# Assessment of lower extremity ischemia using smartphone thermographic imaging

Peter H. Lin, MD,[a,b] *and* Marius Saines, MD,[b] *Houston, Tex; and Los Angeles, Calif*

Conventional diagnostic modalities for assessing arterial circulation or tissue perfusion include blood pressure measurement, ultrasound evaluation, and contrast-based angiographic assessment. An infrared thermal camera can detect infrared radiation energy from the human body, which generates a thermographic image to allow tissue perfusion analysis. We describe a smartphone-based miniature thermal imaging system that can be used as an adjunctive imaging modality to assess tissue perfusion. This smartphone-based camera device is noninvasive, simple to use, and cost-effective in assessing patients with lower extremity tissue perfusion. Assessment of patients with lower extremity arterial ischemia can be performed by a variety of diagnostic modalities, including ankle-brachial index, absolute systolic ankle or toe pressure, transcutaneous oximetry, arterial Doppler waveform, arterial duplex ultrasound, computed tomography scan, arterial angiography, and thermal imaging. We herein describe a noninvasive imaging modality using smartphone-based infrared thermography. (J Vasc Surg Cases 2017;3:205-8.)

## IMAGING TECHNIQUE

During a recent 9 months ending in September 2016, eight patients with lower extremity arterial occlusive disease undergoing endovascular intervention or a surgical bypass procedure were evaluated using the FLIR ONE (FLIR Systems, Inc, Wilsonville, Ore) smartphone-based infrared thermal imaging camera. All patients underwent diagnostic studies including lower extremity arterial duplex ultrasound, infrared thermography, and ankle-brachial index evaluation before and after their interventions. The local Institutional Review Board approved this study. The miniature infrared thermographic camera is attached to a smartphone, and thermal images were taken using a simple point-and-shoot principle (Fig 1). We maintained the room temperature at 71°F to 73°F when thermal images were taken. Efforts were made to avoid taking thermal images adjacent to a source that emits heat energy, such as a window, heating vent, lamp, or computer. A distance of 2 feet between the thermal camera and the patient's leg was maintained in all thermal imaging evaluations.

All eight patients in our series underwent successful endovascular or surgical revascularization procedures. There was corresponding improvement in ankle-brachial indices and thermal imaging after their interventions (Tables I and II). The mean follow-up period was 7 months. Postoperative thermal imaging, ankle-brachial index, and arterial ultrasound were performed at 4 weeks after the interventions (Fig 2). Improvement of thermographic characteristics is recorded by the differential color gradation of the infrared thermographic images. Arterial duplex ultrasound similarly showed improved flow in the lower extremity circulation after the interventions.

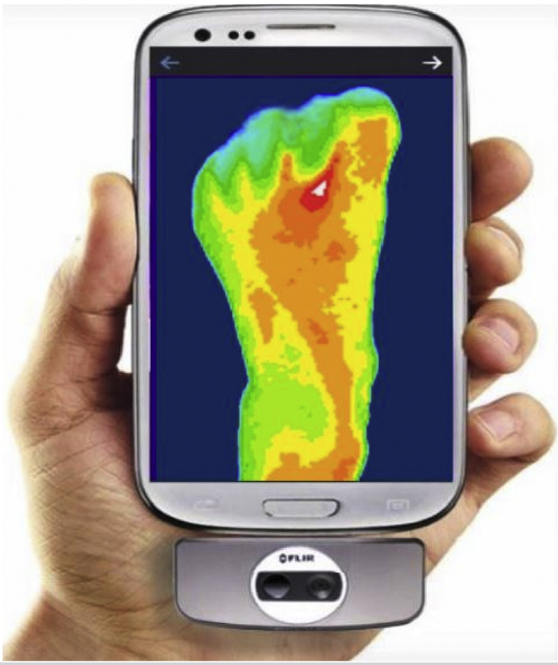


**Fig 1.** FLIR ONE thermal camera (FLIR Systems) is a smartphone-compatible device that captures thermal energy in the form of infrared radiation. The image shown in this smartphone is a left foot thermogram with normal tissue perfusion.

## DISCUSSION

Advances in smartphone technology in recent years have created wide enthusiasm for this hand-held device,

From the Division of Vascular Surgery and Endovascular Therapy, Michael E. DeBakey Department of Surgery, Baylor College of Medicine, Houston[a]; and the University Vascular Associates, Los Angeles.[b]

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Correspondence: Peter H. Lin, MD, Professor Emeritus of Surgery, Michael E. DeBakey Department of Surgery, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030 (e-mail: plin@bcm.edu).

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**Table I.** Clinical variables of eight patients undergoing endovascular or surgical revascularization

| Patient No. | Age, years | Presenting symptoms | | Interventions | Ankle-brachial index | | IT postoperative improvement |
|---|---|---|---|---|---|---|---|
| | | Rest pain | Foot ulcer | | Preoperative | Postoperative | |
| 1 | 68 | + | − | SFA stenting and atherectomy | 0.34 | 0.54 | + |
| 2 | 72 | + | + | Femorotibial bypass | 0.25 | 0.64 | + |
| 3 | 59 | + | − | Femoropopliteal bypass | 0.34 | 0.64 | + |
| 4 | 61 | + | + | SFA stenting and atherectomy | 0.41 | 0.53 | + |
| 5 | 73 | + | + | Iliac and SFA stenting | 0.37 | 0.63 | + |
| 6 | 74 | + | + | Femoropopliteal bypass | 0.45 | 0.67 | + |
| 7 | 68 | + | + | SFA stenting and atherectomy | 0.35 | 0.76 | + |
| 8 | 82 | + | + | Iliac and SFA stenting | 0.27 | 0.56 | + |

*IT,* Infrared thermography; *SFA,* superficial femoral artery.
All patients showed improvement of ankle-brachial index and infrared thermographic tissue perfusion after interventions.

**Table II.** Ultrasound results of patients undergoing endovascular or surgical revascularization

| Patient No. | Preoperative ultrasound finding | Interventions | Postoperative ultrasound finding |
|---|---|---|---|
| 1 | SFA occlusion | SFA stenting and atherectomy | Patent SFA stent |
| 2 | SFA and popliteal occlusion | Femorotibial bypass | Patent SFA and popliteal artery |
| 3 | SFA occlusion | Femoropopliteal bypass | Patent SFA bypass graft |
| 4 | 90% SFA stenosis | SFA stenting and atherectomy | Patent SFA stent |
| 5 | SFA occlusion, 70% iliac stenosis | Iliac and SFA stenting | Patent SFA stent |
| 6 | SFA occlusion | Femoropopliteal bypass | Patent SFA bypass graft |
| 7 | SFA occlusion | SFA stenting and atherectomy | Patent SFA stent |
| 8 | 90% SFA stenosis | Iliac and SFA stenting | Patent SFA stent |

*SFA,* Superficial femoral artery.

and this technologic revolution has spawned innumerable mobile applications and devices for health care providers in patient care. The FLIR ONE thermal camera was developed as a smartphone-mounted device that can capture thermal energy in the form of infrared radiation. The utility of this smartphone infrared thermographic camera has been highlighted in a recent report in which the perforator vessel patency was assessed in patients undergoing abdominal muscle flap reconstructions.[1] Our report underscores the utility of this smartphone-friendly imaging device in a vascular practice; this is a simple, effective, and inexpensive tool in assessing cutaneous temperature as an indirect measurement of tissue perfusion. This noninvasive imaging technique is particularly useful in evaluating patients with critical limb ischemia undergoing revascularization procedures.

The smartphone-mounted infrared thermographic camera used in our report can be purchased online for approximately $200 and is available for various smartphone models. The thermographic sensor captures long-wave (8-14 μm) infrared light energy and has an effective working temperature range of 32°F to 212°F. It contains both a thermal and digital camera that takes photographs simultaneously. To display the thermal image on the smartphone, a visible light camera takes an initial image that is digitally merged with the thermal image. We have found that these images may not be superimposed perfectly onto one another, particularly when the object of interest is too close to the camera. This presumably is due in part to the low-resolution nature and the miniature size of the thermographic camera. To optimize the imaging technique, we maintained a distance of 2 feet between the camera and the patient when taking thermographic images. It is anticipated that newer versions of the smartphone-compatible thermographic camera will have improved hardware and higher resolution to overcome these challenges.

Infrared thermography has been used extensively in the clinical setting. Conditions with inflammatory or neovascularization features, such as infection or neoplasm, can be detected using this technology in part because of their unique infrared thermal signals.[2,3] Clinical reports have underscored the clinical utility of infrared thermography as a breast cancer screening tool.[2,4] Researchers have lauded the utility of infrared thermography in differentiating melanoma vs benign cutaneous pigmented lesions.[5] Another report found this imaging modality to be effective in detecting vascular tumors, including