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*

ABSTRACT

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 and Innovative Techniques 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.

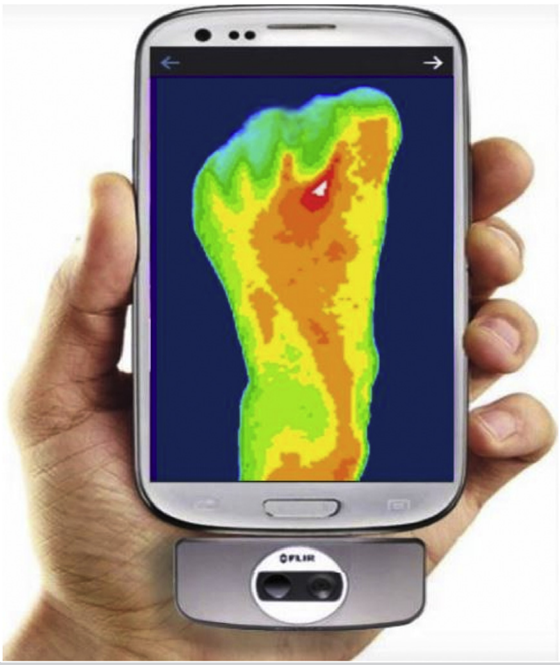

Fig 1. FLIR ONE thermal camera (FLIR Systems) is a smartphone-compatible device that captures thermal energy in the form of infrared radiation. The image shown in this smartphone is a left foot thermogram with normal tissue perfusion.

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.

DISCUSSION

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

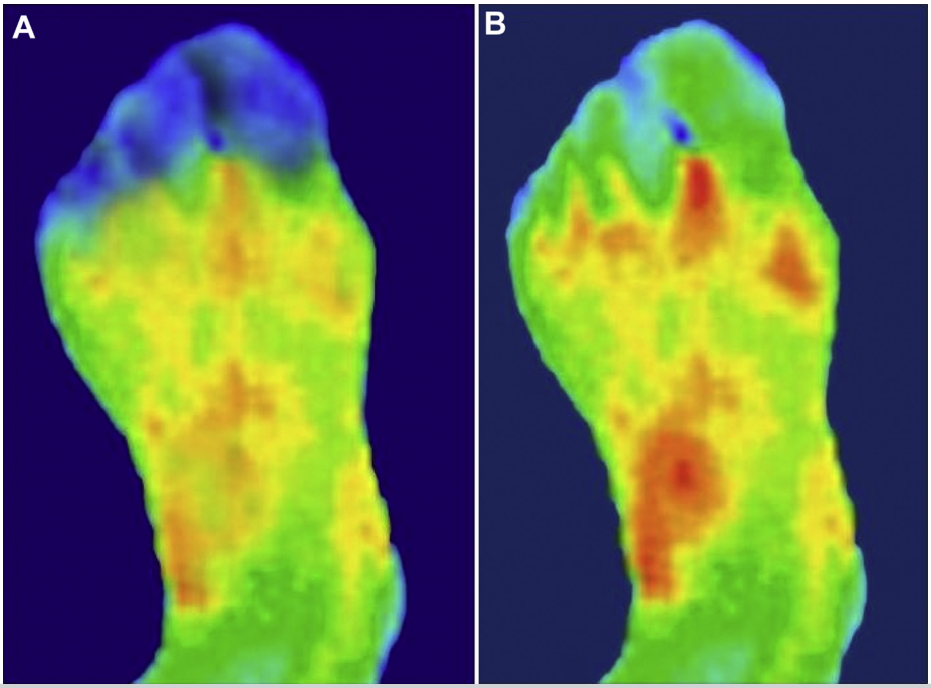

Fig 2. A, Preoperative infrared thermography in a patient (patient 2) with ischemic rest pain in the left foot and toes. **B,** Postoperative infrared thermography after femorotibial artery bypass demonstrated significant improvement in tissue perfusion in the toes.

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 cutaneous hemangiomas and arteriovenous malformation.[6] We recently reported the diagnostic utility of infrared thermography in a patient with Takayasu arteritis because of enhanced thermal signals in the carotid artery, and we subsequently used this imaging modality to assess disease progression after corticosteroid therapy.[7]

To enhance the image quality of the smartphone thermographic camera, Ko and Chiu described their imaging technique for detecting perforators in free flap reconstruction by using a "cold challenge test" in which a cold towel is applied to the area of interest for 30 seconds.[8] The cooled skin temperature would appear dark on the default color background, and the region of heightened thermal signals would appear as bright yellow or red. The contrasting color patterns produced a sharp visual distinction between the region of interest and the background tissue areas. To validate this imaging technique, we applied this method in our patients undergoing lower extremity revascularization and found this method to be impractical and uncomfortable in our patients as the cold towel typically exacerbated their lower extremity ischemic pain. Nonetheless, this imaging technique highlights the principle that sharper thermal images can be better appreciated when the background temperature is kept low. In contrast, when the thermal image is taken in a warm environment, such as adjacent to a heating unit, the sensitivity of the thermal imaging may be diminished because of the reduced temperature gradient between the background temperature and the object of interest. One potential drawback of this imaging modality is the heightened tissue temperature in the setting of infection, which may falsely represent adequate tissue perfusion.

Several researchers recently reported the utility of indocyanine green angiography (ICGA) as this technology provides real-time intraoperative assessment during vascular reconstruction regarding tissue viability based on fluorescent uptake.[9,10] In this imaging method, indocyanine green contrast dye is first injected intravenously, which is followed by ICGA using a laser light source and a charge-coupled camera. Whereas both ICGA and the smartphone-based infrared thermography provide real-time tissue perfusion assessment, ICGA may provide higher imaging resolution and possibly greater diagnostic sensitivity due to fluorescent-based tissue perfusion assessment. In contrast to ICGA, we believe the smartphone-based thermographic imaging technique is easier to use, more cost-effective, and likely to have a greater safety patient profile as it does not require intravenous injection of contrast material or expensive fluorescent imaging equipment.

CONCLUSIONS

The smartphone-based infrared thermal system is a noninvasive monitoring tool that provides real-time screening information of tissue perfusion based on infrared thermal signals. It is easy to use with minimal training required. As a hand-held device, it can be carried in the pocket just like a smartphone with great ease of access. This smartphone thermographic technology will likely improve with device refinement in the future, and it should not be regarded as a standard diagnostic modality in its current state. We believe this can provide helpful supplementary information about tissue perfusion in patients with arterial occlusive disease. Further studies are warranted to validate the diagnostic accuracy of this smartphone imaging modality.

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