
Preoperative Saphenous and Cephalic Vein Mapping as an Adjunct to Reconstructive Arterial Surgery

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B-mode ultrasound was prospectively evaluated for its ability to preoperatively assess the adequacy of venous conduit for arterial reconstruction. Fifty-one patients who had lower extremity revascularization had real-time imaging of the saphenous and cephalic veins. Veins were judged adequate based on size, compressibility, and absence of sclerosis or intraluminal echoes. All mapped veins were explored and assessed by the standard criteria for suitability. Vein size was determined from completion angiograms, and wound complications recorded and compared with patients who had similar procedures in the 12 months before the use of vein mapping. Preoperative mapping was found to be accurate in 50 to 51 patients (98%). Vein size as determined by B-mode ultrasound correlated well with angiograms, $R = 0.8539$ overall with $R > 0.9$ in the last 7 months of the study. Wound complications occurred in 2% of the patients who had preoperative mapping and in 17% of the historic controls. Preoperative vein mapping using B-mode ultrasound is an accurate method of determining vein suitability for use in arterial reconstruction. It improves operative planning and can contribute to a reduction in wound complications. Veins determined to be unusable by preoperative scanning need not be explored.

ADEQUATE PREOPERATIVE IDENTIFICATION of venous conduit for arterial reconstruction has a number of potential advantages. It would (1) allow the determination of venous size and quality in a physiologic situation before manipulation, (2) obviate unnecessary dissection in patients without usable vein, (3) allow a search for suitable alternative venous conduit in the arms or contralateral leg when the ipsilateral saphenous vein is inadequate, and (4) direct skin incisions so that a minimum of dissection would be required for venous exposure. High resolution, B-mode ultrasound

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has been shown to provide high-quality real-time images of the upper and lower extremity venous systems.¹ Saphenous and cephalic veins are particularly well visualized because of their superficial location, and measurements of vein diameter can easily be performed at multiple points along the course of the vein. Preoperative venous mapping using B-mode ultrasound thus appears to be an ideal technique for the preoperative assessment of venous conduit. This prospective study of 51 patients who had venous B-mode ultrasound before lower extremity arterial reconstruction confirms this hypothesis and demonstrates that preoperative saphenous and cephalic vein mapping accurately predicts vein size, quality, and location when compared with surgical exploration and intraoperative completion angiograms.

Materials and Methods

Fifty-one patients who had lower extremity arterial reconstruction over a 12-month period were prospectively studied. The mean age was 62.6 ± 6.5 years and 38% had diabetes mellitus. Rest pain or tissue loss was the indication for arterial reconstruction in 38 of 51 patients (75%), whereas 12 patients (23%) had severe, progressive intermittent claudication. One patient had reconstruction of a popliteal aneurysm. Popliteal and/or tibial artery occlusion was identified on preoperative angiography in 32 patients (62%) so that distal tibial artery bypass grafts were required for limb salvage. Nineteen patients (38%) were believed to need femoral popliteal bypass (73% below knee) for arterial reconstruction.

All patients had preoperative ultrasonic venous mapping after the type of lower extremity reconstruction required had been determined by angiography and

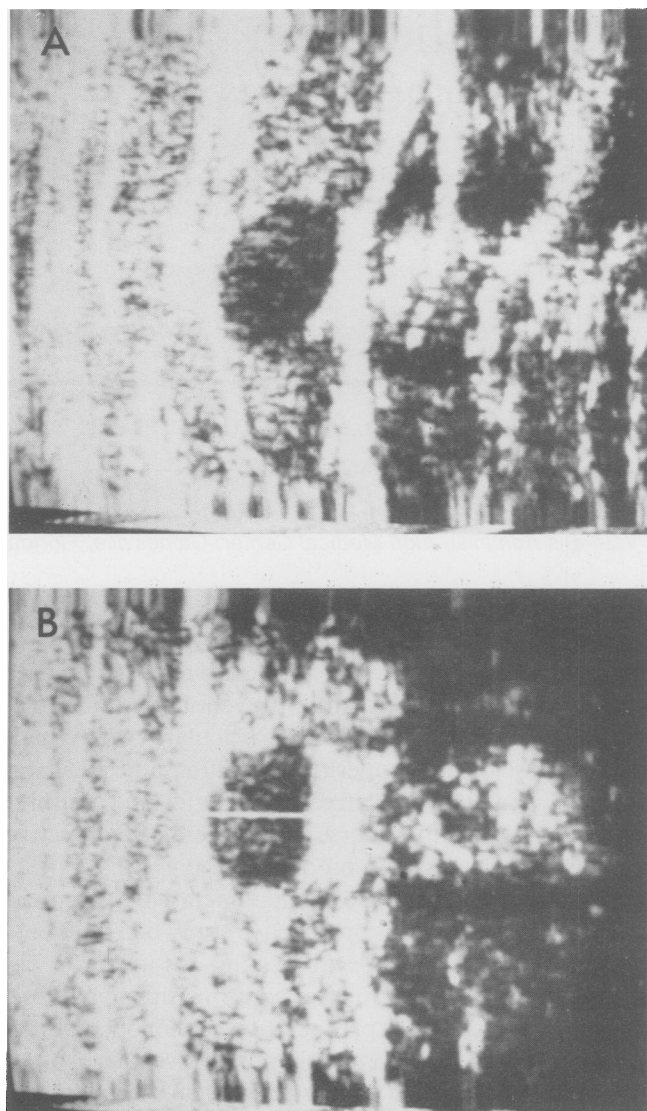
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FIGS. 1A and B. *A.* Cross-sectional image of the greater saphenous vein in the mid-thigh. *B.* Measurement of venous diameter in the same image.

doppler testing. The adequacy of the ipsilateral saphenous vein was investigated first. Saphenous venous images were obtained using a high-resolution real-time imaging system with an 8-mHz transducer (Biosound 2002, Biosound Incorporated, Indianapolis, IN). Using this system, the vein could be visualized either longitudinally or in cross-section, and measurement of venous diameter was possible with a reported axial point-to-point discrimination of 0.3 mm (Fig. 1). The vein was examined from the saphenofemoral junction to the ankle with the patient in a modified reversed Trendelenberg position. Venous images were assessed to determine the degree of compressibility, thickness of the vein wall, and the presence of intraluminal echoes suggestive of previous phlebitis.¹ Measurements of venous diame-

ter were taken in each of six locations (Fig. 2) and recorded. The course of the vein in the lower extremity was then marked with indelible ink if the vein was believed to be adequate for use as a lower extremity arterial bypass graft. Veins were judged to be adequate if the venous diameter was greater than 2.5 mm, the vein was easily and completely compressible, the vein wall was nonsclerotic, and the vein lumen was free of intraluminal echoes over the portion of the vein that would be required for the proposed arterial reconstruction. If the portion of the vein of adequate size and quality was of inadequate length for the proposed reconstruction, it was then judged to be appropriate for use only as the distal end of a prosthetic/venous composite graft.

If the vein was of good quality but of inadequate size, the study was repeated after the patient had been standing for 5 minutes. If the ipsilateral saphenous vein still appeared to be unusable as a complete vein graft, the opposite saphenous vein was then similarly studied. If this was believed to be inadequate, both cephalic veins were studied from the antecubital fossa to the shoulder. Cephalic veins were similarly judged as adequate when the previously stated criteria were fulfilled.

All patients then had arterial reconstruction by one of the two senior authors (JMS, TCF). At the time of surgery all mapped veins were explored and judged as either adequate or inadequate for use as arterial conduit by standard vascular criteria independent of the preoperative vein mapping results. Ipsilateral saphenous vein was used as arterial conduit whenever possible, either as an *in situ* or reversed vein graft based on the surgeon's preference. When only a short segment of adequate vein was available in the ipsilateral leg, it was the policy to use it as the distal portion of a composite graft rather than harvesting vein from the opposite lower extremity. Completion angiograms were obtained as a routine part of the arterial reconstructive procedure.

Preoperative measurements of venous diameter obtained by ultrasonic venous mapping and corresponding values from the same section of the vein on completion angiograms were then compared to assess the accuracy of preoperative venous diameter determinations. The magnification factor on each completion angiogram was determined by comparing measurements of Hemoclips® present on each radiograph to the known length of these devices. Thirty-six pairs of values were obtained from 30 patients. In the remaining 21 patients either completion angiograms were unavailable for review or comparative venous segments on ultrasound and completion angiograms could not be accurately identified. Correlation between these two sets of values was then determined by regression analysis.

Patients achieving immediate limb salvage, defined as an intact extremity after arterial reconstruction for at

least 1 month, were then followed by routine clinical examination and doppler testing to assess graft patency and long-term limb salvage. Long-term follow-up information was obtained from review of the patient's clinical record and was available in 96% of patients in this study. Mean follow-up was 13.3 months, and because of this short follow-up period, graft patency and overall limb salvage results are presented as the percentage of patients with grafts patent and/or limbs intact at 12 months. Differences in immediate limb salvage, graft patency, and overall limb salvage were compared using chi-square analysis.

Results

The preoperative judgment of whether saphenous or cephalic veins were adequate for use as arterial conduit was confirmed to be accurate in 50 of 51 patients (98%). In one patient a vein believed to be of adequate size over an insufficient length for complete vein grafting and thus appropriate only for use as part of a composite graft was used as an *in situ* femoral popliteal bypass. This patient was examined in the recumbent position while in the intensive care unit shortly after an episode of hypotension, and this may have contributed significantly to the incorrect preoperative judgement that the usable portion of this vein would be of inadequate length for the proposed reconstruction.

Twenty-seven of 32 patients judged to have adequate venous conduit for vein grafting by preoperative mapping had vein bypass grafts (Table 1). The remainder of the veins judged adequate for complete venous bypass grafting were used as portions of composite grafts. Composite grafting was necessary in two instances because grafts of unusual length were required for complete arterial reconstruction (1 axillopopliteal composite graft and 1 femoral popliteal posterior tibial sequential graft); in two instances because the operating surgeon chose not to use the portion of the vein that was smaller than 4 mm in diameter and in one instance because a saphenous vein was found to have been divided at the level of the knee during a previous reconstructive procedure and after repair was not of adequate length for a femoral dorsalis pedis bypass. Because the vein was patent just proximal and distal to the point of division, this venous injury was not recognized on preoperative mapping.

Ten patients were identified by preoperative mapping to have vein segments adequate only for composite grafting, including two patients in whom only cephalic veins were adequate for use as arterial conduit. Seven patients had composite prosthetic vein grafts. One patient had a reversed saphenous vein popliteal tibial graft that promptly failed in the early postoperative period

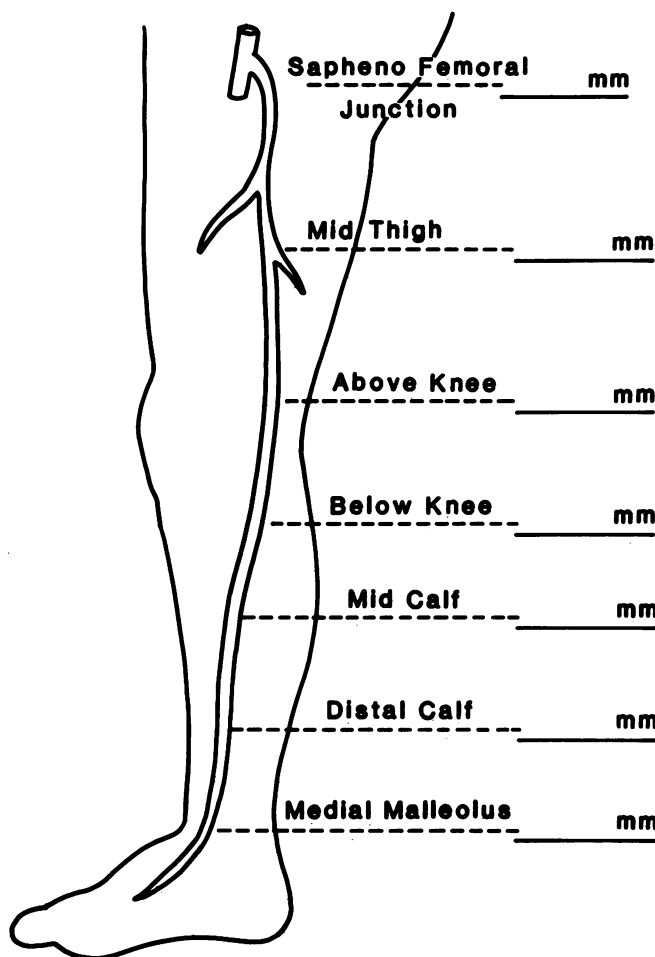


FIG. 2. Location of the six standard measurements that were recorded as part of all venous mappings.

and in retrospect was probably an inadequate conduit. In one patient the short segment of adequate vein was used as a long patch profundoplasty in conjunction with a prosthetic femoral popliteal bypass. The third patient was the one previously described who had successful *in situ* femoral popliteal bypass.

In nine patients judged to have inadequate vein by preoperative mapping, surgical exploration revealed no

TABLE 1. Arterial Reconstructive Procedures Versus Preoperative Mapping Results

Adequate Veins (N = 32)	Adequate Segments (N = 10)	Unusable Vein (N = 9)
Vein grafts (27)	Vein grafts (2)	Prosthetic grafts (4)
Composite grafts (5)	Composite grafts (7)	Vein angioplasty (1)
	Prosthetic grafts (1)	Attempted thrombectomy (2)
		Primary amputations (2)

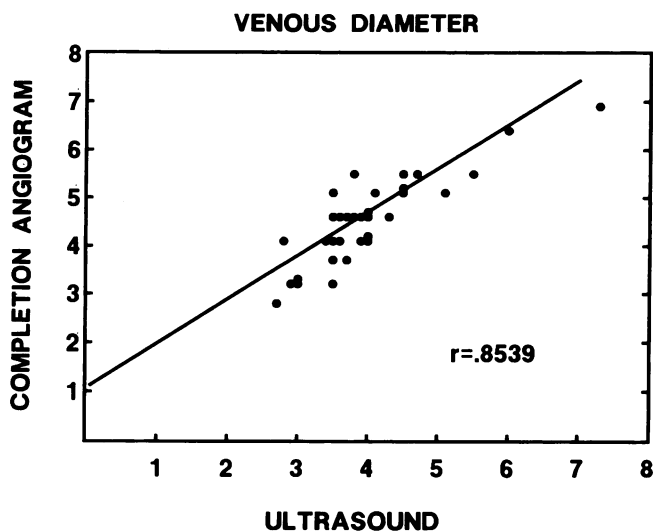


FIG. 3. Scattergram of venous diameter measurements obtained from preoperative ultrasound and completion angiograms. Thirty-six pairs of values were obtained from 30 patients. Measurements are in millimeters.

usable vein. These patients had a variety of operations as shown in Table 1.

Vein diameter as determined by preoperative ultrasonic imaging correlated well with measurements obtained from completion angiograms (Fig. 3). This correlation also improved as experience with the technique increased. Over the last 7 months of the study the correlation coefficient for the two sets of measurements exceeded 0.9 ($R = 0.9069$). As expected, measurements made from the completion angiograms after the vein was distended by arterial pressure were almost always larger than measurements obtained from preoperative mapping. The average increase in vein size after exposure to arterial pressure was 0.49 mm or approximately 12%. In only two instances did the preoperative assessment appear to overestimate venous diameter measured from completion angiography, and in these patients reversed saphenous vein grafting was done so that location of similar vein segments for comparison of preoperative and postoperative measurements was difficult.

TABLE 2. Limb Salvage and Graft Patency Versus Preoperative Mapping (Results at 12 Months)

	Adequate Vein for Grafting (N = 32)	Adequate Segments of Inadequate Length (N = 10)	Unusable Veins (N = 9)
Immediate limb salvage	97%	77%	56%*
Graft patency	87%	70%	25%*
Overall limb salvage	87.5%	72%	25%*

* Adequate vein > unusable vein $p < 0.01$, chi-square analysis.

Because the presence of adequate venous conduit for arterial bypass profoundly affects the success of lower extremity arterial reconstruction, determination of the presence or absence of adequate venous conduit by preoperative venous mapping was predictive of significant differences in immediate limb salvage, graft patency, and long-term limb salvage (Table 2). Immediate limb salvage was higher in patients with adequate vein than patients without usable vein. Long-term graft patency and overall limb salvage were also closely related to the results of preoperative mapping. In patients without usable veins, only the two patients who were candidates for prosthetic femoral popliteal bypass grafting and a patient who had reconstruction with a proximal prosthetic femoral posterior tibial bypass achieved long-term limb salvage. Thus, patients without adequate venous conduit by preoperative mapping who required distal tibial bypass grafting could be identified as having little likelihood of successful arterial reconstruction.

An unexpected but not surprising additional benefit of preoperative venous mapping was a very low incidence of venous wound complications after reconstructive procedures. When the incidence of venous wound complications in patients who had preoperative mapping before reconstruction was compared with a group of patients who had arterial reconstruction by the same surgeons in the same institution the year before the introduction of preoperative venous mapping, a statistically significant drop in the number of venous wound complications was observed (17% vs. 2%, $p < 0.05$). Although the control group used in this comparison is historic, the characteristics of the two patient groups were quite similar, and in particular, the incidence of diabetes mellitus, severe ischemia, and distal reconstructive procedures were similar in both groups. Since preoperative venous mapping reduces the amount of dissection necessary for venous exposure by allowing the accurate placement of skin incisions, this benefit of preoperative mapping is not surprising.

Discussion

Autogenous saphenous vein has been the preferred conduit for infrainguinal arterial reconstruction since it was first used by Kunlin in 1949.² Patency rates of vein grafts are 30–40% greater than those of prosthetic arterial grafts,³ especially in the infrageniculate position. However, suitable saphenous vein may be lacking in 25–50%⁴ of patients requiring lower extremity arterial reconstruction when veins less than 4 mm in diameter are considered inadequate. *In situ* saphenous vein bypass grafts have been reported to be successful using veins as small as 2.5 mm,⁵ thus significantly decreasing the number of patients requiring less suitable prosthetic

arterial grafts. *In situ* saphenous vein bypass grafts to limited outflow beds can also allow limb salvage in patients that might have previously been considered unreconstructable.⁶ Successful use of these small veins requires accurate assessment of saphenous vein size and quality since the margin for error is greatly reduced and the use of inadequate vein dooms the patient to early graft failure and potential limb loss.

The suitability of saphenous vein for use as arterial conduit is usually determined during operation. This commonly involves the exposure of the vein at the groin level and subsequent dissection until adequate length is exposed or until the vein becomes too small. Measurement of size is often arbitrary and of necessity only performed after the vein has been manipulated and is subject to spasm. For this reason some surgeons remove the vein and hydrostatically dilate it before determining whether it will meet minimum size criteria. This is known to result in considerable damage to the endothelium and is not practical for the now popular *in situ* bypass. If the vein is determined to be inadequate, the surgeon may proceed with the planned reconstruction using a prosthetic graft. If a distal tibial bypass is necessary, the surgeon may be tempted to abandon the reconstruction, not being willing to blindly explore the contralateral lower extremity or an upper extremity for vein harvest. In addition, unsuccessful exploration results in a significant amount of unnecessary dissection in an ischemic extremity where healing may be impaired even after revascularization.

Preoperative assessment of the saphenous vein as performed by most surgeons is simply to inspect the vessel, at times with the aid of a tourniquet. If the ipsilateral saphenous vein appears unsatisfactory, the contralateral saphenous vein and perhaps the arm veins are similarly investigated. Preoperative or intraoperative venography has been reported to facilitate the determination of the adequacy of saphenous vein as arterial conduit, particularly when *in situ* bypass grafting is planned.^{7,8} Veith et al.⁷ reports that in 18 of 60 patients the operative procedure was modified based on the information obtained from the preoperative venogram. Although the value of preoperative venography in detecting anatomic variations was obvious, the difference between the vein diameter as measured by venography compared with intraoperative assessment was so large ($73 \pm 5\%$) that no decision as to the adequacy of the vein size could be made on the basis of the venography. In addition, factors other than vein size, such as vein wall thickness, which cannot be readily evaluated by venography have been reported to have a significant effect on vein graft patency.⁹

Sullivan et al.¹ have reported that high-resolution, real-time images of the veins of the upper and lower extremities can be obtained by ultrasound. Venous

thrombosis can be detected by the presence of intraluminal echoes and the absence of venous compressibility. Echo-free, compressible vein was found to be normal. Recent reports^{10,11} have examined the use of B-mode ultrasound in the preoperative assessment of saphenous vein for *in situ* bypass grafting or the evaluation of arm veins as potential arterial conduits. These preliminary studies have clearly suggested the utility of preoperative venous mapping using B-mode ultrasound in patients who have arterial surgery.

The results reported here further document the value of preoperative venous mapping using B-mode ultrasound. As opposed to venography, ultrasound measurements of vein diameter are sufficiently accurate to allow preoperative assessment of the adequacy of saphenous and cephalic veins for use as arterial conduit. In addition, venous imaging allows detection of previous phlebitis or partial thrombosis. Because of the ease with which this information is obtained, if the ipsilateral saphenous vein is unusable, the contralateral saphenous vein or the arm veins can be immediately investigated. Preoperative vein mapping has also been shown to correlate very well with operative findings and in particular to allow exclusion of veins found to be unusable by preoperative studies. Because of this, we no longer explore veins determined to be inadequate by preoperative mapping. Finally, because the amount of dissection is lessened by preoperative mapping, the incidence of wound complications is significantly lessened by this procedure. Preoperative saphenous and cephalic mapping has become an important and routine adjunct to reconstructive arterial surgery in our hands.

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DISCUSSION

DR. JOSEPH LOUIS MULHERIN, JR. (Nashville, Tennessee): Dr. Copeland, I enjoyed your paper. Although we have no first-hand experience with preoperative ultrasound evaluation of veins before femoral-tibial reconstruction, we have believed that the status of the vein used for the conduit was a major factor in the success of operation.

In 1978, Bill Edwards presented to this Society our experience in 100 patients who had femoral-tibial bypass graft and cited the difference in patency rates in patients in whom autogenous saphenous vein graft was available where the patency rate was 78%, and the patency rate when nonautogenous, either Gore-Tex® or umbilical vein grafts were used where the patency rate at 1 year was 25%.

We have, subsequently, in patients requiring femoral-tibial bypasses, made every effort to obtain autogenous tissue whether it be from the arm or, more recently, the lesser saphenous vein, which we have found to be greatly preferable to cephalic veins.

I ask Dr. Copeland two questions. One, have you evaluated the lesser saphenous vein? It is a little bit different anatomically from the saphenous or cephalic veins in that it is located deep to a fascial layer.

Number two, having identified the sources of autogenous tissue, I note that you continue to use composite grafts when the vein in the ipsilateral leg is inadequate using a composite Gore-Tex or other synthetic graft with the usable vein.

Given the information that you now have, have you started to go find the autogenous tissue that you have identified either in the other leg or the arms and put together autogenous composite grafts, and do you believe that this is worthwhile?

DR. ROBERT B. SMITH, III (Atlanta, Georgia): We are indebted to the authors for demonstrating a practical, safe, and reliable method to determine adequacy of the venous conduit before planned arterial reconstruction. If faithfully practiced, their method should greatly reduce the incidence of time-consuming, unnecessary dissections in that 20-30% of patients who turn out to have an inadequate vein after it has been fully surgically exposed.

Others have recommended routine preoperative phlebography to demonstrate the anatomy and dimensions of the greater saphenous system, but that technique is invasive, frequently underestimates the diameter of the vessel, and carries the small, but worrisome, additional risks of nephrotoxicity or chemically induced thrombophlebitis. Clearly all of these problems are avoided by the ultrasound mapping technique advocated by Dr. Copeland and his associates.

I have several questions for the authors: (1) How much time is required for your resident or vascular laboratory technician to perform the preoperative mapping? (2) If you contemplate an *in situ* bypass, can the technique be used to identify with confidence the location of valves and/or branches of the saphenous vein before operation? (3) Do you find that obesity or scars related to previous surgical procedures are significant impediments to the performance of this B-mode examination? (4) What is your philosophy concerning use of the greater saphenous vein from the contralateral limb? Specifically, would you use the contralateral saphenous vein when the reason for operation is other than a limb salvage effort, and would you use it when the arteriogram indicates co-existing significant arterial occlusive disease in the opposite donor leg?

DR. DAVID V. FELICIANO (Houston, Texas): The authors have presented us with another technique of noninvasive vascular screening in the preoperative period, which is more accurate than physical examination and certainly less invasive than a venogram. The correlation between the preoperative real-time ultrasound and subsequent operative inspection of the studied vein was superb. In the absence of a satisfactory venous conduit, the opportunity for limb salvage in many of these patients was essentially lost. With such excellent results the

question simply has to be asked: should anyone perform limb salvage surgery in the lower extremity without preoperative evaluation of the potential saphenous conduit in addition to the standard arteriogram? I do not believe there is enough data available in this study and the other published studies to answer the question at this time.

This is a well-written manuscript, but it does prompt some questions. You chose a venous diameter of 2.5 mm on ultrasound as being characteristic of a satisfactory vein. This would certainly be true if you were performing all *in situ* bypasses but not if you were using reversed saphenous bypasses. How did you decide on this figure, and were all your bypasses performed subsequently in the *in situ* fashion?

Secondly, did you go back and relook at the nine patients who failed their ultrasound examination? Are there multiple common features in these patients that would allow us to predict that their veins are bad based on their age, body size, body habitus, smoking history, etc., without using a venogram or an expensive ultrasound?

There was an implication in the paper that the lack of a satisfactory saphenous or cephalic venous conduit is predictive of a probable poor outcome. I suspect this would offend Dr. Veith, Dr. Ascer, and many other experienced vascular surgeons who, through the use of short, distal bypasses, eversion endarterectomy of the superficial femoral artery, extended profundoplasty, use of the deep femoral vein, etc., have made limb salvage a much more rewarding form of vascular surgery in recent years. The question is: would any of the nine patients without satisfactory venous conduit on your ultrasound studies have benefited from the addition of these admittedly heroic techniques, in retrospect?

DR. CARLOS M. CHAVEZ (Brownsville, Texas): Dr. Copeland's group has introduced an effective and relatively simple method to determine before operation the condition of the saphenous vein for bypass grafting.

We have been using the duplex scan modality with a 10-MHz probe for the follow-up evaluations of patients with bypass and interposition grafts. This is done to anticipate any impending failures and impending occlusive processes or false aneurysms. Serial studies are done at regular intervals and the findings are recorded. This is a noninvasive and painless procedure that can be repeated at will.

I ask Dr. Copeland if he has any experience in the follow-up of his patients and any other patients in whom he has done bypass or graft interpositions with duplex scan.

DR. JAMES M. SEEGER (Closing discussion): Thank you for the opportunity to respond to the questions the discussants of this paper have raised. At the onset I thank the discussants for their careful consideration of our information and for their interesting questions.

The thrust of what we were trying to do in this study is fairly straightforward. In evaluating patients who have limb-threatening ischemia, we all carefully evaluated arterial inflow and arterial run-off before surgery. The third necessary factor for a successful graft, that of adequate arterial conduit, has not been commonly evaluated in the preoperative period.

Dr. Mulherin, we have had minimal experience in evaluating the lesser saphenous vein to date. We have mapped this vein and determined its size in patients who we were planning to use the lesser saphenous vein as part of an autogenous replacement of an infected graft. The number of patients examined is probably only three to four, therefore I cannot comment much on that.

In answer to your second question, which was also asked by Dr. Smith, it has been our policy in patients who have inadequate saphenous vein of the ipsilateral extremity and adequate contralateral saphenous vein not to use the contralateral vein. The reason for this policy is that our patients almost routinely have arterial disease in the contralateral extremity. In the few patients who have had essentially normal arteriograms of the contralateral extremity, we have then gone ahead and harvested the contralateral vein for use. Finally, I agree with