resorbable suture, which was subcuticular at this point, and a small 1 × 1-in dressing was 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 and connected to the external transducer. The patient then assumed a standing position. The external transducer (Transpac IV Monitoring Kit; Abbott Critical Care Systems, North Chicago, Ill) was calibrated and kept at the same level as the tip of the Millar probes as marked on the outside of the limb; thus, all three transducers were at the same level. Pressures were simultaneously recorded from the popliteal/posterior tibial, long saphenous, and dorsal veins while the patient performed 10 toe stands (Fig 3). The external transducer and the catheter tip transducers have been shown to yield identical pressures when used in the same location.[4] After the pressures had returned to baseline, the exercise was repeated with the tip of the Millar probes in the bulky middle third and then in the lower third of the calf, 5 to 7 cm above the medial malleolus. The external transducer was lowered to match the same level as the tip of the catheters. Thus, the reference point was at the same level in all three veins. This positioning provided identical baseline pressures in all three veins at the three levels of pressure measurement.

The baseline venous pressure of the saphenous and the popliteal/tibial veins corresponded to the true hydrostatic pressure in each of those veins

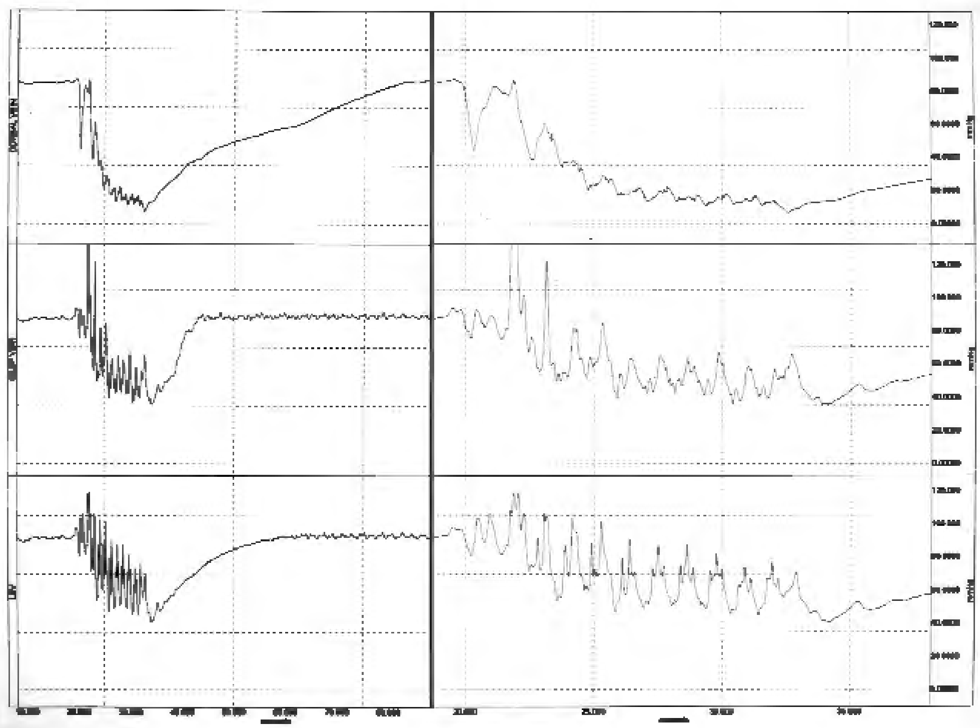

Fig 3. The dorsal foot (*top*), popliteal (*middle*), and long saphenous (*bottom*) venous pressure tracings simultaneously recorded 5 to 7 cm above the ankles during 10 toe stands in patient 1 with no reflux or obstruction. Right set of curves are a magnification of the left set.

because catheter tip–mounted transducers were used. Because the external transducer was raised from the foot to match the level of the tips of the internal catheters, the dorsal foot vein pressure was artificially lowered to correspond with the other venous pressures. Therefore, it did not reflect the true dorsal foot venous pressure. For pressure measurement at the ankle level, the external transducer had to be raised only 5 to 7 cm above the dorsal foot vein puncture site to correspond to the level of the catheter tip transducers (ie, the displayed pressure varied only slightly from the true hydrostatic pressure). This relatively small variation could be ignored, and the three absolute pressures at the ankle level could be considered comparable for the purposes of this study.

RESULTS

Typically obtained pressure curves from the popliteal, long saphenous, and dorsal foot veins are depicted in Fig 4. Patient 8 had an increase in deep venous pressure at all calf levels, whereas pressure decreased in both saphenous and dorsal foot veins. Most patients (7 of 8 limbs) had a drop in venous pressure in all the veins at the knee level (Table III). The average venous pressure drop and recovery time at the knee joint, middle calf, and above the ankle are shown in Table IV. Patient 8 is excluded because the venous recovery time in this patient represents drainage rather than filling of the leg. There is no statistical difference between the pressure drop in the long saphenous vein and the deep vein. The dorsal foot venous pressure drop, however, is significantly more marked compared with the other two veins at all levels. The recovery time is significantly increased in the long saphenous vein compared with the deep vein, and it is then further prolonged in the dorsal foot vein. The limbs with long saphenous vein incompetence showed a pattern similar to those with no reflux at all. This may be due to the fact that reflux was limited to the above-knee segment of the vein and, therefore, probably had little influence on the calf pressure.

DISCUSSION

Pollack and Wood[1] used direct puncture of the long saphenous vein at the ankle to study venous pressure during calf exercise. Höjensgård and Stürup[2] measured simultaneous pressures in the deep and superficial (saphenous) veins during exer-

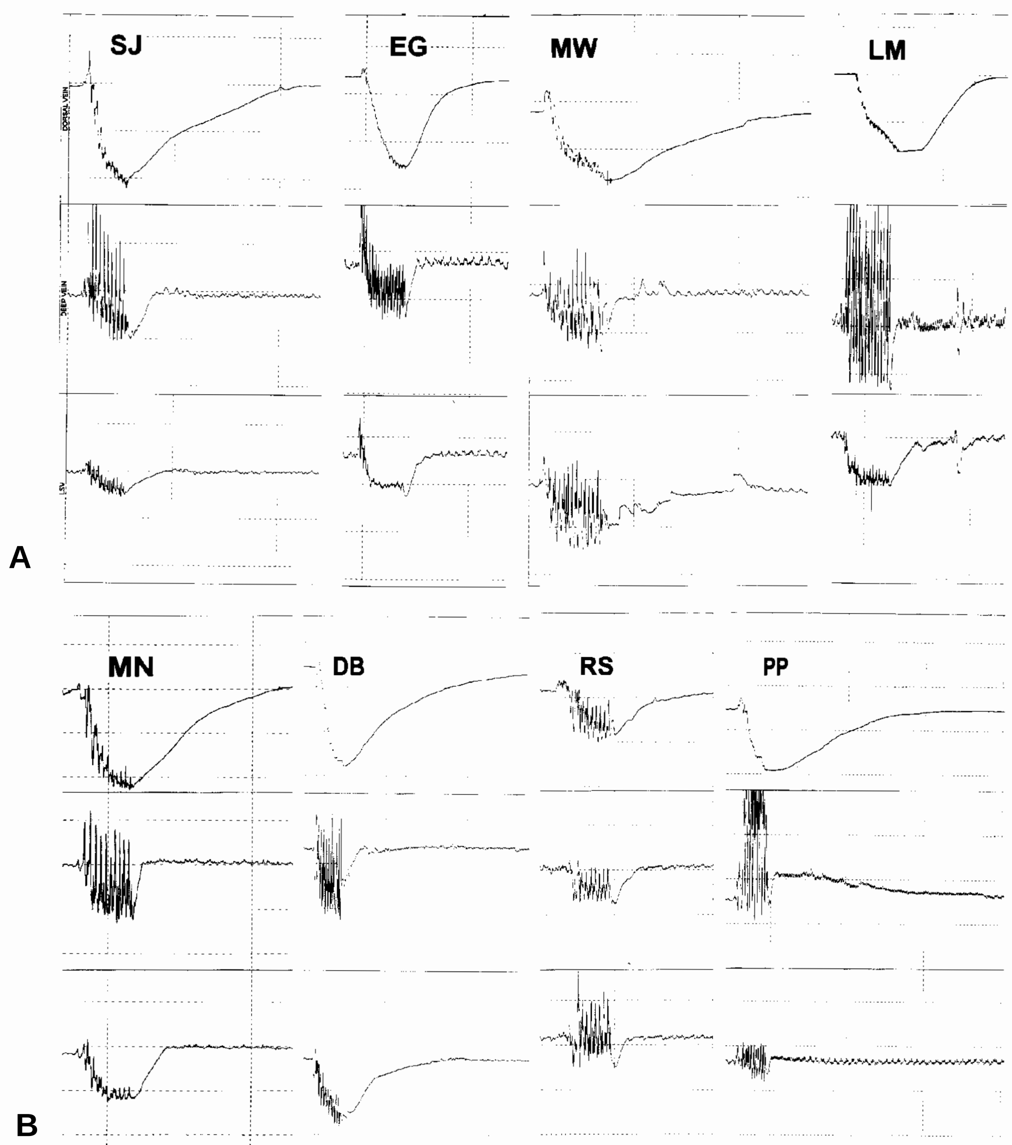

Fig 4. The dorsal foot (*top*), popliteal (*middle*), and long saphenous (*bottom*) venous pressure tracings simultaneously obtained at the level of the middle third of the calf during 10 toe stands in each individual limb. Patient numbers 1-4 (*top,* left to right); patient numbers 5-8 (*bottom,* left to right).

cise. The popliteal vein pressure was found to vary significantly from the saphenous vein pressures, whereas the posterior tibial vein pressures were nearly identical to the saphenous vein pressures. The concept that dorsal vein pressure can be used as a proxy for deep vein pressure became entrenched after the studies of Arnoldi,[3] who showed that tibial vein pressures approximated dorsal vein pressures in patients with extensive valvular incompetence, including verified incompetent perforators. As shown in the current study, however, this may not apply if the valves between the measuring site and the deep system are competent. A rapid equilibration of pressure between the deep and superficial systems can occur when large connections (eg, wide, incompetent perforators) are present between the superficial and deep system. On the other hand, if the connections between the systems are of small caliber and outward flow is prevented by functioning valves, pressure equilibration will be hampered. In a two-tube experimental model with a competent valve in between, both the postexercise pressure and

Table III. Venous pressures obtained simultaneously in the popliteal, long saphenous, and dorsal foot veins with pressure transducers at the knee joint level in all eight limbs

	Popliteal vein		*Long saphenous vein*		*Dorsal foot vein*	
Patient no.	*Pressure change (%)*	*Venous recovery time (s)*	*Pressure change (%)*	*Venous recovery time (s)*	*Pressure change (%)*	*Venous recovery time (s)*
1	–47	7	–23	9	–100	42
2	–44	3	–31	11	–104	24
3	–39	3	–48	20	–77	46
4	–34	2	–26	7	–49	34
5	–31	2	–56	7	–123	40
6	–25	3	–73	13	–117	62
7	–9	4	–12	4	–45	26
8	+17	90*	–14	1	–94	51

*Drainage time, not filling time.

Table IV. Average venous pressures obtained simultaneously in the long saphenous and dorsal foot veins compared with those obtained in the popliteal/tibial vein at different levels of the calf in seven patients with ambulatory venous pressure drop

	At knee joint		*Middle calf*		*Above ankle*	
	Pressure drop (%)	*Venous recovery time (s)*	*Pressure drop (%)*	*Venous recovery time (s)*	*Pressure drop (%)*	*Venous recovery time (s)*
Deep vein	–33 ± 13	3 ± 2	–47 ± 17	4 ± 2	–36 ± 13	4 ± 3
Long saphenous vein	–42 ± 28 (ns)	10 ± 5*	–51 ± 17 (ns)	7 ± 6 (ns)	–47 ± 17 (ns)	13 ± 11*
Dorsal foot vein	–88 ± 28*	39 ± 13*	–71 ± 28*	43 ± 28*	–70 ± 26*	39 ± 22*

Pressure transducers were at the same level (mean ± SD).
*$P < .05$ (Wilcoxon rank sum test for paired observations).
ns, Not significant.

recovery times in the two segments varied depending on tube capacitance, residual volume, compliance, and arterial inflow.[8]

In the current study, the dorsal foot, long saphenous, and posterior tibial veins clearly exhibit different pressure waveforms in response to calf exercise. There is a theoretical possibility that, although the Millar probe only has an outer diameter of 0.7 mm, it would impede outflow or prevent proper closure of valves in the posterior tibial vein. The posterior tibial vein is a paired vein with multiple communicants. It is highly unlikely that this thin catheter, placed in one of the tibial veins, would cause any significant obstruction to outflow. Similarly, larger catheters, inserted from below, were used to inject contrast during descending venography to delineate leakage of diseased valves. Not even these catheters have been shown to cause incompetence in healthy valves transversed by them. Therefore, it is extremely unlikely that the catheter placement per se greatly influenced or could explain the observed pressure patterns.

This study is limited to a few patients and does not aim to define so-called normal pressures, pressure response in different venous diseases, or clinical application of the three knee-vein pressure investigation. However, after the result of the pressure study and other investigations, four patients underwent popliteal vein release on suspicion of popliteal vein entrapment syndrome as described in a previous report.[9] One patient had stripping of the long saphenous vein. The remaining two limbs continued to be treated with conservative therapy, mainly compression.

In conclusion, the main observation of this study is that postexercise pressure, percentage pressure drop, and recovery times are widely different in the deep, long saphenous, and dorsal foot veins, indicating that the three veins behave hydraulically as separate compartments. This may explain why signs and symptoms of chronic venous insufficiency occur with normal ambulatory dorsal foot venous pressures and why dorsal foot venous pressures do not consistently normalize despite clinical improvement after valvuloplasty. Studies of pressures measured simultaneously in the different venous systems in limbs with defined anatomic distribution of reflux and obstruction are necessary for further elucidation of the complex pathophysiology of venous disease.

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DISCUSSION

Dr Olav Thulesius (Linkoping, Sweden). I thank the American Venous Forum for giving me the opportunity to discuss this interesting paper. It was the objective of the authors to show that the recording of ambulatory and postexercise venous pressure in the foot vein does not necessarily reveal proximal valvular insufficiency, and I agree with the authors that their findings give evidence to this conclusion. I have a few comments.

The exercise-induced pressure drop in the veins of the lower extremity depends on the disruption of the hydrostatic column by external pressure exerted by the muscle pump. However, we have to realize that there are important additional pumps in the foot and at the level of the knee joint and the thigh. These pumps are determined not only by kinetic changes of muscles but by the mechanical action of sliding fascia and movements of joints. The postexercise pressure drop was less pronounced at the knee level in the popliteal and long saphenous vein compared with the calf and ankle level. The pressure contour in the deep veins showed a characteristic pattern of high amplitude deflections.

This slide demonstrates high amplitude deflections particularly in the popliteal vein and the long saphenous vein at the knee joint. This could easily be explained—if you see here the high amplitude deflections in the popliteal vein. This might be due to the fact that the authors used tiptoeing. By tiptoeing, you change the hydrostatic level considerably. You do not change the hydrostatic level at the foot. Therefore, you do not have these high amplitude changes. I think it is very difficult to make any calculations as to the pressure drop when you have these high amplitude deflections. My suggestion is, why don't you use knee bending where you have less change in the hydrostatic level? In addition, you activate not only the foot pump and the calf pump but also the knee and the thigh pump, and therefore you subject the proximal valves to higher pumping action. I would suggest that you try that. It is a bit difficult to draw any conclusions from these even in normal cases. You have much shorter refilling time and these high amplitudes compared with the foot veins.

Moreover, I wonder why did you change the reference level for the foot vein to the knee joint? You made your calculation in percentage of pressure drop. You did not make your changes in the absolute pressure drop, so why don't you leave the reference level at the foot as is usually done? I do not understand why you did that, so that is one of my questions.

In your paper, you stated that two patients had long saphenous vein reflux. These are not normal cases. One of the changes you observed in all patients was that the deep venous vein was narrowed. What happens if you insert a catheter even if it is a #2 French catheter all the way up in a narrowed vein? Did that have any implications on your results?

I agree with you, this is a very nice study to show that in patients who have a normal pressure contour at the foot, you might find changes proximal. These might explain changes in symptoms of pain and even ulceration as you have shown in patient PP (8) that was the last patient with an exactly normal pressure curve from the foot but was abnormal higher up. I would suggest that you might change the technique a little bit and would like to hear your comments about the narrowed deep vein and the insertion of a #2 French catheter, if that could have affected your results.

Thank you very much. I appreciate your interesting paper, and I appreciate the opportunity to discuss the paper.

Dr Peter Neglén. Thank you, Dr Thulesius, for your comments. We used tiptoeing because that is our standard movement when we evaluate our venous patients. Interestingly enough, when you blow up the curves much of that oscillation disappears. In addition, when you stretch the curve out, even though it is a digitalized, sensitive curve, those oscillations disappear. However, there are large deflections in pressure, presumably because of a mechanical push on the transducer when the muscle contracts.

We wanted to put the reference point where we had the tip of the catheters to be able to make a direct comparison. There is always confusion when you compare pressures at different sites, when the transducers are at different levels. Using the percent drop from the same level would more clearly illustrate the difference of pressure change. Therefore, we chose to standardize the transducer point to be at each level. The dorsal foot vein pressure is therefore artificially low at the higher levels. On the other hand, we believe that when you measure at the lowest level, which is just above the insertion site of the dorsal vein cannula, nearly the same starting pressures are achieved in all three transducers. This will be at the level for the true dorsal foot vein pressure. Changes between different vein pressures at this level will reflect true differences. However, there was no significant difference of pressure results at whatever level the pressure response to tiptoeing was measured, comparing the upper, middle, and lower part of the calf. I hope that explains some of the thinking behind the choice of the reference point.

When I described in the manuscript the vein to be narrowed, I did it with a few hesitations. It is not a narrowed posterior tibial vein. I was describing a compression of the popliteal vein on ascending phlebography on movement of the foot, most often plantar foot flexion. We have found this in 30% or 40% of patients with no symptoms of venous disease. No other obstruction was found on the phlebographic examination. There was no reflux. It is hard to say if this is important or not. We discussed last year at this forum if popliteal vein entrapment is a clinical and significant finding. There is a lot of disagreement. Maybe I should not even have mentioned it in the paper. It might be that the patient, PP (8), has a popliteal vein entrapment that is clinically important. It is hard to say. The size of the catheter is very small, and the tibial vein is relatively small. Although theoretically the pressure catheter may be an obstacle to outflow, in practice I do not think that this affects the outcome critically.