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Original Article

Free Flap Monitoring Using Infrared Thermography: An Objective Adjunct to Clinical Monitoring

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Abstract

Background Early detection of free flap compromise is critical for salvage of the flap. Various methods of free flap monitoring have been described, but clinical assessment is the standard method for among all. In this study, role of infrared thermography is evaluated for free flap monitoring.

Methods In patients undergoing free flap surgery, monitoring was done using standard clinical parameters and infrared thermography as per our institutional protocol. Mean temperature difference (ΔT) between the flap and the surrounding skin was calculated using the temperature readings from the thermal images intra- and postoperatively. The accuracy of infrared thermography in flap monitoring was assessed in comparison to the standard clinical protocol.

Results Forty-one flaps were included in the analysis, out of which five flaps got compromised. It was observed that the mean temperature difference was higher (mean ΔT 0.20–0.59 vs. 2.38–3.32) when there was a flap compromise, and this temperature difference was evident even before the development of clinical signs. The temperature difference in venous thrombosis (mean ΔT 1.0–2.7) was found to be slightly lower than in arterial insufficiency (mean ΔT 2.1–4.4). For a ΔT cutoff value of 2°C, the thermal camera had a sensitivity of 88.6%, specificity of 98.9%, positive predictive value of 93.9%, and negative predictive value of 97.7%.

Conclusion Infrared thermography is a valuable and noninvasive objective tool in free flap monitoring, which can detect flap compromise (increasing value of ΔT) even before it becomes clinically evident.

Keywords
- thermal imaging
- free flaps
- infrared thermography
- free flap monitoring

Introduction

With advancement and refinement of microsurgical techniques, free flaps have now become the first choice of the reconstructive elevator with proven success rates around 95%.[1] The result of the free-tissue transfer is decided by adequate tissue perfusion via patent arterial and venous anastomoses until growing peripheral vessels establishes the neovascularization.[2]

Compromised circulation of a free flap needs to be corrected within 6 to 8 hours, otherwise salvage of such flaps becomes nearly impossible because of the phenomenon known as “no-reflow.” Therefore, early detection of vascular

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compromise is essential to maximize the chances of salvage and thus success of free flaps.[2]

At present, clinical assessment is the standard method for free flap monitoring that includes flap's physical characteristics, capillary refill time, temperature, and bleeding characteristics after a pinprick. Flap monitoring is usually performed every 2 hours in first 24/48 hours then 4 to 6 hours till fifth postoperative day. Other methods of flap monitoring are blood sugar monitoring of flap and patient, implantable Doppler, microdialysis, etc., but most of these are invasive. A quick, simple, reliable, and easily applicable objective method of monitoring is required to detect the compromise of a free flap early.[3]

Infrared thermal (IRT) imaging is one such method that is noninvasive and simple that has been reported to be used for free flap monitoring. It is based on the principle that an increase in body temperature (due to increased vascularity or metabolic activity) causes a proportionate increase in the amount of infrared radiation emitted. The IRT camera converts infrared energy into a digital image (thermogram). The device can be attached to a smart phone that allows thermal images and their digital counterparts to be readily viewed.[4]

This study was planned to evaluate the accuracy and efficacy of infrared thermography in monitoring free flaps compared with clinical assessment.

Materials and Methods

All patients undergoing free flaps from June 2021 to June 2023 were included in the study after obtaining written informed consent. The patients in whom the skin paddle was unavailable or not accessible for monitoring were excluded. Ethical clearance (AIIMS/IEC/2021/3850) was obtained from institutional review board.

Study Protocol

In each patient undergoing free flap surgery, IRT images were taken intraoperatively and postoperatively. Intraoperative thermal images were used for the assessment of re-establishment of perfusion of the flap after microvascular anastomosis and postoperative images, from the flap and surrounding skin, were used for flap monitoring.

Intraoperative thermal images were taken from the flap and the surrounding skin at three points: before and after pedicle division and after vascular anastomosis to look for reestablishment of perfusion. The temperature difference between the flap and skin was calculated and used to confirm flap rewarming. Standard clinical protocol for flap monitoring was followed in all patients and decision for re-exploration was based on clinical assessment only.

Flap Monitoring

The flap was monitored each time using clinical assessment and thermal imaging. Postoperative clinical assessment and thermal images of the flap were taken every 2 hours for the first day, every 4 hours for the second day, and every 12 hours till postoperative day 5.

Clinical assessment was done using flap color, flap turgor, and bleeding pattern from the flap using pinprick with a 25-gauge needle. Based on the clinical assessment, the hours taken for detection of flap compromise were noted.

Imaging Protocol

The images were captured using FLIR thermal camera (FLIR Systems, Inc., Arlington, VA, United States, model number 435–0005–03) and its associated software with a temperature detection range from −20°C to 120°C. The flap was arbitrarily divided into four quadrants and images were taken from each quadrant of the flap. The mean temperature of the flap was calculated using the temperature displayed on the image from each quadrant. Similarly, four images were taken from the adjacent normal skin, and the mean temperature of the normal skin was calculated. The difference in the mean temperature (ΔT in Centigrade) between the flap and the surrounding skin was calculated. ΔT was compared between the compromised and viable flaps.

Data was analyzed using Statistical Package for Social Sciences (SPSS) version 28. The mean of the temperature difference between adjacent skin and flap before and after pedicle division and after anastomosis was calculated in all flaps. In both arterial and venous compromised flaps, mean time (hours) taken for vascular compromise to appear clinically was calculated. Independent samples *t*-test was used to compare the means of ΔT between the viable and compromised flap groups. The receiver operating characteristic (ROC) curve was conducted to evaluate the diagnostic accuracy of infrared thermography in assessing vascularity. Sensitivity, specificity, negative predictive value, and positive predictive value of infrared thermography were calculated. A p-value less than 0.05 was considered to be significant.

Results

Forty-one patients (32 males and 9 females) undergoing free flap reconstruction were included in the study. The mean age of the patients was 45.36 years (age range: 18–71 years). The most common cause for free flap reconstruction was malignancy (31), followed by posttraumatic defects (10).

Anterolateral thigh flaps were done in 70.7% of the patients, followed by free fibula flap (17.1%). Radial artery forearm flap, deep inferior epigastric perforator (DIEP) and medial sural artery perforator flaps were done in 7.3, 2.4, and 2.4%, respectively.

In the intraoperative infrared image analysis, the mean of the temperature difference between adjacent skin and flap before and after pedicle division and after anastomosis was found to be 0.934, 3.412, and 0.922, respectively (►**Fig. 1A–E**). The temperature difference between the flap and surrounding skin after the pedicle division was higher showing a loss of circulation leading to fall in temperature. After anastomosis, the mean value of difference in temperature of all the flaps with their adjacent skin was less than 1°C showing that the blood supply was re-established and the flap was rewarmed.

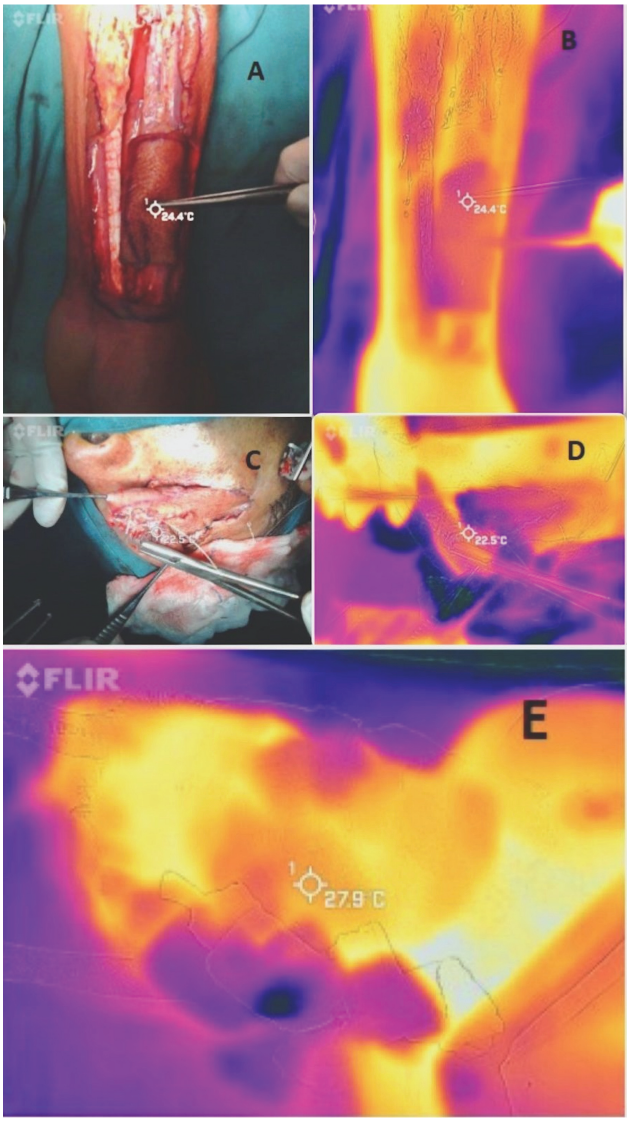

Fig. 1 (**A**) Clinical image of the free radial forearm flap before pedicle division. (**B**) Thermal image of same flap showing 24.4°C before flap division. (**C**) Clinical image of flap after pedicle division and inset for defect after wide local excision of basal cell carcinoma lateral canthus right eye. (**D**) Thermal image after pedicle division and inset showing temperature of 22.5°C. (**E**) Thermal image showing adjacent skin temperature after vascular anastomosis showing temperature of 27.9°C.

On clinical assessment, in the flap monitoring phase, five flaps were found to have signs of vascular compromise at 9.2 mean hours out of which venous thrombosis was detected in three patients at mean 8.6 hours and arterial insufficiency was found in two patients at mean 10 hours. All the compromised flaps were re-explored and were salvaged.

Flap monitoring with IRT imaging showed a temperature difference (ΔT in °C) in the range from 0.208 to 0.598 (mean ΔT 0.150) in viable flaps and from 1.0 to 4.4 (mean ΔT 2.42) in compromised flaps. The difference in mean ΔT in both groups was found to be statistically significant (*p*-value 0.01). ΔT was higher in cases of arterial insufficiency (2.1–4.4) than venous thrombosis (1–2.7). The flap monitoring, with clinical assessment and imaging, for the compromised flaps has been presented in ►**Table 1** and clinical and thermal images of a postoperative flap monitoring are shown in ►**Fig. 2A–G**.

The ROC curve and its area under the curve (AUC) were calculated and have been presented in ►**Fig. 3**. Based on AUC value and associated metrics, at cutoff value at 2.0°C, sensitivity of 88.6%, specificity of 98.9%, positive predictive value of 93.9%, and negative predictive value of 97.7% were calculated. It was found that while thermal camera could detect all the compromised flaps within 6 hours, clinically only one flap could be detected by that duration.

Discussion

IRT has been used in medicine for various indications such as diagnosis of breast cancer,[5] neurological diseases,[6] peripheral vascular diseases,[7] and infective pyrexia screening.[8] Its use in identification of perforators[9] and intraoperative flap integrity[10] has been investigated, Recently, its usefulness in flap perfusion monitoring has gained momentum because it is simple, low cost and noninvasive modality.

In this study, infrared thermography is found to be a good objective method to assess flap rewarming after vascular anastomosis. If ΔT is more than 1°C, it should raise suspicion about poor flap perfusion after vascular anastomosis. Weerd[10] et al investigated the role of IRT in intraoperative DIEP flap monitoring and concluded that it is a valuable method for assessment of flap rewarming.

Table 1 Temperature difference (ΔT in °C) between flap and adjacent skin of all compromised flaps and time taken from clinical assessment

	Intraoperative[a]			Postoperative						Clinically detected (hours)
	ΔT1	ΔT2	ΔT3	ΔT1 2 hours	ΔT2 4 hours	ΔT3 6 hours	ΔT4 8 hours	ΔT5 10 hours	ΔT6 12 hours	
1	1.5	3.4	0.1	1.2	1.0	1.8	–	–	–	6
2	0.9	3.3	1.1	4.0	3.2	2.7	2.5	4.0	–	10
3	0.4	3.4	2.6	2.5	2.1	1.0	2.7	2.2	–	10
4	0.7	3.0	1.1	2.1	2.3	2.9	4.2	4.4	–	10
5	0.6	4.7	3.0	2.1	2.4	2.1	2.5	2.7	–	10
Mean	0.82	3.56	1.58	2.38	2.20	2.10	2.96	3.32	–	9.2

[a]Intraoperative ΔT1, ΔT2, ΔT3 refer to temperature difference after flap raising, after pedicle division, and after anastomosis, respectively.

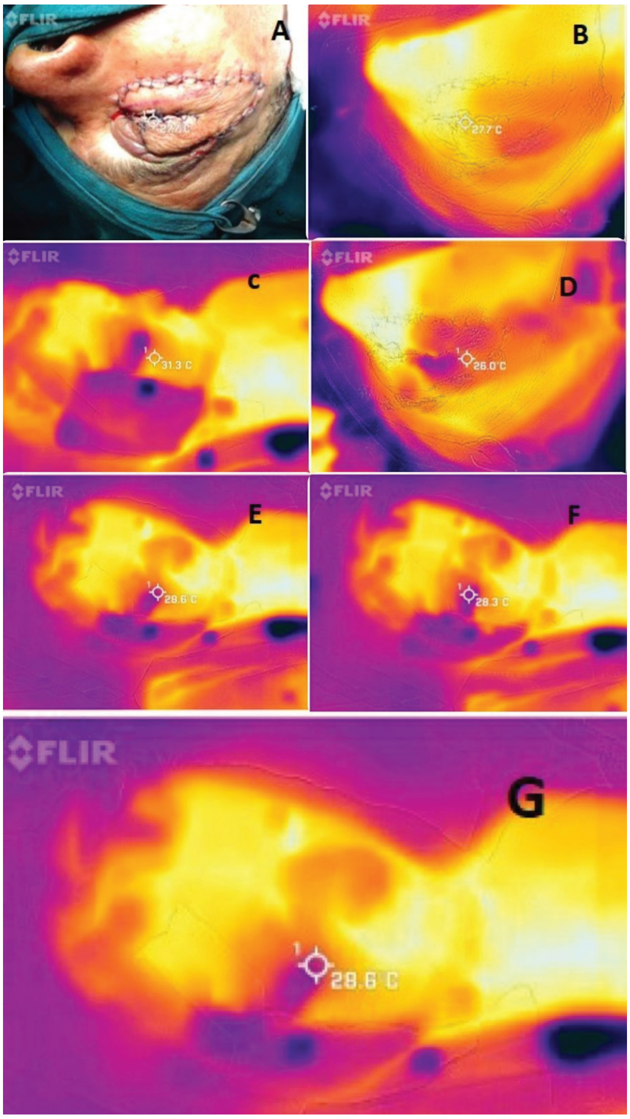

Fig. 2 (**A**) Clinical image showing flap 2 hours postoperatively. (**B**) Thermal image showing flap temperature 2 hours postoperatively. (**C**) Thermal image showing adjacent skin temperature 2 hours postoperatively. (**D**) Thermal image showing flap temperature 4 hours postoperatively. (**E**) Thermal image showing flap temperature 6 hours postoperatively. (**F**) Thermal image showing flap temperature 8 hours postoperatively. (**G**) Thermal image showing flap temperature 10 hours postoperatively.

It was also observed that IRT could detect the flap compromise as early as 2 hours postoperative in comparison to clinical examination that could detect flap compromise earliest at 6 hours. The findings are aligned with the study done by Just[11] et al which found IRT can detect flap compromise even before macroscopic changes become evident. Cruz-Segura[12] et al which reported that IRT can detect vascular compromise from few minutes to several hours earlier than clinical assessment.

Flap monitoring with IRT imaging showed a temperature difference (ΔT in °C) in the range from 0.208 to 0.598 (mean ΔT 0.150) in viable flaps and from 1.0 to 4.4 (mean ΔT 2.42) in compromised flaps. With IRT statistically significant difference was found in mean ΔT between viable and compro-

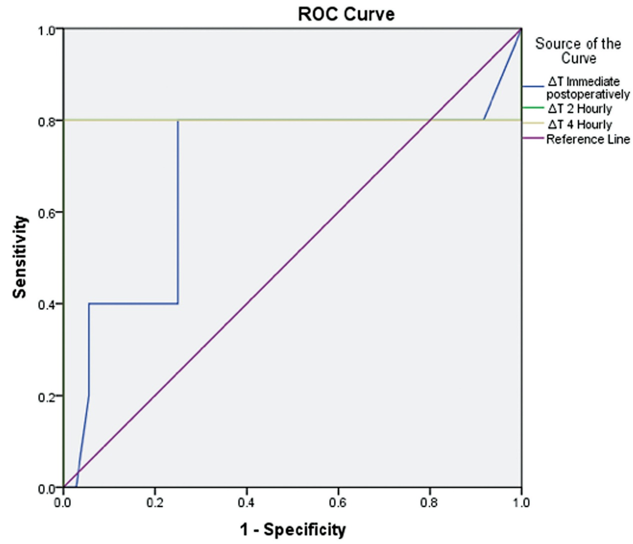

Fig. 3 Receiver operating characteristic (ROC) curve at cutoff value (ΔT) of 2°C.

mised flap. Chava [13] et al reported range of temperature difference of 0.1 to 1.8°C (mean 1°C) in viable flaps, while compromised flaps showed temperature from 2.4 to 5.4°C. Pappilon[14] et al reported temperature difference of 1.5°C in viable flaps and 3.7°C in compromised flaps in a study of 47 free flaps.

It was observed that ΔT in compromised flaps due to venous thrombosis was also higher than viable flaps. However, it was found that the temperature difference in compromised flaps due to venous thrombosis was lower as compared with that due to arterial insufficiency. Therefore, IRT can detect flap compromise due to both venous and arterial insufficiency. Phillips [15] et al used mobile smartphone thermal imaging devices to study blood flow in patients undergoing DIEP free flaps for breast reconstruction obtaining images preoperatively, intraoperatively, and at instances of concern for flap viability. Flaps with arterial insufficiency and venous congestion showed temperature of 28.3 ± 1.9°C and 27.2 ± 0.7°C, while the viable flaps showed temperature of 32.2 ± 1.8°C. Shokri and Lighthall[16] evaluated IRT with indocyanine green (ICG) fluorescence angiography for flap perfusion monitoring in pedicled and free flap and concluded that IRT is an cost-effective method to assess tissue perfusion.

The sensitivity, specificity, positive and negative predictive value for IRT using cutoff values at 2°C were found to be 88.6, 98.9, 93.9, and 97.7%, respectively. Cruz-Segura[12] et al in his study of 2,364 recordings in 40 free flaps reported the sensitivity of 90%, specificity of 85%, positive predictive value of 22%, and negative predictive value of 99 at cutoff. Khouri and Shaw[17] reviewed 62 compromised flaps with surface temperature recording and found the sensitivity of 98% and its predictive value as 80%.

Clinical assessment is still considered as a gold standard method for free flap monitoring that requires certain level of expertise. Early career microsurgeons or trainees may misread the clinical signs because of its subjective nature.[18]

Moreover, continuous clinical observation imposes a heavy workload on medical staff, increasing the risk of misdiagnosis.[19] Several objective methods have been described for flap monitoring. While adjunctive hemodynamic monitoring techniques like laser Doppler flowmetry (LDF), ICG, tissue oximetry, and color Doppler ultrasound have shown effectiveness, they suffer from limitations. LDF, for instance, is seldom used postoperatively due to its high cost and cumbersome operation.[20] ICG, although accurate, is invasive and costly, making it unsuitable for patients with dye allergies.[21] Similarly, tissue oximetry, while offering continuous monitoring, may not be applicable to certain types of flaps and incurs high economic costs.[22] Because of these limitations, clinical assessment is still widely used method for flap monitoring.

Infrared thermography is objective, noninvasive, simple, quick, and cost-effective method of flap monitoring, but this method has also some limitations. Surface skin temperature measurement is influenced by external factors like environmental temperature, humidity, and light. Internal factors like differences in individual body temperature and different body regions also influence the surface temperature.[23] Taking temperature difference (ΔT) rather than absolute value minimizes these influences.[11,13] Thermal sensitivity of the imaging device is another concern, more with the low-resolution thermal devices.[24] Initially IRT devices were cumbersome, nonportable, and costly but smartphone-based thermal camera is promising in accessibility and cost-effectiveness. Randomized control trials with bigger sample size may provide further conclusive evidence of utility of IRT in intra- and postoperative perfusion assessment.

Conclusion

Though clinical assessment is widely used subjective method for evaluating the viability of flaps, IRT is a potential, objective, noninvasive, quick and simple method for flap monitoring during intraoperative and postoperative period. IRT can be applied for early detection of arterial and venous compromise compared with the clinical assessment.

Conflict of Interest
None declared.

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