A rational approach to detection of significant reflux with duplex Doppler scanning and air plethysmography

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Purpose: **Several techniques are currently available for the detection of venous reflux. We have attempted to determine the relative value and accuracy of available techniques to develop a logical strategy of investigation in reflux venous insufficiency.**
Methods: **The morphologic distribution of venous incompetence (erect duplex and descending venography); the results of ambulatory venous pressure measurement, venous refilling time, the Valsalva test, and air-plethysmography (venous refilling index, VFI); and the clinical severity were described in 118 consecutive limbs. In an attempt to validate the tests, results were correlated with the clinical severity classification (class 0, $n = 34$; class 1, $n = 42$; class 2, $n = 11$; class 3, $n = 31$) and with a standardized quantification of reflux (multisegment score) as seen on standing duplex Doppler scanning with rapid deflation cuffs.**
Results: **Twenty-nine percent of limbs with severe venous disease (class 2/3) had pure deep insufficiency, only 6% had pure superficial disease, and the remainder had a combination. A history of previous thrombosis and the presence of posterior tibial vein incompetence were markedly common with ulcer disease (84% and 42%, respectively). The duplex Doppler multisegment score correlated strongly with clinical severity classification ($r = 0.97$). The venous refilling time and VFI had the highest sensitivity in identifying severe venous disease (class 2/3), and the ambulatory venous pressure had excellent specificity.**
Conclusions: **For noninvasive determination of reflux, the combination of VFI and duplex scanning not only localized the reflux but also separated severe clinical vein disease from mild, with high sensitivity and specificity. Air plethysmography may also provide valuable information regarding calf muscle pump and outflow obstruction. (J VASC SURG 1993;17:590-5.)**

Ambulatory venous pressure (AVP) measurement has been the traditional "gold standard" for assessing the amount of reflux. However, it is well known that venous ulcer disease can occur despite normal pressure.[1,2] Ambulatory venous pressure is probably influenced by not only the venous reflux but also other factors (e.g., vein wall properties and calf pump function).[3] A common reflux test is that of the venous recovery time evaluated by the photoplethysmographic technique. Although numerous investigators have described reasonable correlation with results of the venous refilling time measured through the dorsal foot vein,[4] others have suspected that it reflects only regional venous hemodynamics, being more related to superficial than to deep vein incompetence.[5] Recently, additional methods have been introduced. The Valsalva-induced foot venous pressure elevation test has been validated against the methods mentioned above.[6] With air plethysmography the reflux can be quantified noninvasively. An increased incidence of chronic venous insufficiency with increased reflux flow has been reported.[7]

This study describes the morphologic distribution of venous incompetence, results of hemodynamic reflux tests, and signs and symptoms in a group of patients seen consecutively. Our purpose was to validate AVP, including venous refilling time (VFT),

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the Valsalva test, and results of air plethysmography against the clinical severity stage of chronic venous insufficiency. The findings are also correlated to a standardized quantification of reflux with erect duplex ultrasound scanning reported by van Bemmelen et al.[8] A rational approach to the diagnosis of reflux based on the results is outlined.

MATERIAL AND METHODS

Between January 15 and July 15, 1991, pressure measurement through a needle inserted into a dorsal foot vein, air plethysmography, and erect-segmentation duplex Doppler scanning were done in 118 consecutive limbs. In addition, a full history was taken and each lower limb was examined carefully. Descending venography was also performed in 51 limbs. No limb had undergone previous surgery.

Venous pressure measurements

Ambulatory venous pressure measurement. Pressures in a dorsal vein of the foot were recorded with the patient standing still, followed by manual compression of the calf several times (usually six to 10 compressions) until the pressure reached a plateau and then recovered to levels recorded before the simulated exercise. This technique is comparable to the traditional "toe-stand" technique.[6] The time required for the pressure to recover was the VFT.

Valsalva-induced foot venous pressure elevation test. Dorsal foot vein pressure was monitored in the supine patient before and after a standardized Valsalva maneuver (blowing against a mercury manometer to 40 mm Hg).[6] An increase of greater than 4 mm Hg was considered to indicate reflux.

Arm-foot venous pressure differential and reactive hyperemia tests. Arm-foot venous pressure differential and reactive hyperemia tests were performed to detect any significant venous outflow obstruction and are described elsewhere.[9]

Air plethysmography. The details of air plethysmography have been described by Christopolous et al.[10] Part of the test evaluates reflux. The tubular bag of the air plethysmograph (APG-1000; ACI Medical Inc., Sun Valley, Calif.) is placed around the leg with the patient in supine position and the lower limb elevated 45 degrees. Five minutes later the veins are emptied and the leg-cuff temperature has stabilized. The device is then calibrated and the patient is asked to stand up quickly with the weight on the opposite limb, holding onto a frame. The increase in the calf volume is recorded. Because the time factor is known, the average filling rate of the veins can be calculated (venous filling index[VFI] measured in milliliters per second). Other parameters (e.g., residual venous volume fraction after exercise) can also be measured. Residual venous volume fraction is suggested to be closely related to the decline in AVP.[10]

Duplex Doppler scanning. The erect duplex ultrasound scanning (Acuson 128 PV, probe 531; Linear Instruments Corp., Reno, Nev.) was performed as described by van Bemmelen et al.[8] An automatic cuff inflator (Hokanson, Bellevue, Wash.) was used for rapid inflation and deflation of cuffs placed on the thigh (inflation pressure 80 mm Hg; width 24 cm), calf (100 mm Hg; 12 cm), and foot (120 mm Hg; 7 cm). The cuffs were inflated for approximately 3 seconds and then rapidly deflated. Reflux was considered significant if the duration of the retrograde flow exceeded ½ second. It was measured in the common femoral, superficial femoral, long saphenous, popliteal, short saphenous, and proximal and distal posterior tibial veins. Unfortunately, the deep vein could not be visualized consistently. An attempt was made to identify incompetent perforators. Any morphologic changes that indicated previous thrombosis were noted.

Because different levels of the superficial and deep venous system may be involved, a multiple-segment scoring system was used.[11] One point each was awarded to observed reflux in the superficial femoral, long saphenous, popliteal, short saphenous, and proximal and distal posterior tibial veins. Thus the maximum score was 5.

Descending venography. Descending venography was performed according to the technique described by Kistner et al.[12] The patient was placed at 70 degrees in a partially erect position and asked to perform a Valsalva maneuver by blowing against a mercury manometer at 30 to 40 mm Hg.

Clinical classification

The clinical severity was graded according to the "Reporting Standards in Venous Disease" by the Ad Hoc Committee[13]: class 0 = asymptomatic, 1 = mild chronic venous insufficiency with chief complaints of swelling and aching, 2 = moderate chronic venous insufficiency with significant hyperpigmentation and other skin changes but no ulcer, and 3 = severe chronic venous insufficiency with skin changes and an active or recently active venous ulcer. For practical purposes the main division is between clinical severity grades 0/1 and 2/3. Therefore these two major groups were compared.

Wilcoxon-rank unpaired and paired nonparametric tests were used for statistical analysis in the appropriate situations. A p value of ≤ 0.05 was

Table I. Various morphologic data obtained in 118 lower limbs by ultrasound scanning and ascending phlebography; deep vein incompetence was diagnosed by descending phlebography in only 51 limbs

	Clinical severity class (%)			
	0 (n = 34)	*1 (n = 42)*	*2 (n = 11)*	*3 (n = 31)*
Previous DVT	18	10	18	84
Significant obstruction	0	8	0	32
Superficial incompetence only	25	36	9	6
Combined deep and superficial incompetence	11	24	45	65
Deep incompetence only	11	5	37	29
Axial deep incompetence				
CFV or SFV	18	14	27	16
POP or PTV	15	12	0	19
Combination	3	7	36	58
Perforator incompetence	26	31	73	65
Incompetent PTV	6	2	0	42
Incompetent deep vein	57 (n = 14)	56 (n = 18)	14 (n = 7)	50 (n = 12)

DVT, Deep vein thrombosis; *CFV,* common femoral vein; *SFV,* superficial femoral vein; *POP,* popliteal vein; *PTV,* posterior tibial vein.

Table II. Decrease of AVP, VFT, Valsalva test, VFI, and residual venous volume fraction in 118 lower limbs according to clinical severity classification

	Clinical severity class			
	0 (n = 34)	*1 (n = 42)*	*2 (n = 11)*	*3 (n = 31)*
AVP decrease (%)	59 ± 4	58 ± 5 (NS)	51 ± 12*	41 ± 14***
VFT (sec)	36 ± 18	33 ± 16 (NS)	15 ± 11*	9 ± 7***
Valsalva test	2.2 ± 1.2	2.2 ± 1.6 (NS)	4.5 ± 2.1**	5.8 ± 4.5***
VFI (ml/sec)	1.6 ± 1.6	2.3 ± 1.7*	8.0 ± 5.6*	8.5 ± 5.2***
RVF (%)	27 ± 13	32 ± 15 (NS)	49 ± 15**	38 ± 21*

Data are means ± SD.
RVF, Residual venous volume fraction.
Classes 1 to 3 compared with class 0: *NS* = no significance, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

considered significant. All numbers are given as mean ± SD unless otherwise noted. Standard methods were used to calculate correlation coefficient and linear regression analysis.

RESULTS

Distribution of clinical grading of severity status of the 118 limbs was as follows: class 0 = 34, class 1 = 42, class 2 = 11, and class 3 = 31. Changes observed by ascending venography, duplex Doppler investigation, or at later reconstructive surgery suggested previous deep vein thrombosis in 38 limbs (32%). Distribution of morphologic observations is shown in Table I. Significant hemodynamic obstruction[9] was seen in 16% (13/82) of symptomatic legs and in none of the asymptomatic limbs. Previous thrombosis and posterior tibial vein incompetence were markedly more common with ulcer disease, whereas radiologic evidence of deep insufficiency was equally frequent regardless of signs and symptoms. As many as 85% of patients with posterior tibial vein incompetence had an ulcer. The rate of superficial vein involvement was the same in the different symptomatic groups of limbs. A combination of proximal and distal deep vein insufficiency was observed in 18 (58%) of 31 limbs with severe chronic venous insufficiency. Perforator incompetence was identified in all patients with active ulcer at the time of investigation. Incompetent perforators were present in 67% (28/42) of clinical class 2/3 compared with 29% (22/76) of class 0/1 limbs.

Results of the hemodynamic studies in different clinical severity stages are shown in Table II. All tests were significantly abnormal in classes 2 and 3. The high number of patients with superficial venous insufficiency in class 1 (26/42) explained the signif-

Table III. Sensitivity, specificity, and predictive value of hemodynamic and ultrasound tests or combinations of these to separate clinical severity class 0/1 from class 2/3

Test	*Normal value*	*Sensitivity (%)*	*Specificity (%)*	*Predictive value (%)*
AVP decrease	>50%	67	99	97
VFT	>20 sec	90	82	73
VFI	<3.0 ml/sec	90	74	66
Valsalva test	<4.0 mm Hg	55	89	74
RVF	<50%	36	92	71
US	≤1	83	86	76
US + AVP decrease		79	100	100
US + VFT		98	93	89
US + VFI		93	89	83
US + Valsalva test		64	96	90

RVF, Residual venous volume fraction; *US,* multilevel/system scoring of ultrasound scanning.

Table IV. Decrease of AVP, VFT, Valsalva test, VFI, and residual venous volume fraction in 118 lower limbs according to the multilevel/system scoring of the findings at duplex Doppler scanning

	Correlation r	*Clinical severity class*				
		0 (n = 35)	*1 (n = 38)*	*2 (n = 17)*	*3 (n = 17)*	*≥4 (n = 11)*
AVP decrease (%)	0.95	59 ± 4	57 ± 7 (NS)	48 ± 13*	43 ± 16***	43 ± 15*
VFT (sec)	0.92	41 ± 17	28 ± 16**	14 ± 13***	13 ± 9***	11 ± 6**
Valsalva test	0.87	2.1 ± 1.0	2.7 ± 2.8 (NS)	4.7 ± 4.0**	5.2 ± 4.1***	4.6 ± 2.2*
VFI (ml/sec)	0.96	1.4 ± 1.0	2.3 ± 1.6**	6.6 ± 4.0***	9.2 ± 5.8***	9.4 ± 5.5**
RVF (%)	0.80	30 ± 13	30 ± 16 (NS)	41 ± 19 (NS)	41 ± 22 (NS)	39 ± 17 (NS)

Data are means ± SD.
RVF, Residual venous volume fraction.
Scores 1 through 4 compared with score 0: *NS* = no significance, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. In addition, the linear correlation coefficients for the tests are given.

icant rise in the VFI. For practical purposes it is of greater interest to determine which test better separated class 2/3 limbs with severe venous disease and class 0/1 limbs with moderate or no disorder. The sensitivity, specificity, and predictive value of the different hemodynamic tests are shown in Table III. Ambulatory venous pressure measurement and the Valsalva test had the best specificity, but VFT and VFI had superior sensitivity. The poor specificity and predictive value of the last tests in the identification of ulcer disease are attributed to the high rate of superficial venous insufficiency observed in clinical class 1 (but only with moderate symptoms). Significant long or short saphenous vein incompetence was seen in 13 of 16 patients with false-positive VFI.

The average points obtained by the duplex Doppler scanning with the multisegment scoring were directly correlated to the clinical classification ($r = 0.97$). The hemodynamic test results in relation to different scores obtained by ultrasonography are listed in Table IV. A score of 2 points or greater was considered a positive finding (i.e., significant reflux involving at least two levels or two systems). With the exception of residual venous volume fraction, all reflux tests were significantly abnormal above the critical ultrasound score. Decrease of AVP, VFT, and VFI had a highly significant linear correlation, with a correlation coefficient of 0.92 or greater. The significant increase of VFI and VFT in the limbs with a duplex Doppler score of 1 was a result of the frequency of superficial incompetence, which these tests detected with high sensitivity. Therefore the sensitivity, specificity, and predictive value of the above tests to distinguish the group of limbs with major ultrasound scan reflux (score ≥ 2) were similar to those calculated for identifying clinical severity class 2/3 (Table III).

The sensitivity, specificity, and predictive value of the ultrasound scan to place the limb in class 2/3 were 83%, 86%, and 76%, respectively. To improve the diagnostic efficacy, a hemodynamic test was combined with the ultrasound investigation (Table III).

The best results were achieved by the addition of the invasive VFT or the noninvasive VFI.

Coexisting hemodynamic obstruction did not appear to interfere with the reflux measurements. There was no significant difference in any of the hemodynamic tests or the ultrasound investigation score between obstructed and nonobstructed limbs with venous ulcer disease.

DISCUSSION

In this study roughly one third of the limbs had severe chronic venous insufficiency with or without ulcer, one third were moderately symptomatic, and one third were asymptomatic. The patients with severe venous disease had a higher rate of previous deep venous thrombosis (67%; 28/42) than in other reports (33% to 45%).[6,14] This could be attributed to either the selection of patients outside our control or the comprehensive investigations these patients underwent. Significant hemodynamic obstruction was seen in one third of limbs with ulcer disease. Significant outflow obstruction did not interfere with any of the reflux measurements.

Apparently combined superficial and deep system insufficiency is a major contributor to reflux in the symptomatic limbs. Twenty-nine percent of those with severe disease with or without ulcer (class 2/3) had pure deep insufficiency alone or combined with incompetent perforators. The incidence of multisegment axial deep incompetence increased with increasing clinical severity. In this study only 6% of limbs with ulcer had superficial disease alone, a rate similar to those described by others.[6,15] Gooley and Sumner[16] found that 73% of limbs with stasis ulcer had long saphenous involvement (most with concomitant deep disease) and only 10% had pure superficial involvement. These observations were based on studies with continuous-wave Doppler study and VFT by photoplethysmography. In a meticulous duplex Doppler study, Hanrahan et al.[14] reported a similar rate of involvement of the superficial veins (79%) but as many as 36% with no deep venous disease. The variability of the incidence of isolated superficial incompetence in the literature is probably related to the variability of the clinical severity class of the case material being studied. Pure superficial insufficiency is common in patients with class 1 disease. As disease progresses to class 2 and 3 severity, associated deep venous insufficiency occurs.

The importance of distal vein insufficiency in the development of severe chronic venous insufficiency has been emphasized by other authors.[16-18] In this study, incompetence of the popliteal level or below was observed in 77% of cases, three fourths in combination with proximal insufficiency. Isolated proximal incompetence was rare (16%). Using indirect methods, Gooley and Sumner[16] found a similar rate of distal involvement, but the majority (7/10) were isolated. In this study an insufficient posterior tibial vein was seen in almost every other patient with ulcer disease and in only 3% of limbs without ulcer disease. It appears that the posterior tibial vein is a major determining factor for the occurrence of ulcer, as recently noted.[15]

The significantly more frequent incidence of perforator incompetence (67%) observed in the severe venous disease is in agreement with other reports.[7,19] Although the importance of deep vein reflux has been stressed, especially with proximal vein valve reconstruction,[20] no difference was seen when the different clinical stages were compared. However, the material is limited and based only on descending venography.

Thus incompetence of the superficial main stems in association with deep axial veins including posterior tibial and popliteal veins was found to be a major contributor to severe chronic venous insufficiency. No doubt duplex Doppler can accurately identify these sites and in this study allowed a detailed description of the distribution of reflux. Quantitative segmental duplex Doppler scanning performed in the erect patient with standardized cuff inflations is more accurate and better reproducible than is scanning performed in the supine position with manual compression or the Valsalva maneuver.[8,11] Even the status of descending venography as the gold standard is being challenged.[11] However, ultrasound scanning cannot assess the global hemodynamic condition. Therefore it is necessary to combine scanning with a physiologic test to measure the degree of venous insufficiency.

When the tests were compared with the clinical severity class, all tests, except residual venous volume fraction, rose with increased severity. Both AVP and the Valsalva tests had a high frequency of false-negative results, which has been reported previously.[1,2] Perhaps the measurements not only measure reflux but are also influenced by such factors as vein wall properties and calf muscle pump function. On the other hand, VFI and VFT had few false-positive readings but less specificity. It has been suggested that tourniquets be applied to separate superficial from deep vein disease. In our laboratory the results are inconsistent[6] and the method has been abandoned. The tourniquets are feared either to fail to occlude the superficial system or to inadvertently

obstruct the deep system. Similar experience has been reported by others.[21] Venous duplex Doppler appears far superior in discriminating superficial from deep insufficiency.

The simple scoring system for the ultrasound scan used in this study incorporated both the deep and superficial systems but not the perforators or the deep vein because of poor consistency of detection in our hands. The relative contribution of the different levels and systems must be evaluated further. Therefore the classification may need modification in the future. Despite these disadvantages, a highly significant linear relationship to increased severity of the disease was found. The AVP, VFT, and VFI correlated particularly well with the increasing score. Main-stem long or short saphenous insufficiency affected the results of VFT and VFI in limbs with a score of 1, but the mean value was still within normal limits. This observation emphasized further the importance of localizing the reflux. Despite this finding, the critical score chosen was more than or equal to 2 (i.e., at least two levels or systems refluxing). This choice was supported by the fact that superficial incompetence alone in limbs with ulcer disease was rare (6%). The sensitivity and specificity of the ultrasound scan in distinguishing between limbs with class 2/3 and class 0/1 disease were surprisingly high.

No hemodynamic test alone could give sufficiently high specificity and sensitivity to identify severe venous disease. Although normal VFT (>20 seconds) or VFI (<3.0 ml/sec) seemed to exclude marked incompetence, significant superficial involvement may be overlooked. Therefore a combination with the duplex technique appears most logical. This combination (duplex with VFT or VFI) provided results superior to those of any other combination. The VFT was measured as part of the AVP measurement. The VFT can be measured noninvasively by photoplethysmography. The accuracy of this method has been questioned lately.[5,6] We favor a combination of duplex scanning with VFI measured by air plethysmography for initial noninvasive evaluation of venous reflux in patients with class 2 and 3 symptoms. Duplex alone may suffice in patients with class 1 symptoms.

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