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Hemodynamic and clinical impact of ultrasound-derived venous reflux parameters

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Purpose: **This study was undertaken to assess which ultrasound-derived parameter was superior for measuring venous reflux quantitatively and to evaluate the importance of popliteal vein valve reflux.**
Patients and methods: **A retrospective analysis was performed of 244 refluxive limbs in 182 patients who underwent ultrasound scanning, venous pressure measurement, air plethysmography, and clinical classification of severity according to the CEAP score. Reflux time (RT, s), peak reflux velocity (PRV, m/s), time of average rate of reflux (TAF, mL/min), absolute displaced volume retrogradely (ADV, mL) were compared to clinical class, ambulatory venous pressure (% drop), venous filling time (s), and venous filling index (mL/s) using nonparametric statistical tests. A *P* value of <.05 was considered significant. Limbs were divided into 3 groups: (A) axial great saphenous vein reflux only (n = 68); (B) axial deep reflux including popliteal vein incompetence with or without concomitant gastrocnemius or great or small saphenous vein reflux (all ultrasound reflux parameters of each refluxive vein added at the knee level) (n = 79); and (C) all limbs with popliteal vein reflux (the ultrasound data of the refluxive popliteal vein exclusively was used in comparison regardless of concomitant associated reflux) (n = 103). Limbs were also stratified into limbs with skin changes and ulcer (C-class 4-6) and those without (C-class 1-3) and subsequently compared.**
Results: **No meaningful significant correlation was found between RT and the clinical and hemodynamic results in groups A and B. The PRV and TAF correlated significantly with the hemodynamic parameters. The PRV and TAF and clinical severity trended towards correlation in group A (*P* = .0554 and *P* = .0998, respectively), but was significantly correlated in group B. The poor hemodynamic condition in the subset of C-class 4-6 limbs in groups A and B was reflected in a greater PRV, TAF, and ADV in this subset as compared with the limbs in C-class 1-3. RT was not significantly different in the subsets of limbs, further suggesting that RT is not related to hemodynamic or clinical state of the limbs. No meaningful correlations were found in group C. Although the hemodynamic data were significantly poorer in the subset of limbs with C-class 4-6 than in C-class 1-3, the ultrasound-derived parameters were not significantly different.**
Conclusion: **The duration of valve reflux time (or valve closure time) cannot be used to quantify severity of reflux and is purely a qualitative measurement. The PRV and the rate of reflux appeared to better reflect the magnitude of venous incompetence. In the presence of axial reflux, it appeared logical and physiologically correct to sum up these reflux parameters for each venous segment crossing the knee. The popliteal valve reflux (the "gatekeeper" function) was not in itself an important determinant of venous hemodynamics and clinical severity. Additional reflux in other venous segments must be taken into account. (J Vasc Surg 2004;40:303-10.)**

Duplex Doppler scanning is currently the principal tool of investigation of limbs with chronic venous disease. It is highly accurate in detecting segmental venous reflux. The generally accepted definition of reflux at a valve station is a retrograde flow of more than 0.5 seconds.[1] This definition appears to imply that greater duration of reflux may indicate increased severity of reflux, but this is likely to be untrue. The optimal method for quantifying reflux by ultrasound scanning is still unclear. Both reflux velocity and calculated retrograde volume flow appear to be better parameters than duration of reflux.[2-4] Furthermore, venous reflux may occur in the deep or superficial system at different levels, ie, groin and knee (Fig 1). The femoral, profunda femoris, and great saphenous veins may be refluxive at the groin level, and similarly, the popliteal, gastrocnemius, great and small saphenous veins at the knee level. Reflux involving both levels in the same system would be defined as axial. Contrarily, reflux involving only 1 level in the same system is a nonaxial (single level, isolated) reflux. Thus, reflux patterns could be described as single level/single system, single level/multiple system, multiple level/single system (axial), and multiple level/multiple system.[5] The role of perforator reflux in this model is still not fully understood as it is horizontal in orientation. The difficulty is that of combining ultrasound-derived parameters of individual valve stations at different levels and in parallel systems in a meaningful physiological way. This is important in order to be able to evaluate the contribution of each individual valve segment to the global hemodynamic deterioration. If this were possible, surgical intervention could be directed to correcting the major contributor of disease.

This study aims to assess which ultrasound parameter best quantifies reflux by comparison of ultrasound-derived

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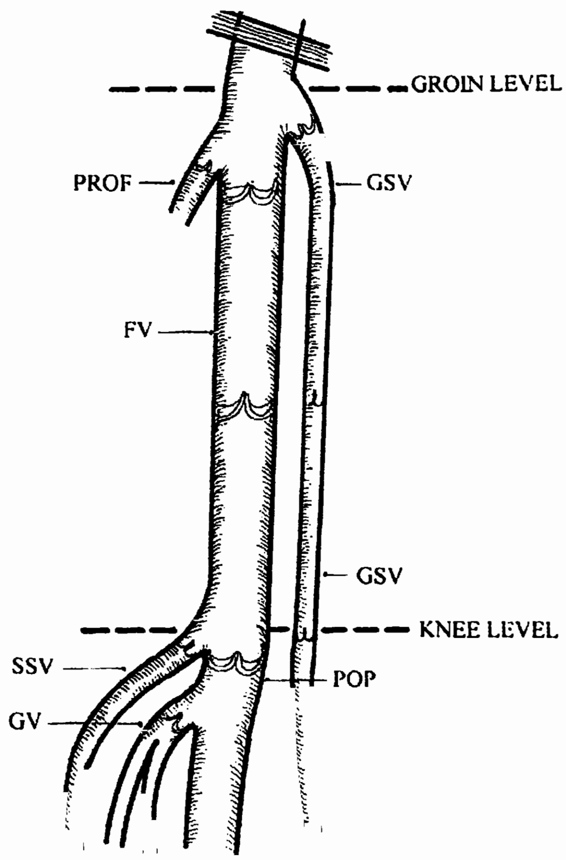

Fig 1. Schematic drawing of the lower limb venous circulation from groin to below the knee. The superficial (*GSV, SSV*) and the deep (*FV, PROF, POP, GV*) systems may be involved at different levels (groin and knee). *GSV*, Great saphenous vein; *SSV*, small saphenous vein; *FV*, femoral vein; *PROF*, profunda femoris vein; *POP*, popliteal vein; *GV*, gastrocnemius vein.

parameters of individual and combined valve stations to the clinical condition of the involved limb and to venous pressure and plethysmographic measurements. The competence of the popliteal vein has been considered exclusively crucial for development of symptoms of chronic venous disease and the valve station is regarded as a "gatekeeper" for the venous calf pump. The importance of this gatekeeper function of the popliteal valve was also assessed.

PATIENTS AND METHODS

Patients. The data were obtained by reviewing 2431 computer-stored venous investigations of the lower extremities performed at the Vascular Laboratory at River Oaks Hospital between March, 1999, and December, 2003. The majority of limbs were studied by ultrasound scanning in combination with air plethysmography. Patients with severe signs and symptoms of chronic venous disease had more extensive hemodynamic testing. These limbs included typically those with hyperpigmentation, lipodermatosclerosis, or active or healed stasis ulcer, but it also included limbs with disabling pain and swelling, sometimes with minimal signs of venous disease. We believe pain is an important sign of chronic venous disease and significant pathology is often overlooked without detailed venous workup. Only complete sets of data were included in the study, ie, ambulatory venous pressure measurement, arm-foot pressure differential, and dorsal foot venous hyperemia pressure, air-plethysmography, and duplex Doppler scanning had been successfully performed. The investigations were made during the same session. The corresponding clinical charts of each patient were reviewed. Patients with previous venous surgery were excluded. The criteria were fulfilled in 244 lower limbs (122 right, 122 left) in 182 patients (109 female patients) with a median age of 58 years (range, 16-88 years). Chronic venous disease was categorized according to the CEAP classification.[6]

Duplex Doppler scanning. Duplex ultrasound scanning was performed according to the technique described by van Bemmelen et al.[1] Early in the series an Acuson 128XP/10 V ultrasound scanning machine (Acuson, Mountain View, Calif) was used with a 5-MHz linear probe (54 limbs) and later a GE Ultrasound Logiq 9 machine (GE Co, Milwaukee, Wis) with a 7-MHz or 10-MHz linear probe depending on patient size (190 limbs). Patients were studied in erect position. An automatic cuff inflator was used for rapid inflation and deflation of cuffs placed on the thigh, calf, and foot. Reflux was considered significant if the duration of retrograde flow exceeded 0.5 second. The terms ***duration of reflux*** or ***reflux time*** (RT) replaces the commonly used term ***valve closure time***. RT is a more appropriate term since valve closure may never occur, although the retrograde flow ceases. Multiple vein segments were studied, including the common femoral, femoral vein below the confluence with the profunda vein, profunda vein, popliteal vein below the confluence with the small saphenous and gastrocnemius veins, posterior tibial vein above the ankle, gastrocnemius vein, proximal and distal (below knee) great saphenous vein, and small saphenous vein. Reflux along the entire length of the great saphenous vein was uncommon. Often the proximal saphenous reflux flow entered varicose anterior and posterior arch veins below the knee, while the distal GSV was competent. Perforators were considered incompetent if the diameter was ≥4 mm and/or had outward directional flow exceeding 0.5 second. The new nomenclature for veins of the lower limbs was used.[7]

The magnitude of reflux at each incompetent valve station was quantified in several ways. When reflux was noted, the reflux time was recorded. Retrograde time average velocity (TAV, m/s) for the duration of reflux and peak reflux velocity (PRV, m/s) was obtained by using the intrinsic software of the scanner. The same formula was used in both machines. The Doppler sample volume was adjusted to insonate the entire lumen of the vessel (cursors placed wall to wall). Since the transverse lumen area was considered nearly circular, the vessel cross sectional area could be calculated by measuring the diameter of the vessel and inserting this value in to the area of a circle, $A =$

$\pi(d/s)^2$. The average rate of reflux, ie, the average retrograde volume flow during reflux (TAF, mL/min), could be calculated by multiplication of the TAV and the vessel area. The amount of blood displaced retrogradely during the reflux time, ie, the absolute displaced volume (ADV, mL), was then obtained but multiplying TAF by RT. Thus, four ultrasound-derived parameters were studied: RT (s), PRV (m/s), TAF (mL/min), and ADV (mL).

For validation purposes of the studied limbs, further scoring was performed of the distribution of reflux (RT > 0.5 s of each valve segment) in individual limbs: (1) in an axial fashion, mimicking Kistner's classification,[8,9] giving 1 to 4 points if the reflux involved common femoral, femoral, popliteal, and distal posterior tibial veins, consecutively; (2) in a multisegment duplex score with 1 point each awarded to the femoral, profunda, popliteal, posterior tibial, gastrocnemius, above and below knee great saphenous, and small saphenous veins (maximum score = 8), whether or not axial reflux was present.[10] This score is a semiquantitative assessment of reflux of an entire limb obtained by simply adding involved segments in different systems at different levels, regardless of any flow connection between these segments. Both scoring systems have been shown to correlate to clinical severity.[10]

Ambulatory venous pressure measurement. The pressure was recorded in the dorsal vein with the patient standing erect and motionless and holding onto a frame, during 10 toe stands, and throughout the period of pressure recovery to baseline level. The ambulatory pressure was measured as percent drop of baseline pressure at rest to the level at the end of the exercise (AVP, %). The time required for the pressure to return to base level was the venous filling time (VFT, s).

Arm-foot venous pressure differential and reactive hyperemia tests. These pressure measurements were performed to detect any significant venous outflow obstruction and are described elsewhere.[11]

Air plethysmography. Details of air plethysmography using APG-1000 (ACI Medical Inc, Sun Valley, Calif) have been described by Christopolous et al.[12] Venous filling index (VFI, mL/s), measured at 90% of total increase of calf volume when shifting from the supine to the erect position, has been shown to be a useful parameter to reflect global venous hemodynamics.[10]

Methods: For validation purposes, correlations of multisegment duplex score, degree of deep axial reflux (Kistner's classification), clinical severity class, and the hemodynamic data obtained by APG and pressure measurements were calculated.

In order to evaluate the ability of the ultrasound-derived parameters to quantify reflux, 2 groups of limbs with different axial reflux patterns were identified (Fig 2). One group of limbs had pure axial GSV reflux with no deep involvement (group A, n = 68). The scanning result of the refluxive great saphenous vein was then compared with clinical and hemodynamic conditions. The next group of limbs had axial deep reflux to below the knee through the popliteal vein with or without great saphenous, small saphenous, and gastrocnemius vein insufficiency (group B, n = 79). The ultrasound-derived parameters were obtained at the knee level for each individual vein, if refluxive, and added. The resulting aggregate number was considered to represent reflux into the calf across the knee. Perforator reflux was disregarded since it is considered horizontal reflux. The perforators may affect the calf muscle pump function but do not add to the axial reflux crossing the knee. The aggregate number was then correlated to clinical and hemodynamic data. Only 17 limbs had pure axial deep reflux. Associated superficial reflux into the calf pump was observed in the remaining 62 limbs (78%), (10/62 limbs, SSV reflux; 28/62, GSV reflux; 24/62, combined GSV and SSV reflux). To further assess the quantifying ability of the ultrasound results, the limbs of these 2 groups (n = 147) were stratified into limbs with no skin changes (clinical classes C1-3) and limbs with skin changes or ulcer (C4-6) and subsequently compared.

All limbs with popliteal vein reflux were selected to analyze the gatekeeper function of the popliteal valve, regardless of whether or not concomitant proximal deep or superficial reflux was present at the knee level (group C, n = 103). Isolated popliteal reflux (no femoral vein reflux) with associated knee-level superficial or gastrocnemius vein reflux was observed in 25 limbs; only 3 limbs had pure isolated popliteal vein reflux. The size of these groups of limbs was felt to be too small for appropriate evaluation and comparison, and to compare axial to non-axial deep reflux is outside the scope of this article. The ultrasound-derived parameters of the refluxive popliteal valve alone in group C limbs were compared with the clinical classification and hemodynamic results. The limbs were also stratified into limbs with no skin changes (C1-3) and limbs with skin changes or ulcer (C4-6) and subsequently compared.

Statistical analysis. Each leg was regarded as an independent unit in the statistical analysis. Statistical analysis was performed using GraphPad Prism version 3.00 for Windows (GraphPad Software, San Diego, Calif). The 2-sample independent non-parametric Mann-Whitney test was used to compare measurements of legs with and without skin changes to evaluate statistical significance. Spearman correlation coefficients were calculated for non-parametric linear association between different factors. The χ^2 test was used to evaluate difference between proportions. A P value of <.05 was considered significant.

RESULTS

The CEAP classification is shown in Table I. More advanced clinical condition (C4-6 in CEAP) was observed in nearly half of the limbs and post-thrombotic disease was found in 27% (66/244). The even distribution between C1-3 and C4-6 and, especially, sufficient numbers of limbs in each clinical class 2, 3, 4, and 6, clearly indicated that the investigated group of limbs are representative for the disease pattern, despite the restrictive inclusion criteria. According to pressure tests, reflux in combination with outflow obstruction was present in 27 % of limbs (66/244). The pressure test was positive in 40 of 176 (20%) and 26 of

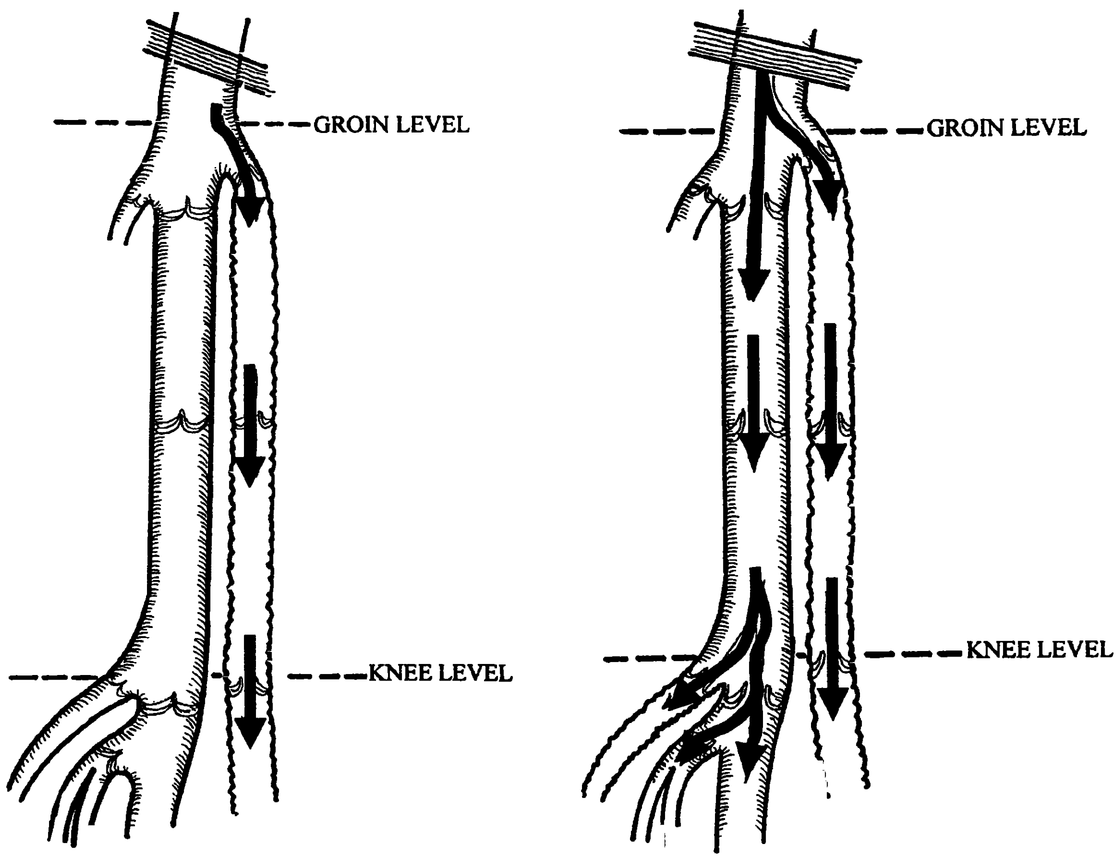

Fig 2. Schematic drawings of different patterns of reflux. **Left**, Diagram of group A limb with axial great saphenous vein reflux to below the knee (single system/multilevel reflux). **Right**, Diagram of group B limb with axial deep and superficial reflux to below the knee. In this particular limb all vessels at the knee level were refluxive (multisystem/multilevel reflux).

66 (40%) limbs with primary and thrombotic etiology, respectively. However, the C1-3 and C4-6 groups had the same distribution of outflow obstruction (27%). Similarly, groups B and C had the same rate of outflow obstruction by pressure measurement (33% and 34%, respectively), while group A had slightly lower prevalence (25%). Thus, the prevalence of obstruction is approximately evenly distributed among the groups, and the influence on the result, if any, is assumed to be cancelled out in the group comparison.

The clinical severity correlated significantly with the number of refluxive venous segments (the multisegment score) ($P < .0001$), the degree of axial reflux (Kistner-type of classification, $P = .0027$), and the hemodynamic parameters (AVP, $P = .0147$; VFT, $P < .0001$; VFI, $P < .0001$). Similarly, the multisegment score correlated significantly with all hemodynamic parameters ($P < .0001$). Using an RT >0.5s as the marker for significant reflux, 747 valve stations in 244 limbs were found incompetent. Ultrasound-derived parameters for the different valve segments are shown in Table II. In these 747 refluxive venous segments, RT was found to significantly correlate with TAF ($P < .0001$) and ADV ($P < .0001$). These findings were not useful in that TAF and ADV are directly dependent on RT in the mathematical calculation of these parameters. The PRV is, however, a non-derived, independent parameter and was found to statistically correlate with TAF ($P < .0001$; $r = 0.46$) and ADV ($P < .0001$; $r = 0.42$), but not with RT.

Quantification by ultrasound scanning. To assess the ability of the ultrasound-derived parameters to quantify reflux, their relationship to the clinical severity (C in CEAP classification) and hemodynamic results (AVP, VFT, and VFI) was analyzed in the groups of limbs with isolated great saphenous vein reflux (group A) or combined superficial and axial deep reflux (group B)(Table III). No meaningful significant correlation was found between RT and the clinical and hemodynamic results in these groups. However, the PRV and TAF correlated significantly with AVP, VFT, and VFI in both groups. ADV showed a better relationship to the hemodynamic data in group A than in group B. There was a trend toward correlation of the PRV and TAF ($P = .0554$ and $P = .0998$) and clinical severity in group A with limbs with isolated GSV reflux, but it never

Table I. CEAP classification in 244 lower limbs

Clinical class	*n*	*Etiology*	*n*	*Anatomic involvement*	*n*	*Pathology*	*n*
C1	10	Primary	178	Superficial	101	Reflux	178
C2	49	Secondary	66	Superficial/deep	83	Reflux/obstruction	66
C3	74			Superficial/deep/perforator	28		
C4	68			Superficial/perforator	12		
C5	3			Deep	18		
C6	40			Deep/perforator	2		

Table II. Ultrasound-derived parameters of 747 individual valve stations

	Duration of reflux (s)		*Time of average reflux velocity (m/s)*		*Peak reflux velocity (m/s)*		*Vessel diameter (mm)*		*Time of average reflux flow (mL/min)*		*Absolute displaced volume (mL)*	
Valve-carrying segment (n)	*median*	*range*	*median*	*range*	*median*	*range*	*median*	*range*	*median*	*range*	*median*	*range*
CFV (47)	2.7	1.0-9.1	0.04	0.01-0.27	0.30	0.07-1.70	14	7-18	318	62-3357	14.1	1.8-151.1
Femoral (87)	3.0	0.6-10.0	0.05	0.01-0.31	0.35	0.01-1.30	9	4-18	162	20-1017	8.1	0.4-72.3
Profunda (26)	2.6	1.0-9.0	0.03	0.01-0.07	0.19	0.08-0.81	7	5-12	58	14-271	2.2	0.3-17.8
Popliteal (103)	3.0	0.6-10.0	0.04	0.01-0.26	0.33	0.01-1.55	8	1-15	131	3-992	5.9	0.1-79.7
Post tibial (25)	2.8	0.5-10.0	0.04	0.01-0.09	0.20	0.06-0.59	3	2-6	17	2-71	0.6	0.1-5.3
GSV, prox (174)	6.1	0.7-10.0	0.05	0.01-0.36	0.27	0.04-3.75	7	2-16	102	4-2543	8.8	0.2-206.0
GSV, dist (84)	3.5	0.7-10.0	0.05	0.01-0.17	0.22	0.07-1.12	4	2-11	35	2-801	1.7	0.1-17.3
SSV (91)	4.6	0.6-10.0	0.05	0.01-1.8	0.20	0.01-1.45	4	1-8	102	4-1387	8.0	0.1-203.4
Gastroc (70)	2.8	0.7-10.0	0.05	0.01-0.22	0.34	0.08-1.63	5	2-8	49	4-378	2.5	0.1-20.2
Perforator (41)	2.1	0.7-10.0	0.03	0.01-0.06	0.15	0.04-0.49	4	1-8	23	1-92	1.0	0.1-13.2
All (747)	3.6	0.5-10.0	0.05	0.01-1.8	0.26	0.01-3.75	6	1-18	81	1-3357	4.8	0.01-206

CFV, Common femoral vein; *GSV*, great saphenous vein; *SSV*, small saphenous vein; *Gastroc*, gastrocnemius vein.

attained statistical significance. In group B with limbs with multisystem, knee-level reflux, however, the PRV and TAF correlated significantly with the clinical severity classification.

Group A and B limbs (n = 147) were also divided into those with skin changes and ulcer (C4-6, n = 70) and those without (C1-3, n = 77) (Table IV). The poor hemodynamic condition in C4-6 limbs was reflected in a greater PRV, TAF, and ADV in this group as compared with the limbs in C1-3. RT was not significantly different in the subset of limbs, further suggesting that RT is not related to hemodynamic or clinical state of the limbs.

The gatekeeper function. To evaluate the gatekeeper function of the popliteal valve, a group of 103 limbs with popliteal reflux was studied. The ultrasound-derived data of the popliteal valve only regardless of concomitant reflux elsewhere were compared with clinical and hemodynamic results (Table V). No meaningful correlations were found. The limbs were also divided into those with skin changes and ulcer (C4-6, n = 41) and those without (C1-3, n = 62) (Table VI). Although the hemodynamic data were significantly poorer in the subset of limbs with C4-6, the ultrasound-derived parameters were not significantly different. As a matter of fact, the RT and ADV were greater in the clinically less diseased legs.

DISCUSSION

This retrospective analysis was designed to assess different ultrasound-derived parameters describing reflux in individual valve stations and their potential impact on the global venous hemodynamics. In our patient cohort, the clinical severity of venous insufficiency was significantly correlated with the measured hemodynamic parameters; ambulatory venous pressure, venous filling time, and venous filling index. It is also significantly related to the presence of axial deep reflux, a fact which is well known but has again been recently re-emphasized.[10,13,14] These findings and the well-balanced distribution of limbs in the C-classes suggest that the selection of limbs is appropriate and representative of the pattern of chronic venous disease.

The RT and the PRV were derived from the software in the ultrasound machine. The rate of reflux and absolute displaced volume, however, are calculated parameters, which assume that the vein is circular in the erect position. The area was calculated from the vessel diameter where the vein was nearly circular. Cross-sectional area was not measured by planimetry, which may be preferred, especially in post-thrombotic veins with irregular lumen. No adjustment was made for this potential error, but it was likely to minimally influence the result in this group comparison. This potential source of error may explain the coefficient of variation, which has been reported to be 12% to 22%.[2] It has been shown, however, that by using cuff compression-deflation in an erect patient such as those in this study, errors can be minimized.[15] Variability in measurement remains a concern, especially in longitudinal studies and evaluation of test accuracy for individual patients, but less so in a population study. In this study, the ultrasound

Table III. Ultrasound-derived parameter correlations to hemodynamic and clinical severity in limbs with great saphenous vein reflux only (Group A, n = 68) and in limbs with axial deep reflux below the knee ± concomitant reflux at the knee level (sum of all reflux parameters at that level) (Group B, n = 79).

	Hemodynamic and clinical parameters	P	*Spearman correlation coefficient (r)*
Group A			
RT vs	AVP	.2588§	
	VFT	.0056†	0.34‖
	VFI	.2203§	
	Clinical class	.1871§	
PVR vs	AVP	.0964§	−0.28
	VFT	.0196*	−0.29
	VFI	.0095†	0.32
	Clinical class	.0554§	0.23
TAF vs	AVP	.0203*	−0.28
	VFT	.0031*	−0.36
	VFI	<.0001‡	0.59
	Clinical class	.0998§	−0.20
ADV vs	AVP	.0569§	−0.23
	VFT	.0372*	−0.26
	VFI	<.0001‡	0.53
	Clinical class	.2377§	
Group B			
RT vs	AVP	.2959§	
	VFT	.3746§	
	VFI	.6723§	
	Clinical class	.6375§	
PRV vs	AVP	.0210*	−0.26
	VFT	.0022†	−0.34
	VFI	<.0001‡	0.46
	Clinical class	.0036†	0.32
TAF vs	AVP	.0100*	−0.29
	VFT	.0044†	−0.32
	VFI	<.0001‡	0.43
	Clinical class	.0490*	0.22
ADV vs	AVP	.0783§	
	VFT	.5523§	
	VFI	.0058†	0.31
	Clinical class	.4637§	

RT, Reflux time; *PVR,* peak reflux velocity; *TAF,* rate of reflux; *ADV,* absolute displaced volume; *AVP,* ambulatory venous pressure; *VET,* venous filling time; *VFI,* venous filling index.
*$P < .05$.
†$P < .01$.
‡$P < .001$.
§Not significant.
‖A non-logical relationship; VFT is positively related to RT, ie, longer filling time is paradoxically associated with increased reflux time.

scanning and the hemodynamic tests were performed in the same session and only group comparison was performed.

The distribution of refluxive vein segments varies greatly in limbs and may involve different systems at multiple levels. Simple qualitative diagnosis and addition of refluxive segments (RT > 0.5 s), regardless of anatomical site and intersegmental relationship, has been shown to significantly correlate with clinical severity and hemodynamic deterioration, as was found in the current study.[16] Quantification of reflux by adding the absolute values for RT, PRV, rate of flow, and ADV, regardless of anatomic distribution, has also been performed and results were similar.[2,17] Considering that axial deep and superficial reflux to below the knee are more frequently seen in limbs with skin changes and ulcer, the anatomic distribution and axial relationship of refluxive segments must be important. It would not appear to be physiologically meaningful to add quantitative ultrasound-derived parameters derived from different levels of the same axial reflux. To do so may simply result in mimicry of the multisegment score. The foregoing observations explain the need for analyzing limbs at one level. The knee level was chosen since this site is presumably critical for the venous circulation of the lower extremity. This is the level of the popliteal valve (the gatekeeper of the calf muscle pump), and measurement of dorsal vein pressure, venous filling time, and APG-derived VFI mainly targets the leg, although it may reflect hemodynamic changes of the whole extremity. Thus, it appears appropriate to measure the collective retrograde flow across the knee into the leg. Since there is still controversy regard-

Table IV. Comparison of two subsets of limbs with C-class 1-3 and 4-6 within the group of limbs with axial deep and superficial reflux (all reflux parameters added at the knee level) (N = 147)

	Axial deep and superficial reflux to below knee. Values for all reflux at knee level		
	Clinical class 1-3 (n = 77) median (range)	*Clinical class 4-6 (n = 70) median (range)*	P
AVP (% drop)	67 (13-98)	56 (12-94)	0.0168*
VFT, s	26 (1-150)	8.5 (1-71)	<0.0001‡
VFI, mL/s	2.4 (0.3-13.0)	3.8 (0.8-18.0)	<0.0001‡
RT, s	8.1 (0.7-33.3)	7.3 (1.6-29.1)	0.6699§
PVR, m/s	0.39 (0.08-13.00)	0.76 (0.12-5.66)	0.0002‡
TAF, mL/min	136 (13-1849)	337 (17-2732)	0.0002‡
ADV, mL	13.0 (0.3-261.0)	21.1 (0.8-134.0)	0.0478*

AVP, Ambulatory venous pressure; *VFT*, venous filling time; *VFI*, venous filling index; *RT*, reflux time; *PVR*, peak reflux velocity; *TAF*, rate of reflux; *ADV*, absolute displaced volume.
*$P < .05$.
‡$P < .001$
§Not significant.

ing the importance of axial and non-axial reflux, only limbs with axial reflux were chosen to evaluate the quantification ability of the ultrasound-derived parameters.

Quantification by ultrasound scanning. Ultrasound-derived parameters measuring venous retrograde flow across the knee level were studied in limbs with axial deep or superficial reflux. The RT in this context was shown to be a poor quantifier of reflux and was not correlated to the severity of disease or hemodynamic state. Furthermore, the RT could not differentiate between limbs with skin changes and ulcer and those without. Excellent correlation, however, was found with PRV and TAF. These parameters appear superior to ADV in measuring severity of reflux and are vastly superior to RT. This is further supported by the observation that the PRV at the 747 examined valve stations significantly correlated with TAF and ADV, but not with RT. Similarly, Yamaki et al[4] have shown significant correlation between TAF and venous filling index measured by APG in limbs with great saphenous vein reflux only. The PRV has also been reported to be superior to RT in determining severity of disease.[4,14]

The gatekeeper function. To test the gatekeeper function of the calf muscle pump by the popliteal valve, clinical classification and hemodynamic parameters were correlated with the ultrasound findings of the popliteal valve segment alone, whether or not additional reflux of deep or superficial veins was present. If the popliteal valve incompetence by itself were critical for venous function, the quantified reflux of this site should correlate to the C-class and hemodynamics. No correlation was found. When these limbs were stratified in C1-3 and C4-6 limbs, the hemodynamic results were, as expected, worse in limbs with skin changes and ulcer as compared with limbs with no skin changes. Despite this finding, the popliteal valve reflux parameters were not different in the 2 subunits, indicating that the status of the popliteal valve per se was not critical for the clinical and hemodynamic outcome. Contrarily, limbs with axial deep or superficial reflux to below the knee and with skin changes or ulcer showed significantly higher PRV, TAF, and ADV than did limbs without skin changes. These findings belie a critical gatekeeper function of the popliteal vein and stress again the importance of a combination deep and superficial reflux in clinically severe venous disease.

Table V. Ultrasound-derived parameters of exclusively the popliteal valve correlated with the hemodynamic and clinical severity in limbs with popliteal vein reflux regardless of presence of concomitant reflux crossing the knee level (n = 103)

Popliteal valve only	*Hemodynamic and clinical parameters*	P	*Spearman correlation coefficient* (r)
RT vs	AVP	0.7224§	
	VFT	0.0288*	0.22‖
	VFI	0.0614§	−0.19‖
	Clinical class	0.6700§	
PVR vs	AVP	0.5183§	
	VFT	0.1642§	
	VFI	0.1523§	
	Clinical class	0.1390§	
TAF vs	AVP	0.8393§	
	VFT	0.9218§	
	VFI	0.8926§	
	Clinical class	0.0272*	−0.22‖
ADV vs	AVP	0.9160§	
	VFT	0.1098§	
	VFI	0.2500§	
	Clinical class	0.0045†	−0.28‖

RT, Reflux time; *AVP*, ambulatory venous pressure; *VFT*, venous filling time; *VFI*, venous filling index; *PVR*, peak reflux velocity; *TAF*, rate of reflux; *ADV*, absolute displaced volume.
*$P < .05$.
†$P < .01$.
§Not significant.
‖A non-logical reversed relationship.

CONCLUSION

The inability of valve RT (or valve closure time) to quantify severity of reflux was shown. RT can probably only

Table VI. Comparison of 2 subsets of limbs with C1-3 and C4-6 within a group of limbs with popliteal vein reflux regardless of presence of concomitant reflux (ultrasound-derived parameters exclusively for popliteal vein) (n = 103)

	Popliteal reflux with or without additional reflux. Only popliteal vein reflux at knee level		
	C 1-3 (n = 41) mean (range)	*C 4-6 (n = 62) mean (range)*	P
AVP (% drop)	65 (22-93)	51 (12-96)	.0492*
VFT (s)	16 (3-93)	7.5 (1-71)	.0044†
VFI (mL/s)	2.5 (0.4-8.9)	3.9 (0.4-16.8)	.0014†
RT (s)	4.1 (1.0-10.0)	2.7 (1.6-10.0)	.0625§
PVR (m/s)	0.31 (0.01-1.55)	0.33 (0.14-1.10)	.4226§
TAF (mL/min)	158 (6-855)	115 (3-992)	.2412§
ADV (mL)	9.7 (0.1-40.2)	5.5 (0.2-79.7)	.0206*‖

AVP, Ambulatory venous pressure; *VFT,* venous filling time; *VFI,* venous filling index; *RT,* reflux time; *PVR,* peak reflux velocity; *TAF,* rate of reflux; *ADV,* absolute displaced volume.
*$P < .05$.
†$P < .01$.
§Not significant.
‖A non-logical reversed relationship.

be used for detection of reflux. In this study, the PRV and the TAF appeared to better reflect the magnitude of venous incompetence. Since PRV is simpler to measure and possibly less prone to error with the present technique, it may be the preferred method. It would, however, appear more logical and physiologically correct to sum up reflux volume flows rather than velocities in different segments at the same level.

Popliteal valve reflux (the gatekeeper function) is not in itself an important determinant of venous hemodynamics and clinical severity. Same level, concomitant great saphenous, small saphenous and gastrocnemius vein reflux and, possibly, proximal incompetence must be taken into account. Perhaps in the future the use of PRV or TAF of individual vein segments will make it possible to assess their contribution to the global hemodynamics and thus direct the optimal plan of treatment.

REFERENCES

1. van Bemmelen PS, Bedford G, Beach K, Strandness DE. Quantitative segmental evaluation of venous valvular reflux with duplex ultrasound scanning. J Vasc Surg 1989;10:424-31.
2. Vasdekis SN, Clarke GH, Nicolaides AN. Quantification of venous reflux by means of duplex scanning. J Vasc Surg 1989;10:670-7.
3. Valentin LI, Valentin WH. Comparative study of different venous reflux duplex quantitation parameters. Angiology 1999;50:721-8.
4. Yamaki T, Nozaki M, Sasaki K. Quantitative assessment of superficial venous insufficiency using duplex ultrasound and air plethysmography. Dermatol Surg 2000;26:644-8.
5. Raju S. Valve reconstruction procedures for chronic venous insufficiency. Sem Vasc Surg 1988;1:101-6.
6. Porter JM, Moneta GL. Reporting standards in venous disease: an update. International Consensus Committee on Chronic Venous Disease. J Vasc Surg 1995;21:635-45.
7. Caggiati A, Bergan JJ, Gloviczki P, Jantet G, Wendell-Smith CP, Partsch H. Nomenclature of the veins of the lower limbs: an international interdisciplinary consensus statement. J Vasc Surg 2002;36:416-22.
8. Kistner RL. Transvenous repair of the incompetent femoral vein valve. In: Bergan JJ, Yao JST, editors. Venous problems. London: Year Book Medical Publishers; 1978. p. 493-509.
9. Herman RJ, Neiman HL, Yao JST, Egan TJ, Bergan JJ, Malave SR. Descending venography: a method of evaluating lower extremity venous valve function. Radiology 1980;137:63-9.
10. Neglén P, Raju S. A rational approach to detection of significant reflux with duplex Doppler scanning and air plethysmography. J Vasc Surg 1993;17:590-5.
11. Raju S. New approaches to the diagnosis and treatment of venous obstruction. J Vasc Surg 1989;10:424-31.
12. Christopoulos DG, Nicolaides AN, Szendro G, Iadving AT, Bull M, Eastcott HHG. Air-plethysmography and the effect of elastic compression on venous hemodynamics of the leg. J Vasc Surg 1987;5:148-59.
13. Welch HJ, Young CM, Semegran AB, Iafrati MD, Mackey WC, O'Donnell TF Jr. Duplex assessment of venous reflux and chronic venous insufficiency: the significance of deep venous reflux. J Vasc Surg 1996;24:755-62.
14. Danielsson G, Eklof B, Grandinetti A, Lurie F, Kistner RL. Deep axial reflux, an important contributor to skin changes or ulcer in chronic venous disease. J Vasc Surg 2003;38:1336-41.
15. Lurie F, Ogawa T, Kistner RL, Eklof B. Changes in venous lumen size and shape do not affect the accuracy of volume flow measurements in healthy volunteers and patients with primary chronic venous insufficiency. J Vasc Surg 2002;35:522-6.
16. Neglén P, Raju S. A comparison between descending phlebography and duplex Doppler investigation in the evaluation of reflux in chronic venous insufficiency: a challenge to phlebography as the "gold standard." J Vasc Surg 1992;16:687-93.
17. Weingarten MS, Branas CC, Czeredarczuk M, Schmidt JD, Wolferth CC. Distribution and quantification of venous reflux in lower extremity chronic venous stasis disease with duplex scanning. J Vasc Surg 1993;18:753-9.

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