# Detection of outflow obstruction in chronic venous insufficiency

**Peter Neglén, MD, PhD,*** and **Seshadri Raju, MD,** *Al-Ain, United Arab Emirates, and Jackson, Miss.*

***Purpose:*** **This study compares three different modes for measuring hemodynamically significant outflow obstruction in chronic venous insufficiency: (1) arm-foot venous pressure differential combined with foot venous pressure elevation to reactive hyperemia, (2) outflow fraction determination with plethysmography, and (3) calculation of resistance from simultaneously obtained foot venous pressure and calf volume curves.**

***Methods:*** **The three techniques were compared in 15 normal limbs and 19 limbs with documented previous deep venous thrombosis. Outflow fraction and resistance were also measured after reactive hyperemia was induced.**

***Results:*** **The arm-foot venous pressure measurements delineated patients with grades 1 through 4 obstruction (Raju's grading). Resistance calculations correlated well with this grading except in patients with severe grade 4 obstruction, in whom low resistance was found. Outflow fraction determinations had marked overlapping between the different obstruction grades, substantially decreasing sensitivity to detect hemodynamically important outflow obstructions. No correlation with the resistance calculations was shown. Inducing reactive hyperemia did not alleviate these findings. The failure of the outflow fraction and resistance methods to detect significant obstruction is probably attributable to the use of plethysmographic techniques for volume measurement, which appears to give false-negative results as a result of a regional volume shift within the lower limb.**

***Conclusions:*** **The combination of the arm-foot vein pressure differential and the foot vein pressure elevation after reactive hyperemia seems to be the only reliable test currently available for detecting and grading global chronic obstruction. (J VASC SURG 1993;17: 583-9.)**

The most common cause of outflow obstruction is acute deep venous thrombosis. With recanalization of the lumen and formation of collaterals, the acute obstruction can be compensated over time. No hemodynamic disturbances may be detected at rest. Thus standard plethysmography may be found falsely negative later in the course of the disease. Most obstructions improve as measured by plethysmography, but sometimes the values do not revert to normal levels.[1-3] In extreme cases the outflow obstruction may lead to "venous claudication" (i.e., pain and tightness in the leg), which usually occurs after vigorous exercise.[4] Usually the patient has to stop the activity and elevate the leg for relief of pain. This extremely rare complication after a venous clot is thought to be caused by increased venous pressure of the lower limb as a result of high blood flow resistance.

Chronic venous insufficiency is most often attributed to valvular incompetence with reflux. Proper identification of disease is relatively straightforward in these cases. However, the most severe condition with lipodermatosclerosis and ulcer is found more often with a combination of significant obstruction and reflux.[3,5,6] Their relative contributions to the clinical presentation are not known; thorough analysis of such complex disease is obviously required for rational treatment. We present below methodologic difficulties encountered in assessing the obstructive component of such combined obstruction-reflux disease.

Obstruction is most often measured by indirect

From the Departments of Surgery, United Emirates University, Al-Ain, and the University of Mississippi Medical Center, Jackson.

Reprint requests: Seshadri Raju, MD, Department of Surgery, University of Mississippi Medical Center, 2500 N. State St., Jackson, MS 39216-3404.

*At the time of the study Dr. Neglén was a visiting professor at the Department of Surgery, University of Mississippi Medical Center.



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plethysmographic methods (strain-gauge, impedance, photoplethysmography, and air plethysmography). To obtain hemodynamic data, transfemoral pressures have been obtained in patients with postthrombotic pelvic vein lesions.[7] The pressure increased greater than 4 mm Hg after exercise and was not normalized within 20 seconds in patients with significant obstruction compared with those with normal legs. Raju[8] reported a similar pressure gradient obtaining arm-foot pressure differential in postthrombotic legs with significant obstruction, regardless of phlebographic localization of the lesion. Despite this well-known fact, ascending phlebography is still used surprisingly often and inappropriately as the "gold standard." Although this method will reveal the anatomic location and sometimes outline the number and size of collaterals, it can never reliably evaluate the functional degree of obstructed outflow.[9] To date there is no accepted reliable method to measure outflow obstruction. Calculation of resistance by use of simultaneous pressure and volume measurements by air plethysmography has recently been advocated as the new gold standard.[10]

The purpose of this study was to compare hemodynamic pressure measurements, outflow fraction determinations by air plethysmography, and resistance calculated from simultaneous volume and pressure curves in detection of outflow obstruction in patients with chronic venous insufficiency.

## MATERIAL AND METHOD

To assess venous outflow obstruction, 15 healthy limbs in 10 subjects with no history of venous disease and 19 limbs in 17 patients with previous deep vein thrombosis were investigated. The postthrombotic state was verified by ascending phlebography. All patients had involvement of at least the superficial femoral vein proximally; in nine patients an extension to the common femoral and iliac veins was shown and in four patients the inferior vena cava was involved. The following tests were performed.

**Foot vein pressure tests.** The venous pressures were measured through a needle inserted into a dorsal foot vein and a dorsal hand vein by a transducer (P10 EZ; Gould Inc., Cleveland, Ohio). The arm-foot venous pressure differential (normal value $<4$ mm Hg) and the foot venous pressure elevation to reactive hyperemia (normal value $<6$ mm Hg) were recorded. These tests were performed to detect and grade any significant venous outflow obstruction and are described in detail elsewhere.[8] In grade 1 (fully compensated) obstruction, both the arm-foot pressure differential and the reactive hyperemic venous pressure elevation are normal, even though anatomic obstruction is seen to be present on duplex or phlebographic examination. In grade 2 (partially compensated) obstruction the arm-foot venous pressure differential is less than 4 mm Hg, signifying adequate collateralization/recanalization at rest, but the reactive hyperemic venous pressure elevation is greater than 6 mm Hg, signifying inadequate compensation under circulatory stress. With grade 3 (partially decompensated) obstruction both the arm-foot venous pressure and reactive hyperemic tests yield abnormal values. In grade 4 (fully decompensated) obstruction the arm-foot venous pressure differential is greater than 4 mm Hg, but the venous pressure elevation to reactive hyperemia is paradoxically less than 6 mm Hg. The latter appears to be the result of the absence of the classic reactive hyperemic response in the presence of a high-grade venous obstruction.[9]

**Outflow fraction determination.** The venous outflow fractions at 1 to 5 seconds were obtained with venous occlusion plethysmography with an air plethysmograph (APG-1000; ACI Medical Inc., Sun Valley, Calif.). The details of this technique have been described by Christopoulos, et al.[11] The venous filling index (in milliliters per second) and functional venous volume (in milliliters) on standing were also calculated. The patient was placed in a supine position with the leg elevated 30 degrees. A thigh cuff was inflated to 70 mm Hg and the volume increase of the calf was registered by the air plethysmograph. When the maximum volume increase was attained, the cuff was deflated immediately and a volume outflow curve was obtained.

**Resistance calculation.** Simultaneously with the plethysmographic volume outflow curves, the pressure of the dorsal foot vein was recorded on a polygraph (model 7E; Grass Instrument Co., Quincy, Mass.). The flow (Q) can be calculated at any point on the volume curve from the tangent at that point (Fig. 1).[10] The resistance (R) is determined by dividing the corresponding pressure (P) on the pressure curve by the flow ($R = P/Q$, mm Hg/ml/min $\times 10^{-2}$).

To produce further stress on the circulation, both the outflow fraction and the resistance were determined, with the occlusion plethysmography performed after induction of reactive hyperemia. The thigh cuff was then initially inflated to 250 mm Hg for 2 minutes and then suddenly deflated to 70 mm Hg. The calf volume increased rapidly; when the curve leveled off the cuff was instantaneously deflated completely. A photoplethysmography (Photopulse

Sensor model PH 77; MedaSonics, Inc., Mountain View, Calif.) attached to the big toe confirmed the lack of flow during ischemia and recorded the induced hyperemia by showing more than doubled pulse amplitude after release of the cuff. The outflow curves obtained with and without reactive hyperemia were similar. However, when the thigh cuff was inflated to induce ischemia, a varying blood volume was initially squeezed distally and proximally. The distal portion could be detected by the plethysmograph (Fig. 2).

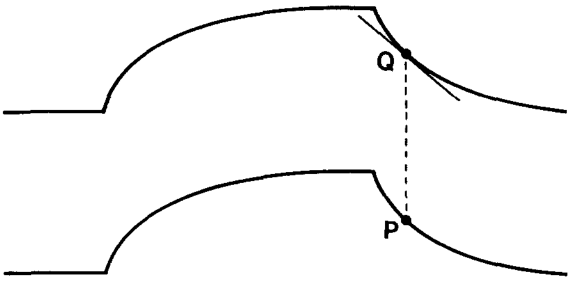


**Fig. 1.** Typical plethysmographic volume *(top)* and dorsal foot vein pressure *(bottom)* curves. Flow Q can be calculated from tangent on volume curve at any point and corresponding pressure P measured. Resistance is determined as P/Q.

## RESULTS

Normal subjects had an arm-foot venous pressure differential less than 4 mm Hg and a reactive hyperemic elevation of the foot vein pressure of less than 6 mm Hg. No hemodynamic obstruction (grade 1) was found in six patients with previous deep venous thrombosis, but grade 2 obstruction was observed in six patients, grade 3 in two patients, and grade 4 in five patients (Table I). There was no consistent relationship between the anatomic localization of obstruction (i.e., proximal vs distal) and hemodynamic severity irrespective of the method used.

When possible, the average outflow resistance was calculated for each group at pressures ranging from 2.5 to 40 mm Hg with and without previous ischemia. The resistance curve after induced reactive hyperemia is depicted in Fig. 3 and values are listed in Table I. As the pressure is reduced, the vein circumference decreases and the resistance increases. Lower limbs with obstruction of grades 2 and 3 had significantly higher resistance. The healthy legs and postthrombotic limbs with no hemodynamic obstruction revealed minor resistance to outflow. The surprising observation was the lack of obstruction measured in grade 4–obstructed limbs according to the resistance calculation.

Fig. 4 depicts the amount of resistance with and without prior ischemia. Lower limbs with grades 2 and 3 obstruction showed a marked increase in resistance after ischemia, whereas the difference was less (although obvious) in normal limbs and legs with grade 1 or 4 obstruction. Inducing ischemia before release better separated the groups but did not influence the individual order. In only one limb with grade 2/3 obstruction were resistance values in the upper level observed among limbs with grade 1 obstruction. Otherwise there was no overlapping. Thus there was a very good correlation between the hemodynamic grading and the resistance calculation, except in limbs with grade 4 obstruction. As will be discussed below, this is perhaps the result of an artifact inherent in the plethysmographic method.

Individual outflow fraction determinations 1 second after cuff release at occlusion plethysmography are shown in Fig. 5. The results are similar when 2- to 5-second fractions were used. The only groups of limbs that differed significantly from the normal limbs were those with grades 2 and 3 obstruction (Table II). Occlusion plethysmography after induced reactive hyperemia did not change this observation dramatically. Overlapping between the different groups markedly decreased the specificity to detect a hemodynamically significant outflow obstruction. No correlation with the resistance calculation was shown.

Other parameters obtained by air plethysmography are also listed in Table II. The maximum volume reached during occlusion plethysmography with the subject in the supine position was higher in the healthy legs than in limbs with significant obstruction (grades 2 through 4). The volume fraction squeezed distally by the tight thigh cuff was significantly larger in patients with a previous deep vein thrombosis. No valves prevented the displacement because they had probably been destroyed in the thrombotic process. The amount of postthrombotic reflux was reflected by the increased venous filling index measured as the patient stood up. On standing, the functional venous volume was higher in grade 4–obstructed limbs compared with grade 2/3 limbs. The high cuff-deflected volume with pronounced reflux and the larger functional venous volume in grade 4 limbs compared with grade 2/3 legs appear to suggest a "dead space" available to be filled when the cuff is released during occlusion plethysmography. This appears to be the main factor to explain the inability of tests that use plethysmographic techniques to

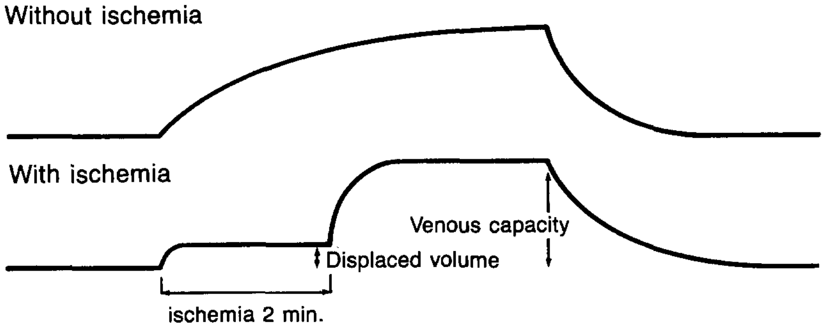


**Fig. 2.** Plethysmographic curves obtained with *(bottom)* and without *(top)* induced reactive hyperemia.

**Table I.** Foot vein pressure elevation with reactive hyperemia (stress test), arm-foot vein pressure differential, and outflow resistance at varying pressures after occlusion plethysmography with reactive hyperemia

| | *Stress test (mm Hg)* | *Arm-foot pressure difference (mm Hg)* | *Resistance ([mm Hg/ml/min] × $10^{-2}$) at pressure (mm Hg)* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | *2.5* | *5.0* | *10* | *15* | *20* | *30* | *40* |
| Normal (*n* = 15) | 3.3 ± 1.4 | 1.1 ± 0.8 | 2.0 ± 1.8 | 2.0 ± 1.8 | 1.4 ± 2.0 | 1.0 ± 0.5 | 1.0 ± 0.2 | – | – |
| Obstruction grade 1 (*n* = 6) | 4.9 ± 0.9 | 1.4 ± 1.3 | – | 3.1 ± 2.0 | 1.9 ± 1.1 | 1.5 ± 0.7 | 1.3 ± 0.5 | 1.4 ± 0.6 | 1.6 ± 0.3 |
| Obstruction grade 2 (*n* = 6) | 9.8 ± 2.2 | 3.1 ± 0.4 | – | – | 15.1 ± 11.1 | 6.5 ± 4.0 | 4.9 ± 2.7 | 3.7 ± 1.5 | 3.1 ± 1.0 |
| Obstruction grade 3 (*n* = 2) | 9.1 ± 0.7 | 9.2 ± 4.0 | – | – | – | – | 15.0 ± 0.9 | 7.6 ± 2.[illegible] | 4.2 ± 0.9 |
| Obstruction grade 4 (*n* = 5) | 4.9 ± 0.5 | 8.5 ± 3.3 | – | – | 3.7 ± 1.6 | 1.9 ± 0.9 | 1.6 ± 0.6 | 1.7 ± 0.8 | 2.0 ± 1.0 |

Data are means ± SD.

detect severe obstruction in chronic venous insufficiency.

## DISCUSSION

Despite the fact that the grade 4 limbs were hemodynamically and phlebographically severely obstructed, neither the resistance calculation nor the outflow fraction determination at 1 second detected this. Either the hemodynamic test for grade 4 (arm-foot vein pressure differential >4 mm Hg) does not truly reflect obstruction or the methods of the resistance calculation and outflow fraction determination are influenced by additional factors (e.g., the plethysmographic volume determination used in both methods). A phlebographically demonstrated venous blockage has been shown to relate poorly to the physiologic importance. For example, iliac vein obstructions can vary widely in hemodynamic severity.[9] Although the majority of crural obstructions are well compensated, some are not,[9] requiring surgical bypass for amelioration of severe symptoms.[8] The hemodynamic severity of an obstructive venous lesion has less to do with its anatomic location than with the degree of collateralization and recanalization that occurs in the individual case. Phlebography is an unreliable index of this process.[12] As may be expected, in this study iliac-vena caval obstructions ranged in severity from mild to severe irrespective of the method used to assess the degree of obstruction. No discernible differences in the hemodynamic pattern were observed between central and more peripheral obstructions in this study.

Occlusion plethysmography has been used mainly to detect outflow obstruction in patients with acute venous thrombosis. These limbs have both low venous capacity and decreased venous outflow.[13] Patients with chronic venous insufficiency may have varying degrees of collateralization to bypass the obstruction and increase the venous volume. A negative test result at rest in these patients may potentially hide a physiologically significant obstruction. This leads us to question the ability of the

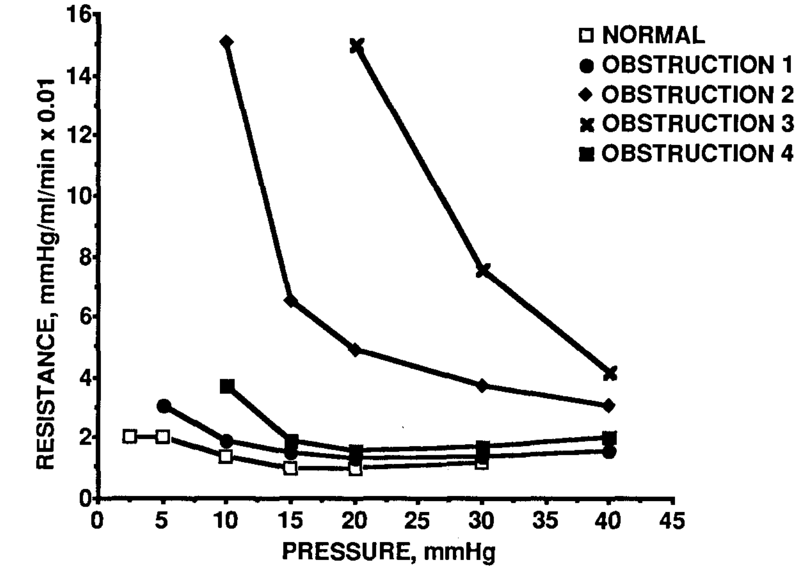


**Fig. 3.** Curves of average resistance calculated in different groups of lower limb obstruction after induced reactive hyperemia.

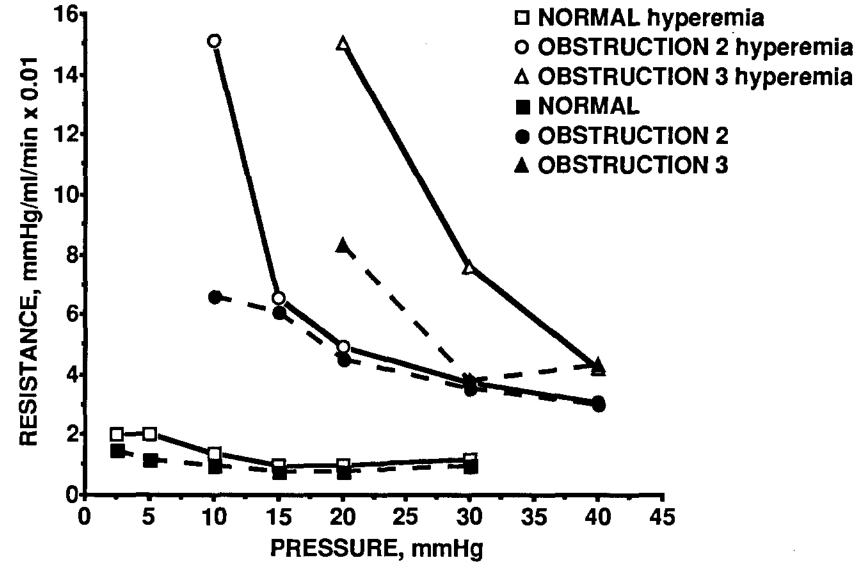


**Fig. 4.** Curves of average resistance calculated in normal and obstructed (grades 2 and 3) lower limbs without and after induced reactive hyperemia.

plethysmographic method to measure significant outflow obstruction adequately in patients with chronic venous insufficiency.

The outflowing blood in grade 4–obstructed limbs must have reached a high volume space with relatively low resistance, explaining the high 1-second outflow fraction and the lack of initial pressure increase. The thigh cuff pushed blood proximally and distally, as shown by the considerable displacement of volume detected by the plethysmograph. Thus the inflated cuff may be in part responsible for the creation of such a dead space.

With the patient in a supine position and the leg raised 30 degrees, the thigh is drained considerably. Therefore the volume displaced by the cuff does not completely reflect the available functional space that can receive the outflow. The functional venous volume of the calf measured plethysmographically on standing is not affected by reflux and obstruction. This volume was found to be significantly lower in

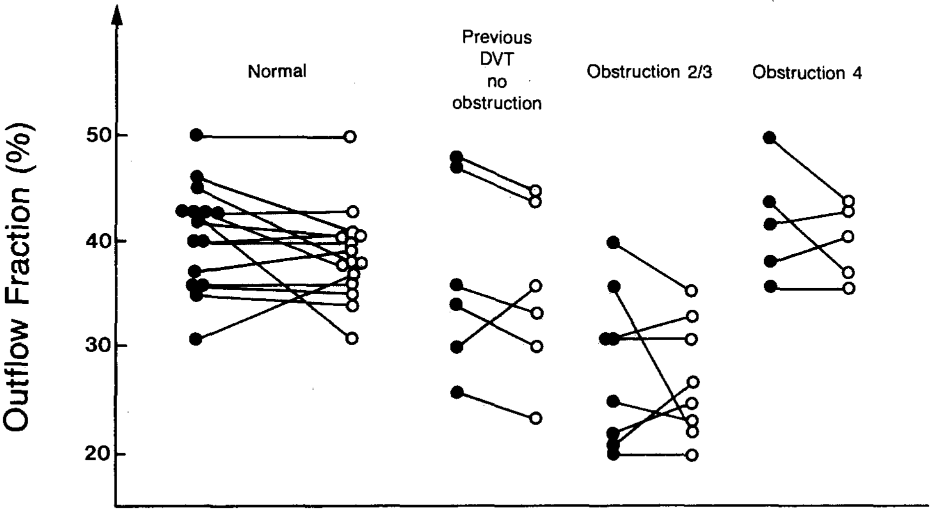


**Fig. 5.** Individual outflow fraction determinations 1 second after cuff release at occlusion plethysmography with (○) and without (●) induced hyperemia in nonobstructed and obstructed lower limbs. *DVT,* Deep venous thrombosis.

**Table II.** Results of air-plethysmographic parameters obtained in postthrombotic legs with and without significant obstruction compared with healthy lower limbs

| | *Normal (n = 15)* | *Previous DVT, no obstruction (n = 6)* | *Grade 2/3 obstruction (n = 8)* | *Grade 4 obstruction (n = 6)* |
|---|---|---|---|---|
| OF 1 sec (%) (no ischemia) | 41 ± 5 | 37 ± 9 | 28 ± 7* | 42 ± 6 |
| OF 1 sec (%) (with ischemia) | 39 ± 4 | 35 ± 8 | 27 ± 6* | 40 ± 4 |
| Maximum volume at occlusion (ml) | 128 ± 29 | 124 ± 33 | 89 ± 24* | 102 ± 16 |
| Fraction-displaced volume (%) | 14 ± 5 | 33 ± 9* | 41 ± 17* | 54 ± 22* |
| Venous filling index (ml/sec) | 0.9 ± 0.4 | 4.4 ± 2.2* | 4.7 ± 3.7* | 13.3 ± 6.1* |
| Functional venous volume (ml) | 143 ± 25 | 133 ± 28 | 105 ± 25* | 158 ± 29 |

Data are means ± SD.
*DVT,* Deep venous thrombosis; *OF,* outflow fraction.
*$p < 0.05$, unpaired nonparametric Wilcoxon-rank test.

grade 2/3 limbs compared with normal limbs. The normal or increased venous volume in grade 4 limbs may reflect a relative abundance of collaterals attempting to compensate for the obstruction of deep veins. A pressure gradient of greater than 5 mm Hg over a vein segment has been shown to stimulate formation of collaterals.[7] This venous collateral capacity in the thigh and pelvic region is an additional low-resistance space for the outflowing blood. Thus a relatively large, low-resistance space may be available to which enough volume can be shifted locally to avoid a pressure buildup.

Cutaneous arterial flow may be increased in the presence of lipodermosclerosis,[14] resulting in shortened venous refilling times in some patients in the erect position. It is uncertain that this factor would have affected venous outflow calculations at 1 to 5 seconds as employed in this study with venous occlusion plethysmography in the recumbent patient with an elevated extremity. We discount this phenomenon to be the basis of the anomalous resistance observation noted with grade 4 obstructions for the following reasons: (1) Lipodermosclerosis was broadly distributed in grade 1 through grade 4 obstructions and was not confined to grade 4 obstruction alone. (2) Resistance calculations did not change significantly when plethysmography was performed with preceding hyperemia (Fig. 4). The only exceptions were a few data points in grades 2 and 3 obstruction at the lower end of the pressure range (i.e., 10 and 15 mm Hg).

It has been suggested that tourniquets be used to occlude the collateral channels during occlusion air plethysmography. Assuming this is possible, separation between those limbs with and without significant deep vein obstruction has been reported.[10] In our laboratory the results have been inconsistent and the method has been abandoned. The tourniquets are feared to either fail to occlude the superficial system or inadvertently obstruct the deep system. Tourniquets have been shown to introduce an error into the evaluation of venous disease because the pressure to occlude the long saphenous vein by a thigh cuff varies from 40 to 300 mm Hg.[15] To date there is no reliable way to assess the importance of the role of deep versus superficial collaterals in alleviation of an obstruction.

The grading of obstruction by foot vein pressure tests correlated significantly with the resistance calculation of simultaneously obtained pressure and plethysmographic volume outflow curves. However, both the resistance calculation and the outflow fraction determination failed to detect hemodynamically defined grade 4 obstruction in patients with chronic venous insufficiency. Both methods measured volume change by plethysmographic technique, which appears to give false-negative results as the result of a regional volume shift within the lower limb. Inducing reactive hyperemia did not alleviate this finding. The use of cuff inflations introduces an error to the evaluation of chronic venous obstruction. It is important to find a method that does not use cuffs for evaluation of the obstruction component of the venous circulation. The resistance calculation according to the described technique cannot be considered a gold standard. The combination of the arm-foot vein pressure differential and the foot vein pressure elevation after reactive hyperemia seems to be the only reliable test currently available for detecting and grading global obstruction.

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