Infrared surface temperature monitoring in the postoperative management of free tissue transfers

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BACKGROUND: Early identification of failing free flaps may allow for potential intervention and flap salvage. The predictive ability of flap temperature monitoring has been previously questioned. The present study investigated the ability of an infrared surface temperature monitoring device to detect trends in flap temperature and correlation with anastomotic thrombosis and flap failure.

METHODS: Postoperative measurement of surface temperature was obtained in 47 microvascular free flaps. Differences in temperature between survival and failure groups were evaluated for statistical significance using Student's *t* test ($P < 0.05$). In addition, a single variable analysis was performed on 30 different flap characteristics to evaluate their prediction of flap failure.

RESULTS: In total, eight flaps failed. Five of these were re-explored, of which one was salvaged. The three other flaps died a progressive death secondary to presumed thrombosis of the microcirculation despite adequate Doppler signals. Temperatures of the flap failure group during the last 24 h yielded a mean difference of 2°C (3.56°F) compared with surviving flaps ($P < 0.05$). The temperature of the failing flaps began to decline at the eighth postoperative hour. Single variable analysis identified prior radiation to be a predictor of flap failure.

CONCLUSIONS: A surface temperature measurement device provides reproducible digital readings without physical contact with the flap. Technical difficulties encountered in previous research with implantable or surface contact temperature probes are obviated with this noncontact technique. Flap temperature monitoring revealed a trend in temperature that correlates with anastomotic thrombosis and eventual flap failure.

Key Words: Free flap; Free flap temperature monitoring; Free tissue transfer; Free tissue transfer postoperative monitoring; Free tissue transfer survival; Microvascular surgery;

In microvascular free flap surgery, monitoring plays a critical role in detecting early postoperative vessel thrombosis. Flap survival can be augmented with timely restoration of blood flow. There have been numerous modalities and methods described for postoperative monitoring; however, no single gold standard exists and research is ongoing evaluating new and old methods of monitoring (1-5). One such modality, flap temperature monitoring, was first described and investigated in 1976 by Baudet et al (6). Since then, numerous papers have described various modalities and methods used for temperature monitoring, with differing results and parameters being reported (5,7-10). Some of the difficulties with these methods include variability in temperature measurement, technical issues with the probes and certain types of flaps, and lack of precise correlation with early thrombosis.

La surveillance infrarouge de la température de surface pendant la prise en charge postopératoire des transferts de tissu libre

HISTORIQUE : Si on dépiste rapidement les rejets de lambeau libre, on pourra peut-être intervenir et sauvegarder les lambeaux. La capacité prédictive de surveiller la température du lambeau a déjà été remise en question. La présente étude a porté sur la capacité d'un dispositif infrarouge de surveillance de la température de surface à déceler les tendances de température des lambeaux et leur corrélation avec une thrombose anastomotique et un rejet du lambeau.

MÉTHODOLOGIE : Après l'opération, on a mesuré la température de surface dans 47 lambeaux libres microvasculaires. On a évalué les différences de température entre les greffes réussies et rejetées pour en établir la signification statistique au moyen du test de Student ($P < 0,05$). En outre, on a procédé à une analyse univariée sur 30 caractéristiques différentes des lambeaux afin d'évaluer la prédiction de rejet.

RÉSULTATS : Au total, huit lambeaux ont été rejetés. Cinq d'entre eux ont été réexaminés, et un a été sauvé. Les trois autres lambeaux sont morts progressivement en raison d'une thrombose présumée de la microcirculation, malgré des signaux Doppler adéquats. La température du groupe de lambeaux rejetés pendant les 24 dernières heures ont présenté une différence moyenne de 2°C (3,56°F) par rapport aux lambeaux survivants ($P < 0,05$). La température des lambeaux rejetés a commencé à baisser pendant la huitième heure postopératoire. L'analyse univariée a établi qu'une radiation antérieure est un prédicteur de rejet de lambeau.

CONCLUSIONS : Un dispositif de mesure de la température de surface fournit des lectures numériques reproductibles sans contact physique avec le lambeau. Les problèmes techniques affrontés lors de l'étude précédente au moyen de sondes de température ou à contact de surface sont évités grâce à cette technique sans contact. La surveillance de la température du lambeau révèle une tendance des températures qui est corrélée avec la thrombose anastomotique et un rejet possible du lambeau.

The purpose of the present study was to investigate the ability of an infrared nonsurface contact temperature-monitoring device (Raytek Corporation, USA) to detect flap surface temperature. An infrared thermometer is a sensor that can measure an object's temperature without any direct physical contact. We sought to determine if temperatures measured in this manner can accurately predict a trend in flap temperatures that correlates with anastomotic thrombosis and ultimate flap failure.

METHODS

A retrospective review identified 47 free tissue transfers that underwent postoperative monitoring using a handheld non-contact infrared temperature-measuring device (DataTemp MX, Raytek Corporation, USA) at Erlanger Medical Center

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TABLE 1
Patient demographics and comorbidities

Patients, n	45
Age, years, mean (range)	42.4 (13–83)
Sex, female/male	11/34
Comorbidities, n (%)	
Tobacco use	22 (47)
Diabetic illness	4 (9)
Pulmonary illness	6 (13)
Routine alcohol use	12 (26)
Body mass index, kg/m ² , mean (range)	27.9 (15–44)

(Chattanooga, Tennessee) from October 2003 to April 2007. Simultaneous measurements of the free flap, adjacent skin and core body temperatures were evaluated. Comparison was made between the temperatures in the group of flaps that survived with the group of flaps that failed secondary to vessel thrombosis. Additionally, flap survival was correlated to patient demographics, patient characteristics (comorbidities, body mass index), flap characteristics (reason, type, recipient site, ischemic time), other methods of postoperative monitoring (Doppler, clinical evaluation) and secondary interventions.

Patient demographics and comorbidities are presented in Table 1. The average patient age was 42.4 years (range 13 to 83 years). Nearly one-half of the patients (47%) had history of tobacco use and 26% of patients routinely used alcohol. There were four diabetic patients and six patients with pre-existing pulmonary disease.

Sixty-eight per cent of patients (n=32) underwent free tissue transfer for closure of a traumatic soft tissue injury. There were nine flaps performed for soft tissue reconstruction of oncological defects, three for burn wound management with exposed bone and/or joint space, and three for chronic wound management. Four different types were used: rectus abdominis (n=31), latissimus (n=8), gracilis (n=4) and radial forearm fasciocutaneous (n=4). These flaps were used at five different recipient sites: leg (n=26), foot (n=9), mouth (n=5), arm (n=5) and scalp (n=2) (Table 2).

Technique

Upon arrival to the intensive care unit for postoperative management, free flap temperature, adjacent skin temperature and core body temperature were recorded every hour for 24 h. Simultaneous presence of Doppler signals was also recorded. Ambient temperature was kept at a standard 26.7°C (80°F). After 24 h, if the flap had maintained a steady temperature and clinical evaluation was satisfactory, monitoring intervals were increased to every 2 h. Forty-eight hours postoperatively, if similar results were found indicating flap viability, the time interval was again increased to every 4 h.

Nurses were instructed to obtain temperatures in a standardized fashion by pointing the infrared temperature device at a previously marked spot on the flap while holding the device approximately 15 cm to 30 cm (6 in to 12 in) from the flap. The device has a single dot laser sighting system that helps with reproducibility of measurements. The temperature is displayed on the unit's liquid crystal display screen. After flap temperature recording, adjacent nonflap skin temperature was

TABLE 2
Flap characteristics

Characteristic	n (%)
Flap indications	
Trauma	32 (68)
Burn	3 (6)
Chronic wound	3 (6)
Cancer	9 (19)
Flap types	
Rectus	31 (66)
Latissimus	8 (17)
Gracilis	4 (9)
Radial forearm	4 (9)
Recipient site	
Leg	26 (55)
Scalp	2 (4)
Foot	9 (19)
Mouth	5 (11)
Arm	5 (11)

measured in a similar fashion. The corresponding core body temperature was also recorded.

Statistical analysis

Differences in temperature between flap survival and flap failure groups were evaluated for statistical significance using the Student's *t* test ($P<0.05$). In addition to this, a single variable analysis was performed on 30 different flap characteristics to evaluate for their prediction of flap failure. Statistical difference for the single variable analysis was performed using both the Fisher's exact test and the Kaplan-Meier analysis, and the log-rank test (Mantel-Cox test). $P<0.05$ was considered to be significant.

RESULTS

Of 47 free tissue transfers, there were eight failures (17%). Five flaps in the series were re-explored for presumed vascular thrombosis. The indication for exploration was derived from a combination of clinical evaluation, loss of Doppler signal and decrease in flap temperature. Of the five flaps that were explored, only one was salvaged. One flap died despite revision of the anastomosis; three flaps were deemed unsalvageable at re-exploration. Of the three flaps that were deemed unsalvageable, one had a patent arterial anastomosis with a thrombosis of the venous anastomosis, one was infected, and the last was deemed nonviable with no other information. The three failed flaps that were not explored died a slow progressive death due to presumed secondary thrombosis of the microcirculation. These flaps had continued presence of Doppler signals despite duskeness of the muscle and patent anastomoses at the time of muscle debridement.

Flap surface temperatures of the flap failure group during the 24 h before documented failure compared with flap surface temperatures of the flap survival group yielded a mean difference of 2°C (3.56°F) (Figure 1). The temperatures between the flap failure group and the flap survival group during this 24 h period were compared at 4 h intervals. In each 4 h time block, the flap failure group produced a statistically significant lower temperature ($P<0.05$) (Table 3).

Figure 1) Temperature comparisons between flap survival group and flap failure group over the last 24 h of flap life. Pink: Mean core body failure group; Dark blue: Mean core body survival group; Red: Mean adjacent skin temperature survival group; Green: Mean adjacent skin temperature failure group; Yellow: Mean flap temperature survival group; Aqua: Mean flap temperature failure group;

TABLE 3
Flap temperature comparisons between flap survival group and flap failure group over the last 24 h of flap life

Group	4 h blocks of time					
	1	2	3	4	5	6
Survival, mean flap temperature, °C (°F)	33.2 (91.8)	33.7 (92.6)	33.7 (92.7)	33.9 (93.1)	33.7 (92.7)	33.7 (92.6)
Failure, mean flap temperature, °C (°F)	30.6 (87.1)	31.8 (89.4)	32.1 (89.8)	31.8 (89.3)	32.0 (89.6)	31.7 (89.0)
P*	0.005	0.038	0.045	0.003	0.005	0.004

*Student's t test, significance at $P < 0.05$. Survival group, $n = 39$; Failure group, $n = 8$

There was also a difference between the flap temperature and adjacent skin temperatures in the two groups. In this same 24 h period, the flap failure group had a 3.7°C (6.6°F) difference between its temperature and the adjacent skin control temperature compared with a 1.5°C (2.7°F) difference in the surviving flaps and their adjacent skin control. The mean temperature difference between the flap failure group and its adjacent skin control compared with the mean temperature difference between the flap survival group and its adjacent skin control in this 24 h period is documented in Table 4, with the failing group producing the largest temperature differences. A graphic chart plotting flap, core body and adjacent skin temperatures of both groups over 71 h was compiled (Figure 2).

An additional graphic chart plotting the first 24 h surface temperature measurements of the failed flaps was compiled (Figure 3). An obvious trend is demonstrated showing the temperatures of the failing flaps beginning to decline at approximately the eighth postoperative hour.

The single variable analysis identified previous radiation, any complication and any additional procedures performed to be predictors of flap failure. All other variables did not produce a statistically significant correlation (Table 5). Four patients received radiation before undergoing free flap reconstruction;

TABLE 4
Temperature comparisons of flap survival group and flap failure group between mean temperature differences of flap and adjacent skin controls for each group

Last 24 h (4 h block average) °F	1	2	3	4	5	6
Mean temperature difference	9.56	7.29	6.69	5.43	4.73	5.72
Failure group (flap-adjacent skin control)						
Mean temperature difference	3.87	3.28	3.16	1.89	1.5	2.48
Survival group (flap-adjacent skin control)

Figure 2) Temperature comparisons between flap survival group and flap failure group over 71 h. Pink: Mean core body temperature failure group; Dark blue: Mean core body temperature survival group; Red: Mean adjacent skin temperature failure group; Purple: Mean adjacent skin temperature survival group; Yellow: Mean flap temperature survival group; Aqua: Mean flap temperature failure group

Figure 3) Mean flap temperature of the flap failure group over the first 24 h postoperatively

two of these flaps failed. For flaps with a documented ischemic time, the total ischemic time was less than 80 min for 16 flaps and greater than 80 min for 17 flaps; there was one failure for an ischemic time of less than 80 min and four failures for ischemic times greater than 80 min. However, this was not statistically significant. There were 11 complications: five flaps had an anastomotic thrombosis, three had presumed secondary thrombosis

TABLE 5
Predictors of flap failure

Predictor	P*
Comorbidities	
Tobacco	0.546
Diabetes	0.383
Pulmonary	0.790
Alcohol	0.408
Flap indications	
Trauma	0.187
Burn	0.100
Chronic wound	0.400
Cancer	0.177
Flap types	
Rectus	0.177
Latissimus	0.471
Gracilis	0.458
Radial forearm	0.507
Destination	
Leg	0.220
Mouth	0.765
Arm	0.215
Flap details	
Prior radiation	0.001
Complications	0.000
Additional procedures	0.000
Ischemic time >80 min	0.147

*Significance at $P < 0.05$

of the microcirculation, two had partial loss of split-thickness skin grafts, and one hematoma. There were 15 additional procedures performed: five re-explorations, four secondary split-thickness skin grafts, four additional free tissue transfers, one evacuation of a hematoma and one amputation.

DISCUSSION

The ability of an infrared nonsurface contact temperature-monitoring device (Raytek Corporation, USA) to detect flap temperature and to accurately predict a trend in flap temperatures that correlates with anastomotic thrombosis and ultimate flap failure has been examined. Other authors have described an absolute cut-off temperature below which flaps do not survive (11), but this was not found to be predictive in other series and is subject to systemic physiological changes in the patient. The lack of clear cut values to predict flap failure, technical difficulties with temperature measuring probes, and concerns regarding the effect of environmental conditions on flap temperature have contributed to the lack of uniform acceptance of temperature measurement as a reliable method of postoperative flap monitoring.

The temperature curves obtained in the present study reveal a temperature difference between the free flaps that survived and those that failed. A clear trend is seen delineating the two groups at approximately the eighth postoperative hour. Based on this, one could suggest that this may be a critical time for detecting flap survival and stringent observation should be carried out particularly during this time period.

During the last 24 h of documented flap clinical viability, the average temperature difference between the flaps that failed and the flaps that survived yielded a mean temperature

difference of 2°C (3.56°F). Also, during this same 24 h period, the failing flaps had temperature differences between the flap and the adjacent intact skin ranging from 2.6°C to 5.4°C (4.73°F to 9.76°F). Previously reported temperature differences between flap and adjacent intact skin controls in the presence of ischemia and thrombosis, have ranged from a 1.8°C (3.24°F) change in the temperature difference between the flap and adjacent control, reported by Khouri and Shaw (10), and 2.4°C (4.32°F) for arterial thrombosis and 2.6°C (4.68°F) for venous thrombosis, reported by Kerrigan and Daniel (13). Our results fall into a range consistent with the above reported temperatures. Other previous results have varied from the above, wherein flaps with documented anastomotic thrombosis have temperature differences between flap and intact skin of only 2°C (3.6°F) and surviving flaps have temperature differences between flap and intact skin greater than 3°C (5.4°F) (10,12). Our results were consistent with these findings, with the temperature differences between flap and adjacent intact skin in two 4 h time blocks averaging 1.8°C and 2.2°C (3.28°F and 3.87°F).

Flap temperatures of the survival group ranged from 28.4°C to 38.1°C (83.2°F to 100.5°F) while flap temperatures from the failing group ranged from 27.8°C to 35.4°C (82°F to 95.7°F). There were no flaps that survived after a temperature drop below 28.4°C (83.2°F). Therefore, we believe that any flap with an unexplained temperature drop below 28.4°C (83.2°F) should be an indication for reexploration.

Of 47 free tissue transfers, we had eight failures. Five of the eight failed flaps were re-explored with the indication for exploration being derived from a combination of clinical evaluation, loss of Doppler flow and decrease in flap temperature. Seven of the flaps that failed were monitored postoperatively with Doppler ultrasound. The Doppler signal was completely lost in only four of these patients. The other three patients had temperature changes and clinical findings suggestive of ischemia, inadequate arterial inflow or venous drainage before Doppler changes.

The temperature measurement apparatus used for our recordings was a handheld noncontact infrared temperature-measuring device. It is currently used in industry, particularly in the automotive industry and heating and cooling industry. The mechanism is based on the principle that the intensity of radiant energy emitted by an object is directly related to its temperature. The infrared sensor measures the intensity of radiation emitted from the object's surface. These types of thermometers have a wide temperature range (−30°C to 500°C), a 500 ms response time and an accuracy of $\pm 1.5\%$ or $\pm 1.5^\circ\text{C}$ (whichever is greater) (14). A noncontact device alleviates the need for prior implanted or surface contact measurements that, if accidentally jarred or moved, could disrupt or disturb the free tissue transfer. This method works well on skin grafted muscle free flaps, which have difficulty with adherence of contact probes. Additionally, because the device is not attached to the patient, we could take temperature recording from multiple sites on the flap and were not be limited to one fixed position. The device provided reproducible measurements. There is no risk of contamination or mechanical effect on the flap. The nursing staff deemed it to be easy to use and had no complaints about its use or function. This is an important aspect of care because they are the ones closely observing the flap postoperatively, and less experienced nurses or

physicians in training may have difficulty performing and interpreting Doppler signals and judging flap viability based upon clinical appearance.

We acknowledge that a decrease in flap temperature may be a late finding in compromised flaps. However, the loss of Doppler flow as well as changes in clinical appearance may also be late findings, particularly in cases of venous thrombosis. Flap temperature may correlate with the degree of vascular compromise, as well as other factors, and a prospective study would be useful in further evaluation of these variables and ultimate flap management. We believe that any change in flap temperature can only add to our clinical decision making and with this technique's reproducibility and effortless use, it is a helpful addition to our armamentarium.

CONCLUSIONS

A surface temperature measurement device, previously used for industrial purposes but not in the medical setting, provides a reliable, accurate, reproducible digital reading without contact

with the flap. Trends in surface temperature monitoring are found to correlate with anastomotic thrombosis. Technical difficulties encountered in previous research with implantable or surface contact temperature probes are obviated with this non-contact technique. The final decision to explore a microvascular anastomosis is usually clinically based, but the trigger to clinically examine a flap may be based on easily obtained surface temperature measurements. Flap temperature monitoring in the present study was safe and easy, and accurately produced a trend in temperature that correlated with anastomotic thrombosis and eventual flap failure.

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