Computed tomography angiography-based evaluation of great saphenous vein conduit for lower extremity bypass

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Objective: Lower extremity computed tomography angiography (CTA) is frequently used for anatomic assessment of lower extremity peripheral arterial disease. When lower extremity bypass is planned, duplex ultrasound (DUS) is routinely obtained to evaluate the great saphenous vein (GSV) for use as conduit. Although GSV can be visualized on CTA images, diameter assessment is not routinely included in formal study interpretation. We hypothesized that CTA images could be used to measure GSV diameters and that CTA-based diameters would correlate with measurements obtained using DUS.

Methods: Consecutive patients undergoing lower extremity arterial bypass who were evaluated preoperatively with both CTA and DUS vein mapping were identified at a single hospital. Minimum above- and below-knee GSV diameters were measured from electronically archived CTA images by two independent observers. CTAs were performed using standard arterial phase protocol without additional venous phase imaging. Between-observer reproducibility of CTA-based diameter measurements was evaluated using intraclass correlation coefficients. Correlation between CTA and DUS-based GSV diameters was evaluated with Spearman correlation coefficients. CTA diameter cut-points for identification of adequate GSV bypass conduit, defined as DUS-based minimum GSV diameter ≥ 3 mm, were determined using receiver-operating characteristic curves.

Results: Sixty-three lower extremities were evaluated in 36 patients. In the absence of previous surgical removal, GSV was visible on all CTAs reviewed. No instances of GSV thrombosis were identified on DUS. Minimum DUS-based above-knee GSV diameter was 2.9 ± 0.1 mm (range, 1.4-4.6 mm), and mean below-knee diameter was 2.6 ± 0.1 mm (range, 1.3-4.0 mm). When GSV was visible and exceeded the minimum diameter threshold for CTA measurement, correlation between CTA- and DUS-based diameters was both positive and highly significant (p = 0.595; P < .0001). CTA-based diameters also had excellent reliability between observers (r [95% CI]: 0.88 [0.85-0.91]). For identification of adequate bypass conduit using CTA, above-knee GSV diameter ≥ 3.9 mm was 67% sensitive and 73% specific; below-knee GSV diameter ≥3.0 mm was 75% sensitive and 84% specific.

Conclusions: CTA-based GSV diameter measurements have good reproducibility and highly significant correlation with DUS-based diameters. CTA-based GSV diameter is a specific but relatively insensitive indicator of adequate bypass conduit. When CTA-based diameters indicate inadequate GSV bypass conduit, confirmatory DUS vein mapping is warranted. Confirmatory DUS vein mapping may be unnecessary when adequate vein diameter is identified on CTA.

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Peripheral arterial disease (PAD) affects 8 million Americans1 and is associated with costs that exceed 4 billion U.S. dollars annually.2 Although digital subtraction contrast angiography is considered the gold standard for anatomic characterization of lower extremity PAD, other less invasive imaging techniques, such as computed tomography angiography (CTA) and magnetic resonance angiography, have been used with increasing frequency and suggested as primary modalities for localizing occlusive lesions.3 In addition to being more cost-effective than conventional angiography,4 CTA also permits cross-sectional evaluation of both arterial and nonarterial anatomy, including the great saphenous vein (GSV).5 Although GSV is the preferred conduit for lower extremity bypass and is easily visualized on cross-sectional CTA, GSV diameter assessment is not routinely included as a part of study interpretation or reporting. Duplex ultrasound (DUS) is considered the standard method for assessment of GSV diameter6 and is usually obtained as a separate study to determine GSV adequacy for use as conduit when lower extremity bypass is planned.

We hypothesized that CTA images could be used for GSV assessment for use as bypass conduit, and that CTA-based diameter measurements are correlated with those obtained using DUS.
METHODS

Data collection and management. This retrospective study was conducted with approval from the Emory University Institutional Review Board and the Atlanta Department of Veterans Affairs Research and Development Committee. Patients undergoing infrainguinal lower extremity bypass at the Atlanta VA Medical Center between November 1, 2005 and 2010 were identified from an operative registry, and those evaluated preoperatively with both CTA and lower extremity DUS vein mapping were selected for analysis. Clinical data, including patient demographic and comorbidity characteristics, were collected from the electronic medical record.

GSV diameter measurement. DUS vein mapping was performed in the Department of Radiology by ultrasound technologists. Patients were imaged in the supine position using a 5-7 MHz Doppler ultrasound probe (LOGIQ E9; GE Healthcare, Waukesha, Wisc). Vein diameters were obtained at the following anatomic locations for each extremity assessed: groin, proximal thigh, midthigh, distal thigh, popliteal, proximal calf, midcalf, distal calf, and ankle.

Lower extremity CTA imaging was performed using a standard protocol with 1.25-mm axial cuts. GSV diameters were measured electronically from archived images using Philips iSite Enterprise software (Philips Healthcare, Foster City, Calif) on standard clinical workstation computers. CTA-based GSV diameters were evaluated from 2 cm distal to the saphenofemoral junction to the level of the ankle and measured from outer wall to outer wall. All CTA-based diameters were measured from arterial and/or noncontrast imaging, and additional venous phase images were not obtained. CTA-based diameter measurements were obtained by two independent observers, and the minimum minor axis GSV diameters above and below the knee (defined as proximal vs distal to the femoral condyles) were recorded. Because diameters ≤1.7 mm could not be measured reliably from CTA images, GSV which were visible on CTA but smaller than this minimum-resolution diameter were categorized as inadequate bypass conduit without diameter measurement.

Statistical analysis. Descriptive statistics are displayed as mean ± SD for continuous variables and number (%) for categorical variables. Interobserver reliability of CTA-based diameter measurements was assessed using intraclass correlation coefficients based on one-way random effects ANOVA.7,8 Correlation between CTA and DUS-based GSV diameter measurements at above- and below-knee anatomic locations was evaluated using Spearman correlation coefficients. For categorical analyses, adequate GSV for use as bypass conduit was defined as minimum DUS-based diameter ≥3.0 mm. CTA diameter cut-points for categorization of GSV as adequate vs inadequate bypass conduit were evaluated graphically using receiver-operating characteristic curves, and validity of CTA-based assessment based on these cut-points was characterized using sensitivity (true positive/[true positive + false negative]) and specificity (true negative/[true negative + false positive]). All statistical analyses were conducted using SAS v. 9.2 (SAS Institute, Inc, Cary, NC).

RESULTS

Preoperative anatomic assessment before lower extremity bypass with both lower extremity CTA and DUS vein mapping was performed on 63 lower extremities in 36 patients during the study period. All patients were male with a mean age of 60.9 ± 7.7 years and a mean body mass index of 27.0 ± 4.8. Eight patients (22.2%) had a previous history of unilateral GSV harvest, and two patients (5.6%) had a previous history of major lower extremity amputation contralateral to the anticipated bypass. Of the 63 lower extremities studied with DUS vein mapping, the GSV could be visualized and measured at all intended above-knee anatomic locations in 59 (93.7%) and all intended below-knee anatomic locations in 51 (90.0%). Among patients evaluated with DUS vein mapping, all visualized GSV were compressible and no instances of asymptomatic GSV thrombosis were identified. Mean GSV diameter measurements stratified by imaging technique and anatomic location are displayed in the Table. Based on DUS, mean above-knee GSV minimum diameter was 2.9 ± 0.1 mm (range, 1.4-4.6 mm), and mean below-knee minimum diameter was 2.6 ± 0.1 mm (range, 1.3-4.0 mm). Based on the minimum diameter criterion of 3.0 mm, adequate GSV bypass conduit was identified above knee in 44.4% of extremities and below knee in 27.9% of extremities evaluated with DUS.

CTA-based GSV assessments were possible in 54/59 (91.5%) above-knee and 43/51 below-knee (84.3%) anatomic locations where DUS measurements were obtained. Qualitative characteristics that limited CTA-based GSV visualization and measurement included lack of adipose tissue surrounding the vein and subcutaneous edema or inflammation (Fig 1). Among CTA-based assessments, minimum-diameter assessment was limited to categorical designation as inadequate because of minimum GSV diameter ≤1.7 mm in 6/54 above-knee (11.1%) and 15/43 below-knee (34.9%) anatomic locations. When GSV was visible and exceeded the minimum diameter threshold for CTA measurement, correlation between CTA- and DUS-

<table>
<thead>
<tr>
<th>Anatomic location</th>
<th>Diameter (mm)</th>
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<tbody>
<tr>
<td>Groin</td>
<td>5.4 ± 1.7</td>
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<tr>
<td>Proximal thigh</td>
<td>3.4 ± 1.1</td>
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<tr>
<td>Midthigh</td>
<td>3.2 ± 0.7</td>
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<tr>
<td>Distal thigh</td>
<td>3.4 ± 0.7</td>
</tr>
<tr>
<td>Proximal calf</td>
<td>3.0 ± 1.1</td>
</tr>
<tr>
<td>Midcalf</td>
<td>3.0 ± 1.1</td>
</tr>
<tr>
<td>Distal calf</td>
<td>2.7 ± 0.6</td>
</tr>
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CTA, Computed tomography angiography; GSV, great saphenous vein. Displayed values represent mean ± SD; excludes GSVs with diameters <1.7 mm.
Based on receiver-operating characteristic (ROC) curve analysis, 3.9 mm was selected as the optimal above-knee diameter cut-point indicating adequate GSV conduit for arterial bypass (defined as DUS diameter ≥3.0 mm) (Fig 2, A). Below the knee, 3.0 mm was identified as the optimal cut-point for adequate GSV conduit for arterial bypass (Fig 2, B). Scatterplots comparing minimum above- and below-knee diameters based on CTA and DUS are shown in Fig 3. For identification of adequate lower ex-
tremity bypass conduit, CTA-based categorical assessment of above-knee GSV had a sensitivity of 67% and a specificity of 73%. Below the knee, CTA-based assessment of GSV had a sensitivity of 75% and a specificity of 84%.

DISCUSSION

Autogenous GSV is considered the conduit of choice for lower extremity bypass when diameter is adequate. Assessment of GSV diameter is, therefore, an important step in preoperative planning for lower extremity arterial bypass, and DUS is considered the standard imaging modality for vein mapping. DUS is a noninvasive, inexpensive, and accurate method for assessing GSV diameter that is also capable of characterizing flow and identifying qualitative findings, such as thrombosis or anatomic variants, which may be relevant to procedural planning. Before the introduction of noninvasive arterial imaging modalities, DUS represented the only widely available technique for GSV conduit assessment before lower extremity bypass. With increasing utilization of noninvasive cross-sectional imaging techniques, such as CTA, however, GSV anatomic data are now available on studies performed for arterial assessment but often overlooked. We retrospectively evaluated correlations between CTA and duplex-derived GSV diameters and the utility of CTA-based categorical assessments of GSV adequacy as bypass conduit. When GSV was large enough for measurement using CTA, we observed significant positive correlations between CTA and DUS-based GSV diameters and good between-observer reliability. We found CTA-based minimum GSV diameter to be a specific but relatively insensitive indicator of adequate bypass conduit, defined as DUS diameter ≥3.0 mm.

Use of CTA for assessment of GSV as conduit for lower extremity bypass has been described previously by Kang et al in their prospective evaluation of nine patients. These authors observed complete agreement between CTA and

![Fig 3. Computed tomography angiography (CTA) vs duplex ultrasound (DUS)-based minimum great saphenous vein (GSV) diameters. Scatterplots demonstrate minimum above-knee (A) and below-knee (B) GSV diameters in millimeters. Solid line indicates adequate bypass conduit definition of 3.0 mm by DUS. Dashed line indicates CTA-based diameter cut-point for above-knee (A) and below-knee (B) locations.](image-url)
DUS for categorizing GSV conduit as adequate vs inadequate based on a diameter cut-point of 2 mm. Although they noted that CTA tends to underestimate GSV diameter relative to DUS, a statistical evaluation of correlation between CTA and duplex-based diameters was not performed as part of their analysis. Based on our clinical practice, we selected a larger DUS-based diameter of 3.0 mm to define adequate bypass conduit, potentially reducing the proportion of extremities with adequate conduit, particularly below the knee. Kang et al also performed their DUS vein mapping procedures with patients positioned in the upright or reverse Trendelenburg position; these maneuvers may have increased vein diameters by creating lower extremity venous distention. In contrast, we measured DUS-based GSV diameters with patients in the supine position, which also may have affected the proportion of patients with adequate GSV due to assessment in a relatively non-distended state, although this same consideration may have facilitated diameter comparisons between imaging modalities because performance of CTA with patients positioned upright is not routinely possible on commercially available scanners.

Because CTAs evaluated in this analysis were performed using a standard clinical protocol, CTA-based GSV diameters were measured from arterial phase images with veins in a noncontrasted state. Inability to assess patency or detect thrombus is, therefore, a potential limitation related to lack of venous phase images; because asymptomatic GSV thrombosis is an uncommon finding on DUS vein mapping, however, the significance of this disadvantage may be minimal. We suspect that chronic GSV thrombosis ultimately results in a small, fibrotic vein that would likely be categorized as inadequate for use as bypass conduit by CTA-based evaluation. Although venous phase-contrast might also improve the ability to distinguish vein edges from surrounding soft tissues (and, therefore, potentially reduce measurement error), routine addition of venous phase imaging to lower extremity CTA protocols would have the disadvantage of increasing associated radiation exposure and therefore cannot be recommended based on our data.

Because CTA was a specific but relatively insensitive screen for adequate-diameter GSV conduit, DUS should be obtained when lower extremity bypass is planned and CTA-based assessment does not identify adequate bypass conduit. Given the resolution limitations we observed with CTA, the role of DUS vein mapping is particularly important when vein diameter is borderline, or technical factors, such as inflammation, edema, or paucity of surrounding adipose tissue, impair visualization with CTA. Confirma- tory DUS may not be necessary, however, when adequate vein is clearly visible on CTA. DUS vein mapping is a technique that is both time- and labor-intensive, requiring 30-45 minutes per extremity by a dedicated vascular technologist. Addition of GSV diameter measurement to routine interpretation of CTAs performed for assessment of PAD, therefore, would potentially improve preoperative planning by eliminating redundant DUS studies for appropriately selected patients, potentially benefiting resource-constrained healthcare environments through more efficient imaging utilization.

Several additional limitations of our study warrant specific discussion. First, we obtained all of our CTA measurements from axial images without utilization of three-dimensional (3D) reconstructions or centerline measurement techniques. Although measurement from axial images is relatively straightforward and easily reproduced on desktop workstations from a variety of software platforms, we are unable to comment on what additional advantages might be gained with use of more advanced image analysis techniques. Because the axial images used to perform CTA-based measurement are not always perpendicular to the long axis of the vein, oblique diameter measurements may have resulted in bias toward overestimation of GSV diameters with CTA. We attempted to limit this effect by only considering the minor axis diameters, which have been shown to be better approximation of true centerline blood vessel measurements. Second, because only selected DUS images were archived electronically, GSV diameters could only be assessed in a continuous fashion from CTA images. It is, therefore, possible that the anatomic location-based approach to DUS vein mapping, although fairly comprehensive, may have omitted true minimum diameters in some extremities and therefore biased the observed correlations toward the null hypothesis. Finally, we did not evaluate operative findings at the time of revascularization or use of GSV for bypass conduit as end points for this analysis. This decision was based on a lack of consistent criteria for the use of vein versus synthetic conduit for lower extremity bypass among surgeons, particularly for above-knee distal targets, which would limit the validity of these end points within our retrospective analysis. Despite these limitations, this analysis suggests that valuable information can be gained from GSV assessment using CTA, and we plan further evaluation of the utility of CTA-based assessment of lower extremity bypass conduit with a prospective study.

CONCLUSIONS

CTA-based GSV diameter measurements are reliable between observers and significantly correlated with DUS-based measurements. CTA-based GSV diameter is a specific but relatively insensitive indicator of adequate bypass conduit, and CTA-based GSV evaluation can be used for decisional support during preoperative planning. Confirmatory DUS vein mapping is warranted when CTA-based evaluation does not identify adequate GSV bypass conduit, but it may be unnecessary when adequate diameter GSV is visible on CTA.

AUTHOR CONTRIBUTIONS

Conception and design: MC, DD, NH, RM, KK
Analysis and interpretation: MC, DD, MH, RM
Data collection: DD, TL, KK, MAC
Writing the article: DD, MC, TL, YD, KK, LB, NH, RM
Critical revision of the article: DD, MC, TL, YD, KK, LB, NH, RM
Final approval of the article: DD, MC, TL, YD, KK, LB, NH, RM
Statistical analysis: MC
Obtained funding: Not applicable
Overall responsibility: MC

REFERENCES


DISCUSSION

Dr Ahsan T. Ali (Little Rock, Ark). I congratulate the authors for submitting this article, where Dr deFreitas and colleagues from Emory University have addressed a practical, nonetheless an important issue. Patients requiring lower extremity bypass are routinely sent to the noninvasive vascular lab for vein mapping, which is time consuming and costly. Their idea was to obtain information about arterial and venous anatomy through a single imaging modality. This has practical implications for the concept of “one-stop” shopping.

In your methods, a retrospective review was undertaken for all the patients that had undergone a CTA for lower extremity ischemia. The ones selected for revascularization then underwent a DUS. The review took place after surgical intention had already been performed. The diameters of the GSV were obtained through DUS. The review could not be confirmed? Likewise, how many did undergo harvest of the GSV and the findings verified in the OR?

I have three questions:
(1) How many patients did NOT undergo harvest of the vein and had a prosthetic graft instead? Thereby, the DUS and CT vein mapping could not be confirmed! Likewise, how many did undergo harvest of the GSV and the findings verified in the OR?
(2) Was a 3D reconstruction used for CT vein mapping? I have found that it gives useful anatomic information especially for anomalies and duplications.
(3) At your institution: Is there a protocol? Is the standard now CTA only or CTA and selective DUS? What prompts you to get a venous duplex in addition to CT?

Dr Dorian J. deFreitas. Response to question 1: We did not analyze intraoperative findings for a number of reasons. This is a retrospective review and comments about the quality of the vein were not universally referenced in the operative notes. In addition, there were multiple surgeons involved in patient care with no standard definition of what represented an adequate vein. Finally, there was preferential use of polytetrafluoroethylene in the above-knee location by one surgeon. I think it is important to correlate CTA-based GSV measurements with intraoperative findings to validate its use. This question is better addressed in a prospective study where the intraoperative definition of an adequate vein and treatment protocols are standardized.

Response to question 2: We did not use 3D reconstructions to evaluate the GSV in this study. We believed that 3D reconstructions would have only been beneficial in the setting of the venous phase. This would allow us to perform central line measurements, and this was possible to compare the distance required for arterial bypass with the distance of adequate saphenous vein.

Response to question 3: To date, we have only evaluated the GSV by CTA in a retrospective fashion. The next step is to perform this prospectively. Based on our data, we would use the CTA-based GSV diameter cut points of 3.9 mm in the above-knee locations and 3.0 mm in the below-knee locations as a trigger points for ordering a duplex. GSV measurements below these diameters should have a confirmatory duplex, and GSV with measurements above these diameters should be deemed adequate.