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Stable Arterial Perforators Mapping in Lower Leg Using Color-Coded Doppler Sonography, Acoustic Doppler, and Thermal Imaging Camera in Patients Undergoing Digital Subtraction Angiography

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Abstract

Background Chronic defects in the lower leg present significant challenges in plastic surgery due to their diverse etiologies and association with impaired peripheral circulation. This study describes the localization of stable perforators and assesses their changing velocities after digital subtraction angiography (DSA) and alterations of flow characteristics.
Methods Ten patients with lower extremity defects requiring DSA had undergone examinations by using standard methods. The localization of 40 stable perforators originating from the anterior tibial artery, posterior tibial artery, fibular artery, and medial sural artery was performed before and after angiography. Where stenoses or occlusions were observed, percutaneous transluminal angioplasty (PTA) was conducted, and velocity changes following reperfusion were measured.
Results Angiographic abnormalities were observed in all of patients, thus necessitating PTA interventions. Prior to PTA, handheld acoustic Dopplers detected 37 out of 40 perforators (90%), whereas color-coded sonography detected 35 out of 40 perforators (87.5%). After PTA, these numbers increased to 38 out of 40 (95%) and 37 out of 40 (92.5%), respectively. The diameter of the perforators ranged between 1.14 and 1.16 mm. The mean flow characteristics included the peak systolic velocities (PSV) of 21.9 and 27.2, end-

Keywords
- acoustic doppler
- color-coded duplex
- DSA
- perforator
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diastolic velocities (EDV) of 9.4 and 11.4, and resistance indexes (RI) of 0.63 and 0.71, respectively. In the postintervention period, 16 microvessels exhibited enlarged lumen diameters ranging from 1 to 3 mm, resulting in increased perfusion values for PSV in 85.2% (21.9/27.2) and EDV in 88.2% (9.4/11.4) of the patients. The RI increased from 0.63 to 0.71. However, two perforators showed decreases in flow velocity after PTA.

Conclusion In most patients with chronic lower leg wounds and other comorbidities, adequate perforators for reconstruction can be identified by using conventional methods. PTA interventions positively impact blood flow in perforators, although they are not necessarily required prior to reconstruction.

Soft tissue defects in the lower leg below the knee joint are highly prevalent among patients with peripheral vascular disease (PVD). These wounds can be acute or chronic, resulting from various causes such as trauma, diabetes, infections, radiotherapy, tumor excision, and surgical wound dehiscence, among others. Chronic wounds in the lower leg pose complex challenges due to being noninvasively treated for prolonged periods, by having delayed surgical interventions, and their potential for superinfection, which may ultimately lead to amputation.

Impaired peripheral circulation in patients with multiple comorbidities is often associated with the majority of nonhealing wounds in the lower legs. Diabetes mellitus and PVD are common in patients with chronic lower limb defects and are the primary causes of nontraumatic amputations in the lower limbs.[1] These patients often undergo less invasive therapies, such as wound dressing and vacuum-assisted closure therapy, followed by skin grafting. However, this approach may not be suitable for patients with tendon or bone exposure, leading to superinfection and ulcerations or necrosis if the treatment is inadequate for an extended period. Reconstructive surgery is a last resort for definitive healing and limb salvaging. In this article, we will focus on the potential use of relatively stable arterial perforators below the knee as treatment modalities for these defects.

Pedicled propeller perforator flaps are becoming more popular as an alternative to free flap transfers in the reconstructive surgery of the lower limb. Although free flaps remain the gold standard for covering large complex defects, many patients are not suitable candidates for this type of surgery due to multiple comorbidities and their inability to tolerate the demands of the microsurgical procedures, the longer intensive care treatment, and the higher risk of donor site morbidities. The concept of local perforator-based flaps introduces fewer potential complications as well as versatility in any anatomical location where a reliable perforator can be identified. These flaps spare the underlying muscles, resulting in reduced donor morbidities, durable coverage, and more aesthetically pleasing outcomes.[2–6]

Proper flap planning is crucial in reconstructive surgery to minimize the risk of flap failure, such as a partial or complete necrosis of the flap, as well as to increase reliability, predictability, and efficiency.[3,7–10] Therefore, preoperative perforator mapping is necessary to ensure the safety and applicability of these flaps. Many authors have described the distribution of perforators originating from the popliteal artery (AP), medial sural artery (MSA), anterior tibial artery (ATA), posterior tibial artery (ATP), and fibular artery (AF), as well as their angiosomes.[11–13] The aim of this study was to confirm the most stable perforators in the lower leg by using color-coded duplex sonography (CCDS) devices, thermal imaging cameras (TIC), handheld acoustic Doppler (HHAD) devices, and computed tomography angiography (CTA), and to assess the changes in these perforators after digital subtraction angiography (DSA) and percutaneous transluminal angioplasty (PTA) interventions. We also provided an illustrative scheme for the quick and easy identification of these common perforators (►**Fig. 1**).

Methods

A group of 10 patients with lower limb defects of various etiologies, scheduled for DSA, were examined at three university hospital departments of radiology. Initially, TIC scans of the legs were performed on each side to visualize the defects (►**Fig. 2**). In cases where computed tomography (CT) scans were available, the most visible perforators were identified, and their locations were noted (►**Fig. 3**). The most common locations out of the 40 perforators from the AP, ATA, ATP, and AF were measured and marked with a permanent marker within a circle (►**Fig. 2**). The highest acoustic signal from one perforator was then identified by using a HHAD device and was marked with a cross sign. To confirm the presence of this perforator, a portable ultrasound (PU) device combined with CCDS was used (►**Fig. 3**). The diameter and velocity parameters, including the peak systolic velocity (PSV), end diastolic velocity (EDV), and resistance index (RI), were all recorded (►**Table 1**). The same procedure was repeated after DSA/PTA intervention, and the changes in the microvessels were compared and analyzed. Simultaneously, patient data and wound size measurements were collected (►**Table 2**). The perforators were mapped by using the following modalities.

Thermal Imaging Camera

Images were taken with a TIC (FLIROne for the iPhone, manufactured by Flir Systems Inc., USA) from the frontal, dorsal, fibular, and tibial sides of the lower limb before and

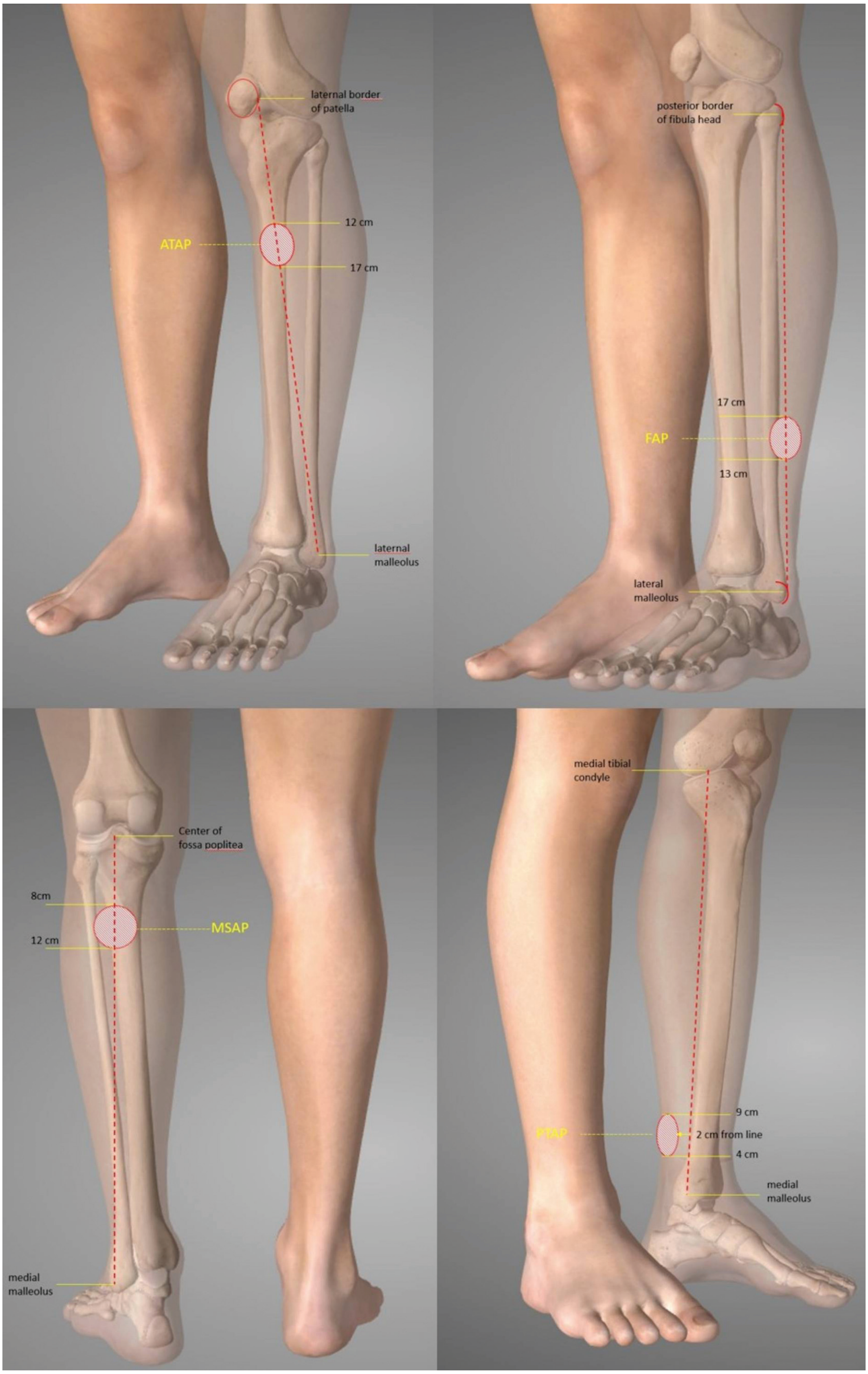

Fig. 1 The detection and the measurements of the stable perforators. ATAP, anterior tibial artery perforator; FAP, fibular artery perforator; MSAP, medial sural artery perforator; PTAP, posterior tibial artery perforator.

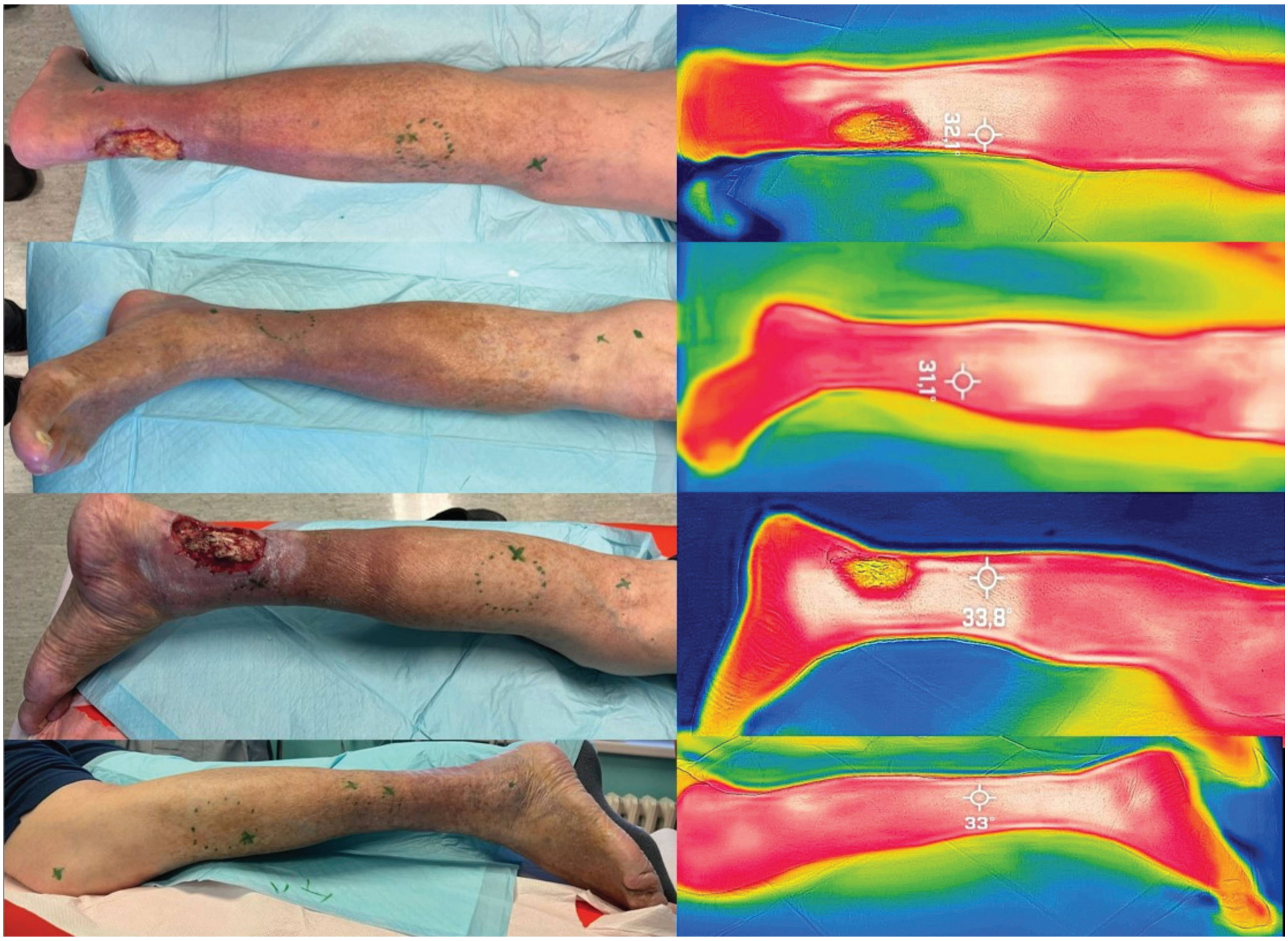

Fig. 2 The localization and the marking of the perforators by a handheld acoustic Doppler device and their examination with a thermal imaging camera (patient no. 7).

after DSA intervention (►**Fig. 2**). The recommended measuring distance was approximately 100 cm, and the thermal range was set between 25 and 30°C. The color scale ranged from blue (representing the coldest parts) to green, yellow, red, and white (representing the hottest areas). Venous temperature appeared as white spots, whereas arterial perfusion appeared as red spots, as previously defined by Paul et al.[14] Before the examination, the skin was allowed to cool to room temperature for approximately 3 minutes.[15]

Handheld Acoustic Doppler

A standard 8 MHz doppler device (Bi-directional Doppler ES-100V3, manufactured by Hadeco, Japan) was used to initially locate and mark the perforators with the highest acoustic signals (►**Fig. 2**). These marked spots were then confirmed by using a PU device and compared with the CT scan findings.

Color-Coded Duplex Sonography

CCDS has become a highly valuable imaging tool for identifying micro vessels with a high sensitivity.[16–19] Plastic surgeons commonly use CCDS for perforator mapping and flap planning in their daily practice. The confirmed perforators identified by acoustic doppler were examined twice. First, a plastic surgeon used a handheld wireless color Doppler linear probe with a 3 to 12 MHz frequency (Vscan Air, GE Healthcare, USA) and then a radiologist conducted high-resolution CCDS examinations. A standardized ultrasound protocol, including B-mode US, CCDS, pulse wave, and power Doppler (PD), were applied to all patients. The diameter of the perforators, PSV, EDV, and RI were measured and calculated (►**Fig. 3**).

Digital Subtraction Angiography

DSA is a real-time imaging technique that enables the visualization of blood vessels and detects blood flow abnormalities. The procedure was performed under moderate analgosedation. Approximately 12 mL of a radiopaque contrast dye was applied into the femoral artery. When occlusions or stenoses were detected, PTA endovascular interventions were performed. Each of the images prior to and after reperfusion was recorded (►**Fig. 4**). There were no observed allergic reactions to the contrast solution.

Computed Tomography Angiography

CTAs were not performed in all patients prior to DSA. Although there were no specific guidelines regarding the necessity of CT scans prior to carrying out DSA, they are generally recommended in most institutions. In cases where CT scans were available, their results enabled the retrospective confirmation of the location of specific perforators (►**Fig. 3**).

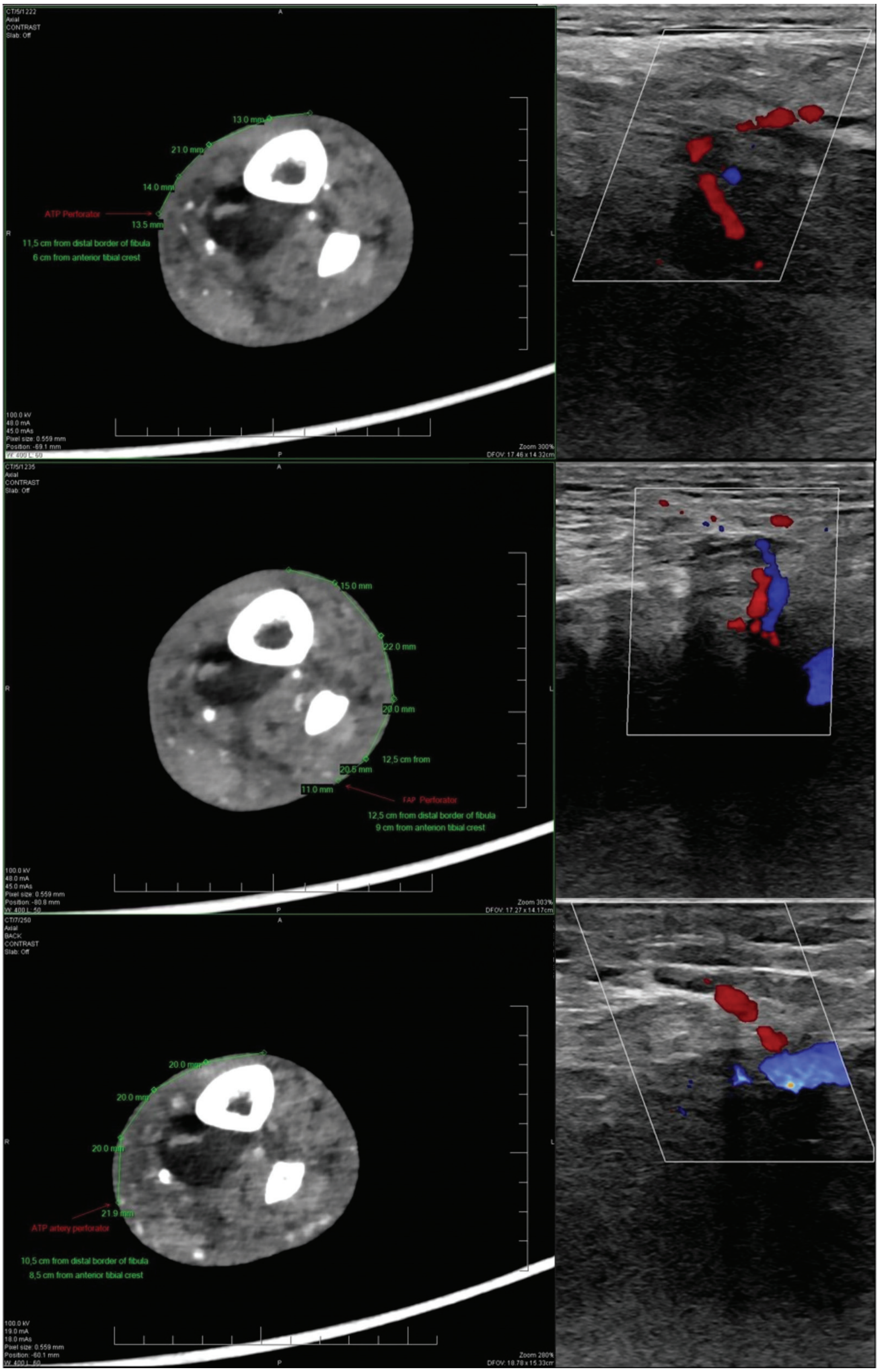

Fig. 3 Perforator mapping with computed tomography angiography and color-coded duplex sonography in patient no. 7. ATP, artery tibial perforator; FAP, Fibular artery perforator.

Results

This study included a total of 10 patients with chronic lower leg defects of various etiologies who underwent DSA. Among the patients, 6 out of 10 were diagnosed with diabetes mellitus, and all cases were associated with multiple comorbidities. The age range of the patients was between 53 and 81 years, with an average age of 66.9 years. Wound infections

Table 1 Perforator localization by handheld acoustic Doppler and color-coded duplex sonography, evaluation of flow characteristics

Patient no.	Perforator mapping	Perforator-confirmed AD pre-DSA	Perforator-confirmed AD post-DSA	Perforator-confirmed CCDS pre-DSA	Perforator-confirmed CCDS post-DSA	Perforator diameter (mm) pre/post-DSA	PSV cm/s pre/post-DSA	EDV cm/s pre/post-DSA	RI pre/post-DSA	Artery of intervention
1	PTAP	Yes	Yes	Yes	Yes	1.4/1.4	18/50	10/15	0.44/0.70	Yes
	ATAP	Yes	Yes	Yes	Yes	1.6/1.6	59/65	27/16	0.54/0.75	No
	FAP	No	Yes	No	Yes	None/1.3	None/65	None/15	None/0.77	Yes
	MSAP	Yes	Yes	Yes	Yes	0.8/0.8	20/50	10/15	0.50/0.70	–
2	PTAP	Yes	Yes	Yes	Yes	0.9/0.9	31/19	13/8	0.58/0.58	No
	ATAP	Yes	Yes	Yes	Yes	1.0/1.4	36/84	11/10	0.69/0.88	Yes
	FAP	Yes	Yes	Yes	Yes	0.8/1.4	28/62	11/9	0.61/0.77	No
	MSAP	Yes	Yes	Yes	Yes	1.4/1.4	49/67	10/11	0.80/0.84	–
3	PTAP	Yes	Yes	Yes	Yes	1.5/1.4	24/24	9/10	0.62/0.58	No
	ATAP	Yes	Yes	Yes	Yes	0.9/1.1	36/25	8/9	0.78/0.64	No
	FAP	Yes	Yes	Yes	Yes	1.0/1.2	22/35	5/10	0.77/0.71	No
	MSAP	Yes	Yes	Yes	Yes	0.9/0.9	18/26	5/8	0.72/0.69	–
4	PTAP	Yes	Yes	No	No	None/none	None/none	None/none	None	No
	ATAP	Yes	Yes	Yes	Yes	0.9/1.0	23/25	8/9	0.65/0.64	No
	FAP	Yes	Yes	Yes	Yes	1.0/1.0	35/42	12/13	0.66/0.69	No
	MSAP	Yes	Yes	Yes	Yes	1.1/1.3	40/44	10/11	0.75/0.75	–
5	PTAP	Yes	Yes	Yes	Yes	0.9/1.2	30/64	11/12	0.63/0.81	Yes
	ATAP	Yes	Yes	Yes	Yes	1.0/1.4	25/25	9/9	0.64/0.64	No
	FAP	Yes	Yes	Yes	Yes	1.0/1.4	27/60	6/9	0.78/0.85	No
	MSAP	Yes	Yes	Yes	Yes	1.3/1.3	40/53	10/11	0.75/0.79	–
6	PTAP	Yes	Yes	Yes	Yes	0.9/1.1	19/39	8/10	0.58/0.74	Yes
	ATAP	Yes	Yes	Yes	Yes	1.4/1.4	13/84	6/10	0.54/0.88	Yes
	FAP	Yes	Yes	Yes	Yes	1.4/1.0	13/62	6/9	0.54/0.86	Yes
	MSAP	Yes	Yes	Yes	Yes	1.4/1.6	67/52	11/24	0.84/0.54	–
7	PTAP	Yes	Yes	Yes	Yes	1.3/1.4	21/35	10/12	0.52/0.66	Yes
	ATAP	Yes	Yes	Yes	Yes	1.3/1.3	56/75	13/13	0.79/0.83	Yes
	FAP	Yes	Yes	Yes	Yes	1.5/1.5	19/34	9/10	0.53/0.71	Yes
	MSAP	Yes	Yes	Yes	Yes	1.1/1.2	24/31	12/13	0.50/0.58	Yes

(*Continued*)

Table 1 (*Continued*)

Patient no.	Perforator mapping	Perforator-confirmed AD pre-DSA	Perforator-confirmed AD post-DSA	Perforator-confirmed CCDS pre-DSA	Perforator-confirmed CCDS post-DSA	Perforator diameter (mm) pre/post-DSA	PSV cm/s pre/post-DSA	EDV cm/s pre/post-DSA	RI pre/post-DSA	Artery of intervention
8	PTAP	No	No	No	No	None/none	None/none	None/none	None	No
	ATAP	Yes	Yes	Yes	Yes	1.1/1.1	23/45	5/6	0.78/0.87	No
	FAP	Yes	Yes	Yes	Yes	1.0/1.2	10/28	5/7	0.50/0.75	Yes
	MSAP	Yes	Yes	Yes	Yes	1.1/1.2	21/31	5/8	0.76/0.74	–
9	PTAP	Yes	Yes	Yes	Yes	1.3/1.4	31/35	8/9	0.74/0.74	No
	ATAP	Yes	Yes	Yes	Yes	0.9/1.1	30/31	12/14	0.60/0.55	No
	FAP	Yes	Yes	Yes	Yes	1.0/1.0	21/29	6/8	0.71/0.72	No
	MSAP	Yes	Yes	Yes	Yes	0.9/0.8	20/23	5/5	0.75/0.78	–
10	PTAP	Yes	Yes	Yes	Yes	0.8/0.8	15/43	10/14	0.33/0.67	No
	ATAP	Yes	Yes	Yes	Yes	1.0/1.0	23/50	12/15	0.48/0.70	Yes
	FAP	No	Yes	No	Yes	None/0.9	None/10	None/8	None/0.20	No
	MSAP	No	No	No	No	None/none	None/none	None/none	None	–
Mean		36 yes/4 no	38 yes/2 no	35 yes/5 no	37 yes/3 no	1.14/1.16	21.9/27.2	9.4/11.4	0.63/0.71	

Abbreviations: AD, acoustic Doppler; ATAP, anterior tibial artery perforator; CCDC, color-coded duplex sonography; DSA, digital subtraction angiography; EDV, end diastolic velocity; FAP, fibular artery perforator; MSAP, medial sural artery perforator; PSV, peak systolic velocity; PTAP, posterior tibial artery perforator; RI, resistance index.
Notes: *Green color*—perforators not found, *light orange color*—patient no. 4 where PTA was unsuccessful, *dark orange color*—value of the perforator was paradoxically worse after PTA, *blue color*—value of the perforator was same after PTA, *red color*—mean calculation.

Table 2 Patients' data, defect description, arteriogram findings, and method of endovascular intervention

Patient no.	Age (y)	Gender	Mean BMI	Smoker	Comorbidity	Cause of defect/etiology	Local infection	Side of defect	Defect location	Defect size (cm × cm)	Abnormal arteriogram	Stenosis or occlusion	Endovascular intervention
1	72	M	27.5	Ex-smoker	DM, AH, atrial fibrillation, COPD	Diabetic ulcer	Gangrene	l.sin.	Heel, fingers II, III	5 × 3	Abnormal	AFS, ATP, AF	PTA
2	53	F	30.5	No	DM, AH, DLP, CHRI	Diabetic ulcer	None	bilat.	St.p. fingers amputation	3 × 2	Abnormal	ATA	PTA
3	64	M	20.5	Yes	CLI	Injury	None	l.sin.	Distal 1/3	5 × 4	Abnormal	AFS	PTA
4	72	F	26	Ex-smoker	AH, CLI	Impaired venous circulation	None	l.sin.	Distal 1/3	3 × 2	Abnormal	AFS, AP, ATP	Failed
5	72	F	33.3	No	DM, AH, DLP, CLI	Diabetic ulcer	None	l.sin.	Hallux	2 × 2	Abnormal	ATP	PTA
6	60	F	23.5	Ex-smoker	HCH, CLI, CHRI	Impaired venous circulation	None	l.sin.	Distal 1/3	10 × 5	Abnormal	ATP, ATA, AF	PTA
7	69	F	20.4	No	AH, DLP, CLI	Angiofibrosarcoma	Yes	l.dx.	Achilles tendon	8 × 6	Abnormal	AP, ATP, ATA, AF	PTA
8	81	M	28.5	No	DM, AH, CHRI, DLP	Diabetic ulcer	None	bilat.	Fingers I, II, III, IV, V	1 × 2	Abnormal	AFS, AP, AF	PTA
9	58	M	27.8	Yes	DM, st.p. CVA, AH	Diabetic ulcer	None	l.dx.	Hallux	1 × 1	Abnormal	AFS, AP	PTA
10	68	F	25.2	Yes	DM, AH, CVI, DLP	Combined etiology	None	l.sin	Multiple small	Few small	Abnormal	AP, ATP, ATA, AF	PTA

Abbreviations: AF, fibular artery; AFS, superficial femoral artery; AH, arterial hypertension; AP, popliteal artery; ATA, anterior tibial artery; ATP, posterior tibial artery; BMI, body mass index; CHRI, chronic renal insufficiency; CLI, critical limb ischemia; COPD, chronic obstructive pulmonary disease; CVA, cerebral vascular accident; DLP, dyslipoproteinemia; DM, diabetes mellitus; F, female; M, male; HCH, hypercholesterolemia; st.p., status post; l.sin., lateralis sinister; bilat., bilaterlis; l.dx., lateralis dexter.

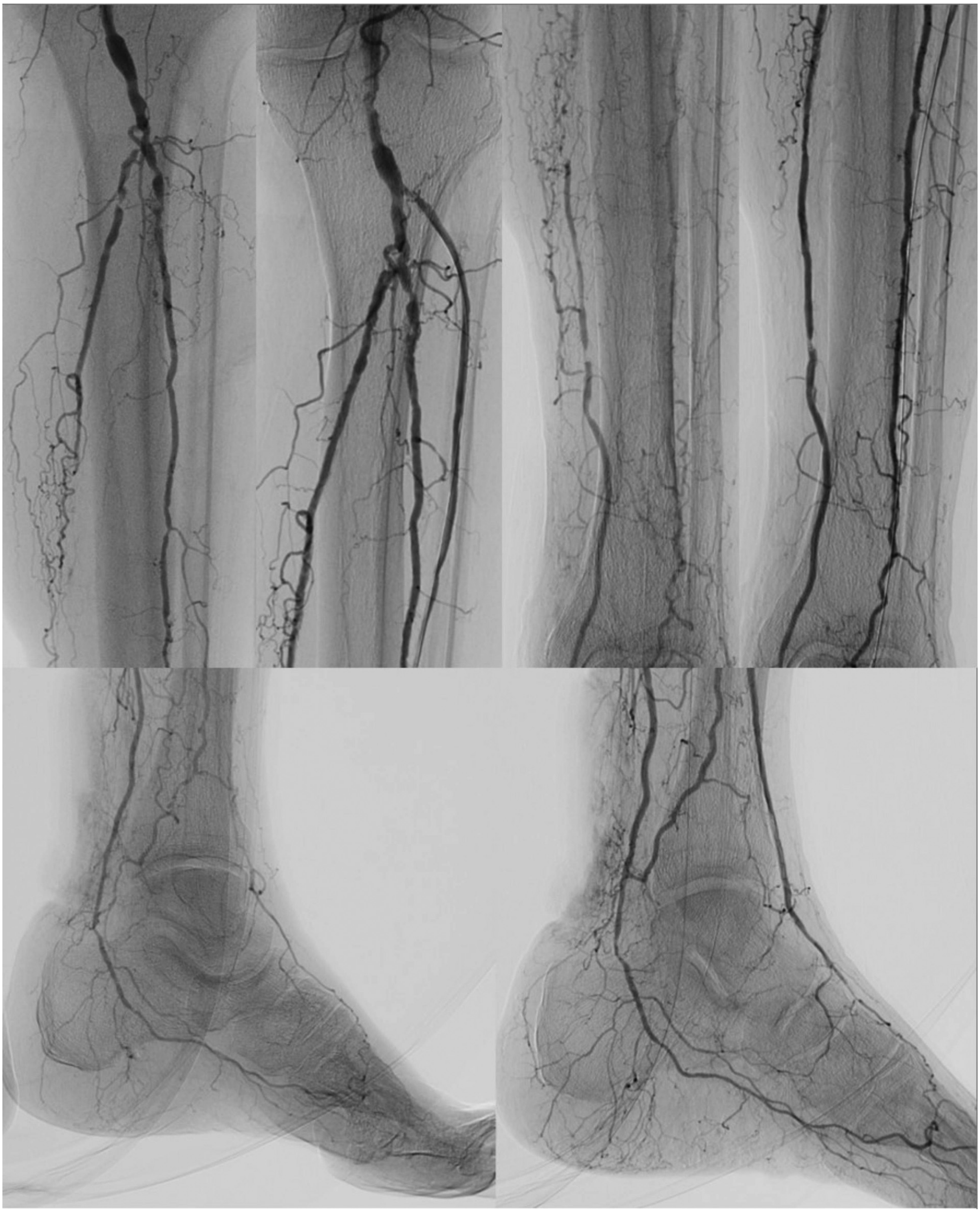

Fig. 4 Digital subtraction angiography right and left PTA (percutaneous transluminal angioplasty) of the AP (popliteal artery), ATP (artery tibial posterior), ATA (anterior tibial artery), and AF (fibular artery).

were observed in only two patients, whereas necrotic tissue was present in five cases. DSA revealed pathological arteriograms in all cases. PTAs were performed in all patients except for one, where the attempt was unsuccessful (►**Table 2**). The quantitative assessments of the perforators were conducted by using HHAD devices and CCDS measurements. Out of the expected 40 perforator locations, we were able to detect 37 stable perforators from the posterior tibial artery perforator, the anterior tibial artery perforator, the fibular artery perforator (FAP), and the medial sural artery perforator (MSAP) by using HHAD prior to and after PTA intervention in 90 and 95% of the cases, respectively. The same perforators were detected by using CCDS in 87.5 and 92.5% of the cases, respectively. The mean diameters of the perforators prior to and after PTA were 1.14 and 1.16 mm, respectively. The flow characteristics showed mean PSV of 21.9 and 27.2 cm/s, mean EDV of 9.4 and 11.4 cm/s, and mean RI of 0.63 and 0.71, respectively (►**Table 1**). Although there were only slight enlargements in the diameters of the perforators after PTA in almost half of the cases, there were significant increases in the perfusion values, with the PSVs increasing by 85.2% (from 21.9 to 27.2 cm/s) and the EDVs increasing by 88.2% (from 9.4 to 11.4 cm/s). The RIs also increased from 0.63 to 0.71. However, it is worth noting that two vessels showed decreased flow rates after PTA intervention (►**Table 1**).

Discussion

Chronic wounds in the lower leg continue to pose a significant burden on the health care system and have considerable socioeconomic consequences. Inadequate and delayed medical interventions can negatively impact morbidity, mortality, and the quality of life of the patients.[20] The definition of a chronic wound varies, with some authors suggesting a timeframe of 4 weeks instead of 3 months for a failure of the repair processes.[20] Despite the substantial number of patients worldwide suffering from nonhealing lower limb defects and their increasing trends due to an aging population, there are currently no standardized protocols for examination and treatment guidelines.

Given the complex and diverse etiologies of these wounds, as well as the presence of comorbidities, it is essential for the patients to be referred to specialists and for multidisciplinary collaboration to take place. In this study, we focused on the various aspects of reconstructive plastic surgery, specifically on stable perforator mapping and evaluation. We believe that understanding the flow-through system in arterial perforators will contribute to the further development of patient management guidelines. Before considering the use of a perforator flap to cover the defect, it is crucial to identify the most suitable perforator closest to the wound with optimal pulsation and blood volume in mind. Reliable preoperative navigation can optimize surgical strategies by providing a basic understanding of the stable anatomical locations of the perforating arteries and guiding plastic surgeons in determining the approximate size and orientation of the fasciocutaneous, musculocutaneous, or free flaps.

Our first step was to analyze, compare, and confirm the presence of stable perforators originating from the main arteries of the lower leg below the knee, as reported in the literature. According to Low et al,[4] stable perforators from the ATA can be classified into two main groups. The first group, the proximal perforators, predominantly from the intermuscular septae, are the largest and emerge 21 to 26 cm above the intermalleolar line. The second group, the distal perforators, which are smaller in size, are commonly found between the tendons of the muscles in the anterior compartment, 4 to 9 cm above the intermalleolar line. The largest perforators from the ATP are concentrated in three clusters located in the middle third of the septum between the soleus and the flexor digitorum longus muscles. These clusters are found at 4 to 9, 13 to 18, and 21 to 26 cm from the intermalleolar line. Most peroneal perforators are situated 13 to 18 cm above the lateral malleolus, emerging from the septum of the flexor hallucis longus and the peroneus brevis muscles. The distal perforators from the AP emerge approximately 5 cm proximal to the lateral malleolus.[4,11,14] Chaput et al[2] described two locations of perforators originating from the MSA, which branches off the AP. The first perforator is approximately 8 cm from the midpoint of the popliteal crease, whereas the second perforator is around 12 to 15 cm from the popliteal crease. Other authors have also mentioned similar locations for these perforators.

Finally, based on the literature, we may present a scheme illustrating the most stable locations of the perforators in their respective angiosomes. The most stable perforators from the ATA were found 12 to 17 cm distally from a transverse line connecting the lateral border of the patella and the lateral malleolus. The perforators from the ATP were located along a line connecting the medial tibial condyle and the medial malleolus, 4 to 9 cm above the medial malleolus, and 2 cm posterior to the line. The FAPs were identified 13 to 17 cm proximal to a line connecting the posterior border of the fibular head and the lateral malleolus. The MSAPs were localized 8 to 12 cm distally along a transverse line between the center of the popliteal fossa and the medial malleolus.

Out of the 40 previously defined areas representing the vascular territories of each main artery, we found at least one perforating artery in 37 locations both before and after DSA/PTA, except for three locations. When multiple acoustic signals were detected, we chose the strongest signal and correlated it with the findings from the TIC, the ultrasound scans, and, where available, CTA. In other words, we confirmed the presence of the same perforators in each patient by using three to four modalities simultaneously before and after carrying out DSA.

HHAD examination remains the gold standard due to its speed, affordability, and its use is relatively easy to learn. However, Doppler alone may not be sufficient in identifying especially small perforator locations and false positive results have been reported in up to 45% of the cases.[21] In our practice, when we are searching for perforators, we always start with acoustic Doppler examinations. We then compare the findings with the CT scans, although not all patients have CTA available at the time of the preoperative examination. In CT scans, we look for perforators as tiny vessels arising from the main trunks, and we can measure the distance in centimeters by using standard imaging software from easily palpable landmarks on the skin, such as the inferior border of the patella in the proximal–distal direction and the tibial crest in the sagittal direction. This allows us to transfer the measured distance onto the skin and approximate the location of the perforators. CT scans can guide the surgeon in identifying the perforating vessels, although they require some orientation skills. In this study, the efficiency of each perforator mapping by utilizing CTA was not correlated due to its unavailability in all cases.

The TIC was the next step in confirming the approximate location of the perforators. This relatively new and innovative method has been primarily used for assessing burn depth. Just like acoustic Doppler, it is affordable and requires minimal training. The TIC provides a basic orientation of "hotspots," indicating areas where perforators may be found as well as information about the complex vascular status of the lower limb and the wound's borders. However, thermal imaging is prone to thermal interference with the background and artifacts.[15] It is important to consider that venous temperature is usually higher than arterial temperature.[14] The hotspots identified by using thermal imaging represent the preliminary areas where the perforators may be present and should be confirmed with available supplementary methods.

Currently, CCDS is the most popular modality for preoperative vessel imaging in providing a model for navigation during surgery. Ultrasound-guided perforator mapping has significantly simplified the design of the perforator flaps and surgical planning. However, it is challenging to learn how to effectively detect low-flow microvessels, which device settings to use and of which ultrasound mode to choose, are all crucial decisions in achieving successful outcomes. CCDS provides sensitive data, including flow characteristics and microvessel diameters, thus allowing for the selection of the most suitable perforators for defect coverage. Systematic reviews of the literature have shown that CCDS has the highest sensitivity and positive predictive values for identifying perforators of the flaps in the extremities. Additionally, CCDS does not expose patients to radiation unlike CTA and DSA.

In our study, the HHAD method identified slightly more perforators in comparison to the CCDS method, which may be influenced by the lower specificity of HHAD. In three cases, we were unable to find any perforators. Two of these cases involved fully occluded main arteries, even after performing PTA, whereas in one case, the entire PTA intervention had failed. Interestingly, we observed that in two instances, perforators were not found before PTA but were present after the intervention procedures (►**Table 2**).

DSA or PTA is a standard procedure for diagnosing PVD and allows for endovascular interventions. According to Janhofer et al,[1] performing these procedures before reconstructive surgery allows for optimal flap vessel selection, with low complication rates and optimized flap survival. From our perspective, if there are no symptoms of PVD or other comorbidities related to impaired vascular function, waiting for these procedures can delay reconstructive surgery and increase the risk of wound superinfection. We found that perforators with relatively optimal calibers were present in 92.5% of the cases, even when the main arteries were subtotally occluded or showed tight stenoses on arteriography. This may be attributed to the presence of collateral arteries from the other main arteries. PTA does not significantly impact the lumen diameter of the artery, but it was noticeable in 16 microvessels. As expected, most perforators showed improved flow parameters after PTA, even when the main artery was not the target of the intervention. However, in a few cases, we observed the opposite effect, with decreased flow values after PTA interventions in three perforators (►**Table 2**). These perforators were not from the main arteries where the PTAs were performed. This effect could be due to false measurements or a steal phenomenon caused by the collateral arteries. Suh et al offered other explanations for this paradoxical effect in previously recanalized fully occluded vessels, such as a reocclusion of the arteries after PTA due to intimal lesions and thromboses or a narrowing of the lumens resulting from the accumulation of calcified plaques remaining within the lumen after angioplasty.[22]

Based on our findings, we recommend the following clinical practice algorithm for the preoperative evaluation of patients with chronic wounds:

- CTA should be performed in all patients with chronic wounds who are older than 50 years and have associated comorbidities. It should be performed prior to reconstruction, if feasible and without causing any delays in surgical interventions. CTA provides valuable information about the vascular system in general such as information about arterial stenoses, occlusions, and optimal perforator localizations, particularly with respect to defect localization.
- Perforator mapping for surgical planning should be conducted by using a combination of a HHAD device or a TIC to identify potential perforator locations. These findings should then be confirmed by using additional modalities such as CCDS or CTA by skilled plastic surgeon or radiologist.
- CCDS is particularly useful as it provides important data on flow characteristics and perforator diameters, enabling for the selection of the most suitable microvessels for reconstruction. CCDS has been shown to have high sensitivities and positive predictive values for identifying perforators in the extremities.
- DSA or PTA should be considered in patients with vascular pathology observed during the preoperative evaluation. These procedures allow for optimal flap vessel selection and can optimize flap survival, but they should be performed in a timely manner to avoid delaying surgical intervention.

It is important to note that our results were not conclusive, and further data from a larger and more representative sample of patients are necessary to better understand the vascular patterns in soft tissue and to improve the preoperative evaluation and planning for reconstructive surgery in patients with chronic wounds.

Conclusion

In conclusion, our study demonstrates that flap reconstruction can be effectively planned prior to DSA or PTA, even in patients with severely impaired peripheral vascular circulation. The identification of stable perforators is possible, regardless of the presence of arterial occlusions or stenoses. Furthermore, in older polymorbid patients, it is crucial to involve radiologists in the preoperative evaluation process. Successful PTA interventions can objectively improve the flow-through characteristics not only in the perforators but also in the entire lower leg, which ultimately has a positive impact on the overall outcome of the healing processes of the wounds. It is important to note that our study provides valuable insights into the planning and management of chronic lower leg wounds, but further research is needed to expand our understanding of soft tissue vascular patterns and to validate our findings.

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Conflict of Interest
None declared.

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