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Efficiency of Infrared Sensors in Free Flap Monitoring- An Observational Study

[1] Alden Schnyder Jason D, [2] Gidean Arularasan S*, [3] Murugesan Krishnan, [4] M. P. Santhosh Kumar, [5] Saravanan Lakshmanan

[1] Postgraduate Resident, Department of Oral and Maxillofacial Surgery, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

[2] Assistant Professor, Department of Oral and Maxillofacial Surgery, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

[3] Head of the Department, Department of Oral and Maxillofacial Surgery, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

[4] Professor, Department of Oral and Maxillofacial Surgery, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

[5] Assistant Professor, Department of Oral and Maxillofacial Surgery, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

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KEYWORDS

Maxillofacial Reconstruction, Infrared Sensors, Post-Surgical, Trauma

ABSTRACT:

Introduction: Free flap reconstruction is crucial in maxillofacial surgery for restoring form and function following trauma or oncological resection. Vascular compromise within the first 48 hours postoperatively poses the greatest threat to flap viability. Early detection is critical to improving salvage rates. Conventional monitoring techniques—clinical observation, Doppler ultrasound, and tissue oximetry—are limited by subjectivity, cost, invasiveness, or intermittent assessment.

Objective: This observational study evaluated the effectiveness of a novel, non-invasive, near-infrared (NIR) sensor system for real-time free flap monitoring using a compact ESP8266-based wireless module.

Materials and Methods: Following ethical approval, the sensor was tested on five healthy individuals using radial artery occlusion simulated with a blood pressure cuff. Data were collected before, during, and after induced ischemia. Readings were analyzed to determine sensitivity, specificity, and accuracy in detecting vascular compromise.

Results: Out of 20 total test instances, the sensor achieved a sensitivity of 90%, specificity of 70%, and overall accuracy of 80%. The average time to detect a change post-occlusion was 57 seconds. The F1 score was 81.8%, with a diagnostic odds ratio of 21. These results demonstrate the system's potential in accurately identifying circulatory changes in a controlled setting.

Conclusion: This NIR-based prototype offers a promising, objective, and low-cost tool for continuous flap monitoring. While early results are encouraging, further validation in clinical settings and diverse patient populations is necessary. Integration into post-surgical workflows could enhance flap salvage rates by enabling timely intervention.

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1. Background

Maxillofacial reconstruction is vital for restoring form and function in patients affected by trauma, tumor resection, congenital deformities, or extensive tissue loss. Among the available reconstructive options, free flaps—vascularized tissue segments harvested from one body region and transferred to another—remain indispensable. These flaps, which may consist of skin, fascia, muscle, or bone, provide the necessary structure and vascularization for functional restoration. Microsurgical techniques allow for the anastomosis of donor and recipient vessels, maintaining the flap's viability through adequate blood flow. Vascular compromise, particularly within 48 hours post-surgery, can result in flap failure due to ischemia or venous congestion if not promptly addressed (1–3). Different types of free flaps are chosen based on anatomical and reconstructive requirements, with commonly used flaps including the radial forearm free flap (RFFF), free fibula flap (FFF), anterolateral thigh flap (ALT), deep circumflex iliac artery flap (DCIA), latissimus dorsi flap, and scapular flap. Each type presents distinct challenges in terms of vascular integrity, highlighting the necessity for precise and individualized monitoring strategies (4).

Flap viability hinges on continuous arterial inflow and venous outflow, as vascular occlusions—either ischemic or congestive—can jeopardize tissue perfusion and oxygenation (5). Ischemia results from arterial obstruction, while congestion is due to impaired venous return. Both conditions can cause flap necrosis if not identified and corrected early. Flap failure rates due to vascular compromise range from 2–5%, but early surgical re-intervention can salvage 30–70% of compromised flaps (6–8). Given that salvage is time-sensitive, ideally within 6 to 8 hours, early detection of circulatory abnormalities is paramount (9). Traditional flap monitoring techniques include clinical examination, handheld Doppler ultrasound, implantable Doppler probes, tissue oximetry, and color duplex ultrasonography. Clinical evaluation remains the most common and cost-effective method, involving assessment of skin color, temperature, capillary refill, and bleeding response to pin-pricks (8). However, these signs may appear only after significant ischemia, delaying intervention.

Although accessible and widely used, clinical observation has limitations due to its subjectivity and potential delays in detecting vascular compromise. Doppler assessment offers additional insight into intravascular blood flow, especially for buried flaps, but is operator-dependent and not continuous (5,8). Implantable Doppler systems like the Cook–Swartz probe enable real-time monitoring and early identification of flow loss at the anastomosis site, improving salvage chances (8,10). Tissue oximetry provides non-invasive oxygen saturation measurements but may fail to detect acute vascular events. Color duplex ultrasonography, while effective for visualizing flow in anastomosed vessels, requires costly equipment and trained personnel, and is often used as a supplementary method to confirm suspected abnormalities (11–14). Despite advancements, these conventional approaches lack the capability for continuous, real-time, and objective monitoring, which is critical for early intervention in the postoperative window.

To address these limitations, research has increasingly focused on developing sensor-based systems that offer non-invasive, real-time monitoring of flap viability. Temperature differentials between the flap and surrounding tissue can serve as indicators of compromised blood flow, with differences of more than 1–3°C suggesting circulatory issues (15). Infrared thermography (IRT) and non-contact infrared thermometers (NCITs) have shown promise in providing accurate surface temperature measurements under certain conditions (16). IRT, in particular, is a non-invasive and portable method that transforms infrared radiation into thermal images, offering visual and quantitative data on tissue perfusion. Devices like the FLIR ONE smartphone-compatible camera make thermography accessible and practical in clinical settings (17–19). Thermography also aids in preoperative planning by identifying perforator arteries, facilitating better flap design. The ultimate goal is the development of a compact, wireless, infrared sensor system capable of continuous, objective monitoring, integrated into a 3D-printed silicone model for validation. This innovative solution has the potential to significantly improve free flap outcomes by enabling timely detection of vascular compromise and reducing the reliance on subjective clinical assessments (20–22).

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2. Materials and Method

Overview of the ESP8266 Module:

In the realm of IoT applications, the ESP8266 stands out as a versatile and energy-efficient Wi-Fi system-on-chip (SoC), offering an ideal platform for compact and dependable wireless communication. With fully integrated networking capabilities, it can function autonomously or in coordination with another microcontroller. When running applications directly on the ESP8266EX, the device boots directly from onboard flash memory. Notable features of the ESP8266 include support for 802.11 b/g/n (2.4 GHz) protocols, throughput up to 72.2 Mbps, packet fragmentation handling, two virtual Wi-Fi interfaces, automatic beacon scanning via hardware TSF, and operation in Station, SoftAP, or Promiscuous modes.

The institutional ethical committee was approached with the study and clearence obtained with the following Institution Human Ethical Committee number: IHEC/SDC/OMFS-2202/25/020. This study received approval from the institutional ethics committee. After successful testing on a 3D-printed model, preliminary human trials were performed on five healthy individuals. Both the right and left radial arteries were palpated and marked, and any data points from individuals with anatomical variations were excluded. A total of ten datasets were collected. The infrared sensor was positioned over the radial artery and secured with micropore tape at the point where the strongest pulse was felt. This allowed for real-time data acquisition.

To evaluate the sensor's effectiveness in detecting vascular occlusion, a manual blood pressure cuff was used to simulate temporary arterial blockage. Both the cuff and sphygmomanometer were standardized across all participants to ensure consistency. Initially, the sensor was calibrated and placed on the forearm to establish a baseline signal. A cuff was then wrapped around the upper arm and inflated to 80 mmHg above the individual's systolic pressure, effectively halting blood flow for 90 seconds. The pressure was then released for 120 seconds to allow reperfusion. This was followed by a second occlusion phase using a pressure of 100 mmHg for another 90 seconds, with a subsequent 120-second recovery period.

It is understood that while 70 mmHg may only impair superficial vasculature, 100 mmHg exerts a more significant ischemic impact on deeper vessels. Throughout the procedure, changes in sensor readings and the time lag between occlusion/release and sensor response were carefully monitored.

3. Results

The model correctly identified 9 instances as positive when they were truly positive (Table 10). However, the model also incorrectly predicted 3 instances as positive when they were negative. Additionally, the model missed 1 positive instance, incorrectly predicting it as negative. Finally, the model correctly predicted 7 instances as negative when they were indeed negative.

Table 1: Confusion matrix

	Predicted Positive	**Predicted Negative**
Actual Positive	9 (True positive)	3 (False positive)
Actual Negative	1 (False negative)	7 (True negative)

The sensitivity, specificity and accuracy of the sensor were 90%, 70% and 80% respectively (Table11). The device has high sensitivity (90%), reliably detecting blood flow when the cuff is not inflated. The specificity is lower (70%), indicating a moderate rate of false positives when the cuff is inflated. The F1 score (81.8%) balances precision and recall, showing robust overall performance despite imperfect specificity. LR+ (3.0) suggests a positive test triples the odds of true blood flow, while LR− (0.14) indicates a negative test strongly ruling out blood flow. DOR (21.0) highlights good discriminatory power between true positives and false negatives.

Table 2: Performance Metrics of the prototype

Parameter	**Percentage**
Sensitivity (Recall)	90
Specificity	70
Accuracy	80

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Positive Predictive Value (PPV)	75
Negative Predictive Value (NPV)	87
Positive Likelihood Ratio (LR+)	3
Negative likelihood ratio (LR-)	0.14
Diagnostic Odds Ratio (DOR)	21
F1 Score	81.8

The average BP cuff value was 204 mmHg (190-220 mmHg) (Table 2). On an average, 57 seconds (35-85 seconds) were needed for the reading to change.

Table 3: Summary of BP Cuff and Measurement Times

Parameter	Average	Minimum	Maximum
BP Cuff Value	204 mmHg	190 mmHg	220 mmHg
Time Taken for Reading to Change	57 secs	35 secs	85 secs

4. Discussion

In testing conducted on healthy volunteers, the prototype sensor demonstrated a sensitivity of 90%, specificity of 70%, and an overall accuracy of 80% in detecting the radial pulse. In comparison, prior research utilizing near-infrared (NIR) technology by Berthelot et al. [23], Tran et al. [24], and Kumbasar et al. [25] reported perfect sensitivity and specificity rates of 100%, with no false positives or negatives—results superior to those seen in our current version, indicating room for enhancement.

The device developed in this study is a prototype employing NIR-based tissue oxygen saturation (SpO_2) measurements to continuously assess blood flow and tissue perfusion. Intended as an auxiliary tool for monitoring free flaps postoperatively, the system incorporates Arduino programming that allows it to operate without individualized calibration. This design feature accounts for physiological variability among subjects while still enabling reliable monitoring.

Near-infrared spectroscopy (NIRS) provides a standardized, objective method for bedside flap assessment, enabling any member of the clinical team—regardless of their specialty—to recognize potential complications early and alert the operating surgeon. The added advantage of remote monitoring, as highlighted by Bian et al. [26], further enhances its clinical value. Despite its promise, NIR technology has recognized limitations. Studies have noted that NIRS readings can be affected by external influences, with regional tissue oxygen saturation showing interindividual and intra-flap variation. Additionally, systemic oxygen levels may influence the readings [27,28]. To minimize these effects, we developed a wireless NIR device inspired by the work of Berthelot et al. [23], and used opaque adhesive tape to shield the sensor from ambient light.

A notable challenge with NIR monitoring is the occurrence of false alarms, which can create unnecessary anxiety for patients and complicate clinical decision-making. In our study, there were three false positives and one false negative, likely due to the limited sample size. A systematic review found only two trials reporting substantial false positive/negative rates [29,30]. In the Whitaker study, which involved only ten flaps, sensitivity was reported at 66.7%, possibly affected by the small cohort. Ouyang et al. [30] acknowledged that the TSAH-100 device used in their study had limitations in tissue penetration depth, potentially leading to missed detections in obese patients or those with significant postoperative swelling.

Alternative modalities currently used for flap monitoring include microdialysis, color duplex sonography, and implantable Doppler systems. NIRS offers distinct advantages over these methods. Unlike Doppler probes, it is non-invasive and avoids the risk of disturbing the vascular anastomoses. Compared to duplex sonography—which requires a detailed anatomical understanding—NIRS is easier to operate and interpret [31]. The findings of our research support the feasibility of using a non-invasive NIR sensor for continuous flap monitoring, capable of detecting early hemodynamic changes prior to visible clinical deterioration.

Nonetheless, the study had limitations. Variations in skin pigmentation may have influenced perfusion readings. Individuals with medical conditions such as respiratory disorders or vascular abnormalities, which could impact

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oxygenation levels, were excluded. Future research involving a larger and more diverse sample, including individuals with various health conditions, will be critical for further validation. Additionally, testing on different flap designs may help improve detection accuracy and refine the device's software algorithm.

Conclusion:

This NIR-based prototype offers a promising, objective, and low-cost tool for continuous flap monitoring. While early results are encouraging, further validation in clinical settings and diverse patient populations is necessary. Integration into post-surgical workflows could enhance flap salvage rates by enabling timely intervention.

Reference:

1. Vincent M, Baj A, Spano G, et al. Free flap reconstruction in oral cancer: a retrospective study. J Craniomaxillofac Surg. 2019;47(4):558–63.
2. Zoccali C, Molina M, Farhadi J. Timing of vascular compromise in free flaps. Microsurgery. 2017;37(6):518–24.
3. Chiu T, Chang M, Perng C. Salvage of free flaps in head and neck reconstruction. Plast Reconstr Surg. 2017;140(5):839e–49e.
4. Mittal G, Agarwal A, Kataria T. Free flaps in head and neck reconstruction: a review. J Maxillofac Oral Surg. 2018;17(1):3–10.
5. Knoedler B, Weber S, Gaba B, et al. Vascular compromise in free tissue transfer: pathophysiology and prevention. J Reconstr Microsurg. 2023;39(2):120–30.
6. Kroll SS, Schusterman MA, Reece GP, et al. Timing of free flap failure. Plast Reconstr Surg. 1996;98(7):1230–3.
7. Hidalgo DA, Jones CS. Predictors of free flap failure. Plast Reconstr Surg. 1998;102(2):401–6.
8. Kohlert S, Sinha S, Yoo J. Flap monitoring and outcomes in free tissue transfer. J Otolaryngol Head Neck Surg. 2019;48(1):43.
9. Karakawa R, Yamamoto Y, Akamatsu T. No-reflow phenomenon in free flaps. Microsurgery. 2018;38(1):56–60.
10. Swartz WM, Jones NF, Cherup L, et al. Direct monitoring of microvascular anastomoses with the 20-MHz ultrasonic Doppler probe. Plast Reconstr Surg. 1988;81(2):149–53.
11. Schön M, Kreusch T. Evaluation of flap perfusion using duplex ultrasound. Eur J Plast Surg. 2003;26(3):143–7.
12. Sekido M, Yamamoto Y, Sugihara T. Duplex Doppler evaluation of free flaps. Ann Plast Surg. 2005;54(3):269–73.
13. Vakharia KT, Hanna IA, Chalian AA. Use of color duplex ultrasonography in flap monitoring. Laryngoscope. 2012;122(8):1810–4.
14. Khalid FA, Mah E, Townsend CM. Postoperative flap monitoring using color duplex ultrasound. J Plast Reconstr Aesthet Surg. 2006;59(12):1343–7.
15. Chen KT, Mardini S, Chuang DC, et al. Timing of ischemia and clinical outcome in free flap surgery. Plast Reconstr Surg. 2007;120(3):764–71.
16. Rogoń P, Rybak A, Wcisło S, et al. Infrared thermometry in free flap monitoring. Sensors. 2024;24(2):411.
17. Zhao H, Bergmann JH. Evaluation of non-contact infrared thermometers and thermal imaging. Therm Med Int. 2023;41(1):12–20.
18. McGrouther DA, Sully L. Thermographic assessment in flap surgery. Br J Plast Surg. 1980;33(1):19–24.
19. Singla A, Goyal A, Kumar A. Smartphone-based thermography in perforator flap design. J Reconstr Microsurg. 2024;40(1):45–50.
20. John HE, Niumsawatt V, Rozen WM, et al. The use of the FLIR ONE smartphone-based thermographic camera. Plast Reconstr Surg Glob Open. 2016;4(8):e849.
21. Chubb D, Taylor GI, Ashton MW. True and 'choke' anastomoses between perforator angiosomes. Plast Reconstr Surg. 2013;132(6):1447–56.
22. Xie T, Liu Y, Zhang Y, et al. Wireless infrared sensor for flap monitoring. Front Bioeng Biotechnol. 2023;11:1139247.

Journal of Chemical Health Risks

www.jchr.org

JCHR (2025) 15(3), 445-450 | ISSN:2251-6727

23. Berthelot M, Yang L, Lo J. Noninvasive monitoring of tissue perfusion using near-infrared spectroscopy. *J Biomed Opt*. 2017;22(2):025001.

24. Tran P, Nguyen T, Lee K. Advances in flap monitoring using near-infrared spectroscopy: A prospective study. *Microsurgery*. 2021;41(6):503–10.

25. Kumbasar U, Aydin G, Sahin B. Reliability of near-infrared spectroscopy for free flap monitoring: A clinical evaluation. *Ann Plast Surg*. 2021;86(4):420–5.

26. Bian Z, Pek Y, Hwee L. Real-time flap monitoring using wireless NIRS: A feasibility study. *Sensors (Basel)*. 2022;22(3):985.

27. Ozturk S, Uyar M, Arslan H. Influence of pigmentation on NIRS-based tissue oxygenation measurements. *Clin Plast Surg*. 2015;42(2):293–300.

28. Salgarello M, Visconti G, Barone-Adesi L. NIRS variability across different areas of the same flap: A prospective analysis. *Eur Rev Med Pharmacol Sci*. 2018;22(10):3201–8.

29. Whitaker IS, Gulati V, Foo IT. A review of monitoring techniques for free flaps. *Ann Plast Surg*. 2012;68(3):222–8.

30. Ouyang Z, Wang H, Liu J. Clinical evaluation of a new NIRS device (TSAH-100) for flap monitoring. *J Reconstr Microsurg*. 2021;37(7):552–60.

31. Smit JM, Zeebregts CJ, Acosta R, Werker PM. Advancements in free flap monitoring: An overview of current techniques. *Ann Plast Surg*. 2010;64(6):710–6.