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Editorial

JOURNAL OF ENDOVASCULAR THERAPY
A SAGE Publication
An official publication of the ISEVS

Journal of Endovascular Therapy
1–3

DOI: 10.1177/15266028231187604
www.jevt.org
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Chronic Limb-Threatening Ischemia: When is Enough Enough?

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Keywords
ischemia, plantar acceleration time, contrast-enhanced ultrasound perfusion, angiography, revascularization

Following a successful and uncomplicated revascularization of the severely diseased superficial femoral artery under local anesthesia, a below-the-knee angiography reveals crural pathology while treating a patient with a diabetic foot ulcer. The patient gets uncomfortable due to back pain and the inability to hold the lower leg still. Nowadays, the interventionalist relies on some good old "eye-balling" to decide what to do next. Is the stenosis in the anterior tibial artery significant? Do we need to treat the crural vessels in the same session, although the patient is uncomfortable which increases the risk of complications? Why don't we have advanced tools to assess tissue perfusion accurately during arterial revascularisation? We definitely need to know when enough is enough. However, current daily practice is still to wait and see if the wound heals. This editorial calls for the development of novel techniques to quantify tissue perfusion during intervention, to ultimately guide intra-operative decision-making by the interventionalist. Fortunately, there are ongoing innovations in this field to help treat these vulnerable patients.

The increasing prevalence of chronic limb-threatening ischemia (CLTI) is becoming a pressing global health issue as it substantially impacts patient quality of life and places a significant burden on healthcare systems around the world.[1] Most patients with CLTI require revascularization, but despite all efforts, a substantial part of patients will eventually undergo a major amputation. Given the lack of information as described above, most of us tend to pursue aggressive treatment of all accessible lesions (including below the knee) due to the uncertainty of when to stop and the desire to treat with the mindset of "the first blow is worth a thaler." Additionally, for patients with both macrovascular and microvascular diseases, who are at risk of undergoing a major amputation in the future, aggressive intervention, and subsequent interventions may not have any effect. It is therefore clear that we need tools that can quantify peripheral vascular perfusion besides imaging only the macrovascular level. Currently some innovative tools are in the pipeline to be integrated into clinical practice, but data are still scarce.[2] Several preoperative modalities, including contrast-enhanced ultrasound perfusion, perfusion computed tomography (CT), various magnetic resonance imaging (MRI)-based perfusion techniques, planar scintigraphy or single-photon emission computerized tomography (SPECT)/CT imaging, are not appropriate for use during interventions.[3] On the other hand, there are perfusion assessment tools that are suitable during intervention to obtain a direct impression of distal tissue perfusion.

Duplex ultrasound (DUS) for instance can serve as an intraprocedural tool. Plantar acceleration time (PAT) and maximal systolic acceleration (ACCmax) are promising DUS parameters, which reflect distal perfusion of the arteries.[4–6] However, to the best of our knowledge no concrete data is yet published about the applicability of these modalities during intervention. Real-time measurement of tissue oxygen saturation is a simple and distinct way to monitor the regional tissue oxygen saturation in the skin and subcutaneous tissue during endovascular therapy. This technique might be useful in predicting wound healing intraoperatively, however, lack of reliability seems to impede clinical usability.[7,8] Another non-invasive modality is transcutaneous oxygen measurement, which has been shown to predict non-healing of wounds in several series.[8] The use of this technique besides clinical judgment is, however, still subject to debate.[9] One other category of potential intraprocedural tools utilizes optical imaging to capture high-resolution images of biological tissues and organs in the body. This type of imaging typically employs low-energy light sources, such as lasers or LEDs, to illuminate the tissue of interest. The light is then detected by a camera or other optical detector, which generates an image based on the light patterns that

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have been transmitted or reflected by the target tissue. For imaging during vascular procedures, it can be roughly categorized into two groups: the first uses light to distinguish specific tissue characteristics (such as oxygenated hemoglobin) and includes techniques such as laser speckle contrast imaging and (hyper/multi) spectral imaging.[10,11] The second group employs safe and straightforward intravenous contrast agents (indocyanine green is mostly used) to image and to evaluate perfusion. Following intravenous or intra-arterial administration, indocyanine green is confined to the vascular component, making it feasible for perfusion assessment. While illuminating the target area using near-infrared fluorescence imaging, the fluorescence pattern of indocyanine green can be described in time-intensity curves, enabling quantification of inflow and outflow.[12,13] Several cohort studies have shown significant improvement in this quantified perfusion assessment in patients before and after successful revascularization.[14,15] Studies exploring the value of this technique for the identification of the foot at risk during revascularization have yet to be performed.

A novel approach involves utilizing traditional angiography data to extract two-dimensional (2D) and three-dimensional (3D) perfusion angiographies.[16] This method allows for the monitoring of distal perfusion during interventions. 2D perfusion angiography uses postprocessing algorithms to acquire color map images and functional parameters, while 3D perfusion angiography is less frequently used and involves rotational angiography data. It can demonstrate improvement in perfusion of local tissue over time. Both of these techniques could prove directly useful to interventionists in identifying the relationship between areas of reduced perfusion and wound locations. A new area of imaging that aims to image and measure tissue perfusion is intra-arterial 4D-CT angiography in an interventional suite and during intervention. This technique merges dynamic perfusion CT imaging and intra-arterial digital subtraction angiography during intervention and is promising to provide valuable extra information during minimally invasive procedures.[17]

An enhancement beyond the realm of introducing new techniques involves managing the produced data during intervention in a more intelligent manner. By utilizing imaging data (intraprocedural DUS, angiography and/or optical imaging), computations can be made and ultimately combined with clinical data, such as wound healing. Advanced AI tools can then predict clinical outcomes based on medical imaging parameters.

In conclusion, it is crucial to reevaluate our approach to treating patients with CLTI. We should prioritize timely interventions that include assessment of perfusion during the procedure, with the goal of utilizing robust data to guide our actions in the future. Advancements in imaging technology and enhanced clinical decision-making support are essential for expanding our understanding and improving outcomes for CLTI patients.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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