The clinical and hemodynamic results after axillary–to–popliteal vein valve transplantation

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Purpose: **To evaluate the results of axillary vein to popliteal vein valve transplantation (VVTX), we reviewed the clinical, phlebographic, and noninvasive hemodynamic results in 15 patients.**
Methods: **All patients had postthrombotic destruction of deep venous valves as determined by ascending phlebography, whereas descending phlebography demonstrated grade III or IV reflux in all patients. A segment of valve-bearing axillary vein was transplanted to the popliteal vein in the affected limb. Postoperative evaluation was by clinical, noninvasive, and phlebographic means.**
Results: **Over a mean follow-up period of 5.3 years (1.25 to 11 years), 13 of 14 patients (93%) had symptomatic improvement with relief of swelling, whereas all 14 patients who were admitted with pain had relief after operation. Thirteen of 15 patients (87%) returned to work or household duties. Physical findings of edema, skin pigmentation, and lipodermatosclerosis improved in most patients. Only three patients (21%) had development of recurrent ulcers, with an average postoperative ulcer-free interval of 4 years by life-table analysis. The cumulative ulcer-free survival rate for the group averaged 62% at late follow-up. All three patients with ulcer recurrence had a functioning valve by descending phlebography, but recurrent perforating veins were found in two patients, and deep venous thrombosis above a patent VVTX was observed in the third. Late assessment of reflux by venous filling index and valve closure times for the entire sample demonstrated mean values of 4.9 seconds in the latter and 6.8 ml/sec in the former. Residual volume fraction, which correlates with invasive ambulatory venous pressures, was reduced to a mean of 31%. No deterioration in late sequential noninvasive values could be detected.**
Conclusion: **VVTX is a durable procedure for preventing recurrent venous ulcers. (J VASC SURG 1995;21:110-9.)**

Although deep venous reconstruction was first described in animal models in 1953[1] and subsequently in human beings by Kistner and Sparkuhl[2] in 1979, only recently has there been any substantial information on the long-term results of such procedures. Masuda and Kistner[3] recently described their long-term results with valvuloplasty by open technique in 51 limbs. In that series, the 10-year cumulative success rate, as defined by long-lasting relief of symptoms, was 60%. An important observation in that series was that patients with reflux caused by postthrombotic deep venous insufficiency had poorer outcomes than those with primary valvular incompetence alone. Cheatle[4] has recently reported excellent short-term results in a series of 52 patients who underwent superficial femoral vein valvuloplasties.

Several other authors have described results that deteriorated after surgery for postthrombotic deep venous reflux. Johnston et al.[5] observed worsening of

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clinical and hemodynamic results within a year after venous transposition procedures for postthrombotic deep venous reflux. Finally, Taheri et al.[6] and Raju and Fredericks[7] noted progressive dilation and deterioration of valve function after brachial vein valve transplantation to the femoral vein level.

We have described previously a method of vein valve transplantation that differed from previous approaches for the management of deep venous valvular reflux caused by postthrombotic disease.[8] The larger caliber axillary vein was transplanted to the above-knee popliteal vein position. The rationale for this approach was twofold: (1) to provide a better size match of the transplanted axillary vein segment to the host popliteal vein, which might avoid late dilation and subsequent valvular dysfunction, and (2) to restore popliteal vein valve function at the critical "gate-keeper" position above the calf muscle venous pump.[9] The major problem in assessing results of deep venous reconstruction has been the vagueness and highly qualitative methods of describing postoperative results.[10] Terms such as "mild" and "severe" symptoms provide little concrete evidence to the reader on the benefits of a particular procedure. The most objective indicator of success after the surgical treatment of stage III venous disease should be restoration and preservation of epithelial integrity. As Browse et al.[11] has stated, "while most ulcers can be healed on a conservative regimen, it is the recurrence of ulcers that is the object of therapeutic efficacy." Finally, as in any vascular reconstructive procedure, long-term follow-up should be used as an index of efficacy.[12]

Duplex scanning assessment of valve closure time[13] and air plethysmography (APG)[14] represent two, new, noninvasive techniques for determining the hemodynamic status of deep venous function. Measurement of the valve closure time by duplex scanning assesses reflux *duration,* whereas venous filling index by APG provides information on the volume of reflux over time. APG also measures the efficacy of the calf muscle pump by ejection fraction (EF) and yields a noninvasive measurement of the ambulatory venous pressure, which correlates with the residual volume fraction (RVF). Unfortunately, little information is available on the long-term functional results of venous reconstruction with use of these noninvasive techniques. It is the purpose of this report to present our clinical results and noninvasive hemodynamic findings in 15 patients undergoing vein valve transplantation (VVT). APG studies and valve closure times were obtained at late follow-up because this instrumentation was unavailable to us before operation. This limits the interpretation of these values; therefore these results are compared with available data in the literature.

Table I. Clinical data

No. of patients	15
Average age (range/yrs)	53 (30-69)
Sex (male/female)	12.3
Previous surgery	9
Edema	14
Pain	14
Pigmentation	15
Liposclerosis	15

MATERIAL AND METHODS

Fifteen patients underwent axillary-to-popliteal VVT performed by one surgeon (TFO'D) between 1983 and 1992 for postthrombotic chronic venous insufficiency associated with advanced stage II (1 patient) or stage III[15] (14 patients) venous disease. Patients selected for VVT were limited to those who had failed prolonged courses of conventional medical therapy. Patients were evaluated for their long-term clinical, hemodynamic, and anatomic results with duplex imaging and APG. Before operation, patient symptoms of leg pain, edema, eczema, and ulceration were detailed. In addition, the number of ulcer recurrences before surgery and previous corrective venous surgeries were documented. At initial clinical examination, the presence of pigmentary changes, lipodermatosclerosis, dilated superficial veins, venous eczema, and ulcer size were recorded.

Preoperative characteristics. The average age of the patient population was 53 years (30 to 69 years) with men predominating 4:1. Deep venous thrombosis had been documented previously in nine of 15 (60%) patients. With the Kistner scoring of venous symptoms,[3] moderate to severe limb swelling and pain were present in 14 patients (93%). Nine patients had also undergone previous surgical procedures, including vein stripping[7] or incompetent perforator ligation,[2] and yet they had ulcer recurrence (Table I). Thirteen paients (87%) had active ulcers at the time of surgery, one had a healed ulcer (14 stage III), and one had intractable symptoms of pain and edema (advanced stage II disease) despite aggressive medical management. The average time between the onset of symptoms referable to venous disease (stage II) and valve transplantation was 14.2 years (1.7 to 27 years), whereas the average time between the first appearance of the ulcer (stage III) and surgery was 7.4 years (0.3 to 22.6 years). Thirteen patients (87%) had at

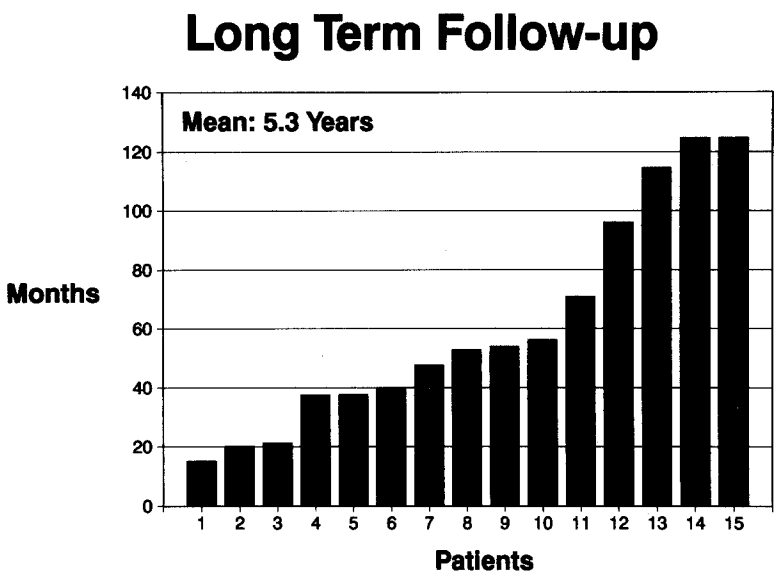

Fig. 1. Individual postoperative follow-up of 15 patients that underwent axillary to popliteal vein valve transplantation.

least two or more ulcer recurrences. The average ulcer diameter at the time of surgery was 1.9 ± 0.3 cm.

The clinical response to VVT was determined in sequential postoperative office visits, with particular attention paid to length of time to ulcer healing, relief of both leg pain and edema, and improvements in skin nutrition and lipodermatosclerosis. Ulcer recurrence was defined as any loss of epithelial integrity. The use of elastic stockings and concomitant anticoagulation were detailed. Finally, the ability to return to work was assessed. In the latter part of the study, patients routinely underwent hypercoagulable state screening and, if their results were positive, were excluded as candidates for deep venous reconstruction.

Phlebography

Ascending phlebography was carried out after the method of Lea Thomas and McDonald[16] to eliminate the presence of significant venous outflow obstruction. The ascending phlebogram also demonstrated the condition of the deep veins with regard to the presence of recanalization, duplication, occlusion, valve destruction, and the presence and site(s) of perforator vein incompetence. Ascending phlebography confirmed postthrombotic recanalization and absence of iliofemoral venous outflow obstruction in all patients. Incompetent perforating veins were identified phlebographically in 11 patients. Descending phlebography was then performed via puncture of the common femoral vein. The anatomic level of contrast reflux was assessed with the patient on a tilt table at 45 and 60 degrees, both at rest and after Valsalva maneuvers. The descending phlebograms were graded by use of the method of Ferris and Kistner.[17] Descending venography demonstrated grade III or IV reflux in all patients without evidence of reconstructible valves.

Noninvasive hemodynamic evaluation

Photoplethysmography. Outpatients underwent light reflection rheography before operation by standard techniques described previously by us[18] and others.[19] The preoperative venous refill time was abnormal (< 25 seconds) in all patients, with a mean of 7.2 seconds.

Because duplex measurement of valve closure time and APG were not available to us for most of these patients before operation, these studies were obtained only in the postoperative evaluation of patients.

Duplex assessment of venous reflux. Quantitative evaluation of venous valvular reflux was performed by use of the technique of van Bemmelen et al.[13] Patients were examined in the standing position with an ATL Ultramark 9 high definition color-flow duplex scanner (Advanced Technology Laboratories, Bothell, Wash.) while their weight was supported on the contralateral leg. For evaluation of the superficial femoral vein, a 24 cm thigh cuff was inflated to 80 mm Hg for approximately 3 seconds and then rapidly deflated within 0.3 seconds. When evaluating the popliteal vein, a 12 cm cuff was applied to the calf,

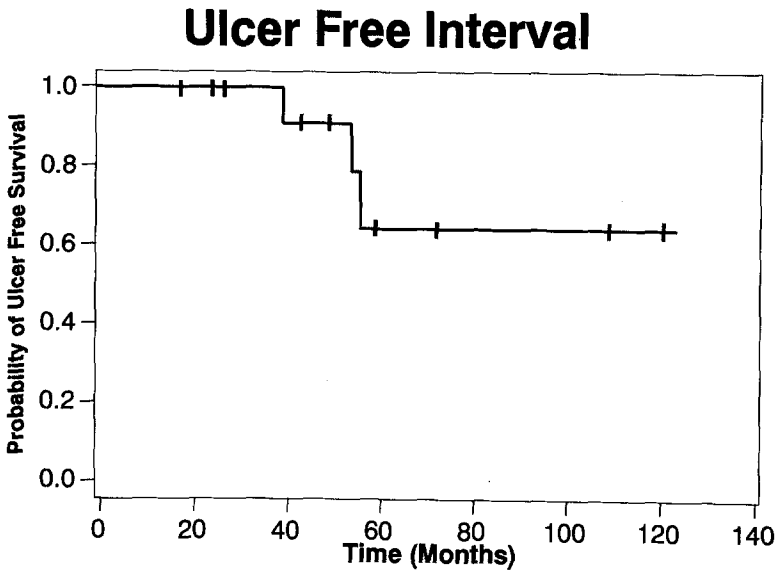

Fig. 2. In this series, probability of remaining free of recurrent venous ulceration is in excess of 60% after 5 years.

inflated to 100 mm Hg and then rapidly deflated. The distance between the cuff and transducer was always less than 5 cm. Both color-flow Doppler scanning and spectral analysis were recorded, and the latter was used to assess the duration of reflux.

APG. APG was carried out with use of the method of Christopoulos et al.,[14] which has been described by us and will be outlined briefly.[20] After the tubular polyvinyl chamber is applied to the calf, it is calibrated with known volumes of air. The leg is then elevated to 45 degrees, which reduces the calf volume by evacuation of venous blood. Once a steady state is achieved, the patient quickly stands and is supported by a walker, with full weight bearing on the contralateral leg. Venous filling of the leg is then recorded continuously. A plateau is reached after refilling of veins, which represents the functional venous volume (VV). Venous filling index (VFI) is calculated by dividing 90% VV by the time in seconds that it has taken to achieve 90% VV. Tourniquets are applied to assess the contribution of the superficial system. The patient next performs one tip-toe movement to activate the calf muscle pump. The decrease in calf volume associated with one exercise represents the ejection volume (EV). The ejection fraction (EF) is then calculated based on total VV (EV/VV × 100). After a steady plateau is achieved, the patient is asked to perform 10 rapid tip-toe exercises to empty the calf venous volume. The resultant residual volume (RV) is the difference between the VV and the calf volume after tip-toe exercises. The RVF, which has been shown to correlate with ambulatory venous pressure, is calculated by RVF = RV/VV × 100.

Operative technique. Our technique for performing VVT has been described previously.[8] In this technique a 5 to 6 cm segment of axillary vein containing usually one valve is exposed through a longitudinal incision parallel to the neurovascular bundle. Before harvesting, competence of the axillary valve is assessed by the "strip test." The popliteal vein is exposed through a standard above-knee approach and dissected free from the adjacent popliteal artery. Phlebographically identified incompetent collateral veins adjacent to the above-knee popliteal segment (one case) or the presence of duplicated popliteal veins with dual incompetence (two cases) are identified during operation. Collateral veins and the smaller or more diseased popliteal vein in a duplicated system should be ligated. Systemic heparin is administered, and atraumatic vascular clamps are applied to the popliteal vein. A short segment of vein is excised, and the axillary vein segment is interposed in the above-knee popliteal vein with interrupted 6-0 or 7-0 monofilament sutures. Patency and competence of the valve-bearing segment is assessed with use of continuous-wave Doppler scanning during unrestricted venous flow and after Valsalva or abdominal compression, respectively. If incompetence is noted the valve may be rendered competent by the external suture technique of Kistner.[21] External valvuloplasty was required in two valves, whereas two other valves

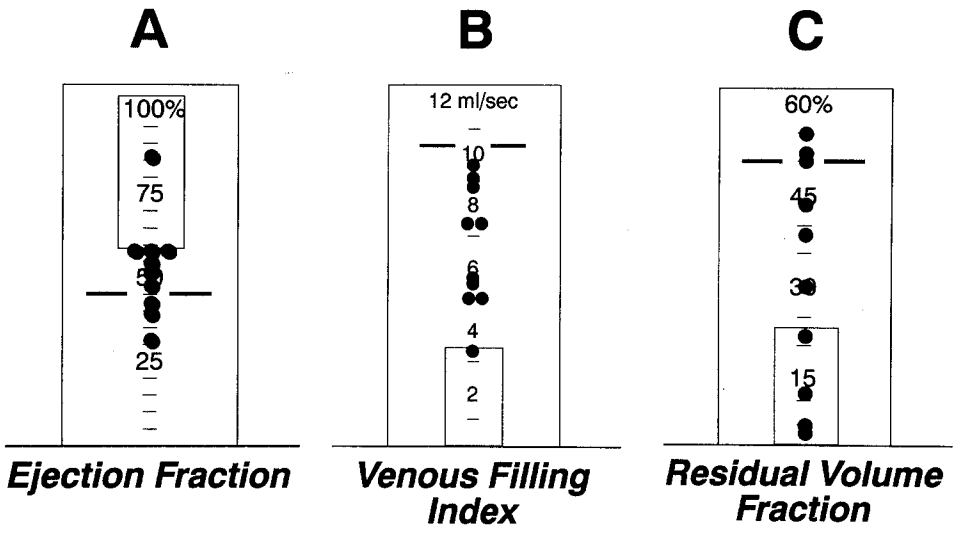

Fig. 3. Postoperative air plethysmographic results: *Boxed area* represents normal range in our laboratory. *Solid bar* represents mean value for patients with stage III disease in our laboratory. *Dots* represent plotted individual patient values. **A,** There was one value for EF in normal range, and no significant difference between mean postoperative EF and mean value for all patients with stage III disease. **B,** Only one patient had VFI in normal range, whereas mean value averaged 6.8 ml/sec. All values were below 10.3 ml/second, mean value for patients with stage III disease. **C,** RVF correlates with invasively measured venous pressures. Four of 10 values were in normal to near-normal range.

were rendered competent with use of an open valvuloplasty via longitudinal paravalvular venotomy before the introduction of the closed technique[21] in 1990. Incompetent perforating veins were ligated at the time of VVT in six patients. After operation, low-molecular weight dextran is administered intravenously for 48 hours. Intermittent pneumatic compression boots are applied immediately after operation to augment venous flow through the transplanted segments. Patients are maintained with intravenous heparin therapy and subsequently discharged receiving warfarin sodium therapy.

The major clinical endpoint of the study for individual patients occurred at the time of ulcer recurrence.

RESULTS

Clinical. Fifteen patients underwent VVT, with an average follow-up of 5.3 years (1.25 to 11 years) (Fig. 1). One patient died of a neoplasm 3 years after operation with a healed ulcer.

Postoperative ascending and descending phlebography was performed in patients initially, whereas duplex assessment was used in the latter part of the study. Eleven of the patients underwent concomitant interruption of incompetent perforating veins. All transplanted vein segments were patent initially and at late follow-up. The average time required for ulcers to heal after operation was 55 days. One patient underwent successful placement of a split thickness skin graft in a large ulcer to accelerate healing. The remaining 13 patients had healed ulcers without skin grafts. All fourteen patients admitted with incapacitating pain had relief (100%), whereas 13 of 14 patients (92%) had relief of edema. Thirteen patients returned to work or household duties. All patients reported compliance with elastic stockings. Fig. 2 demonstrates the cumulative ulcer-free survival, which reveals that the probability of remaining free of recurrent ulceration was 62% at late follow-up. This value reflects ulcer recurrence in three of eight patients monitored more than 4 years. These patients (21%) had recurrence with an average ulcer-free interval of 4 years. No patient who had recurrence had required valvuloplasty at the time of the valve transplantation. Two of the patients with ulcer recurrence underwent additional surgery after descending phlebography demonstrated a competent transplanted valve, but ascending phlebography identified incompetent perforating veins. Neither patient had undergone interruption of incompetent perforating veins at the time of VVT. After perforator ligation 3 years ago, neither patient has had development of a recurrent ulcer. The other patient who had significant edema had development of a recurrent ulcer 5 years after operation. Ascending and descend-

ing phlebography in this patient demonstrated a patent and competent valve transplant at the popliteal level; however, more cephalad, a recurrent nonocclusive deep venous thrombosis of the superficial femoral vein was identified. This patient is presently being treated without operation with oral anticoagulation.

Postoperative noninvasive hemodynamic evaluation

APG and duplex assessment of valve closure time were obtained in the late follow-up period in 10 patients. The mean postoperative venous refill time with use of photoplethysmography was 17.4 seconds. In the early study period, more than 5 years ago, patients underwent routine ascending and descending venography to assess VVT competence and patency. This group included the five patients who were not studied with APG or duplex imaging. Once these noninvasive modalities became available, only patients with recurrent ulceration after VVT were subjected to additional phlebography. Figures illustrating the noninvasive data[3,4] compare the values for patients with values for control patients and those with stage III disease obtained in our vascular laboratory.[20]

Air plethysmography

EF. In Fig. 3, *A*, the normal range for EF is 57% and above in our laboratory. After operation, only three of the individual values were below the mean value for all patients with stage III disease.

VFI. Fig. 3, *B* describes the individual values obtained in the late postoperative period, which range from a low of 3.4 ml/sec to a high of 9.4 ml/sec, with a mean of 6.8 ml/sec. Only one value was in the normal range.

RVF. In Fig. 3, *C*, RVF as obtained noninvasively by APG has been correlated with invasively measured ambulatory venous pressure. Four of the 10 postoperative values were in the normal range, with an overall mean of 31%. No value was above 55%. At the level of 50%, Christopoulos et al.[14] has shown a probability of ulceration of less than 30%.

Duplex assessment of valve closure time. In Fig. 4, the postoperative valve closure times were distinctly abnormal. No value fell within the normal range. There was no significant difference between the postoperative mean valve closure time (4.9 seconds) and the mean for all patients with stage III disease (4.4 seconds).

Assessment of potential deterioration of VVT. Fig. 5 compares the postoperative VFIs obtained 3 years previously in seven of these patients at up to 8 years follow-up to the most recent values. There was no significant change in these values by paired *t*-testing.

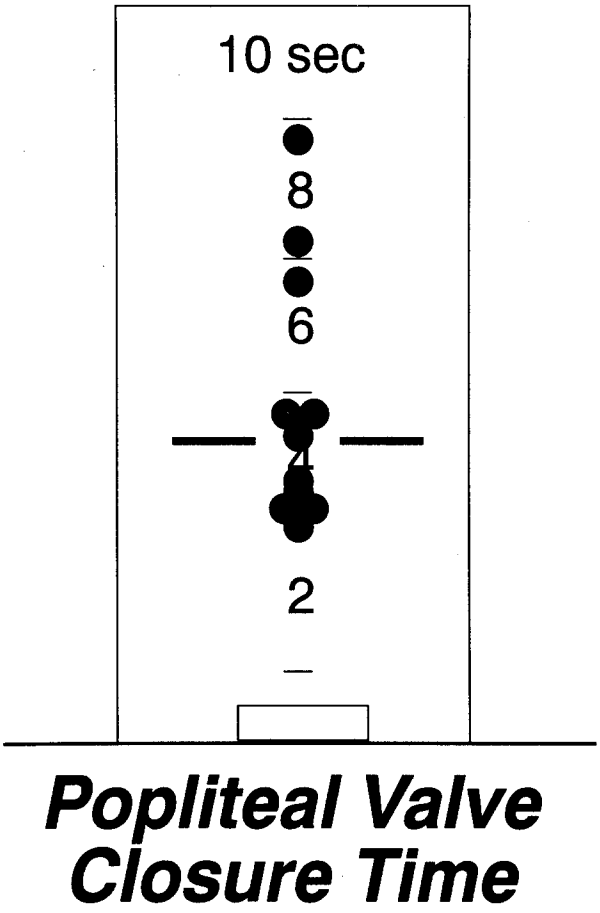

Fig. 4. No patients had valve closure times at popliteal level within normal range.

Incidence of ulceration. Fig. 6 correlates EF with VFI to determine the probability of ulceration.[14] All but one of our 10 patients have hemodynamic values compatible with a probability of ulceration of 30% or less.

DISCUSSION

Our late follow-up study of 15 patients undergoing VVT shows that ulcer recurrence was prevented in 79% of patients with a 6-year cumulative ulcer-free survival rate of 62%. Our policy is to reserve deep venous reconstructive surgery for those patients in whom conservative management of stage III disease failed. The preoperative characteristics of our patients emphasize both the chronicity and highly selected nature of this surgical group. At least two or more

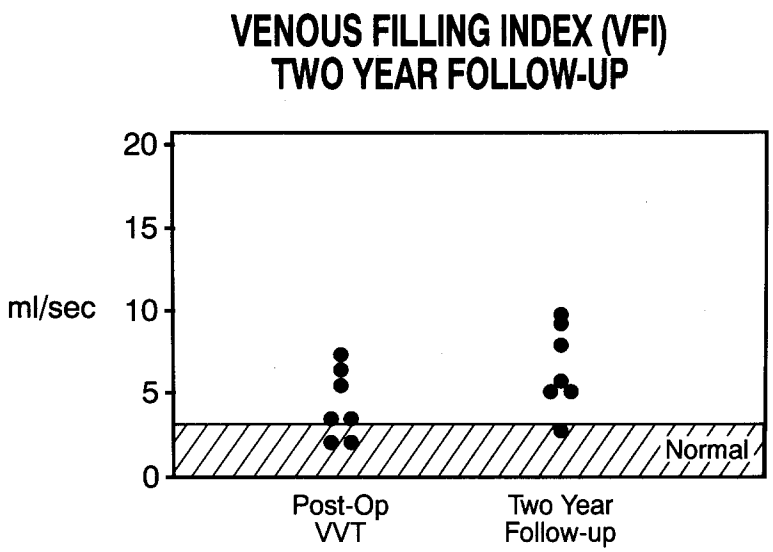

Fig. 5. Sequential APG studies in seven patients up to 8 years after VVT revealed no significant hemodynamic deterioration when restudied 2 years later in 1993.

recurrences of ulcers had occurred in 87% of the series, whereas the average duration of stage 3 disease before VVT was 7.4 years. Table II compares our data with those series in the literature with (1) at least five or more VVT procedures, and (2) a minimum of 1 year postoperative follow-up. Three other series including Nash,[22] Sottiurai,[23] and Cheatle and Perrin,[24] restricted VVT predominantly to patients with stage III disease. By contrast, Taheri et al.[6] reported only a small percentage of patients with stage III disease. Superficial venous disease is generally corrected as the initial approach even though deep venous incompetence may be demonstrated. Conservative measures, such as elastic compression to reduce peak venous systolic pressure[25] and wound care to promote epithelial healing, should be primary objectives.

Preoperative evaluations are performed to characterize not only hemodynamic abnormalities by vascular laboratory studies but also anatomic changes by ascending and descending phlebography. Ascending phlebography rules out significant outflow obstruction and defines the presence and sites of incompetent perforating veins. Descending phlebography determines the level of valvular incompetence. In our series, valve transplantation was restricted to patients with grade III or IV reflux. Our recent study has shown that duplex scanning assessment of valve closure times can accurately separate patients with grades I and II reflux from those with grades III and IV.[20] In this manner, phlebography is restricted to the latter group of patients.

We have advocated the use of axillary vein segment with transplantation to the above-knee popliteal vein for two reasons: (1) a better size match of the transplanted valve containing segment to the host venous segment which may avoid late dilation, and (2) a competent valve is placed in the critical "gate-keeper position" to correct the adverse hemodynamic effects of reflux above the calf muscle pump. Of the six series tabulated in Table II, Eriksson and Almgren[26] used the axillary vein–to–popliteal vein approach in three-quarters of his patients, whereas Nash[22] transplanted the smaller brachial vein to the above-knee popliteal position. Whether the differences in both vein donor and recipient sites play a role in long-term clinical results is not settled by our study.

The relative contributions of simultaneous superficial venous surgery and deep venous reconstruction to long-term relief of ulceration has been a subject of debate. In appropriately selected patients with severe and refractory stage III disease, venous ligation and stripping or interruption of incompetent perforating veins would solve one of two problems and would be unlikely to result in a satisfactory long-term result. Sottiurai[27] prospectively compared patients with refractory venous ulceration and deep venous insufficiency with superficial venous surgery alone or in combination with simultaneous deep venous reconstruction. This study demonstrated a statistically significantly better outcome for those patients treated with the combined approach at a mean follow-up of greater than 2.5 years. In this study, recurrent

ulceration in two of three patients healed after incompetent perforator ligation. Our study also supports a combined approach to deep venous reconstruction when superficial venous insufficiency is present.

An axiom adopted by vascular surgeons when judging the results of reconstructive procedures is that only long-term results have any substantial meaning. As shown in Table II, four of the six reports have a mean follow-up of less than 3 years. A prolonged follow-up period is especially important for judging a procedure in which dilation of the transplanted segment and deterioration of valve function is a major consideration. Because accurate clinical results can only be obtained by direct examination of the patient, questionnaires as used by Taheri et al.[6] are of questionable validity. In our follow-up, more than 90% of patients had relief of their preoperative symptoms of pain and edema, which is superior to other series in which symptom relief was reported. Improvement in skin nutrition with lightening of pigmentary changes and softening of subcutaneous fibrosis was observed in all patients.

The most objective assessment on the efficacy of deep venous reconstruction is ulcer recurrence.[11] In Table II ulcer recurrence ranges from a low of 6% to a high of 54%. Our recurrence rate in three limbs (21%) is comparable to that of Sottiurai[23] and to Nash,[22] but lower than that of Raju and Fredericks.[7] With long-term follow-up ulcer recurrence can be assessed in a cumulative life-table format that takes into account the loss of patients to death or to length of follow-up. The probability of remaining free from recurrent ulceration stabilized after 5 years of follow-up at 62% as shown in Fig. 2. Late recurrence of ulcers in three patients more than 4 years after operation underscores the necessity of long-term follow-up.

Previous investigators have characterized the hemodynamic abnormalities associated with venous ulceration. In an earlier study[28] carried out by the senior author in patients with stage III venous disease and phlebographic evidence of postthrombotic changes, the percent change in ambulatory venous pressure during exercise averaged 17% and was unchanged with a tourniquet, which was in contrast to the mean 68% change in pressure found in control subjects. Recently, Nicolaides et al.[29] demonstrated that the incidence of venous ulcer paralleled increasing levels of ambulatory venous pressure. He emphasized the important difference between changes in ambulatory venous pressure and venous refill or recovery time. This relationship is nonlinear so that

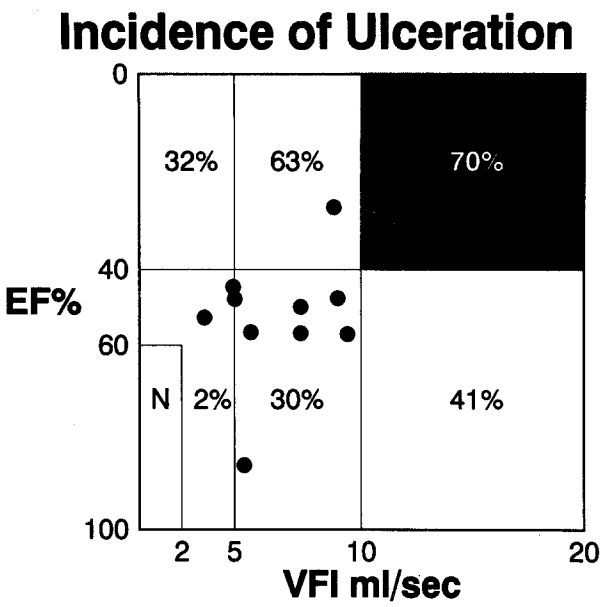

Fig. 6. EF is correlated with VFI. All but one patient had hemodynamic values consistent with probability of ulceration of 30% or less.

a change in ambulatory venous pressure may not be matched by an improvement in venous refill time. Thus the latter measurement may have limited use for quantitating reflux.

Two new noninvasive methods were used for assessing the response of venous hemodynamics to deep venous reconstructive surgery—APG and duplex assessment of valve closure time. Christopoulos et al.[14] have characterized by APG the hemodynamic abnormalities in patients with stage III venous insufficiency. RVF, which noninvasively measures ambulatory venous pressure, was increased in these patients and showed a similar relationship between probability of venous ulcer and level of RVF as suggested by Nicolaides et al.[29] Besides the elevated RVF, these patients usually had poor EF. Both Christopoulos et al.[14] and later Welkie et al.[30] noted that the EV is lower in patients with postthrombotic deep venous disease because of increased outflow resistance. An increase in resting VV compounds the reduction in the EF in these patients. Finally, the predominant pathologic condition of deep venous disease is further detailed by both the VFI and by duplex assessment of valve closure time. The VFI in patients with stage III disease appears to vary from institution to institution (Table III). In the original description by Christopoulos et al.[14] the VFI averaged 12 ml/sec, but in a recent study by Welkie et al.,[30] it averaged 8.28 ml/sec. In our own laboratory, patients with stage III disease and grade III to IV

Table II. Comparison of results with VVT

FACTOR							
Author	Taheri[6]	Nash[22]	Raju[7]	Eriksson[26]	Sottiurai[23]	Cheatle[24]	Present study
Year published	85	88	88	88	91	93	94
Number	66	23	18	35	8	26	15
Ulcers (%)	27	74	42	–	100	74	93
Procedure	B to F	B to P	A to F	A to F (26%) A to P (74%)	B to F	A to F	A to P
Follow-up results							
Mean (years)	–	1.5	>2	2.3	2.8	4	5.3
Symptomatic relief	78	–	50	–	–	48	92
Ulcer recurrence (%)	6	18	54	–	25	31	21
VVT thrombosis (%)	3	0	–	–	0	48	0

B, Brachial; *F,* femoral; *P,* popliteal valve; *A,* axillary.

Table III. Hemodynamics in stage III chronic venous insufficiency: comparison to postoperative values

	APG			
Author	*VFI (ml/sec)*	*RVF (%)*	*EF (%)*	*Duplex VCT (sec)*
Christopoulos[14]	12	60	35	–
Neglen[32]	8.5	38	–	–
Welkie[30]	8.3	49	45	–
Gillespie[33]	14.7	54	52	–
Welch[20]	10.3	50.1	49	4.2
Present study (Post-op)	6.8	31	53	4.9

reflux, it averaged 10.26 ml/second.[20] At a mean follow-up of 5.3 years after operation, the mean VFI was 6.8 ml/sec. Christopoulos et al.[14] has emphasized that ulcer recurrence is greater in limbs with VFIs greater than 7 ml/sec irrespective of superficial or deep venous incompetence. The finding of patient values below this critical index may explain the durable clinical results reported in this study. There has been no deterioration in this value in seven patients measured 2 years previously, which suggests that hemodynamic function of the transplant is stable.

In contrast to the improvement in noninvasive hemodynamics observed with APG in patients after VVT, duplex assessment of valve closure time revealed consistently abnormal values. The explanation for this is not clear, but certainly reflux *time* may not relate directly with reflux *volume.* For example, a large volume of blood could reflux across a valve initially and then only small volumes leak through the valve in the latter phases. Indeed, the prolonged valve closure time may represent partial incompetence because of deterioration of valve function. Serial noninvasive examinations will be necessary for surveillance of VVT function and to determine whether reflux time or calculated reflux volume is a more reliable parameter as a predictor of clinical outcome.

The noninvasive hemodynamic values obtained in a late postoperative state are in distinct contrast to those observed with valvuloplasty. We showed normalization of the valve closure time, as well as VFI in patients with competent valvuloplasties.[31] The explanation for this paradox is not clear. Despite the somewhat variable results with noninvasive venous evaluation, the clinical benefits from this procedure remain clear.

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