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Role of Infrared Thermography in Planning and Monitoring of Head and Neck Microvascular Flap Reconstruction

Sravan Kumar Chava, MBBS, MS*
Mansi Agrawal, MBBS, MS†
Konduru Vidya, MBBS, MS†
Rajinikanth Janakiraman, MBBS, MS, MRCS‡
Kuppan Palaniyandi, PhD§
Oyyaravelu Ramachandran, PhD§
Amit Jiwan Tirkey, MBBS, MS†

Background: Reconstruction using microvascular free flaps has become the standard of care in head and neck cancer surgery, and their success lies in appropriate planning, adequate revascularization, and early detection of flap compromise so that prompt salvage is possible. This study evaluates the role of infrared thermography in the planning, execution, and postoperative monitoring of microvascular flaps in head and neck reconstructions.

Methods: This is a single institutional, prospective observational study conducted at a tertiary care hospital in South India for 13 months. Twenty patients were included, and their thermographic images were captured in the preoperative, intraoperative, and postoperative settings using the infrared camera FLIR T400. These images were analyzed along with the Doppler, and clinical monitoring findings in all the settings and the temperature difference were calculated postoperatively.

Results: Hotspot perforator marking was made using infrared camera, and perforator marking was made using hand-held Doppler preoperatively, which correlated in 93% of cases. Intraoperatively, flap rewarming was successfully demonstrated in 19 of 20 cases. Postoperatively, flap compromise was observed on infrared thermography during the first 24 hours but not on clinical monitoring in three cases. The temperature difference values recorded were 5.4°C, 2.4°C, and 4.9°C. The mean of temperature difference of the healthy flaps was 1.0°C (range 0.1°C–1.8°C).

Conclusion: Infrared thermography provides simple and reliable imaging, which can be used in perforator marking and flap designing preoperatively and checking the flap perfusion and vascular anastomosis patency intra- and postoperatively.
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INTRODUCTION

Microvascular flap transfer has become the standard of care in head and neck reconstruction, with success rates of more than 95%.[1,2] The key to further enhance the free-flap success rate includes appropriate planning, adequate revascularization, and early detection of flap compromise so that blood flow can be restored. There are many imaging techniques available for preoperative localization of the perforators, including color Doppler, ultrasound, and computed tomography (CT) angiography, which are time-consuming, expensive, and involve the use of ionizing radiation. Most commonly, hand-held Doppler is used to locate the cutaneous perforator because it is easily available and simple to use, with varying accuracy.

Intraoperatively, after the completion of vascular anastomoses, the adequacy of revascularization is ensured by fresh bleeding and return of the color of the flap while postoperatively, monitoring is mainly by clinical evaluation, which includes skin color, turgor, capillary refill, and Doppler signal of the arterial pulse. Early detection of flap compromise involves considerable experience and clinical judgement, as early re-exploration

*From the *Department of Head and Neck Surgical Oncology, Basavatarakam Indo American Cancer Hospital & Research Institute, Banjara Hills, Hyderabad, Telangana, India; †Department of Head and Neck Surgery, Unit-2, Christian Medical College, Vellore, Tamil Nadu, India; ‡Department of Maxillofacial/Head and Neck Surgery, Royal Darwin Hospital, Tiwi, NT, Australia; and §Department of Manufacturing Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India.*

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(within 6 hours) could salvage the flap.[1,2] However, this method is subjective and observer-dependent. The ideal postoperative monitoring method should be noninvasive, reliable, accurate, inexpensive, and easy to use even for inexperienced personnel, and should provide real-time information.[3–7] Recent advances in flap monitoring methods include implantable Doppler, surface temperature probes, near infrared spectroscopy, tissue oximetry, duplex sonography, laser Doppler flowmetry, and micro-dialysis,[3–7] but no single technique has fulfilled all the requirements for an ideal monitoring method. The limitation of the hand-held Doppler is its inability to access the recipient vessels. The cost associated with the disposable probes and the fact that they are invasive are themselves limiting factors. Laser Doppler flowmetry and tissue oximetry, although noninvasive, are restricted because their effectiveness depends on the experience of personnel for interpretation.[3]

Infrared thermography is a simple, noninvasive, and reliable imaging technique that provides indirect and real-time information on skin perfusion by measuring skin temperature of the free flaps, and it helps the surgeon to select the most suitable perforator in the preoperative phase and evaluate the blood perfusion in both intra- and postoperative phases. This technique involves observing changes in temperature as well as the temperature distribution in an area of interest following a thermal challenge. In practice, the skin area being examined is subjected to a thermal stress by fan cooling or by applying cold objects to the skin surface, and then the thermal images can be analyzed with respect to the rate and thermal pattern of recovery, both of which are dependent on the amount of blood perfusing the flap.[8] Hotspots with a rapid rewarming appeared as bright hotspots on the thermal image. These hotspots were all associated with an arterial sound that could be heard with a small hand-held Doppler device. Hence, we conducted this study to evaluate the role of infrared thermography in the planning, execution, and postoperative monitoring of microvascular flap reconstructions in head and neck malignancies.

Takeaways

Question: What is the role of infrared thermography in planning, execution and monitoring of microvascular flaps?

Findings: This is a single institutional, prospective observational study of 20 patients who underwent head and neck microvascular flap reconstruction, analyzing their thermographic images taken using infrared camera along with Doppler and clinical monitoring findings. The perforator markings correlated in 93% of cases preoperatively. Postoperatively, flap compromise was observed on infrared thermography during the first 24 hours but not on clinical monitoring in three cases.

Meaning: Infrared thermography is a simple and reliable imaging which can be utilised in perforator marking, checking the flap perfusion, and vascular anastomosis patency.

METHODS

This is a single institutional, prospective observational study conducted at a tertiary care hospital in South India for 13 months. This study was approved by the institutional review board. A total of 20 patients were included, and all patients signed an informed consent, wherein they consented for participation and their images to be shared for publication. Infrared camera FLIR T400 (FLIR Systems, Wilsonville, Oreg.) was used for the study. The camera has a resolution of 76,800 pixels (320 × 240), 0.05°C thermal sensitivity, and temperature range from −20°C to 1200°C. The images acquired with this camera were analyzed using FLIR Tools software version 5.13.17214.2001 from FLIR Systems Inc., and reports were generated. The thermographic images captured for the study are analyzed using rainbow palette, as this is the preferred color scale for thermal imaging in medicine, where hot is represented as red and cold as blue/black.

Preoperatively, an infrared camera is used for perforator marking along with hand-held Doppler. The donor site is cooled with an ice pack, and the perforators show themselves as hotspots immediately after cooling. Thermal images are taken using infrared camera. Perforator markings done with infrared camera and hand-held Doppler are analyzed and correlated intraoperatively.

Intraoperatively, the infrared camera is used to take pictures of the flap after harvesting it from the donor site and again after completion of microvascular anastomoses, and these photographs are analyzed. Postoperatively, all the flaps were monitored with the help of clinical monitoring, hand-held Doppler and infrared camera. Clinical monitoring was done by the surgical team as per existing protocols, hourly for the first 12 hours, every 2 hours for next 24 hours, and then every 4 hours until 72 hours. The infrared camera was used by the principal investigator to monitor the flaps at regular intervals of 1 hour, 12 hours, and 24 hours after surgery.

The decision to explore in case of vascular compromise was entirely based on clinical monitoring; data from infrared thermography was not used to alter or modify this decision. In most of the cases, infrared thermography identified the flap compromise before the clinical signs of compromise became appreciable. We calculated the temperature difference between the flap temperature and surrounding skin/mucosal temperature.

RESULTS

Twenty patients were included in the study, of whom 15 patients had carcinoma gingivobuccal complex, three patients had carcinoma tongue, one patient had dermatofibrosarcoma protuberans of face, and one patient had ameloblastoma mandible. Male-to-female ratio was 14:6, with the age ranging from 18 to 66 years. All patients underwent primary resection and reconstruction using free-flaps.

Preoperatively, all 20 cases had perforator marking done using hand-held Doppler, whereas only 14 cases (10 fibula free flaps and four anterolateral thigh flaps) had perforator marking done using infrared thermography

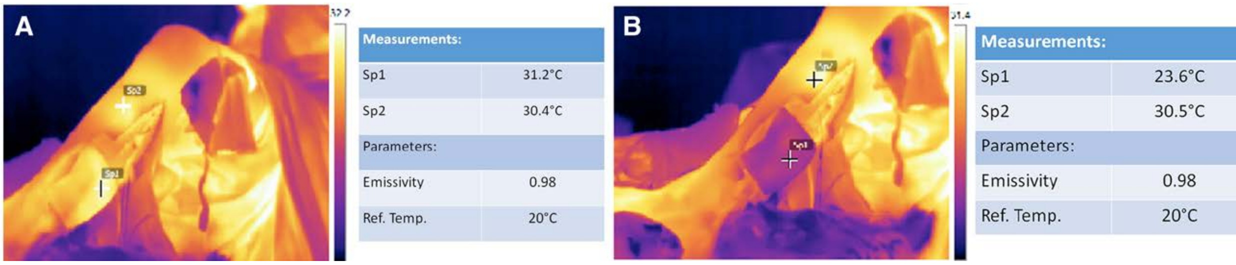


Fig. 1. Thermographic images of free fibula flap. A, Before ligation of the vascular pedicle. B, After ligation of the vascular pedicle.

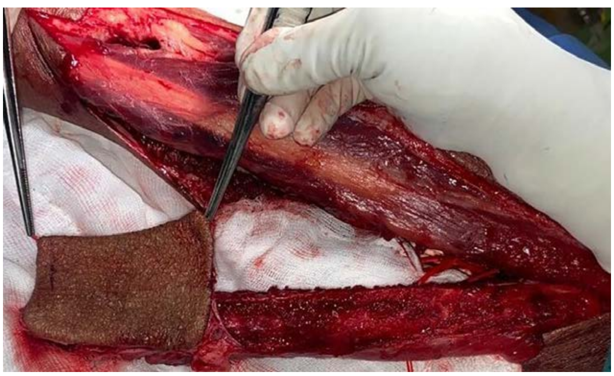


Fig. 2. Clinical photograph of the free fibula flap at the time of harvest.

due to the unavoidable circumstances that led to the delay in camera procurement. Also, it was not used for the patients undergoing reconstruction with free radial artery forearm flap. Hotspots marked by infrared thermography and perforator markings with hand-held Doppler were correlated with intraoperative locations of the perforators. Hotspot locations exactly correlated with intraoperative location of perforators in 13 of the 14 cases (93%).

We used infrared thermography for all the 20 cases intraoperatively, and observed that after the flap is disconnected from the donor area, it enters the stage of ischemia, during which it cools down to room temperature and loses active circulation, as shown in Figures 1 and 2.

After vascular anastomoses, the flaps become warmer due to re-establishment of circulation, as demonstrated by dynamic infrared thermography either by serial static images or video. If some deficiencies are identified on the infrared images regarding the inadequate rewarming, corrective measures are taken to prevent compression and kinking of the vessels.

All the cases in the study except one (19 of 20) showed rewarming after arterial anastomoses, indicating successful re-establishment of arterial supply, as depicted in Figure 3. Figures 4 and 5 depict the healthy flap status immediately after vascular anastomoses and after 12 hours.

In one of the cases (one of 20) where anterolateral thigh flap was done for subtotal glossectomy defect, there was no rewarming seen after arterial anastomosis, the perforator was found to be sheared after careful inspection, the flap was abandoned, and reconstruction was done with pectoralis major myocutaneous flap.

Of the 20 flaps, five cases had flap issues, and four cases required re-exploration in the postoperative period. Of these four cases, three cases had venous thrombosis. The thrombus was evacuated, venous anastomosis was redone, and all these these cases were successfully salvaged. These cases had flap compromise, which was observed on infrared thermography during the first 24 hours of the postoperative period but not on clinical monitoring. The temperature differences recorded were 5.4°C, 2.4°C, and 4.9°C.

The other two cases (fourth and fifth) developed flap compromise after the first 24 hours of the postoperative period. During this initial postoperative period, both the clinical and infrared thermography monitoring showed healthy, well-perfused flaps. Their temperature differences recorded during the first 24 hours were 1.4°C and 0.9°C. One of these cases had compromise of a perforator of the anterolateral thigh flap; the flap partially necrosed, for which re-exploration and salvage reconstruction was done with radial artery forearm flap, as depicted in Figures 6 and 7. The fifth case in its initial postoperative period showed multiple cold spots over the surface of the skin paddle, suggesting inadequate perfusion, but the flap was normal on clinical monitoring and hence, re-exploration was deferred. On the fifth postoperative day, the skin paddle developed partial necrosis for which debridement was done bedside, and the wound healed by secondary intention, following which the patient was discharged and the flap healed well.

The mean of temperature differences of the healthy flaps (15 of 20) was 1.0°C, with a minimum value of 0.1°C and maximum value of 1.8°C. The temperatures measured and the differences are shown in Table 1.

According to Khouri and Shaw,[9] temperature difference greater than 1.8°C is indicative of flap compromise.

Monitoring of intra-oral free flaps is different from that of other free flaps because intra-oral flaps do not lose heat and can give false readings on infrared thermograhy.[10] Infrared thermography can detect early venous compromise, as the Doppler used routinely in flap monitoring can give a false reading because of patent arterial flow.

DISCUSSION

Free-flap reconstruction is an integral part of patient care in breast cancer, head and neck cancer, and limb salvage after trauma. Loss of a free-flap is a devastating

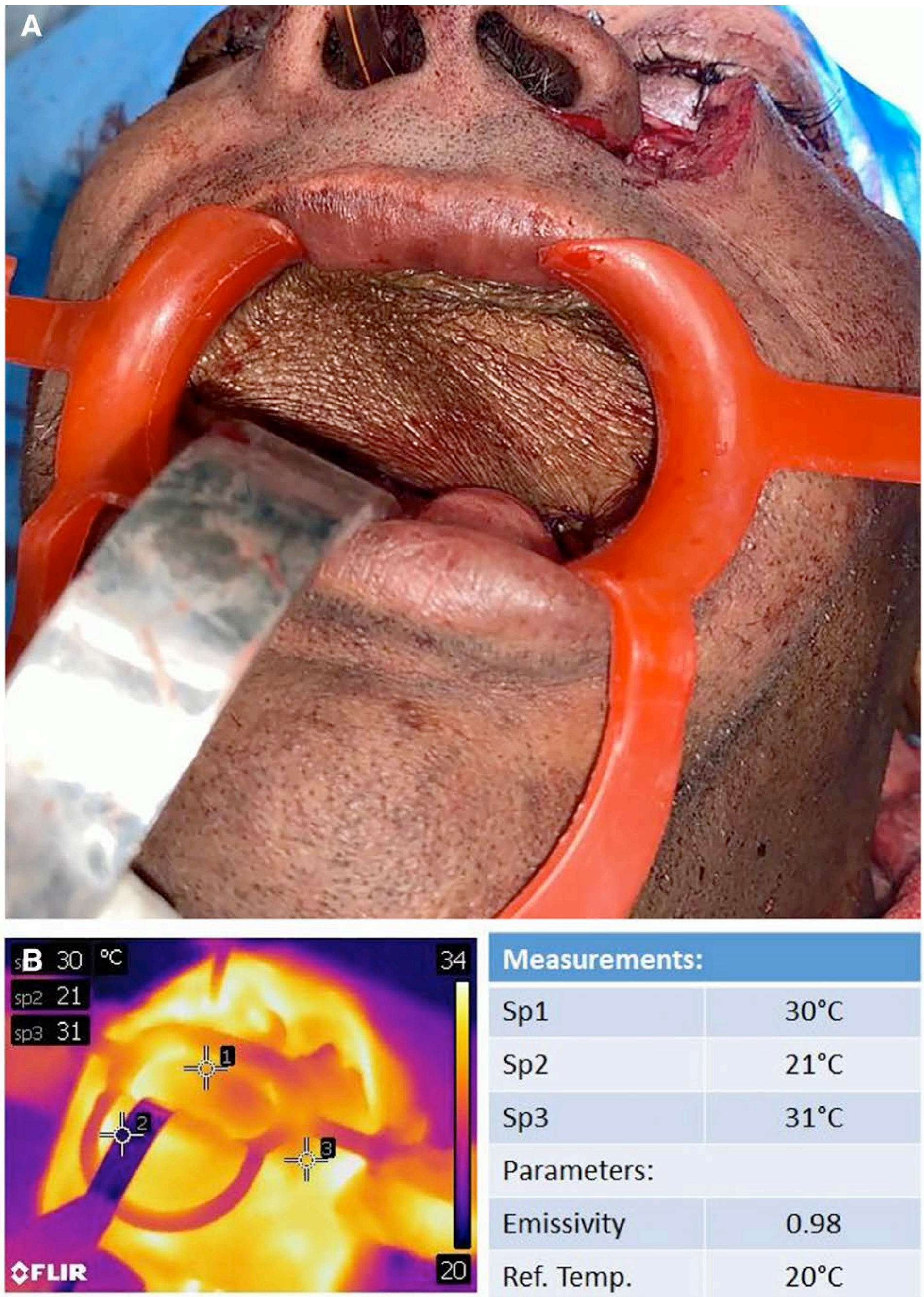


Fig. 3. Images of free fibula flap after completion of vascular anastomoses. A, Clinical image. B, Thermographic image.

experience to both the surgeon and the patient. The incidence of re-operation ranges from 2% to 9% of all free tissue transfer cases.[1,2] Typical causes of thrombosis are anastomotic errors, kinking or compression of the vessels, or hematoma and thrombosis secondary to various coagulation disorders. Monitoring of a free-flap in the postoperative period is important because salvage rates for anastomotic thromboses are 50% or better, and are directly related to the amount of time that elapses from the event to the correction,[3] and the commonest cause of failure is a problem with the venous anastomosis occurring within the first 24–48 hours postoperatively.[4] If circulation in a compromised flap is not re-established within 8–12 hours, salvage of such free tissue transfer may be impossible due to the "no-reflow" phenomenon. This phenomenon occurs due to accumulation of sludge and thrombosis in the microcirculation along with swelling of endothelial cells.[5] So early recognition of flap compromise leads to successful salvage of the flap; hence, monitoring of free-flaps is an integral part of microvascular surgery.

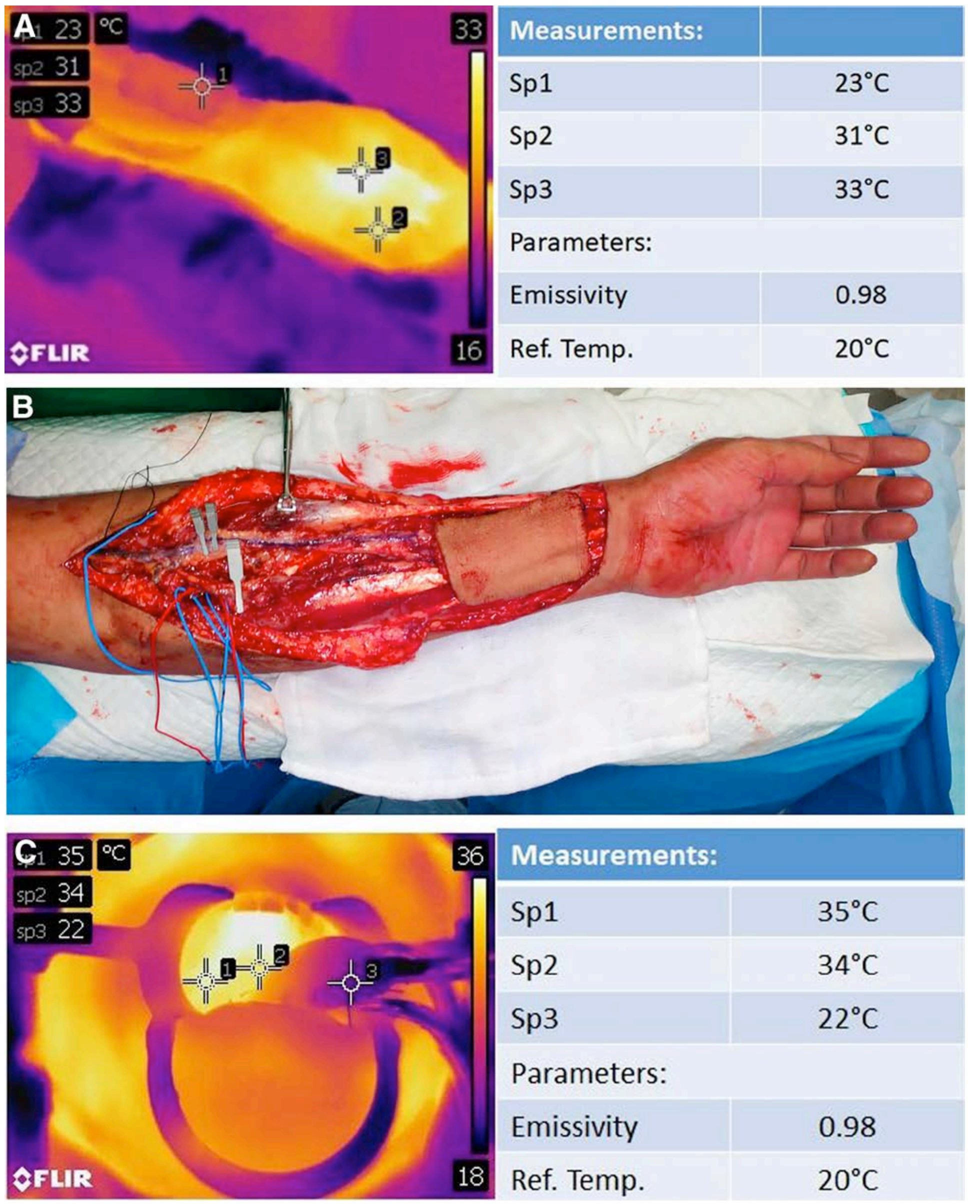


Fig. 4. Images of free radial forearm flap. A, Thermographic image after ligation of vascular pedicle. B, Clinical image after ligation of vascular pedicle. C, Thermographic image after completion of vascular anastomoses.

Thermal imaging became available for nonmilitary applications in 1958.[7,8] Infrared thermography works on the principle that all material objects emit thermal energy in the form of infrared radiation depending on the temperature of the object.

Human skin behaves as an almost blackbody with an emissivity of 0.96–0.98.[11] This energy level is directly proportional to tissue temperature indicating perfusion status of human tissues. The infrared radiation is invisible to the naked human eye but can be detected by thermal cameras, which convert these infrared signals into electrical signals using sensitive sensors. By analyzing these signal differences in the color spectrum, thermal images of the human body named thermogram are acquired. Hence, it can be used to show physiological change and metabolic processes by using surface temperature distribution.[11,12] Thermal imaging has numerous established industrial applications; its use in modern medicine is limited at present. The various applications for infrared thermography imaging are monitoring of skin temperature and the detection of breast cancer, skin cancer, and inflammation. Its use is also being investigated in neurosurgical and plastic breast reconstruction.[7,13–17] Although infrared thermography is an old concept, it has not gained popularity due to its certain limitations. It provides two-dimensional information only pertaining to perforator location and not to entire morphology, unlike CT or magnetic resonance angiography, which give three-dimensional details

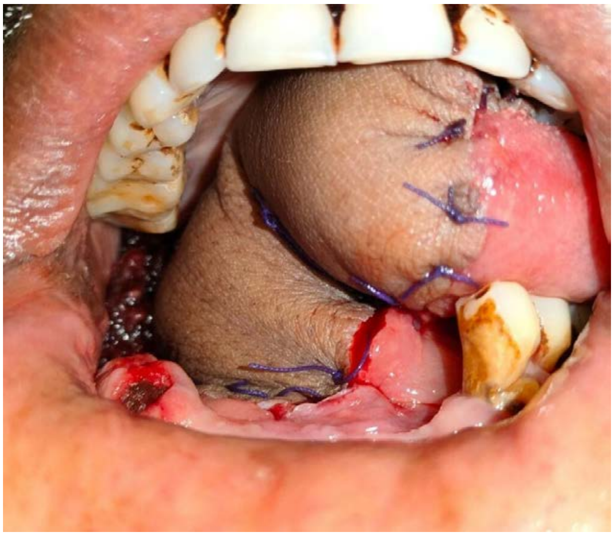


Fig. 5. Clinical photograph of the flap after completion of vascular anastomoses.

regarding the entire vascular pattern. Moreover, this technique comes with the additional cost of the specific camera as well as the training required to handle the camera and interpretation of the images. However, in this study, we used this concept as an adjunct to the color Doppler in the perioperative period to help surgeons check the accuracy of the perforator locations and to pick up any vascular compromises, facilitating timely salvage of the flap.

Preoperative Use of Infrared Thermography

In 1993, Itoh and Arai[18] described the use of dynamic infrared thermography for perforator mapping in deep inferior epigastric perforator flaps. Mercer et al[19–21] have concluded that identification of a suitable perforator should fulfill the following criteria:

1. A rapidly appearing hotspot after the cold challenge.
2. This hotspot is associated with an audible Doppler sound.
3. The perforator is not located at the edge of the flap.

Weum et al[22] and Chubb et al[23] have compared dynamic infrared thermography with CT angiography for perforator mapping and found that the first appearing hotspots on infrared thermography were always associated with arterial Doppler sounds as well as clearly visible perforators on CT angiography and intraoperatively. We too, in our study, have observed that the hotspot that appears first after a cold challenge test corresponds with the dominant perforator found intraoperatively.

Even though CT angiography is considered a gold standard for perforator mapping by some, the main disadvantages are exposure to ionizing radiation, use of intravenous contrast medium, high costs, and high waiting time in getting the imaging done.

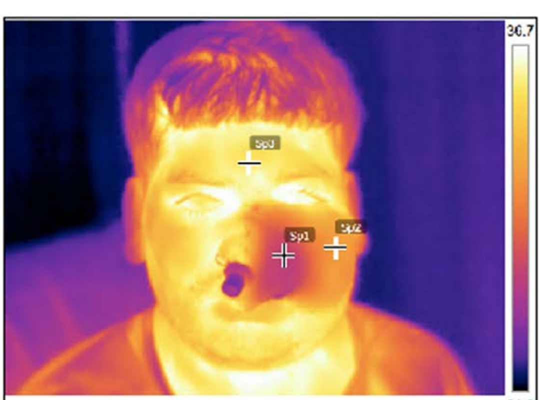
Infrared thermography, on the other hand, does not use ionizing radiation and is a fast and easy procedure with minimal cost, but it does not provide information on the intramuscular course of the perforators. The thermography camera used by us has an inbuilt laser, which accurately helped in localizing hotspots for marking perforators.

Intraoperative Use of Infrared Thermography

Salmi et al[24] in 1995 utilized infrared thermography for intraoperative and postoperative monitoring of free transverse rectus abdominis musculocutaneous flaps. According to Rosenbaum and Sundtl[25] and Wolff et al,[26] the risk of arterial thrombus formation is highest at 15 minutes after clamp release and usually occurs during the first 45 minutes. Hence, our study protocol included intraoperative flap monitoring to identify vascular compromise, which can be corrected on table.

The temperature of the flap measured by the infrared camera depends on multiple factors like flap size, location, body temperature, fever, respiratory flow, and vascular circulation, depending on the applied anesthesia, angle between the tissue surface temperature, and air humidity.[7]

As the temperatures of both the flap and surrounding tissues are measured at the same point of time with the same ambient temperature and other external factors like humidity and wind direction, the temperature difference calculated is absolute temperature difference, which is independent of external factors.[27]



Measurements:	
Sp1	30.2°C
Sp2	33.1°C
Sp3	35.6°C
Parameters:	
Emissivity	0.98
Ref. Temp.	20°C

Fig. 6. Thermographic image of the free anterolateral thigh flap showing partial compromise in the first 24 hours.

Fig. 7. Clinical image of the flap in the first 24 hours, showing a healthy flap.

Postoperative Use of Infrared Thermography

The infrared camera used in this specific study is portable, easy to use, and is easily handled by head and neck staff and intensive care unit nurses. The camera has the ability to take a normal photograph, which can be compared with the infrared photograph. The pictures generated by the camera are easy to interpret because of the colorful pictographic representation. Hence, flap compromise can be easily picked up by staff, and physicians can be alerted much earlier before the clinical features of flap compromise set in. In contrast to clinical monitoring, these pictures can be stored for future reference, research, and also for medico-legal purposes.

These pictures can be used to provide real-time imaging of the flap, which can be shared among the team members at regular intervals and used to update the patient's relatives about the status of the flap in need of re-exploration. We also observed that these pictures were easy to interpret in dark-skinned patients, as the dark pigmentation leads to misinterpretation of color changes on clinical monitoring, providing false results.[20]

According to Mercer and de Weerd,[21] the correlation between thermographic and laser Doppler velocimetric results is good. Just et al[13] conducted a prospective study on 16 patients using infrared thermography for intraoperative and postoperative free-flap monitoring after oropharyngeal reconstruction by free radial forearm flap. They concluded that static and dynamic infrared thermography is a promising, objective method for monitoring of free-flaps in head and neck surgery and to detect perfusion failure, before macroscopic changes in the tissue surface are obvious.

With this study, we found that using infrared thermography in addition to clinical monitoring helps save time and reduce the cost because an earlier re-exploration can

Table 1. Table Showing Temperatures Measured and Temperature Difference (Δt) of All 20 Cases

S. No.	Reconstruction	Clinical: First 24 h	IR: First 24 h	Avg. tF (°C)	Avg. tS (°C)	Avg. Δt (°C)	Clinical: After 24 h	Re- explo.	Final Outcome
1	FFF	H	H	31.2	32.5	1.3	H	No	H
2	ALT	H	Partial FC	30.2	35.6	**5.4**	FC	Yes	Second flap was needed
3	ALT	H	H	33.0	34.1	1.1	H	No	H
4	RAFFF	H	H	33.8	34.9	1.1	H	No	H
5	FFF	H	H	34.3	35.1	0.8	H	No	H
6	FFF	H	FC	31.4	33.8	**2.4**	FC	No	Skin paddle loss
7	FFF	H	H	34.5	35.9	1.4	H	No	H
8	RAFFF	H	H	27.5	28.4	**0.9**	FC	Yes	H
9	RAFFF	H	FC	28.5	33.4	**4.9**	FC	Yes	H
10	ALT	—	—	—	—	—	—	—	Second flap
11	FFF	H	H	36.2	36.3	0.1	H	No	H
12	FFF	H	H	31.3	32.2	0.9	H	No	H
13	RAFFF	H	H	33.7	34.6	0.9	H	No	H
14	RAFFF	H	H	34.4	35.8	**1.4**	FC	Yes	H
15	FFF	H	H	37.0	38.2	1.2	H	No	H
16	FFF	H	H	34.4	35.0	0.6	H	No	H
17	FFF	H	H	35.7	36.9	1.2	H	No	H
18	RAFFF	H	H	29.2	31.0	1.8	H	No	H
19	ALT	H	H	33.3	34.7	1.4	H	No	H
20	FFF	H	H	35.2	36.2	1.0	H	No	H

H, healthy; FC, flap compromise; ALT, anterolateral thigh; IR, infrared thermography; FFF, free fibula flap; Avg., average; RAFFF, radial artery free flap; tF, temperature of flap; tS, temperature of surrounding tissue.
Values in boldface indicate the five flaps which had issues in the postoperative period.

potentially salvage the flap and avoid the expense of a second reconstructive procedure, which can cost between $1500 and $2000 for each case requiring a second flap. This study had only 20 cases. Because of the small number of patients included in this study, statistical and cost effectiveness analysis of the results could not be conducted, and significance could not be achieved, but this study helped in analyzing the aspects of infrared thermography for free-flap reconstruction and its clinical use in all the phases.

CONCLUSIONS

Infrared thermography provides a simple and reliable imaging solution to a surgeon, which can be used in perforator marking and flap designing during the preoperative phase, and provides real-time information on the perfusion of the flap and patency of the vascular anastomoses during both intraoperative and postoperative phases.

Monitoring with infrared thermography has its own share of advantages and disadvantages. Postoperative monitoring of free flaps in head and neck regions is difficult and different in comparison with similar reconstructions in other parts of the body. Most of the head and neck free flaps are used for internal mucosal lining, where clinical observation of entire flaps is difficult. Monitoring of buried free flaps is also a challenge because they do not have an external skin paddle for clinical monitoring. However, infrared thermography has potential in various fields of modern medicine, and identifying its uses will help with easy access and availability to surgeons for regular use, although further research is necessary to improve these infrared cameras in terms of image resolution and temperature.

Amit Jiwan Tirkey, MBBS, MS (General Surgery)
Department of Head and Neck Surgery, Unit-2
2nd floor, Paul Brand Building
Christian Medical College Hospital Campus
Vellore 632004, Tamil Nadu
India
E-mail: ajtirkey@yahoo.com

DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

PATIENT CONSENT

All patients signed an informed consent wherein they consented for participation and their images to be shared for publication for this study.

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