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Accuracy and Cutoff Values of Five-Point versus Single-Point Flap Temperature Monitoring for Predicting Vascular Crisis: A Postprint Study

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Abstract

Background: Skin flap transplantation is a commonly used surgical approach for repairing various wounds. Flap temperature reflects the blood supply and venous return status of the flap, facilitating early detection of vascular crisis. However, the methodology for accurate measurement of flap temperature and its specific predictive value for vascular crisis remains unclear. Objective: To investigate the difference between "five-point" and "single-point" flap temperature measurements and their predictive accuracy for vascular crisis along with optimal cutoff values. Methods: Adult inpatients undergoing flap surgery from January 2021 to July 2023 were enrolled. Starting from postoperative day 1, flap temperature was measured every 2 hours using a non-contact infrared thermometer according to the "five-point method": the flap center point and edge points at the 12, 3, 6, and 9 o'clock positions. The thermometer was positioned 3 cm from each site with a 3-second pause to obtain temperature readings. The average of the "five-point" temperatures was calculated and compared with the single-point temperature at the flap center. Concurrently, the "cotton swab compression method" was employed to monitor flap capillary response, and flap color was observed. Monitoring was performed continuously for 5 days. Results: A total of 66 patients undergoing various flap surgeries were included, with males and females comprising 59.09% (39/66) and 40.91% (27/66), respectively, and a mean age of (45.17$±$16.77) years. The changing patterns of both "five-point" and "single-point" flap temperatures from postoperative days 1-5 demonstrated the lowest temperature on postoperative day 1, with gradual increase thereafter. The incidence of vascular crisis was 15.15%, occurring predominantly within 3 days post-surgery. The "five-point" flap temperature was significantly lower than the "single-point" flap temperature ($P<0.001$). Receiver operating characteristic curves were constructed for both "five-point" and "single-point" flap temperatures to predict vascular crisis. The results indicated that the area

under the curve for "five-point" flap temperature in predicting vascular crisis was 0.87 (95%CI: 0.74, 0.99), with sensitivity and specificity of 90% and 75%, respectively, a Youden index of 0.65, and an optimal cutoff value of 35.96℃. For "single-point" flap temperature, the area under the curve was 0.76 (95%CI: 0.61, 0.91), with sensitivity and specificity of 70% and 71%, respectively, a Youden index of 0.41, and an optimal cutoff value of 36.18℃. Conclusion: The "five-point" flap temperature is lower than the "single-point" flap temperature, with slightly superior accuracy and validity in predicting vascular crisis. Clinical application of the "five-point method" for flap temperature measurement is more accurate.

Full Text

Accuracy and Cut-off Values of "Five-Point" Flap Temperature and "Single-Point" Flap Temperature in Predicting Vascular Crisis

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Abstract

Background: Skin flap transplantation is a common surgical method for repairing various types of wounds. Flap temperature reflects the blood supply and venous return of the flap, which can help detect vascular crises in the early stage. However, how to accurately measure flap temperature and its specific predictive role in vascular crises remains unclear.

Objective: To explore the difference in flap temperature between the "five-point" and "single-point" methods and their accuracy and optimal cut-off values in predicting vascular crisis.

Methods: Adult inpatients who underwent flap surgery from January 2021 to July 2023 were included. Beginning on postoperative day 1, non-contact infrared thermometers were used every 2 hours to measure flap temperature using the "five-point method" at the center point and edge positions at 12, 3, 6, and 9 o'clock. Temperature readings were obtained by pausing for 3 seconds at a distance of 3 cm from each site, and the average temperature of the five points was calculated. This was compared with the single-point temperature

at the flap center. Simultaneously, the "cotton bud compression method" was used to monitor capillary response, and flap color was observed for 5 consecutive days.

Results: A total of 66 patients undergoing various flap surgeries were included, with males and females accounting for 59.09% (39/66) and 40.91% (27/66), respectively. The mean age was (45.17$±$16.77) years. The pattern of temperature change for both "five-point" and "single-point" flap temperatures from postoperative days 1-5 showed the lowest temperature on day 1, gradually increasing thereafter. The incidence of vascular crisis was 15.15%, occurring mainly within 3 days after surgery. The "five-point" flap temperature was significantly lower than the "single-point" flap temperature ($P<0.001$). Receiver operating characteristic (ROC) curves were plotted for both methods. The area under the curve (AUC) for "five-point" flap temperature in predicting vascular crisis was 0.87 (95%CI: 0.74, 0.99), with sensitivity and specificity of 90% and 75%, respectively, a Youden index of 0.65, and an optimal cut-off value of 35.96℃. For "single-point" flap temperature, the AUC was 0.76 (95%CI: 0.61, 0.91), with sensitivity and specificity of 70% and 71%, respectively, a Youden index of 0.41, and an optimal cut-off value of 36.18℃.

Conclusion: The "five-point" flap temperature is lower than the "single-point" flap temperature, and the former demonstrates slightly better accuracy and validity in predicting vascular crisis. Clinical measurement of flap temperature using the "five-point method" is more accurate.

Keywords: Flap transplantation; Temperature measurement; Non-contact infrared thermometer; Vascular crisis; Prediction

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1. Subjects and Methods

Flap transplantation is a common surgical procedure in burn and plastic surgery for repairing various traumatic wounds and chronic ulcers. Flap temperature indirectly reflects the blood supply and venous return status of the flap, which is closely related to flap survival and constitutes an important aspect of postoperative nursing observation [1-3]. Clinical methods for observing flap temperature mainly include traditional finger palpation, infrared thermometer measurement, and infrared thermal imaging [2-4]. Infrared thermometers have become a new method for flap temperature measurement due to their low cost, simple operation, and high accuracy, playing an important role in postoperative flap temperature monitoring [2,5-7]. However, several issues remain unclear: First, the appropriate measurement site is uncertain. Some studies suggest measuring the central flap temperature as the representative temperature [4-5], while others report that temperature in vascularized flap regions is higher than surrounding skin, recommending measurement of multiple flap regions to observe microcirculation changes and detect flap circulation disorders early [8]. There is no clear consensus on how to position temperature measurement sites. Existing research

shows that axillary temperature > neck temperature > forehead temperature > wrist temperature when measured with non-contact infrared thermometers [6]. Second, the relationship between postoperative flap temperature patterns and vascular crisis is not well established. Current studies only report temperature change values and differences between flap temperature and contralateral normal skin temperature [4-5], without exploring the predictive value of temperature changes for vascular crisis or their clinical nursing guidance significance. Therefore, based on the principle and method of wound “five-point temperature measurement” [9-10], this study designed the “flap five-point temperature measurement method” and conducted a prospective observational study to investigate the differences between “five-point” and “single-point” flap temperatures and their accuracy and optimal cut-off values in predicting vascular crisis, providing reference for accurate flap temperature measurement and early detection of vascular crisis.

1.1 Study Subjects

This study used convenience sampling to select patients who underwent various flap transplantation surgeries in the Department of Burns and Plastic Surgery at Eastern Theater General Hospital from January 2021 to July 2023. Seventy-three patients meeting inclusion and exclusion criteria were initially enrolled. Seven patients were lost to follow-up due to transfer to other departments within 3 days postoperatively, leaving 66 patients who completed the 5-day postoperative flap observation protocol. This study was approved by the Ethics Committee of Eastern Theater General Hospital (Approval No.: 2020NZKY-027-02).

Inclusion criteria: (1) Patients undergoing flap transplantation for trauma or chronic ulcers, regardless of location or flap type; (2) Age $\geq$ 18 years; (3) Conscious with normal communication ability; (4) Normal postoperative vital signs, particularly body temperature <37.5℃; (5) Presence of a temperature observation window or physician order for flap temperature measurement. All criteria had to be met simultaneously.

Exclusion criteria: (1) Patients requiring reoperation due to failed flap transplantation; (2) Patients receiving vasoactive drugs or anticoagulants postoperatively; (3) Flap transplantation for secondary osteomyelitis or malignant lesion excision; (4) Poorly controlled hyperglycemia or diabetes postoperatively; (5) Lower extremity ulcers with arterial or venous disease; (6) Current smokers; (7) Postoperative local infection or body temperature $ $37.5℃.

This study used the single-group target value method to estimate sample size [11]. Based on the principle of wound “five-point temperature measurement” [9-10], we designed the “flap five-point temperature measurement method,” which uses a non-contact infrared thermometer to measure temperatures at five sites (flap center, 12, 3, 6, and 9 o’clock positions) and calculates the mean value for comparison with the single-point center temperature. In a pilot study of 10 patients, the difference between “five-point” flap temperature (35.6℃) and “single-

point" flap temperature (36.5℃) was 0.9℃. According to reports, the accuracy of non-contact infrared thermometers for single-site flap temperature measurement is approximately 75% [5]. We anticipated that the five-point method could improve accuracy to 90% as the primary evaluation indicator (higher-is-better) [11]. With a one-sided test level of 0.025 and power of 1-β=80%, using the formula: $[Z_1 \ \sqrt{}(\pi_0(1\text{-}\pi_0)) + Z_1 \ \sqrt{}(\pi_1(1\text{-}\pi_1))]^2/(\pi_1\text{-}\pi_0)^2$, the estimated sample size was 51.84 cases. Considering a possible 15% dropout rate, we ultimately needed to enroll 52÷0.85   62 patients.

1.2 Research Methods

(1) Flap temperature measurement: Enrolled patients began flap temperature measurement 2 hours after returning to the ward, with measurements taken every 2 hours until postoperative day 5. Before measurement, doors and windows were closed, and ward temperature was uniformly adjusted to 24-25℃ using air conditioning. Patients with cold sensations due to anesthesia or surgery were provided with additional blankets and warm milk, and intravenous fluids were warmed until cold sensation resolved. Patients were instructed to take deep breaths and relax completely. If local infrared warming was used, it was removed 30 minutes before temperature measurement [5]. Measurement method: The measurement site was exposed, and trained ward nurses used a non-contact infrared thermometer (domestic model YHW-2) to measure temperature at five sites (flap center, 12, 3, 6, and 9 o'clock positions) from a distance of 3 cm, pausing 3 seconds at each site to obtain readings. The average of the five measurements was taken as the overall flap temperature ("five-point" flap temperature), while the center point temperature was recorded separately ("single-point" flap temperature).

(2) Flap observation: During temperature measurement, flap color was observed for ruddy appearance, purple or pale discoloration, swelling, or other changes, with abnormalities reported promptly to physicians [12-14].

(3) Capillary refill monitoring: After each temperature measurement, the "cotton bud compression method" was used to assess capillary refill response. A sterile cotton bud was gently pressed on the central flap skin until color change occurred, then quickly removed. The time for color return to normal was recorded. Color return within 1-2 seconds was considered normal, while >2 seconds indicated delayed capillary refill [12-14].

(4) Vascular crisis judgment: Vascular crisis was diagnosed if flap temperature decreased (below body temperature), skin color changed (purple or pale), or capillary refill was delayed (>2 seconds) [15], requiring immediate physician notification and interventions such as infrared irradiation to promote circulation, heparin irrigation, or needle pricking for early venous congestion [14,16-17].

(5) Quality control: A dedicated "flap observation data collection form" was designed, including patient demographics (age, sex, primary diagnosis, hospital ID), surgical data (anesthesia type, flap type, location, area), and flap obser-

vation data (observation time, temperature, color, capillary response, interventions, evaluator signature). Hospitalization duration was obtained through the electronic medical record system. Ward nurses with senior professional titles and graduate students were uniformly trained by the research team on all data collection and recording methods in the "flap observation record form," and only those who demonstrated proficiency through assessment were qualified to participate. Data for each patient were kept by designated personnel, and a database was established after dual verification.

1.3 Statistical Methods

Data entry and management were performed using Epidata 3.2 software, and statistical analysis was conducted using SPSS 22.0. Normally distributed continuous data were expressed as mean ± standard deviation, with paired t-tests used for comparing "five-point" and "single-point" flap temperatures. Non-normally distributed data were expressed as median (P25, P75), with Mann-Whitney U tests for between-group comparisons. Categorical data were expressed as frequency or percentage (%), with ^{2} tests or Fisher's exact tests for between-group comparisons. Using vascular crisis occurrence as the outcome variable, receiver operating characteristic (ROC) curves were used to determine the area under the curve (AUC), optimal cut-off values, sensitivity, specificity, and Youden index for both "five-point" and "single-point" flap temperatures in predicting vascular crisis. Larger AUC indicates higher accuracy: AUC $ $0.50 indicates no predictive accuracy, 0.51-0.69 indicates poor accuracy, 0.70-0.79 indicates acceptable accuracy, 0.80-0.89 indicates good accuracy, and AUC $ $0.90 indicates excellent accuracy [18-19]. Sensitivity represents the proportion of true positive cases correctly identified (0-100%), with higher values indicating better identification of actual cases [18-19]. Specificity represents the proportion of true negative cases correctly identified (0-100%), with higher values indicating better identification of non-cases [18-19]. The Youden index evaluates the validity of cut-off values (0-1), with higher values indicating better validity; the cut-off value corresponding to maximum AUC and Youden index was considered optimal [18-19]. P<0.05 was considered statistically significant.

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2. Results

2.1 Patient Basic Data

The study initially enrolled 73 eligible patients undergoing flap transplantation. Seven patients were lost to follow-up due to transfer to other departments within 3 days postoperatively, leaving 66 patients who completed the 5-day observation protocol (dropout rate: 9.59%). The mean age of included patients was (45.03$±17.00)*years, withmeanhospitalizationdurationof*(28.89±$16.87) days. Males and females accounted for 59.09% (n=39) and 40.91% (n=27), respectively. Preoperative diagnoses included post-traumatic skin defects

(30.30%, n=20), chronic ulcers (37.88%, n=25), and postoperative soft tissue defects (31.82%, n=21). General anesthesia and epidural anesthesia were used in 81.82% (n=54) and 18.18% (n=12) of patients, respectively. Detailed information is shown in Table 1 .

2.2 Flap Temperature Measurement Results

The mean flap area was (73.46$\pm$82.15)cm^{2}, with a median area of [49.00(27.75, 90.25)] cm^{2}. The "five-point" flap temperature was significantly lower than the "single-point" flap temperature on postoperative days 1, 2, 3, 4, and 5 ($P<0.001$), as shown in Table 2 . During the 5-day postoperative period, the "five-point" flap temperature was consistently lower than the "single-point" temperature across different flap locations, types, and areas ($P<0.005$), as shown in Table 3 .

Among the 66 patients, 10 developed vascular crisis (15.15%), including 7 cases of venous crisis (10.61%) and 3 cases of arterial crisis (4.55%), occurring mainly within 3 days postoperatively. Venous crisis cases resolved with early intervention, while arterial crisis cases required reoperation within 2 days. Both "five-point" and "single-point" flap temperatures were significantly lower in patients who developed vascular crisis compared to those who did not ($P<0.001$), as shown in Table 4 .

2.4 Predictive Value of Flap Temperature for Postoperative Vascular Crisis

The AUC for "five-point" average flap temperature in predicting vascular crisis within 3 days postoperatively was 0.87 (95%CI: 0.74-0.99), with sensitivity and specificity of 90% and 75%, respectively, a Youden index of 0.65, and an optimal cut-off value of 35.96℃. The AUC for "single-point" average flap temperature was 0.76 (95%CI: 0.61-0.91), with sensitivity and specificity of 70% and 71%, respectively, a Youden index of 0.41, and an optimal cut-off value of 36.18℃ (Figure 1 [Figure 1: see original paper]).

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3. Discussion

3.1 Postoperative Monitoring Methods and Predictive Value of Flap Temperature for Vascular Crisis

With the development of microsurgical techniques, flap transplantation is increasingly used to repair various traumatic wounds and chronic ulcers. Microvascular thrombosis leading to flap crisis, including arterial and venous crises collectively termed vascular crisis, is one of the most concerning complications, often occurring within 2 days postoperatively [13,17,20-22]. Early detection of flap vascular crisis is a key focus of postoperative nursing care [4-5,8,20]. Ideal flap monitoring technology should be continuous, accurate, low-cost, non-invasive, safe, objective, recordable, repeatable, highly sensitive, easy to use,

and applicable to all flap types [21-24]. However, no current technology meets all these criteria. Although advanced techniques such as near-infrared spectroscopy, hyperspectral imaging, infrared thermal imaging, and color Doppler have been developed to measure flap blood flow, temperature, and moisture, improving accuracy in detecting vascular crisis, their complex procedures and expensive equipment and labor costs limit widespread clinical application [8,22-28]. Therefore, traditional monitoring techniques remain the gold standard for early postoperative flap monitoring, capable of detecting over 95% of flap vascular problems [21,25-27]. These techniques include non-invasive temperature measurement, manual observation of flap color and capillary refill time, and elasticity monitoring, all of which can be mastered by trained clinical nurses [21,25-27].

Current controversies primarily concern the normal flap temperature measured by different methods and the temperature threshold for predicting vascular crisis. Early studies using electronic thermometers to measure distal and central temperatures in 456 perforator flaps reported normal postoperative temperatures of 29.8-31.0℃ on days 1-10 [20]. Arterial crisis is characterized by a sharp temperature drop >3℃ and pale flap changes, typically occurring within 24 hours postoperatively, while venous crisis manifests as dark purple ecchymosis and a 1-2℃ temperature decrease in the entire flap, usually occurring within 2 days postoperatively. The first 3 days represent an unstable period for flaps, with stabilization beginning on day 4 [20]. Therefore, monitoring flap temperature within 3 days postoperatively is crucial for early detection of vascular crisis [2,20]. Another study using non-contact infrared thermometry to measure central single-point temperature in 18 patients reported a normal flap temperature of (32.94$±$1.55)℃ in patients without vascular crisis [5]. In contrast, our study found both normal and abnormal (vascular crisis) temperatures measured by five-point and single-point methods to be higher than those reported in previous literature but lower than those in a retrospective study of 69 patients undergoing breast reconstruction with DIEP flaps using infrared electronic thermometry [16]. Our results also differ from a study using infrared thermal imaging in 16 flap patients, where well-perfused flaps showed temperature differences within 2℃ of surrounding normal skin, while poorly perfused flaps showed >2℃ temperature differences between distal and proximal regions [8]. These discrepancies may be attributed to different sample sizes and monitoring devices/methods, representing the primary reason why global consensus on standardized normal and abnormal flap temperatures and their predictive thresholds has not been reached [22,25]. Therefore, investigating methods for continuous, accurate, non-invasive, and safe flap temperature measurement and their critical temperatures for predicting vascular crisis aligns with the goals of ideal flap monitoring technology and is clinically significant for improving vascular crisis detection.

3.2 Predictive Value of "Five-Point" vs "Single-Point" Flap Temperature for Vascular Crisis

In this study of 66 flap patients, the overall vascular crisis incidence was 15.15%, with venous crisis (10.61%) occurring more frequently than arterial crisis (4.55%), mainly within 72 hours postoperatively, consistent with HALANI et al.'s systematic review [24]. Both "five-point" and "single-point" flap temperatures showed similar patterns from postoperative days 1-5, with the lowest temperature on day 1 gradually increasing thereafter. However, daily mean temperatures measured by the five-point method were consistently lower than those by the single-point method. Similarly, five-point temperatures across different flap locations, types, and areas were significantly lower than single-point temperatures. This difference likely occurs because the five-point method includes the average of five sites: flap center, and edges at 12, 3, 6, and 9 o'clock positions. The 6 o'clock position represents the free edge of the flap, which is the lowest temperature site and most vulnerable to vascular crisis, while the 12 o'clock position is closely connected to normal skin and shows the highest temperature. The central flap temperature is similar to the 12 o'clock position, with 3 and 9 o'clock positions showing similar temperatures. Previous studies have shown that the free edge of flaps has finer vessels and relatively less blood supply, making it more prone to poor circulation and temperature reduction. A temperature difference of 3℃ compared to surrounding skin often predicts arterial crisis [29]. Therefore, five-point flap temperature more comprehensively reflects circulation in all flap directions, similar to the principle of infrared thermal imaging technology that measures entire flap temperature rather than local regions [4,8,12,29]. This explains why our study found higher AUC and sensitivity for five-point flap temperature in predicting vascular crisis, with a lower optimal cut-off value than single-point temperature. Additionally, the 10 patients with vascular crisis had a 0.41℃ lower mean three-day postoperative five-point temperature compared to the 56 patients with normal circulation. Early detection enabled interventions such as infrared irradiation, heparin irrigation, and needle pricking [14,17], which resolved 70% of venous crises. Only 3 arterial crisis cases required reoperation within 2 days, demonstrating that accurate temperature measurement has good predictive value for vascular crisis and can prevent flap necrosis when detected early. Furthermore, we found that flaps >50 cm^2 had higher temperatures than those $ 50cm^{2}$, possibly related to larger anastomotic vessels and more abundant blood flow in larger flaps, though the exact mechanism requires further investigation.

3.3 Conclusions and Limitations

This study employed two flap temperature measurement methods to preliminarily establish the postoperative temperature pattern from low to high and demonstrated that five-point flap temperature is lower than single-point temperature with superior predictive value for vascular crisis. We conclude that

the five-point method provides more accurate flap temperature measurement, offering guidance for clinical practice in accurately measuring flap temperature and enabling early detection and intervention for vascular crisis.

Limitations include the inability to perform random sampling due to the limited number of eligible flap cases during the study period, which may affect generalizability. Future studies should include more cases of different flap types to further validate the predictive value of five-point flap temperature for vascular crisis in various flap types to obtain more accurate results and better guide clinical monitoring.

Author Contributions: JIANG Qixia conceived the study objectives, designed the research, and supervised implementation. XIE Haoting, WANG Huajun, LI Xiuyun, ZHU Yuling, and ZHU Wenjun collected, organized, verified, and entered data according to protocol. JIANG Qixia performed statistical analysis and drafted and revised the manuscript. JIANG Qixia and YUAN Siming were responsible for quality control, overall article responsibility, and supervision.

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