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Vascular mapping techniques: advantages and disadvantages

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ABSTRACT

At present, an arteriovenous fistula is the best available access when compared with an arteriovenous graft or a tunneled hemodialysis catheter. Preoperative vascular mapping has been shown to result in an increased placement of arteriovenous fistulae. In general, 3 modalities (physical examination, ultrasound examination and angiographic evaluation) are available for vascular evaluation. Both arterial as well as venous examination can be conducted using physical examination. However, this technique is known to miss veins, especially in the obese, and result in exclusion of patients who do not show adequate veins on clinical inspection, but who have suitable veins (proven by the other modalities) for AVF construction. Ultrasound examination of the vessels is an objective assessment. It provides an excellent evaluation of both arteries and veins for creation of an arteriovenous fistula. The technique is limited by its inability to directly visualize the central veins. Although imaging of the veins by the administration of radiocontrast dye optimally visualizes peripheral as well as central veins, it exposes the patient to the risk of radiocontrast-induced nephropathy. This article presents advantages and disadvantages of the 3 mapping techniques and proposes a strategy to conduct vascular mapping in patients with chronic kidney disease.

Key words: *Hemodialysis access, Interventional nephrology, Vascular mapping, Vascular ultrasound, Venography*

INTRODUCTION

Based on the reduced incidence of complications, lower management costs, morbidity and mortality, an arteriovenous fistula (AVF) is the best available vascular access for chronic hemodialysis compared with an arteriovenous graft or a tunneled hemodialysis catheter. It is for these reasons that both the National Kidney Foundation Dialysis Outcomes Quality Initiative (NKF-DOQI) for vascular access and the National Vascular Access Improvement Initiative (Fistula First) mandate vascular mapping to assess the presence of vessels suitable for creation of an arteriovenous fistula in all patients approaching chronic dialysis. Indeed, preoperative mapping results in a marked increase in placement of arteriovenous fistulae (1-3) and a reduction in the use of tunneled hemodialysis catheters (4). For this approach to be optimally effective, vascular mapping should be performed before the patient is scheduled for surgery.

In simple terms, vascular mapping is a way of evaluating of arteries and veins for fistula creation. For optimal results, both arterial and venous evaluation is required for fistula creation. In general, 3 means are available to perform such mapping: physical examination, ultrasound assessment and venography.

PHYSICAL EXAMINATION

Physical examination is a simple tool that can be employed to conduct vascular mapping. Both arterial as well as venous examination can be conducted using physical examination. In

simple terms, venous evaluation is performed to assess the diameter, cannulation segment length and approximate distance of the vein from the surface. Arterial evaluation is performed to ensure adequate inflow to the fistula. In general, a tourniquet is placed around the upper arm and veins of the extremity are inspected. Venous diameter as well as the length of the veins observed can be recorded using a simple ruler. Physical examination must include the inspection of the chest wall for a catheter scar or the presence of a tunneled dialysis catheter. In this context, the possibility of a central venous stenosis should be entertained and evaluated using appropriate study. Pulse examination, differential blood pressure measurement and Allen's test to assess the patency of the palmar arch can easily be performed using physical examination.

While physical examination is one of the modalities for performing vascular mapping, its utility in the eventual creation of an arteriovenous fistula is less than optimal. This is especially the case in obese patients and those patients whose veins are not readily apparent on clinical examination. If the veins are not seen easily with the naked eye after application of the tourniquet, the patient is considered to not have "good" veins for AVF creation. This approach may result in exclusion of patients who do not show adequate veins on clinical inspection, but who have suitable veins for AVF construction. A recent study (5) documented that visibility of veins by clinical inspection was present in only 54 of 116 consecutive patients (46.5%), whereas poor clinically visible or clinically absent veins were found in 62 patients (53.5%). Patients with poor clinically visible or clinically absent veins then underwent ultrasound examination. Notably, a majority (77%) of these 62 patients showed adequate veins on duplex ultrasonography for successful AVF creation. It is for this reason that physical examination is unreliable in accurately assessing vessels for an arteriovenous fistula creation. However, the exam is free.

ULTRASOUND EXAMINATION

Because of its noninvasive nature, ease of performance, safety and success, ultrasonography has emerged as a critically important tool for vascular mapping. It is an objective assessment and allows for accurate measurements of a variety of parameters related to arteries and the extremity veins. As mentioned above, this technique using duplex ultrasonography (DU) can identify veins otherwise missed by clinical examination. We believe that the evaluation should be performed by the individual who will be constructing the AVF and that it should become a routine tool of all vascular access surgeons. Routine use of upper-extremity DU identifies many patients with veins that are suitable for use and also determines which arteries have optimal arterial inflow for successful AFV creation (6).

Many investigators have demonstrated a marked improvement in fistula placement with the use of vascular mapping (1-3). Allon et al (3) documented a dramatic increase in arteriovenous fistula creation when preoperative vascular mapping using ultrasonography was employed compared with the traditional physical examination approach (preoperative physical examination, 34%; preoperative sonographic vascular mapping, 64%; $p<0.001$). Indeed, a preoperative mapping approach by these investigators doubled the fraction of patients dialyzing successfully with a fistula (preoperative physical examination, 16%; preoperative sonographic vascular mapping, 34%; $p<0.001$) (3). Another study documented a significant improvement in arteriovenous fistulae creation (from 14% to 63%), reduction in graft placement (from 62% to 30%) and reduction in tunneled hemodialysis catheters insertion (from 24% to 7%) when preoperative mapping of the arteries and veins was performed using duplex Doppler ultrasonography (1). These studies applied preoperative vascular assessment by ultrasonography to the patients initiating chronic hemodialysis (7).

Preoperative ultrasound examination has also been used to investigate the subsequent function of the fistula. In a recent report, Malovrh (5) used duplex ultrasonography to examine forearm arteries and veins before creating AVFs in 116 consecutive patients. In this study, various parameters, including feeding-artery internal diameter (IDA), resistance index (RI), blood flow (Qa) before and after reactive hyperemia (RH), and internal diameter of the vein (IDV) before and after proximal vein compression (PVC) were obtained before AVF construction. The AVF primary patency rate (successful constructed AVFs) was 80.2%, mean values for IDA were 0.26 cm, RI at RH was 0.50, and Qa was 54.5 ml/min in this group. After PVC, IDA increased by 59.3%. In the group with failed AVFs (19.8%), mean IDA was 0.16 cm, RI at RH was 0.07, and Qa was 24.1 ml/min. Here, IDA increased by only 12.4% after PVC. The investigator also found that the feeding-artery Qa of 300 ml/min was achieved in the group that had an IDA greater than 0.16 cm in less than 1 week compared with 3 to 8 weeks when IDA was less than 0.16 cm ($p<0.01$). Similarly, the group with an RI at RH before surgery of 0.07 or greater took 3 to 8 weeks to show a Qa of 300 ml/min, whereas the group with an RI at RH less than

0.07 achieved a feeding-artery Qa of 300 ml/min in less than a week ($p<0.01$). The investigator concluded that duplex ultrasonography helps identify the optimal location for successful creation of vascular access and the time necessary for its development. This approach is particularly helpful in patients with diabetes and in the elderly.

Arterial narrowing and calcification are relatively common in patients with chronic kidney disease (CKD), especially those that are diabetic and hypertensive. The presence of a stenotic or calcified artery may jeopardize the surgeon's attempt to create an AVF. It is for these reasons that arterial evaluation should be seriously carried out. In general, preoperative arterial diameter equal to or exceeding 1.6 mm and venous diameter of 2.5 mm at the anastomosis in the hands of a skilled surgeon are required for fistula creation (1, 5). In addition to the above-cited parameters, optimally veins should be no more than 0.5 cm deep from the skin and posses an 8-10 cm straight segment for successful and repetitive cannulation. In cases where veins lie deep in the extremity, a superficialization procedure is often required for successful cannulation. While ultrasound examination provides an accurate assessment of peripheral vasculature, it does not provide direct visualization of the central veins, a weakness which could potentially result in development of swelling associated with central stenosis after AVF placement.

Radiocontrast examination

Vascular mapping can also be conducted using radiocontrast administration. For the most part, veins are examined when this technique is employed; however, arteries can also be imaged using this technique. Briefly, a peripheral vein on the dorsum of the hand is cannulated. A small amount (10-20 mL) of low-osmolar contrast medium is diluted with 10-20 mL of normal saline and injected through the cannula. Fluoroscopy is performed using the pulse (15 pulses per second) and road map feature (15 frames per second). Images are obtained from the wrist veins to the right atrium. The criteria used to determine suitability of veins include vein diameter of at least 2.5 mm, absence of stenosis within the vein, a straight cannulation segment of 8-10 cm long and continuity with central patent veins. This technique allows for direct visualization of the peripheral as well as the central veins. Patency as well as the site and degree of stenosis can all be observed.

In contrast to the above-cited ultrasound studies, in a recent analysis (4), we prospectively identified hemodialysis patients who were consigned to permanent long-term treatment by means of tunneled catheters and performed venography to investigate the presence of veins suitable for fistula creation. Of note is the fact that, upon our asking, all the patients in this study denied having been educated regarding vascular access types, their associated complications and morbidity and mortality or having been given the option of vascular mapping prior to interaction with the interventional nephrology team. However, it is conceivable that some of these patients may have been asked for access placement in passing. Of 86 catheter-consigned patients agreeing to venography, 82 patients (95%) were found to have patent veins suitable for arteriovenous access placement. Only 4 patients (5%) were found not to have suitable veins for placement of an arteriovenous access and therefore were truly dependent on tunneled catheters for hemodialysis therapy. It is noteworthy that 97% of patients with no prior arteriovenous accesses (64/66) had suitable veins and that 90% of patients with previously failed arteriovenous accesses (18/20) had suitable veins – all basilic veins in the latter cases (forearm + arm, n=2; arm, n=16). Out of the 82 patients with suitable veins for a fistula creation, 10 refused surgery. The remaining 72 received an arteriovenous access successfully (AVF, n=68; grafts, n=4). All 4 patients with a graft had a basilic vein suitable for AVF creation; however, the decision to place a graft was based on findings at the time of surgery. Angiography was not used to evaluate arteries in this study. Instead, simple physical examination was employed to accomplish this task.

Is venography superior to sonographic evaluation? To the best of our knowledge, there have not been any randomized studies comparing venography and vascular ultrasound mapping to establish the superiority of one preoperative imaging technique over the other. In the absence of such studies, it is difficult to report which mapping technique is superior. Indeed, using a combination of preoperative noninvasive (Doppler ultrasound) and invasive (venography and arteriography) techniques, Huber et al (8) did demonstrate an excellent percentage of fistulae creations. In this study, the optimal configuration for an AVF was determined (criteria: vein >3 mm, no arterial inflow stenosis, no venous outflow stenosis) using DU, and unilateral arteriography/venography was performed to confirm the choice. A total of 139 new access procedures were performed in 131 patients. The noninvasive imaging showed that 83% of the patients were candidates for AVF, with a mean of 2.7 ± 2.1 possible configurations. Invasive imaging was abnormal in 38% with forearm arterial disea-

se being more common than central vein stenosis leading to a change in the operative plan in 19%. An AVF was created in 90% of the cases (brachiobasilic > brachiocephalic > radiocephalic > radiobasilic). Among the patients who underwent AVF, 24% needed a remedial procedure. The AVF matured sufficiently for cannulation in 84% of those with sufficient follow-up and was suitable for cannulation by a mean of 3.4 ± 1.8 months. On the basis of an intention to treat, an AVF sufficient for cannulation developed in 71% of the 139 cases. As in many other series, multivariate analysis predicted that female gender (odds ratio [OR] = 9.7; 95% confidence interval [95% CI], 2.2-43.5) and the radiocephalic configuration (OR=4.6; 95% CI, 1.1-18.6) were independent predictors of failure of the fistula to mature.

One clear advantage of venography is direct imaging of the central veins instead of the indirect assessment provided by Doppler evaluation. Alternatively, ultrasound offers the advantage of noninvasive arterial evaluation. Regardless, both techniques offer a clear advantage over inspection of veins by the naked eye using a tourniquet. Nevertheless, administration of radiocontrast material does expose the patient to the risk of the development of acute renal failure.

Radiocontrast administration and the risk of nephropathy

Although venography can successfully identify peripheral and central veins, the development of acute renal failure owing to the use of radiocontrast medium is worth mentioning in patients with advanced renal failure who have not yet initiated dialysis. Recent data have emphasized that a low dose of low-osmolar contrast agent may be safer in patients with stages 4 and 5 CKD (9, 10). A recent prospective study has evaluated the safety of radiocontrast medium in CKD stage 4 and 5 patients (9). In this analysis, 25 consecutive patients (CKD stages 4 and 5) undergoing venography for fistula creation were enrolled. Radiocontrast-induced nephropathy was defined as a 20% decrease in the estimated glomerular filtration rate (GFR) from the baseline value at 48 hours after contrast administration. Venography was performed by using 10-20 cm of low-osmolar contrast medium. Complete sets of pre- and post-procedure GFRs were available in 21 patients. At 48 hours, there were no differences between the pre- and post-procedure GFRs. At 4 weeks of follow-up, only 1 patient required dialysis owing to the development of flu-like syndrome and ensuing volume depletion.

In a retrospective analysis, Kian et al (7) reported on the incidence of radiocontrast-induced nephropathy in 34 CKD stage 4 patients undergoing salvage procedures for non-maturing fistulae. Radiocontrast-induced nephropathy was defined as a 25% increase in serum creatinine from the baseline value. Serum creatinine was obtained pre-contrast administration and 2- and 7 days post-contrast administration. In this study, the mean contrast volume was 7.8 mL per procedure. The incidence of acute renal failure was 4% at 2 days and 4.6% at 1 week. All values returned to baseline within 2 weeks. None of the patients required acute dialysis. On the basis of these studies, dose limitation of a radiocontrast agent is of paramount importance to minimize the risk of nephropathy in advanced CKD patients who have not yet initiated dialysis. Although these reports are encouraging, large-scale studies with a longer follow-up are needed to conclusively establish the safety of low doses in the development of acute renal failure.

Vascular mapping proposal

The above-cited studies demonstrate the value of vascular mapping in detecting vessels suitable for arteriovenous access placement, even in patients previously consigned to percutaneous catheters because of prior vascular access failures. Indeed, these results virtually mandate the search for patent veins suitable for arteriovenous access placement in every patient dialyzing with a percutaneous catheter. Even when a forearm AVF is not feasible, there are at least 3 valid options from which to choose to best accommodate each patient's antecubital anatomy (10).

Optimal features for venous evaluation on physical examination include the presence of a vein that is superficial and has a straight segment of at least 8-10 cm. In addition, a negative history of a tunneled hemodialysis catheter insertion highlights a reduced risk of central venous stenosis but does not completely exclude this possibility. Good arterial pulses (not diminished or absent) and a negative Allen's test (patent palmar arch) indicate an adequate arterial system. In addition, a difference of less than 10 mm Hg in blood pressure measured in the 2 arms should be considered as normal (a difference of 20 or more should suggest proximal arterial disease). A patient who meets all these criteria suitable for fistula creation might not need further studies. However, from a practical standpoint only a minority of patients fit this category. In many patients, the veins are not visible on clinical exami-

nation. In these individuals ultrasound examination may be required to optimally identify the vessels suitable for creation of an arteriovenous fistula. Finally, catheter-consigned patients might require optimal evaluation of the central veins. Here, angiography might be needed. These patients also need arterial evaluation, which can be accomplished with ultrasound or physical examination.
It is important to note that having discovered patent veins; the surgical challenge is to successfully create a functioning arteriovenous access suitable for hemodialysis therapy. A surgeon must be willing to utilize a full range of appropriate surgical approaches including vein transpositions, to successfully create an AVF, be willing to work closely with the nephrologist and have a basic knowledge of the complications associated with dialysis (11).

Conclusion

High complication rates, morbidity and mortality associated with the use of an arteriovenous graft or a tunneled dialysis catheter should not be accepted. Every effort must be made to ensure that patients needing dialysis are given the opportunity to have an arteriovenous fistula as their permanent vascular access. Data show that preoperative vascular mapping can have a significant impact in maximizing fistula use in our patients. Such an intervention must be undertaken before a patient is scheduled for vascular access surgery.

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