Early Detection of Vascular Obstruction in Microvascular Flaps using Thermographic Camera

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ABSTRACT

Objective: To evaluate the early detection of vascular obstruction in microvascular flaps using a thermographic camera.

Study Design: A cross-sectional study.

Place and Duration of the Study: Department of Plastic Surgery, Jinnah Burn and Reconstructive Surgery Centre, Lahore, Pakistan, from July to December 2023.

Methodology: Microvascular flaps with cutaneous islands were monitored postoperatively with a thermographic camera in addition to conventional clinical methods. The decision to re-explore was based on conventional methods, and confirmation was achieved through intraoperative findings of vascular obstruction during re-exploration.

Results: Thirty-one patients who underwent microvascular surgery were monitored postoperatively with a thermographic camera. There were 20 (64.5%) anterolateral thigh flaps, 4 (12.9%) radial forearm flaps, 3 (9.7%) scapular-parascapular flaps, 1 (3.2%) medial plantar flap, 1 (3.2%) myocutaneous gracilis flap, 1 (3.2%) latissimus dorsi (LD) flap, and 1 (3.2%) chimeric adductor longus and gracilis flap. Three (9.7%) flaps developed postoperative vascular obstruction. The thermographic camera detected complications two to four hours earlier than conventional methods, with a statistically significant difference ($p > 0.109$).

Conclusion: A thermographic camera is a valuable, non-invasive, and simple tool for monitoring microvascular flaps. It can detect complications several hours earlier and has the potential to be a practice-changing modality.

Key Words: *Microvascular flaps, Thermographic camera, Vascular obstruction.*

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INTRODUCTION

Microvascular tissue transfer is a routine practice in the current era. It was first documented in 1972 when McLean and Buncke used an omental-free flap to reconstruct a defect in the scalp.[1] Intraoperatively and postoperatively, microvascular obstruction is a common occurrence, with an incidence of approximately 8-20%.[2-6] If not detected and managed promptly, it can lead to flap failure.[7]

Monitoring microvascular flaps is crucial, and timely intervention can significantly decrease failure rates.[5,7] Conventional clinical methods include clinical examination (colour, refill, warmth, turgor, and Doppler ultrasound). However, these traditional methods often lack the sensitivity and specificity needed for the early detection of vascular compromise.[8] As a result, the timely identification of vascular obstruction remains a challenge, hampering the overall success of microvascular flap procedures.

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Many new methods for monitoring free flaps have been described, both invasive and non-invasive. Non-invasive methods include thermographic cameras, spectrophotometry, colour Doppler sonography, and laser Doppler flowmetry.[9] Invasive methods include implantable Doppler, contrast-enhanced Doppler, invasive temperature monitoring, oxygen tension / partial pressure monitoring, tissue pH measurement, and lactate level assessment.[9-12] These procedures are expensive and, in some cases, carry the risk of contrast injection, while in others, they pose the risk of multiple invasive sampling.

Among these, the use of infrared thermography, which records the infrared radiation emitted by the body's surface, has shown great potential in various medical applications.[13,14] Thermographic cameras are recently used clinically in microvascular flaps for perforator detection.[15,16] Infrared thermography is also used in perforator detection and postoperative flap monitoring,[17] although it can be quite expensive. The concept of using thermography for vascular monitoring is based on the principle that alterations in blood flow and tissue metabolism are reflected in temperature variations on the skin surface.

This research study used an inexpensive infrared forward-looking infrared (FLIR) one thermographic camera to monitor microvascular flaps postoperatively. By capturing thermal patterns, these cameras can potentially identify perfusion deficits and ischaemic areas, enabling clinicians to intervene promptly and salvage the flap before irreversible damage occurs.

The successful implementation of thermographic cameras for the early detection of vascular obstruction in microvascular flaps could significantly enhance the safety and success rates of reconstructive surgeries.[18] Moreover, it has the potential to reduce healthcare costs associated with flap failures and re-interventions.[8] The objective of the study was to evaluate the early detection of vascular obstruction using a thermographic camera. This research endeavour may pave the way for the integration of thermography into standard surgical practice, providing surgeons with a valuable tool to safeguard the viability of microvascular flaps and improve patient outcomes.

METHODOLOGY

A cross-sectional study was conducted at the Department of Plastic Surgery, Jinnah Burn and Reconstructive Surgery Centre, Lahore, Pakistan, from July to December 2023. The inclusion criteria were free tissue transfers with cutaneous islands in patients aged 10 years and above, with a diverse aetiology (trauma, tumour, congenital conditions, and infections). The study adhered to all research protocols; the initial study draft was prepared, presented to the Ethical Review Board, and an approval was obtained. Informed consent was acquired in accordance with the Declaration of Helsinki. The exclusion criteria included removal of the cutaneous island intraoperatively, age below 10 years, significant comorbidities (uncontrolled diabetes mellitus, severe cardiovascular disease, pre-existing vascular disorders, skin conditions that could alter thermographic camera readings), pregnancy, and enrolment in other ongoing clinical studies using monitoring devices or interventions that might influence the results of this research.

The position of the dominant perforator was marked with a suture, following conventional clinical methods to record Doppler signals.[19] Additionally, another mark was made on the adjacent skin of the flap within 5 cm (Figure 1). During dressing, care was taken to keep both reference points exposed. Postoperatively, monitoring was performed according to conventional clinical methods (colour, warmth, refill, turgor, and Doppler). In addition to these, thermographic readings were obtained on both the flap marking and the adjacent skin reference, marking every hour postoperatively for the first 2 days, and then every 3 hours until the patient was discharged, as per the guidelines.[2,3] Thermographic readings were taken by a separate observer who was blinded to the clinical findings.

The thermographic camera used for this study (Figure 2), had a resolution of 160 × 120. It has a temperature range of -20°C to 120°C, a thermal sensitivity/NETD of 70 mK, and weighs 36.5 g.

The method for taking readings from the thermal camera involved recording separate readings from both the flap and adjacent skin reference points. The device was positioned vertically at a distance of half the arm's length or 35 cm. Both readings were recorded on a chart; their difference was calculated and documented. A difference of ±2°C between consecutive readings was considered a positive result.[20] The decision to reoperate was based on clinical findings. The person responsible for surveillance using clinical methods was not aware of the thermal camera readings and was the one who would lead the re-intervention surgery. During re-intervention, any form of vascular obstruction in the artery or vein due to intrinsic blockage or extrinsic compression was considered the gold standard for this test.

The recorded variables included age, gender registration number, diagnosis / aetiology, flap type, clinical findings, thermographic camera readings and their differences, vascular obstruction, and the time in minutes required to detect or diagnose vascular obstruction using conventional methods and thermography. Data were entered and analysed using SPSS version 21.0. Frequencies and percentages were calculated for nominal variables. The Wilcoxon Signed-Rank test was applied to assess time differences, with a p-value of <0.05 considered statistically significant.

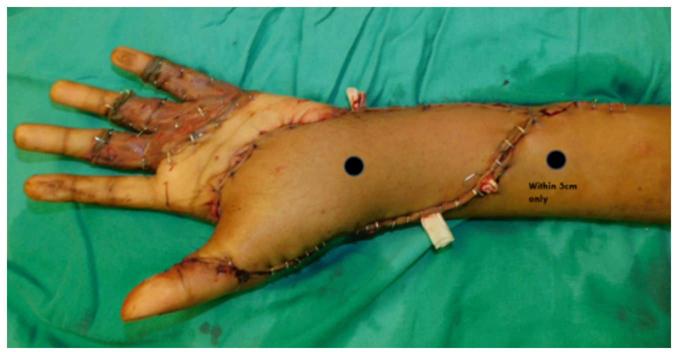

Figure 1: Reference points on the flap and adjacent skin (within 5cm of the flap).

Figure 2: Thermal camera.

RESULTS

In this study, a total of 31 patients met the inclusion criteria. In this consecutive series, four patients were excluded due to the removal of the cutaneous island. Additionally, a few others were excluded due to comorbidities and factors that did not meet the inclusion criteria. During post-operative surveillance, the ambient room temperature was consistently maintained at 20°C ± 2°C.

Table I: Demographic and clinical details of patients.

Demographics		Vascular obstruction (n = 3)	No vascular obstruction (n = 28)
Age	11 - 20	0 (0.0%)	13 (46.4%)
	21 - 30	2 (%)	6 (21.4%)
	31 - 40	-	1 (3.6%)
	41 - 50	1 (%)	5 (17.9%)
	51 - 60	-	3 (10.7%)
Gender	Male	2 (66.6%)	24 (85.7%)
	Female	1 (33.4%)	4 (14.3%)
Aetiology	Trauma	2 (66.6%)	16 (57.1%)
	Tumour	1 (33.4%)	6 (21.4%)
	Brachial plexus injury	-	2 (7.1%)
	Congenital	-	2 (7.1%)
	Post burn / HVECI	-	2 (7.1%)
Region	Head and neck	1 (33.4%)	4 (14.2%)
	Upper limb	1 (33.4%)	15 (53.%)
	Lower limb	1	6 (21.4%)
	Urogenital	-	2 (7.1%)
	Breast	-	1 (3.6%)
Flaps	Anterolateral thigh flap	2 (66.6%)	18 (64.3%)
	Radial forearm flap	1 (33.4%)	3 (10.7%)
	Scapular parascapular flap	-	3 (10.7%)
	Medial plantar flap	-	1 (3.6%)
	Latissimus dorsi flap	-	1 (3.6%)
	Chimeric gracilis + adductor longus	-	1 (3.6%)
	Myocutaneous gracilis	-	1 (3.6%)

Table II: Clinical outcome of patients with postoperative complications.

Patient ID	First positive reading with thermographic camera (minutes)	First positive test with clinical findings (minutes)	Time difference (minutes)	Type of vascular obstruction (on re-exploration)	Outcome
6	0	120	120	Venous	Saved flap
5	120	360	240	Arterial	Saved flap
16	1500	1680	180	Venous	Partial necrosis

Figure 3: (A, B): Free radial forearm flap performed on a patient following the excision of buccal squamous cell carcinoma. (C, D): At 2 hours, the thermal camera began showing positive readings according to the set criteria (difference of more than 2°C). (E, F): At 6 hours, the thermal camera continued to show positive readings. At this point, clinical findings were suspicious, and the patient was taken for re-exploration. (G, H): Thermal camera readings post-exploration were normal. (I, J): At 15 hours, thermal camera readings were normal.

A total of 31 free microvascular flaps were monitored: Twenty were anterolateral thigh flaps, 4 were radial forearm flaps, 3 were scapular or parascapular flaps, 1 was a medial plantar flap, 1 was a myocutaneous latissimus dorsi flap, 1 was a chimeric gracilis + adductor longus, and 1 was a myocutaneous gracilis flap (Table I). During postoperative surveillance, three flaps showed complications. In all three cases, the thermographic camera detected positive readings according to the set criteria, showing a difference of ±2°C between two reference points earlier than conventional methods (Figure 3).

The decision for re-exploration was based on clinical findings, with the gold standard being the detection of vascular obstruction during operative intervention. Of the three flaps, two exhibited venous obstruction and one exhibited arterial obstruction. In two cases, the flaps were completely salvaged, while in 1 case, partial necrosis occurred (Table II).

Early detection was statistically evaluated for time differences between the thermal camera and conventional methods using the Wilcoxon Signed-Rank test, with the assumption that the time scores for the thermal camera and conventional methods were independent of one another. The Wilcoxon Signed-Rank test indicated that the median post-test ranks for the thermal camera were not statistically significantly different (using a two-tailed test) from the conventional method ranks ($Z = -1.604$, $p > 0.109$). Clinically, although the early detection was not statistically significant, it highlights the potential of thermography for early recognition of vascular obstruction in microvascular flaps, potentially preventing flap failure and improving surgical outcomes.

DISCUSSION

In today's era of microsurgery being routinely performed, surgeons occasionally encounter complications such as vascular obstruction.[5] To address this, various monitoring methods, both non-invasive and invasive, are employed. Conventional methods, which include monitoring colour, warmth, refill, turgor, and surface Doppler, are operator-dependent.[19] Other non-invasive methods include spectrophotometry, colour Doppler sonography, and laser Doppler sonography.[9]

To improve the overall survival rate of microvascular flaps, invasive monitoring methods are also employed. These include implantable Doppler, an ultrasonic instrument.[21,22] Other methods encompass contrast-enhanced Doppler, invasive temperature monitoring, oxygen tension / partial pressure monitoring, pH level monitoring, and lactate level monitoring.[9-12] While these methods vary in efficacy, they all involve significant costs and are time-consuming.

In this study, a simple, non-invasive, and cost-effective tool was used: A thermographic camera that attaches to a smartphone. This device is time-efficient, easy to use, and not user-dependent. The camera does not need to come into direct contact with the wound; it can be operated from a distance of 35 cm.

It was hypothesised that postoperative surveillance with a thermographic camera could predict vascular obstruction earlier than conventional methods. A difference of ±2°C for more than two consecutive readings was considered a positive test.[20] Meanwhile, continuous monitoring with routine methods was conducted, and a comparison was made for the time difference in detecting complications between both approaches. The thermographic camera demonstrated excellent results, providing positive readings up to 4 hours earlier than routine methods. This early detection can offer a significant advantage for re-intervention and potentially improve the overall flap survival rate.

The main limitation of flap monitoring with a thermographic camera is that it can only monitor flaps with cutaneous islands. The thermal camera is not effective for muscle-only or bone flaps. Despite this, the results of monitoring with the thermographic camera are excellent. It can significantly reduce the time required for salvage, improve the overall flap survival rate, and consequently decrease both patient discomfort and the burden on the healthcare system. The main limitation of this study was the small sample size.

CONCLUSION

A smartphone-compatible thermographic camera is a valuable, non-invasive, cost-effective, and simple tool for monitoring microvascular flaps. It can detect complications several hours earlier and has the potential to be a practice-changing modality for identifying vascular obstruction sooner than routine methods.

ETHICAL APPROVAL:
This study received approval from the Institutional Ethical Committee of the Jinnah Burn and Reconstructive Surgery Centre, Lahore, Pakistan before commencing.

PATIENTS' CONSENT:
Informed consent was obtained from all patients.

COMPETING INTEREST:
The authors declared no conflict of interest.

AUTHORS' CONTRIBUTION:
BU: Literature review, data collection, and manuscript writing.
HKA: Data compilation.
BB: Data analysis and image collection.
AR: Critical review of the manuscript.
MTI: Literature review, reference studies, and formatting of the tables.
KK: Conception of idea, study design, and review suggestions.
All authors approved the final version of the manuscript to be published.

REFERENCES

1. McLean DH, Buncke HJ, Jr. Autotransplant of omentum to a large scalp defect, with microsurgical revascularization. *Plast Reconstr Surg* 1972; **49(3)**:268-74. doi:10.1097/00006534-197203000-00005.
2. Brands MT, van den Bosch SC, Dieleman FJ, Berge SJ, Merkx MA. Prevention of thrombosis after microvascular tissue transfer in the head and neck. A review of the literature and the state of affairs in Dutch head and neck cancer centers. *Int J Oral Maxillofac Surg* 2010; **39(2)**:101-6. doi:10.1016/j.ijom.2009.11.020.
3. Kroll SS, Miller MJ, Reece GP, Baldwin BJ, Robb GL, Bengtson BP, *et al*. Anticoagulants and hematomas in free flap surgery. *Plast Reconstr Surg* 1995; **96(3)**:643-7. doi:10.1097/00006534-199509000-00017.
4. Khouri RK, Cooley BC, Kunselman AR, Landis JR, Yeramian P, Ingram D, *et al*. A prospective study of microvascular free-flap surgery and outcome. *Plast Reconstr Surg* 1998; **102(3)**:711-21. doi:10.1097/00006534-199809030-00015.
5. Salemark L. International survey of current microvascular practices in free tissue transfer and replantation surgery. *Microsurgery* 1991; **12(4)**:308-11. doi:10.1002/micr.1920120415.
6. Sweeny L, Curry J, Crawley M, Cave T, Stewart M, Luginbuhl A, *et al*. Factors impacting successful salvage of the failing free flap. *Head & Neck* 2020; **42(12)**:3568-79. doi:10.1002/hed.26427.

7. Shen AY, Lonie S, Lim K, Farthing H, Hunter-Smith DJ, Rozen WM. Free flap monitoring, salvage, and failure timing: A systematic review. *J Reconstr Microsurg* 2021; **37(03)**:300-8. doi:10.1055/s-0040-1722182.
8. Meyer A, Roof S, Gray ML, Fan CJ, Barber B, Miles BA, *et al*. Thermal imaging for microvascular free tissue transfer monitoring: Feasibility study using a low cost, commercially available mobile phone imaging system. *Head Neck* 2020; **42(10)**:2941-7. doi:10.1002/hed.26350.
9. Kohlert S, Quimby AE, Saman M, Ducic Y. Postoperative free-flap monitoring techniques. *Semin Plast Surg* 2019; **33(1)**:13-6. doi:10.1055/s-0039-1677880.
10. Lin SJ, Nguyen MD, Chen C, Colakoglu S, Curtis MS, Tobias AM, *et al*. Tissue oximetry monitoring in microsurgical breast reconstruction decreases flap loss and improves rate of flap salvage. *Plast Reconstr Surg* 2011; **127(3)**: 1080-5. doi:10.1097/PRS.0b013e31820436cb.
11. Jonas R, Schaal T, Krimmel M, Gulicher D, Reinert S, Hoffmann J. Monitoring in microvascular tissue transfer by measurement of oxygen partial pressure: Four years experience with 125 microsurgical transplants. *J Craniomaxillofac Surg* 2013; **41(4)**:303-9. doi:10.1016/j.jcms.2012.10.008.
12. Koolen PGL, Vargas CR, Ho OA, Ibrahim AMS, Ricci JA, Tobias AM, *et al*. Does Increased experience with tissue oximetry monitoring in microsurgical breast reconstruction lead to decreased flap loss? The learning effect. *Plast Reconstr Surg* 2016; **137(4)**:1093-101. doi:10.1097/01.prs.0000481071.59025.82.
13. Lubkowska A, Pluta W. Infrared thermography as a non-invasive tool in musculoskeletal disease rehabilitation-The control variables in applicability-A systematic review. *Applied Sci* 2022; **12(9)**:4302. doi: 10.3390/app12094302.
14. Frohwitter G, Nobis CP, Weber M, Oetter N, Rau A, Kesting MR, *et al*. Thermal imaging in a clinically non-assessable free flap reconstruction of the face. *Plast Reconstr Surg Glob Open* 2021; **9(2)**:e3440. doi:10.1097/GOX.0000000000003440.
15. Rabbani MJ, Ilyas A, Rabbani A, Abidin ZU, Tarar MN. Accuracy of thermal imaging camera in identification of perforators. *J Coll Physicians Surg Pak* 2020; **30(5)**:512-5. doi:10.29271/jcpsp.2020.05.512.
16. Pereira N, Valenzuela D, Mangelsdorff G, Kufeke M, Roa R. Detection of perforators for free flap planning using smartphone thermal imaging: A concordance study with computed tomographic angiography in 120 perforators. *Plast Reconstr Surg* 2018; **141(3)**:787-92. doi:10.1097/PRS.0000000000004126.
17. John HE, Niumsawatt V, Rozen WM, Whitaker IS. Clinical applications of dynamic infrared thermography in plastic surgery: A systematic review. *Gland Surg* 2016; **5(2)**: 122-32. doi:10.3978/j.issn.2227-684X.2015.11.07.
18. Raheman FJ, Rojoa DM, Patel NG. Performance of infrared thermography and thermal stress test in perforator mapping and flap monitoring: A meta-analysis of diagnostic accuracy. *J Plast Reconstr Aesthet Surg* 2021; **74(9)**: 2013-25. doi:10.1016/j.bjps.2021.03.088.
19. Jacobson A, Cohen O. Review of flap monitoring technology in 2020. *Facial Plast Surg* 2020; **36(06)**:722-6. doi:10.1055/s-0040-1721105.
20. Cruz-Segura A, Cruz-Dominguez MP, Jara LJ, Miliar-Garcia A, Hernandez-Soler A, Grajeda-Lopez P, *et al*. Early detection of vascular obstruction in microvascular flaps using a thermographic camera. *J Reconstr Microsurg* 2019; **35(7)**: 541-8. doi:10.1055/s-0039-1688749.
21. Rothfuss MA, Franconi NG, Star A, Akcakaya M, Gimbel ML, Sejdic E. Automatic early-onset free flap failure detection for implantable biomedical devices. *IEEE Trans Biomed Eng* 2018; **65(10)**:2290-7. doi:10.1109/TBME.2018.2793763.
22. Lenz Y, Gross R, Penna V, Bannasch H, Stark GB, Eisenhardt SU. Evaluation of the implantable doppler probe for free flap monitoring in lower limb reconstruction. *J Reconstr Microsurg* 2018; **34(3)**:218-26. doi:10.1055/s-0037-1608628.