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Smartphone Thermal Imaging as an Adjunct to Identify Free Flap Perforators and Assisting Flap Design: A Pilot Study

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ABSTRACT

Background: The main technique for identification of free flap perforator vessels is Doppler sonography, which is not always accurate, user dependent and affected by the patient's body habitus.

Methods: Adult patients undergoing head and neck resection and free flap reconstruction at two academic institutions were enrolled. Doppler sonography was used to identify perforators, and were marked using a skin marker. The donor site was cooled down for 3 min using a sterile iced saline bag. FLIR-ONE (FLIR Systems Inc., Wilsonville, OR) camera was used to assess for "hot spots" during a 3–5 min period of re-warming as a surrogate for cutaneous blood flow. The distance between the Doppler signal location, and the "hot spot" was recorded. The position of the perforator was then identified intraoperatively and the distances between the surgical position, the Doppler and "hot spot" were recorded.

Results: A total of 28 patients were included. For all flap types, FLIR thermal imaging measurements consistently tended to be closer to the surgical site compared to Doppler ultrasound. In anterolateral thigh flaps ($n = 20$), thoracodorsal artery perforator flaps ($n = 5$), and fibula osteocutaneous flaps ($n = 3$), absolute mean differences ranged from 0.62 to 1.33 cm, with trends favoring FLIR. While paired *t*-tests did not reach statistical significance, both methods correlated with intraoperatively identified skin perforators, and distances generally ranged between 0 and 2 cm.

Conclusion: We demonstrate that a smartphone-based thermal imaging system has the potential to serve as an adjunct for identifying flap perforators, with the possibility of reducing operative times and minimizing patient morbidity.

Level of Evidence: Level 3.

1 | Introduction

Cutaneous perforator flaps are commonly used in head and neck soft tissue reconstruction [1]. Effective reconstruction necessitates a thorough grasp of the underlying vascular anatomy, as the precise identification of perforators is imperative for the viability of the free flap. Currently, hand-held Dopplers, computed tomographic angiography (CTA), and magnetic resonance angiography (MRA) are the most common methods used for preoperative free flap planning. These methods have been shown to reduce operative time and donor site morbidity while enhancing the success of head and neck reconstructions [2].

While these methods have achieved success in contemporary reconstructive surgery, they have limitations that can hinder their effectiveness. CTA, for instance, is not performed in real-time and is not suitable for contrast-allergic patients or patients suffering from renal disease, in addition to being time-consuming and costly [3]. Moreover, CTA exposes individuals to excessive radiation, and the contrast agents used may pose a risk of nephrotoxicity. Pencil Doppler and Doppler imaging identification is limited by excess fat, movement, and anatomical/physiological variations, which can influence flow patterns and make it challenging to standardize Doppler imaging across patients [4]. Furthermore, color sonography typically generates complex anatomical images and thus its effectiveness relies on the technician's expertise [5]. Research has indicated that MRA can effectively visualize perforators with diameters exceeding 1.0 mm but is less accurate in depicting perforators with diameters below 1.0 mm [6]. Moreover, MRA is time-consuming and contraindicated for claustrophobic patients or those with metal implants. Recent technological advancements have introduced affordable thermal imaging cameras that can be attached to most smartphones (FLIR Systems). These devices enable real-time thermographic capture and integration with visible light cameras, aiding surgeons in identifying "hot spots" during surgery [7].

Thermal imaging is predicated on the primary mechanism for maintaining body temperature equilibrium which relies upon the skin's capacity for radiative heat loss into the surrounding environment [8]. This process is manifested through the emission of infrared radiation, which operates in the invisible range of the electromagnetic spectrum (700–1200 nm) [9]. Vital to this temperature regulation is our circulatory system, where blood serves as the primary medium for heat transport. Changes in local blood flow and perfusion have a direct impact on the skin's temperature [10]. Contemporary thermal imaging technology has harnessed this phenomenon, quantifying observed infrared radiation to interpret variations in skin temperature. These devices adeptly identify these variations as "hot spots" on the skin's surface, effectively serving as thermal markers. Each "hot spot" signifies regions where dominant perforators release elevated thermal energy, gradually revealing the surrounding vascular network associated with that perforator [11].

The objective of this current study is to determine whether smartphone thermal imaging can serve as a precise method for identifying perforator vessels commonly used in head and neck reconstruction, including: anterolateral thigh, fibula osteocutaneous, and thoracodorsal artery perforator flaps.

2 | Methods

Adult patients undergoing head and neck surgery and free flap reconstruction at Sunnybrook Health Science Centre and the University Health Network from 2022 to 2023 were enrolled in this pilot study. REB (Research Ethics Board) approval was obtained from both institutions. All patients enrolled in the study were approached during their pre-operative clinic visits or their stay in the pre-operative units and their written consents were obtained. The inclusion criteria were as follows: (1) patients who were 18 years or older and able to provide informed consent and (2) any patients undergoing free flap reconstruction of oncologic defects using anterolateral thigh free flap, fibula osteocutaneous free flap, and/or thoracodorsal artery perforator flap.

Known anatomic landmarks were marked as per routine protocol. Doppler sonography was used to identify potential perforators, and these were marked using a skin marker. The donor site was evenly cooled down for 3 min using a sterile iced saline bag. Next, the FLIR ONE (FLIR Systems Inc., Wilsonville, OR) smartphone-compatible thermal imaging camera was used to assess for "hot spots" within the planned harvest site during a 3–5 min period of re-warming as a surrogate for cutaneous blood flow; therefore, signifying a perforator. Photographs were taken both using the thermal camera and the regular smartphone color camera (Figure 1). Once the flap was harvested, the distance between the Doppler signal location, and the "hot spot" was recorded. The position of the perforator was then identified intraoperatively and the distances between the surgical position and the Doppler and "hot spot" were recorded. The distance from the surgical site to the Doppler signal and the "hot spot" was measured.

3 | Results

Doppler sonography images were obtained for 28 patients, of which 89% were males and 11% were females. The demographic information of the patients is summarized in Table 1. With regards to the free flap donor site, 71% were anterolateral thigh flaps, 11% were fibula osteocutaneous flaps, and 18% were thoracodorsal artery perforator flaps. The mean and standard deviations were calculated using Microsoft Excel (version 16.77). Since the data includes two measurements (FLIR and Doppler distances) taken from the same flap instance (e.g., anterolateral thigh flap) on the same patients, paired t-tests were performed to compare Doppler and FLIR imaging measurements across the three flap types. The analysis was conducted using the SPSS software program. After analysis, 39 hot spots and 39 cold spots were identified and obtained with a smartphone device. All patients in the study were noted to have at least one Doppler signal and at least one "hot spot." For the anterolateral thigh flaps ($n = 20$), the mean distance measured using FLIR was 1.14 cm (SD = 1.02), while the mean distance measured using Doppler was 1.77 cm (SD = 1.06), resulting in an absolute mean difference of 0.62 cm (95% CI: −1.29 to 0.04). The paired t-test approached statistical significance (t (19) = 1.95, $p = 0.066$),

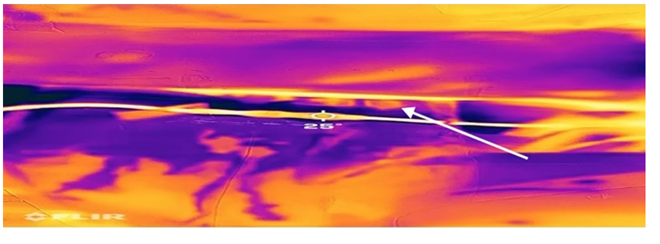

FIGURE 1 | Demonstrates FLIR ONE smartphone-compatible thermal imaging and the identification of hot spots as perforators. The arrow highlights a vessel, indicating a hot spot.

suggesting a trend toward Doppler measurements being larger than FLIR measurements. For the thoracodorsal artery perforator flaps ($n=5$), the mean FLIR distance was 0.20 cm (SD = 0.45), compared to 1.50 cm (SD = 0.71) for Doppler, with an absolute mean difference of 1.30 cm (95% CI: −2.92 to 0.32). Although the paired *t*-test was not statistically significant ($t(4)=2.23$, $p=0.090$), the results demonstrated a trend toward FLIR measurements being closer to the flap compared to Doppler measurements. For the fibula osteocutaneous flaps ($n=3$), the mean FLIR distance was 0.50 cm (SD = 0.29), while the mean Doppler distance was 1.83 cm (SD = 0.76), with an absolute mean difference of 1.33 cm (95% CI: −2.64 to −0.03). The paired *t*-test approached statistical significance ($t(2)=4.00$, $p=0.057$), indicating that FLIR measurements were closer to the flap compared to Doppler measurements.

TABLE 1 | Patient demographics.

Characteristics	Value
Number of patients	28
Median age, years (range)	65 (56–78)
Gender	
Male	25 (89.3%)
Female	3 (10.7%)
Primary cancer	
Mucosal squamous cell carcinoma	28 (100%)
Ethnicity	
Caucasian	19 (67.9%)
Indigenous	2 (7.1%)
South Asian	2 (7.1%)
East Asian	2 (7.1%)
Black	1 (3.6%)
Hispanic/Latino	1 (3.6%)
Middle Eastern	1 (3.6%)
Median BMI, kg/m^2 (range)	25.2 (16.8–41.7)
Underweight (< 18.5)	4 (14.3%)
Normal Weight (18.5–24.9)	11 (39.3%)
Overweight (25.0–29.9)	7 (25.0%)
Obese (Class I) (30.0–34.9)	4 (14.3%)
Obese (Class II) (35.0–39.9)	1 (3.6%)
Obese (Class III–Severe) (≥ 40.0)	1 (3.6%)

Both markers correlated with an actual skin perforator identified intraoperatively. The distance from the surgical site to the Doppler signal and to the "hot spot" generally ranged between 0 and 2 cm. Results are summarized in Table 2. Overall, while none of the comparisons reached statistical significance at the conventional threshold ($p<0.05$), there was a consistent trend across all flap types—FLIR measurements tended to be closer to the flap compared to Doppler ultrasound measurements.

4 | Discussion

The use of smartphone thermal imaging to identify potential perforators is a novel technology that can be used in the armamentarium of the surgeon. FLIR is based on the principle that temperature rises lead to heightened radiation emissions, particularly in areas with high vascularization, known as "hot spots" [12]. These "hot spots" have traditionally been captured by an infrared camera; however, the results of this study indicate that smartphone thermal imaging systems can accurately identify the position of the perforator intraoperatively and thus can be as effective as the current gold standard during flap harvest which can serve as an adjunct to identify the perforators by providing quick real-time visual feedback to the surgeon in the form of a heat map. This technique may allow reconstructive surgeons to design free flaps more precisely by capturing these "hot spot" areas in their cutaneous incisions.

Prior studies have depicted the efficacy of using smartphone thermal imaging in detecting potential perforators. Within plastic surgery literature, researchers conducted a study with 10 plastic surgery reconstruction patients, using the FLIR ONE smartphone thermal imaging camera to potentially identify anterolateral thigh and deep inferior epigastric artery perforators [13]. Ultimately, they were able to successfully locate "hot spots" corresponding to the known anatomical locations of these perforators.

Moreover, smartphone thermal imaging is a cheap, portable, and accessible method of perforator identification. The average cost of the smartphone thermal imaging system can range from $250 to 400 USD depending on the model of the device. One of the benefits of smartphone thermal imaging is its low variability when identifying perforator location among technicians and medical professionals. Furthermore, FLIR requires minimal training and there are no reported adverse effects as it doesn't involve contrast or ionizing radiation risk [14]. Other studies have also attested to the efficacy of smartphone thermal imaging in identifying potential perforators in soft tissue defect reconstruction. In a study conducted by Pereira et al., smartphone thermal imaging presented a sensitivity of 100% and a specificity

TABLE 2 | Results summary.

Flap type	Sample size	Mean FLIR distance (cm)	Mean Doppler distance (cm)	Absolute mean difference (cm)	*t*-statistic	*p*
ALT	20	1.14	1.77	0.62	1.95	0.066
TDAP	5	0.20	1.50	1.30	2.23	0.090
Fibula	3	0.50	1.83	1.33	4.00	0.057

of 98% in identifying potential perforators and these results were comparable to the current gold standard of identifying perforators—CTA—and thus depicts its value in modern-day perforator detection [7]. Sheena and colleagues also demonstrated that for the anterolateral thigh flap, 94% of the thermal imaging-identified hot spots corresponded with an audible Doppler signal [15]. Our findings demonstrate a strong concordance in perforator identification between thermal images captured using a smartphone device and Doppler sonography.

However, discrepancies between thermal imaging and Doppler can arise, particularly in challenging cases. While FLIR excels in detecting surface temperature variations, its reliance on superficial thermal signals can result in the under-detection of deeper perforators located beyond 2 cm in the subcutaneous tissues. Such limitations can be particularly problematic in patients with thick adipose tissue, scars, or variations in local vascular anatomy, where surface temperature changes may not adequately reflect deeper vascular structures [16]. In contrast, Doppler sonography provides audible feedback of blood flow independent of depth, allowing for greater accuracy in identifying deeper vessels that may remain undetected on thermal imaging [15].

Additionally, in circumstances where surrounding tissue perfusion is compromised, such as in irradiated or traumatized areas, the ability of thermal imaging to identify clear "hot spots" may be diminished. The reduced skin perfusion in these cases can obscure thermal variations that otherwise signal underlying perforators, whereas Doppler imaging may still detect residual blood flow and thus remain more reliable in such contexts [17]. These discrepancies emphasize the need for surgeons to integrate multiple imaging modalities, combining the speed and ease of thermal imaging with the depth precision of Doppler sonography.

Despite its proven efficacy in identifying viable perforators, there are additional limitations to using smartphone thermal imaging. For instance, while FLIR is accurate in identifying the location of perforators, it does not provide much data on the origin or path of the vessel [7, 16]. Second, in contrast to the three-dimensional information provided by CTA or MRA, any anatomical data provided by smartphone thermal imaging is presented as a superficial two-dimensional map. Therefore, it remains crucial for the surgeon to maintain a comprehensive understanding of the local vascular and flap anatomy when interpreting these images [17]. Moreover, as smartphone thermal imaging provides a two-dimensional map, its information is limited to superficial structures, typically up to a depth of 2 cm, as it relies on surface skin temperature gradients. As discussed above, deeper perforators located within subcutaneous tissues or underlying muscle may remain undetected, limiting its utility in certain flap planning scenarios. In such cases, CTA remains the preferred modality for precise identification and mapping of deeper vessels [18].

Finally, it's important to acknowledge the limitation of the small sample size in our study. As indicated previously, while none of the comparisons reached statistical significance at the conventional threshold, there was a consistent trend across all flap types. FLIR measurements tended to be closer to the flap compared to Doppler ultrasound measurements. A future study with a larger sample size is needed to corroborate our findings more comprehensively to determine whether in fact measurements captured by FLIR imaging are more accurate than those captured via Doppler sonography. Nonetheless, this pilot study suggests a significant role for smartphone thermal imaging in perforator localization, including but not limited to supplementing current techniques for perforator localization and quickly detecting perforators before Doppler imaging, among various other applications. The integration of both methods can potentially mitigate discrepancies and provide a more comprehensive assessment of perforators, enhancing precision in flap planning and execution.

5 | Conclusion

Thermographic images captured using a smartphone thermal camera potentially demonstrate strong agreement with the established gold standard for perforator detection in free flap reconstruction. The efficacy of the smartphone thermal camera was found to be on par with Doppler sonography, rendering it as a valuable tool for perforator mapping. Thermal camera offers rapid real-time visual feedback to the surgeon in the form of a heat map as a surrogate for skin blood flow. A limitation of this study is its small sample size. To establish the use of smartphone thermal imaging as a valuable tool in free flap planning, larger controlled trials are necessary. This study strongly suggests there is a beneficial role of smartphone thermal mapping for the free flap microvascular surgeon.

Conflicts of Interest

The authors declare no conflicts of interest.

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