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Reconstructive

Limitations of Computed Tomography Angiography in Preoperative Planning of Peroneus Brevis Rotational Flap

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Background: The distally based peroneus brevis (PB) rotational flap has been shown to be a reliable method of coverage of distal third tibial wounds. The flap is perfused via retrograde flow from distal PB perforators located within 8 cm of the lateral malleolus. The ability to assess patency of these vessels preoperatively facilitates surgical planning, and computed tomography angiography (CTA) has been used for perforator assessment of other lower extremity flaps. The purpose of the present study is to establish the potential utility of standard CTA for locating distal PB perforators by examining uninjured lower extremities.

Methods: Twenty-five patients who underwent bilateral lower extremity CTAs using standard lower extremity protocol were retrospectively identified. Axial two-dimensional images were scanned craniocaudally using our institution's standard CT image viewing software, Merge Radsuite (Merge Healthcare, Hartland, Wis.).

Results: The average location of distal-most PB perforators identified on CT angiogram was 13.1 ± 5.1 cm proximal to the distal fibula, or 34.5% ± 13.5% of total fibular length. Standard CTA was only able to locate a pedicle within 8 cm of the lateral malleolus (20.9% of fibular length) in three of 25 patients (12%).

Conclusions: Previous studies have described a reliable pedicle within 8 cm of the distal fibular tip upon which to design a distally based PB rotational flap. The absence of such perforators in the CT angiogram suggests that standard CT angiogram is not a reliable technique for identifying the patency of such perforators when evaluating the utility of a distally based PB flap. *(Plast Reconstr Surg Glob Open 2023; 11:e4774; doi: 10.1097/GOX.0000000000004774; Published online 25 January 2023.)*

INTRODUCTION

The distally based peroneus brevis (PB) rotational flap for coverage of the distal lower extremity was first described by Eren et al in 2001,[1] and since then, it has been repeatedly shown to be a reliable method of coverage in an area that had once been thought to require free tissue transfer.[2,3] The PB is perfused via perforators originating from both the peroneal and anterior tibial arteries. The described distally based flap is perfused via retrograde flow as these arteries form an anastomosis around the lateral malleolus.[1,2,4–6] Much of the utility of this flap lies in coverage of distal third tibia wounds given the distal location of the key perforators, classically described as lying within 8 cm of the lateral malleolus.[2,7–10] However, given their close proximity to the distal fibula, these vessels are at risk of disruption in patients with lower extremity fractures. Since these same injuries may also lead to wounds requiring soft tissue coverage, accurate preoperative assessment of the patency of the distal perforator vessels may be helpful in proper flap selection (PB versus free tissue transfer) to prevent early flap failure.

In the distally based PB flap, the origin of the muscle belly is detached proximally and elevated in a proximal to distal direction, with care taken to avoid damage to the superficial peroneal nerve. Multiple proximal perforators are ligated, and the muscle is elevated off of the fibula and interosseous membrane until the flap reaches its desired location or the distal-most perforator is approached, approximately 8 cm proximal to the tip of the fibula (Fig. 1). An accurate understanding of the location of this

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perforator is critical to successful flap harvest. If elevation is not carried distally enough, the flap will not reach its intended target; if elevation proceeds beyond the level of the perforator, the flap will be irrevocably damaged. Therefore, knowledge of the exact location of the distal perforator will facilitate efficient and safe flap harvest. Preoperative evaluation of the location and patency of this perforator with handheld Doppler or computed tomography angiography (CTA) has been recommended in the technical description of this flap,[11] but it is unknown whether the intended perforators can be adequately visualized on CTA, even in the absence of trauma.

CTA has shown consistent accuracy in identification of lower extremity perforators. Its use has been advocated in preoperative planning for free fibula transfer,[12,13] lateral femoral condyle flap,[14] anterolateral thigh (ALT) flap,[15] medial sural artery perforator (MSAP) flap,[16,17] and propeller flaps of the lower extremity.[18] Widespread access to CTA technology combined with promising results from studies of similar lower extremity perforator flaps suggests that CTA would be a useful tool in preoperative evaluation of viability of a distally based PB rotational flap. The purpose of the present study is to establish the accuracy of standard CTA for locating perforator vessels for PB muscle flaps in uninjured lower extremities. A better appreciation of the diagnostic sensitivity of CTA in identifying these small perforator vessels may assist surgeons with clinical decision-making and judicious use of advanced imaging. We hypothesized that CTA would allow preoperative confirmation of PB perforator arteries, with specific utility in assessing this flap as an option in the setting of lower extremity trauma.

Takeaways

Question: Is standard lower extremity computed tomography angiography (CTA) reliable for preoperative evaluation of distal peroneus brevis (PB) pedicles for flap surgery?

Findings: Twenty-five patients with uninjured legs who underwent bilateral standard lower extremity CTA were identified. Standard CTA was able to locate a pedicle within 8 cm of the lateral malleolus in three of 25 patients (12%). Previous anatomical studies and operative findings suggest that preserving these vessels is required for the flap, and they are present in all patients.

Meaning: Standard lower extremity CTA is not a reliable method of visualizing distal peroneus brevis perforators during preoperative evaluation for a distal PB flap.

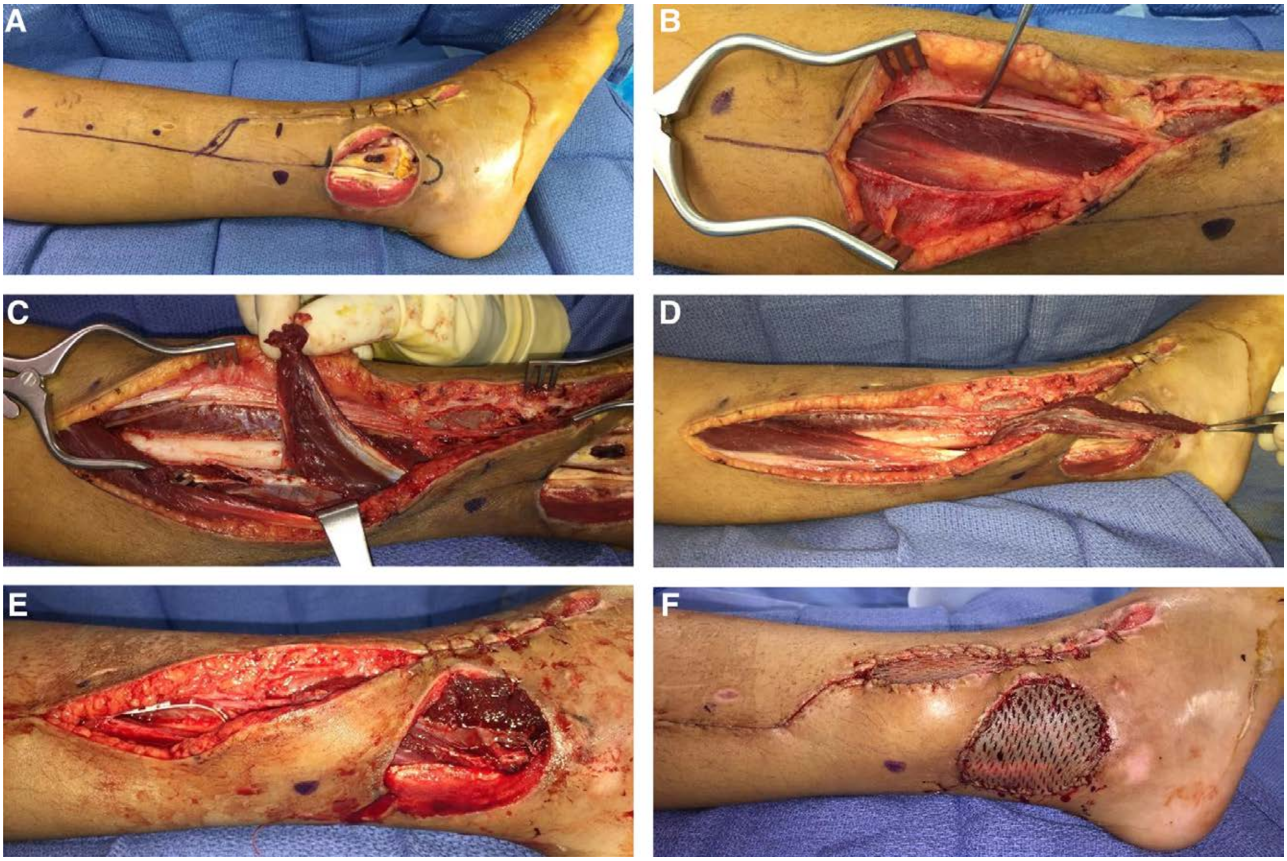

Fig. 1. Techniques of peroneus brevis flap harvest. A, Exposed fibula after debridement of lateral ankle abscess. B, Exposure of peroneus longus and PB. C, Proximal PB mobilization. D, Reflection of PB distally. E, Lateral ankle defect covered by reflected PB. F, Inset with split-thickness skin graft.

MATERIALS AND METHODS

Patient Selection

To identify the accuracy of CTA in visualizing suitable distal perforators for the PB flap, we sought to identify the presence or absence of these perforators in nontraumatized limbs through a retrospective study utilizing our institution's imaging database. After obtaining institutional review board approval, we retrospectively identified 44 patients who underwent bilateral lower extremity CTAs in our adult Emergency Department between January and July 2019. Inclusion in the study required a complete CT angiogram of bilateral lower extremities, from anterior superior iliac spine (ASIS) through the distal fibular tip, with at least one uninjured leg. Patient histories were reviewed to identify indications for CTA and to identify the uninjured limb, which was used for the analysis. To avoid false negative results, patients were excluded if their scan did not show three-vessel runoff at the level of the ankle mortise, with visualization of submillimeter branches distal to this level. Patients with a known history of vasculopathies such as peripheral vascular disease or vascular trauma of the uninjured limb were also excluded, as well as patients with incomplete imaging of the entire limb or prior lower extremity fractures. A total of 25 patients met these criteria and underwent CT angiogram analysis, the specifics of which are detailed below.

CTA Technique

All CTAs were performed on a Siemens SOMATOM scanner, with dual row detectors, 192 slices per detector, and spatial resolution of 0.24 mm. Contrast was Optiray-350, administered at a dose of 70–130 ml, with delay of 70 seconds, per our standard lower extremity protocol.

Image Analysis

As CTA analysis of perforators to the PB has not previously been reported, we sought to first validate our image analysis technique by identifying the location of perforators used for the ALT flap and MSAP flap. The perforator vessels for both of these flaps have previously been shown to be identifiable in standard CTA, enabling validation between the findings of this study and existing literature. For each angiogram of the uninjured leg, the ALT and MSAP perforator were first identified and their locations and diameters recorded in a standard fashion.

Identification of the ALT and MSAP vessels followed previously described techniques,[15–17,19] which were also applied for identifying PB vasculature. Axial two-dimensional images were scanned craniocaudally using our institution's standard CT image viewing software, Merge Radsuite (Merge Healthcare, Hartland, Wis.). Perforator vessels were first identified by following branches antegrade off of known source vessels until their insertion in

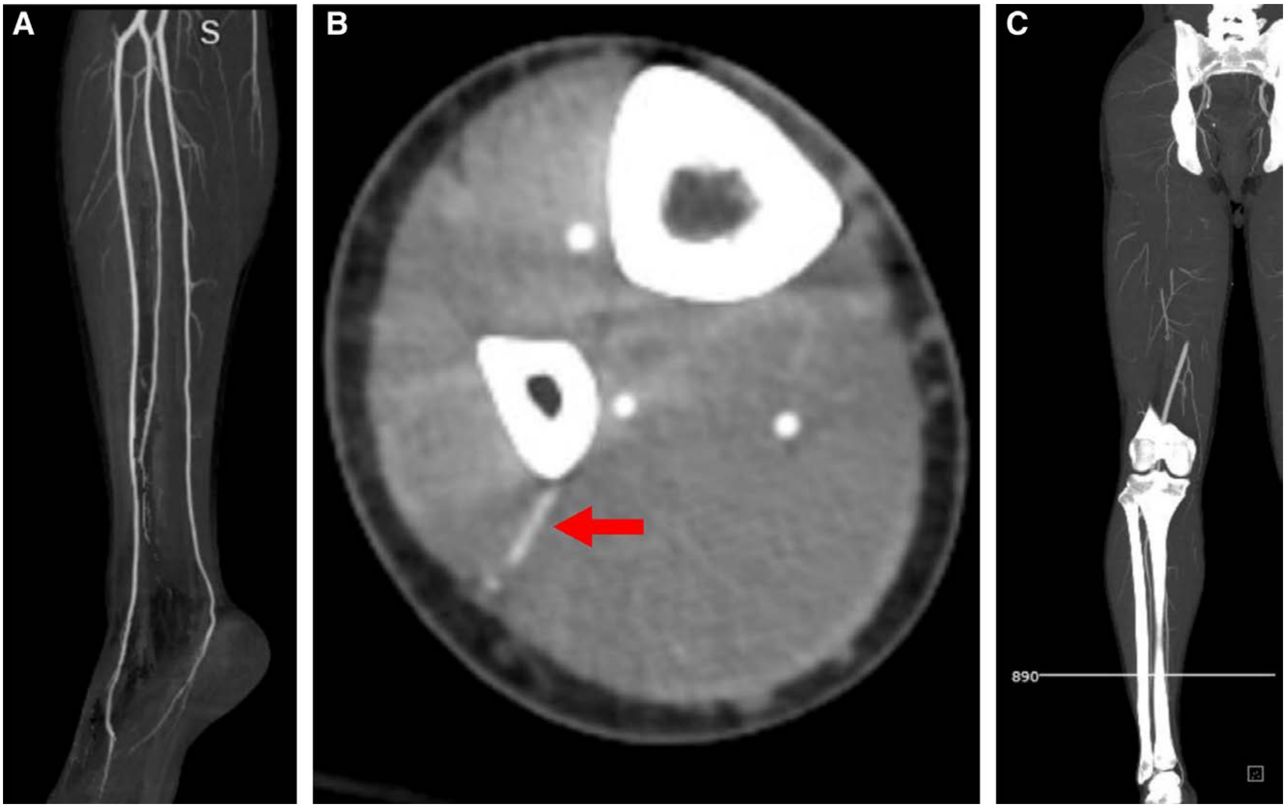

Fig. 2. Lower extremity angiogram was utilized to identify peforators. A, Example of lower extremity computed tomography angiogram. B, Perforator identified (red arrow) originating from the peroneal artery. C, Location of perforator in the middle third of the fibula.

target tissue, and then secondarily by identifying fascial/muscular perforators in the area of interest with retrograde tracing to confirm the appropriate origin vessel. An example of perforator identification on lower extremity CTA is provided in Figure 2.

The pedicle diameter was recorded at the vessel takeoff. Existing studies vary in their description of perforator locations as either absolute distances or as percentages of relevant landmarks. To aid in comparison, we measured pedicle location both as absolute distance from relevant landmarks, and as percentage of relevant thigh length or fibular length. The ALT vasculature was identified off of the descending branch of the lateral circumflex femoral artery (LCFA), and perforator location was reported as the distance of the vessel takeoff proximal to the popliteal crease. It was then compared against the thigh length (TL), defined as the length from the ASIS to the superolateral pole of the patella. Similarly, the MSAP pedicle originates off of the medial sural artery, which has variable branching from the popliteal artery.[16] MSAP location was measured from its distance below the popliteal crease, and compared against the fibula length (FL), defined as the length from the proximal tip of the fibula to the distal tip of the lateral malleolus. The PB perforators were identified originating from the peroneal artery (PBPA) or anterior tibial artery (PBTA), measured as the distance proximal to the distal fibular tip, and reported as a percentage of the FL. Previous reports have identified numerous perforators for the PB, both proximally and distally; therefore, all identifiable perforators in each CTA were recorded.

Values were reported as mean ± standard deviation, with range where applicable. Distal perforators to the PB were deemed suitable as the source of a distally based rotational flap if they were within the distal 8 cm of the fibula, based on a conservative summary of the previous literature.[2,5,7,20]

RESULTS

The study population of 25 patients included 18 men and seven women, with a mean age of 33.6 ± 14.7 years (range, 9–65). The reason for obtaining CTA for all patients was concern for posttraumatic vascular injury in the contralateral, injured leg, with mechanism of trauma classified as motor vehicle crash in 13 patients, gunshot wound in eight patients, and mechanical fall in four. All included patients had an uninjured leg included in the CTA, which was used for analysis. The average thigh length of the uninjured leg was 45.4 ± 3.7 cm (range, 36.9–52.3 cm), and average fibular length was 38.2 ± 1.8 cm (range, 30.0–43.1 cm).

Overall, a total of 330 perforators were identified among all flap types, with 93 ALTs, 77 MSAPs, 70 PBTAs, and 90 PBPAs. Table 1 shows the average number of perforators, pedicle diameter, and pedicle distance from landmarks as absolute distance and as proportional distance for ALT, MSAP, PBTA, and PBPA. With regard to perforators of the PB muscle from the anterior tibial artery and the peroneal artery, the average number of perforators was 2.8 ± 1.1 and 3.6 ± 1.7, respectively, with an average vessel caliber of 1.4 ± 0.4 and 1.3 ± 0.3 mm. The average location of the perforators, as measured from the distal fibula, was 21.8 ± 6.0 and 19.4 ± 6.2 cm. When expressed as a percentage of fibular length, the average location was 57.5% ± 14.8% and 50.7% ± 15.9%. The average location of the distal-most identified perforator for either the PBTA or PBPA was found to be proximal to the distal fibula tip by 13.1 ± 5.1 cm or 34.5% ± 13.5% of total fibular length. The distal-most perforator was from the PBPA in 18 patients, and off the PBTA in seven patients.

Table 1. Perforator Data Averages from CTA

ALT	
No. perforators	3.8 ± 1.1 (2–7)
Pedicle diameter (mm)	1.7 ± 0.5 (0.7–3.1)
Distance from popliteal crease (cm)	29.3 ± 6.4 (8.3–34.5)
Percentage of thigh length	46.5% ± 13.1% (19.0%–73.3%)
MSAP	
No. perforators	3.1 ± 1.2 (0–7)
Pedicle diameter (mm)	1.4 ± 0.5 (0.5–3.1)
Distance from popliteal crease (cm)	12.3 ± 4.5 (4.4–29.7)
Percentage of fibular length	27.1% ± 11.8% (5.6%–70.3%)
PBTA	
No. perforators	2.8 ± 1.1 (1–6)
Pedicle diameter (mm)	1.4 ± 0.4 (0.6–2.5)
Distance from distal fibula (cm)	21.8 ± 6.0 (11.3–34.5)
Percentage of fibular length	57.5% ± 14.8% (30.6%–86.8%)
PBPA	
No. perforators	3.6 ± 1.7 (0–7)
Pedicle diameter (mm)	1.3 ± 0.3 (0.7–2.2)
Distance from distal fibula (cm)	19.4 ± 6.2 (6.2–32.7)
Percentage of fibular length	50.7% ± 15.9% (16.5%–79.3%)

Values are reported as average ± standard deviation (range).

The distribution of all identified perforators from the anterior tibial artery and the peroneal artery with respect to fibular length is shown in Figure 3, with percentages of all perforators listed per decile. To validate our methods of CTA analysis, we compared our findings regarding perforators for ALT and MSAP with previously published data. The distribution of all identified perforators for the ALT, MSAP, PBPA, and PBTA in this study is shown in Figure 4.

DISCUSSION

Using standard CTA, only three of 25 patients (12%) had an identifiable artery to the PB within 8 cm of the distal fibular tip (or 20.9% of fibular length), and only seven of 25 (28%) within 12 cm (or 31.4% of fibular length). Using these values as conservative measures of where to find the critical distal perforators based on previous studies, our hypothesis was refuted and CTA did not consistently identify perforators suitable for a distally based PB rotational flap in nontraumatized limbs. Based on the retrospective design of the study, we classify our evidence as diagnostic level III.

Comparison of the present study's data with previously reported values is shown in Table 2. For MSAP pedicles, our CTA method allowed identification of an average of 3.1 perforators per leg, with an average caliber of 1.4 mm

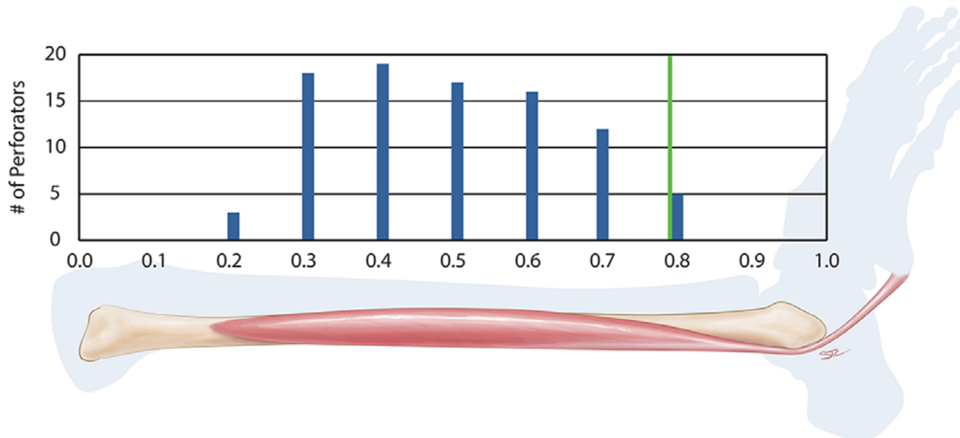

Fig. 3. The decile distribution of perforators to PB as identified by computed tomography angiography along the fibula. The green line represents the maximum distance from the distal fibula for a perforator to be viable for rotational flap surgery.

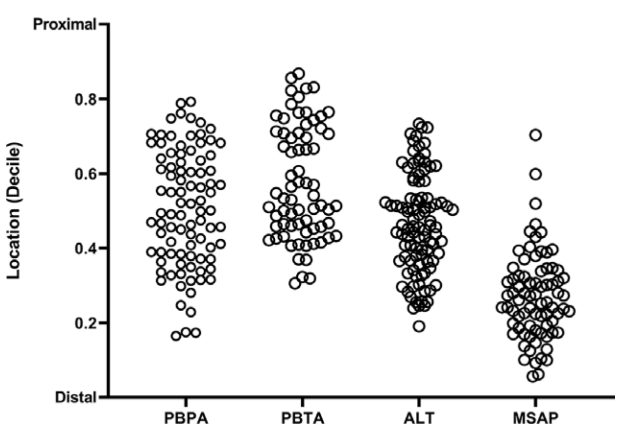

Fig. 4. A scatter plot of the location of all perforators identified by computed tomography angiography. Perforators include those to the PBPA, those to the PBTA, those for the ALT, and those for the MSAP. Their location is represented by decile distribution along relevant anatomical measurements: thigh length for ALT, and fibular length for PBPA, PBTA, and MSAP.

and an average distance of 12.3 cm from the popliteal crease. Previous studies have identified an average of 2.1 pedicles with a caliber of 2 mm, at an average distance of 12.9 cm from the popliteal crease.[16,21–23] For the ALT flaps, CTA identified an average of 3.9 perforators with an average caliber of 1.7 mm and an average distance of 29.3 cm from the popliteal crease. This is similar to previous studies that showed an average of 2.2 perforators, which were 0.9 mm in diameter.[15,24] The similarities between our data and the existing literature suggest that our use of CTA was as sensitive as previous work in identifying perforators and vascular pedicles. The present study was actually able to identify more ALT and MSAP perforators of similar caliber and location than previous studies, suggesting its validity in perforator mapping. The caliber and location of PB perforators located via CTA are represented in Figure 5.

The distally based PB rotational flap has shown to be a versatile, reliable technique with expanding indications. The initial description of its use cited coverage of lateral malleolus and calcaneus wounds as the most common indication, followed by Achilles tendon, distal anterior tibia, and medial malleolus, all of which have been reinforced by subsequent studies.[1,2,5,25] It has been reported for use in soft tissue coverage after debridement of ankle osteomyelitis, and as a composite flap.[26–28] While all rotational flaps rely on use of uninvolved tissue to compensate for neighboring areas of injury, the ankle region is unique in its relative lack of sufficient adjacent muscle for pedicled rotational flaps. Given the utility of the PB flap, preoperative assessment of its vascular supply in the setting of prior trauma or operative fixation of fibula fractures would be helpful in appropriate flap selection for nonhealing or traumatic wounds.

The redundant vascular supply of the PB from both the anterior tibial and peroneal arteries has been well documented.[1,2,4–6] In the setting of ankle trauma and/or fracture, these perforators are at risk of disruption. However, there has been little previous data on the efficacy of CTA in identifying distal PB perforators for preoperative planning. In our analysis, we were only able to locate a pedicle to PB within 8 cm of the distal fibular tip in three of 25 patients (12%). Only seven of 25 patients (28%) had a visible pedicle within 12 cm of the fibular tip. Comparison of these findings with the large amount of previous anatomic and clinical studies supporting the consistent presence of distal perforators within 8 cm of the fibular tip[2,5,8–10] suggests that CTA is not a reliable way to identify perforator viability for distally based PB flaps.

Many different modalities have been utilized for preoperative assessment of lower extremity perforator location and viability, including thermal cameras,[29] ultrasound,[6,30] MRI,[31] and CTA.[12–17] Of these methods, it is the authors' experience that CTA generally offers the best combination of accuracy, availability, consistency between performing technicians, and cost. The accuracy of CTA in locating perforators has been consistently shown to be excellent when compared with surgical findings, with Higueras Suñé et al reporting 100% specificity.[12,13,16–18]

Limitations of the present study include the use of our institution's standard CTA protocol, which was not

Table 2. Validation of Perforation Identification based on Previous Literature

	ALT		
	No. Perforators	**Location**	**Caliber (mm)**
Current study	3.8 ± 1.1 (2–7)	29.3 ± 6.4 cm (8.3–34.5) from popliteal crease	1.7 ± 0.5 (0.7–3.1)
Kim et al (2010)[15]	2.28 (0–4)		
Valdatta et al (2002)[24]	2.1 (1–4)	96% within 5 cm of ALT midpoint	0.85
	MSAP		
	No. Perforators	**Distance to Popliteal Crease (cm)**	**Caliber (mm)**
Current study	3.1 ± 1.2 (0–7)	12.3 ± 4.5 (4.4–29.7)	1.4 ± 0.5 (0.5–3.1)
Cavadas et al (2001)[21]	2.2 (1–4)	9–18	1.5
Dusseldorp et al (2014)[16]	2	13 ± 2	2.3 ± 0.4
Altaf (2011)[22]	2 ± 0.3 (1–5)	10 ± 0.02 (9–12) and 16 (14–17)	3 (2–4)
Hallock (2001)[23]	9.6 total, 2.3 major	12.6	
He et al (2014)[17]			1 ± 0.3
	PBTA		
	No. Perforators	**Location**	**Caliber (mm)**
Current study	2.8 ± 1.1 (1–6)	21.8 ± 6.0 cm (11.3–34.5) from distal fibula	1.4 ± 0.4 (0.6–2.5)
Abd-Al-Moktader (2018)[2]	7 (5–9)	Lowest perforators 0–3 cm superior to distal fibular tip	
Ensat et al (2014)[25]	1.4 ± 0.9		
	PBPA		
	No. Perforators	**Location**	**Caliber (mm)**
Current study	3.6 ± 1.7 (0–7)	19.4 ± 6.2 cm (6.2–32.7) from distal fibula	1.3 ± 0.3 (0.7–2.2)
Abd-Al-Moktader (2018)[2]	5 (4–7)	Lowest perforators 3–6 cm superior to distal fibular tip	
Ensat et al (2014)[25]	3.4 ± 1.1		

Values are reported as average ± standard deviation (range).

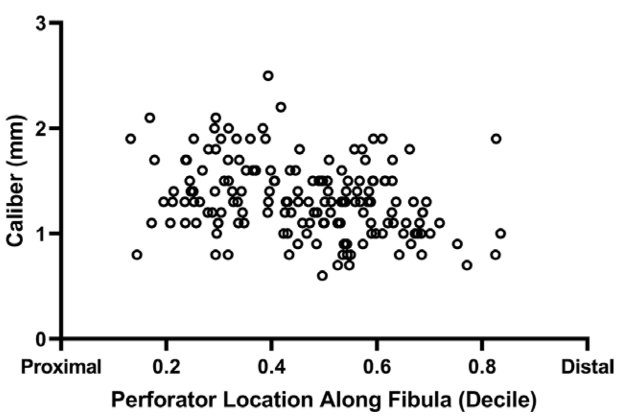

Fig. 5. A scatter plot of the caliber of all identified PB perforators with respect to their location, represented as distance along the fibula.

specifically optimized for evaluating distal extremity perforators. With a modified CTA protocol, perforators as small as 0.3 mm in diameter have been identified.[32] However, our choice of a standard CT angiogram demonstrates the inadequacy of normal CTA techniques. This makes the present study more applicable to standard trauma practice and is consistent with previous studies. The protocol used for this study did accurately identify perforators in the upper and lower leg for other common flaps, validating the measurement techniques and overall adequacy of the CT scans. The ability to identify ALT and MSAP perforators but not distal PB perforators using this method is likely due to differences in vessel caliber. In the present study, the average caliber of the most distal identified PB pedicle was 1.2 mm, compared with an average of 1.7 and 1.4 mm for ALT and MSAP flap perforators, respectively. There is consensus that CTA can reliably identify vessels as small as 1.5–2 mm in diameter,[15] which may explain why the smaller distal PB pedicles were not reliably detected.

Additionally, we recognize the value of pursuing surgical correlation with CTA findings. Given the overwhelming evidence from previous studies and personal experience that distal perforators do exist,[2,7–10] it is the authors' opinion that lack of perforator identification on CTA is an indictment of the chosen imaging modality, and not proof of absence. Similarly, while having multiple authors reviewing the images would improve the reliability of measuring vessels had they been found, we believe a single reviewer can accurately report the absence of a structure. The use of a single reviewer also eliminates confounding variables such as differences in skill/experience with diagnostic angiogram interpretation.

To ensure confidence in the reliability of the distal PB flap in the setting of fibular fractures, it would be helpful to establish a reliable method of preoperatively evaluating the distal pedicles from the anterior tibial and peroneal arteries. Alternative options include color Doppler sonography or handheld pencil Doppler to identify these perforators, but more research is needed to establish the efficacy of these and other ultrasound modalities. CT angiogram does not seem to be a reliable method of evaluating perforator viability preoperatively.

In conclusion, the distally based rotational PB flap is a versatile method of covering soft tissue defects around the ankle. To expand its indications to include deficient soft tissue from distal fibular fractures, preoperative assessment of distal pedicle patency must be reliable. We conclude that standard CTA protocols are not a reliable method of determining the presence of distal perforators necessary for PB flap survival. Handheld Doppler with careful intraoperative assessment may prove to be a more reliable method to assess possible perforator viability, but more investigation is needed.

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