

# Optimisation of the blood supply at the flap donor site through the application of cutaneous negative pressure

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At present, perforator flaps are a very popular technique in reconstructive surgery. However, in spite of the fact that perforator flaps provide favourable aesthetic results, their use is often related to complications in the form of transplanted tissue perfusion disorders.

**OBJECTIVE** — to investigate the possibility of optimising the blood supply at the flap donor site through the application of cutaneous negative pressure (NP).

**MATERIALS AND METHODS.** The study was carried out from 2019 to 2021. A single-arm clinical trial consisted of 20 individuals who presented with deep wound defects requiring flap coverage. A dynamic thermography study was conducted to examine the chosen donor site before and after dressing with NP.

**RESULTS.** The temperature measurements obtained from the two selected warm perforator points and the point in the cool area between perforators prior to the application of NP showed a steady downward trend in temperature. Specifically, the temperature in the cool area was observed to be lower by an average of  $-1.89^{\circ}\text{C}$  and  $-2.12^{\circ}\text{C}$  as compared to warm points. The application of local NP had an impact on trend analysis of skin temperature, which demonstrated a significant decrease in the differences between values seen in the cool and warm areas. This effect was already noted after the first day of the NP system application, as evidenced by the everyday data collection. The «levelling» of temperature curves was associated with temperature rises both in the cool area and at the perforator exit points.

**CONCLUSIONS.** The findings obtained from thermography analysis suggest that the application of NP has the potential to enhance blood circulation in the intended donor area. Therefore, it is plausible to discuss the possibility of improved microcirculation in the skin and the beneficial effect of local cutaneous NP application on the state of anastomoses between perforators.

## KEYWORDS

cutaneous negative pressure, perforator flaps, anastomoses between perforators, thermography.

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At present, perforator flaps are a very popular technique in reconstructive surgery. However, in spite of the fact that perforator flaps provide favourable aesthetic results, their use is often related to complications in the form of transplanted tissue perfusion disorders.

Fundamental anatomical studies of skin blood supply remain in the active phase. Ian Taylor's angiosomes theory, which was put forward in 1987 [21], won acceptance and stimulated the development of perforator flap surgery. In 2009, M. Saint-Cyr et al.

[14] published the results of their research, where they explained that to define and estimate the full vascular area of one perforator, such a perforator must be cannulated and counterstained in an isolated way. This is of great clinical importance, as the majority of flaps are based on one perforator. Thus, knowledge of axial blood current, interaction with adjacent perforators, and influence of the subdermal plexus and fascia — all of those things are important for perforator flap design. This study encompasses a comprehensive examination of the anatomical

aspects of perforator flaps, which were collected over a period of three years [13, 15–17]. The majority of the flaps included perforators that were cannulated in an isolated way to evaluate the individual vascular territory of the perforator; this territory was called the «perforasome» (arterial). The vascular and perfusion territory of perforators is very complex and variable. Nevertheless, some common principles were reproduced in all the numerous injection studies of perforators. One of those principles lies in the fact that each perforasome is connected to adjacent perforasomes through two main mechanisms, which include both direct and indirect vascular connections. Direct-connecting vessels are the large vessels that are connected directly from one perforator to another and can cover adjacent perforasomes via the flow mechanism between perforators.

In 2011, Taylor et al. published their studies on perforasomes [20], and in 2013, the findings of the study on true and choke anastomoses between perforator angiosomes in various regions of the body and their role in flap survival [18] were published. They indicated in their studies that, as a rule, true anastomoses between perforators are located parallel to nerves and veins. The calibre of the blood vessels, which form true anastomoses, does not change, while the vessels, which form «choke» anastomoses, reduce their calibre depending on their physiological state.

Thus, according to current anatomical theories, each perforator has its own unique vascular arterial territory, which is defined by the term «perforasome» (Fig. 1A). A group of perforasomes connected with vascular subdermal anastomoses is defined as «angiosome», or skin territory, which is fed by one axial vessel and can be isolated and elevated on such an axial perforator without the risk of ischemia and tissue death (Fig. 1B).

Functional ability of subdermal vascular anastomoses between individual perforasomes specifically defines survival probability for the flap distal part, which contains perforasomes of the second and third order (Fig. 2). Thus, theoretical data on the perforator flap type and its anatomic features, axial blood current, and interaction with adjacent perforators via the subdermal plexus are critically relevant in perforator flap design.

In 2013, Taylor et al. addressed the issue of identifying the state of anastomoses between perforators at the flap planning stage, suggesting for this purpose the use of dynamic thermography [8]. The infrared thermography method allows evaluating the functional ability of subdermal vascular anastomoses between individual perforasomes and angiosomes being included in the flap, which is reasonably acceptable for clinical practice.

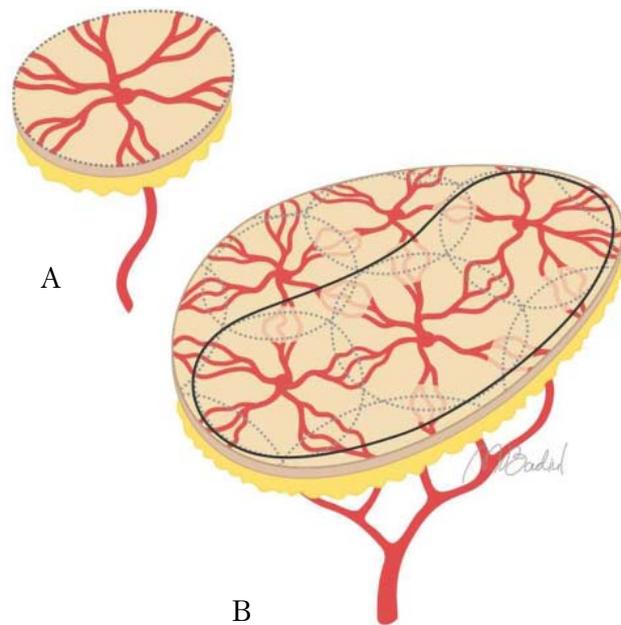


Figure 1. **Schematic representation of the perforasome, or individual vascular territory of an isolated perforator (A). Schematic representation of angiosome, or skin territory, which consists of a group of perforasomes connected with vascular subdermal anastomoses (B).** The black marker shows the flap design, which will include perforasomes with true vascular anastomoses, while the introduction into the flap of two other perforasomes connected with choke vessels implies a high risk of ischemia and necrosis of this part of tissue (On the left)

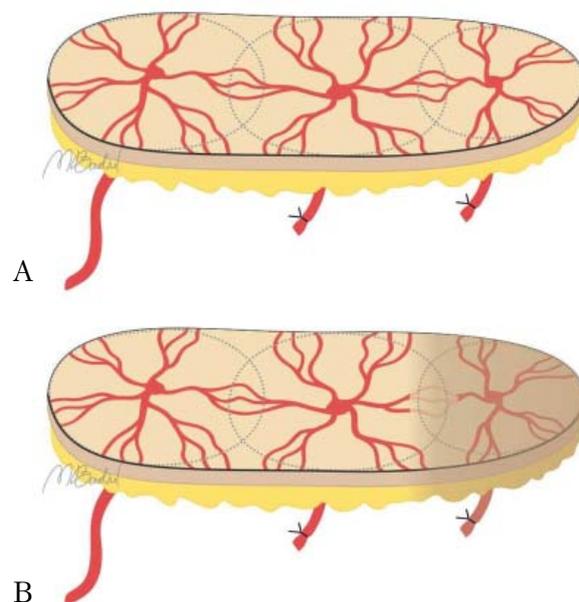


Figure 2. **Schematic representation of mobilized perforator flap containing perforasomes of the second and third orders, which are vascularized with true vascular subdermal anastomoses (A) and the similar flap, where between the second and third segments there are «choke» vessels responsible for the development of ischemia and necrosis in the distal part of the flap (B)**

Currently, there is an ongoing investigation regarding the performance characteristics of anastomoses between perforators, with a focus on the possibility of influencing their state in order to transform «choke» anastomoses into true ones [19]. Additionally, there is a broader body of research aimed at improving flap perfusion [5, 9].

Our research team initiated an investigation into strategies for enhancing the blood supply in perforator flaps through the application of negative pressure (NP) on the donor area skin. This technique facilitates the opening of «choke» anastomoses between adjacent perforasomes. We use the NP method of acting upon the estimated donor area.

**OBJECTIVE** – to investigate the possibility of optimising the blood supply at the flap donor site through the application of cutaneous negative pressure (NP).

## Materials and methods

The study was carried out from 2019 to 2021. A single-arm clinical trial consisted of 20 individuals, ages 25 to 70 (5 women and 15 men), who had suffered full-thickness burns, injuries, or had had surgeries resulting in deep defects requiring flap coverage. The exclusion criteria were as follows: cardiovascular diseases (decompensation stage), atherosclerosis, obliterative vascular diseases, diabetes in the decompensation stage, acute cancer, prior angioplasty, and systemic chronic diseases (systemic lupus erythematosus, rheumatic disease). 9 of those patients underwent daily measurements for a period of 5 to 7 days (Group 1). A total of 11 patients had the NP system taken off and were subsequently assessed for outcome measures on the 5th-7th day (Group 2).

*The study methodology was as follows:*

1. The anticipated donor area was subjected to cooling by means of plastic bags that were filled with 20°C to 22°C water and applied for 5 minutes;
2. Donor area temperature measurements were taken using a Dali TE-W2 Thermal Image Camera at 5, 10, and 15 minutes after cooling;
3. Two warm points of the perforator (Point 1, Point 2) and a point in the cool area between perforators (Point 3, Cold Point) were selected, and the temperature at those points was evaluated (Fig. 3A). Upon that, the cutaneous NP system was placed in the cool area for 5–7 days (Fig. 3B).
4. Upon taking off the cutaneous NP system and skin cold treatment, measurements were taken once a day under the same conditions for 5 days (Group 1). At that point, the NP system was placed back in place after each measurement. Group 2 had

the cutaneous NP system taken off and measurements done on the 5th-7th day.

The NP pressure setting was maintained at a continuous value of –125 mm Hg.

The temperature measurements at the selected points and thermogram data visualisation were obtained using Dali Thermal Images Analysis Report Software.

**Statistical analysis.** Statistical analysis was performed using descriptive and analytical statistical methods [1] using Statistica 6.1 software (Palo Alto, California, StatSoftInc.; serial No: AGAR909E-415822FA).

Taking into account the normal law of test characteristic distribution (Shapiro-Wilk criterion), but with a small sample of the study, the descriptive statistic was given as a mean (M), standard deviation (SD), and 95% confidence interval for the mean (95% CI), and as a basis for comparison, we used the Wilcoxon signed rank test and the Mann-Whitney U-test for independent samples.

2-tailed 5% significance ( $p \leq 0.05$ ) was used for all analyses.

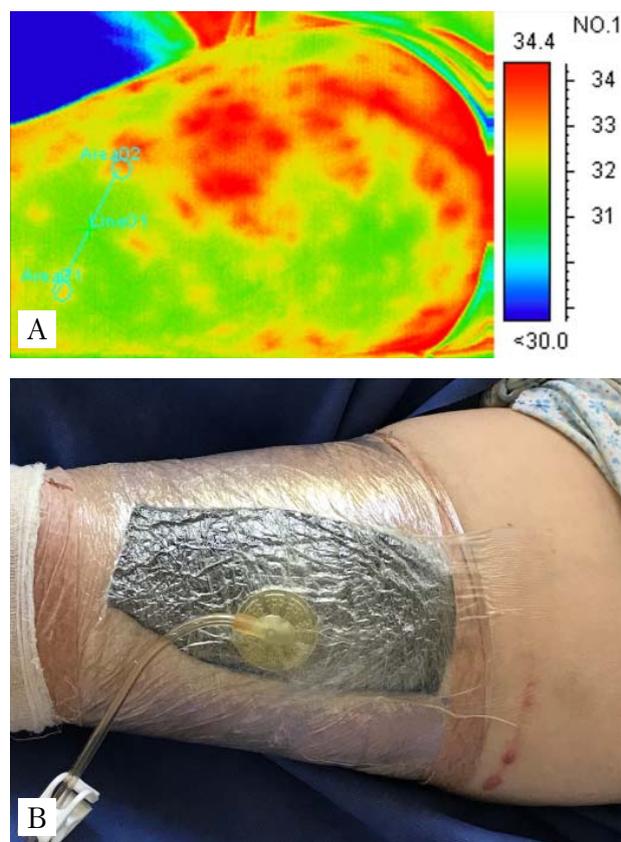


Figure 3. **Thermography of the anticipated donor area, where perforator exit points and the point in the «cool» area are defined (A). Next, the skin NP system is placed on this area (B)**

## Results

The temperature measurements obtained from the two selected warm perforator points (Point 1, Point 2) and the point in the cool area between perforators (Point 3) prior to the application of the cutaneous NP system showed a steady downward trend in temperature ( $p < 0.1$ ). Specifically, the temperature in the cool area was observed to be lower by an average of  $-1.89^{\circ}\text{C}$  (95% CI  $-2.27... -1.51^{\circ}\text{C}$ ) as compared to Point 1, and  $-2.12^{\circ}\text{C}$  (95% CI  $-2.54... -1.69^{\circ}\text{C}$ ) as compared to Point 2 (Table 1).

The application of local NP in Group 1 had an impact on the trend analysis of skin temperature, which demonstrated a significant decrease in the differences between values seen in the cool and warm areas. This effect was already noted after the first day of the cutaneous NP system application, as evidenced by the everyday (during 5–7 days) data collection (Table 2). The «levelling» of temperature curves was associated with temperature rises both in the cool area and at the perforator exit points.

The rate of skin temperature increase in Point 1 and Point 2 in the patients of Group 1 ranged from

$1.78^{\circ}\text{C}$  (5.6%) and  $1.40^{\circ}\text{C}$  (4.4%) on the second day after the cutaneous NP system was placed to  $2.82^{\circ}\text{C}$  (8.9%) and  $2.52^{\circ}\text{C}$  (7.8%) as compared to the basic value after 5–7 days of treatment. In the cool area between perforators, the rate of skin temperature increase was almost twice as high, from  $3.09^{\circ}\text{C}$  (10.3%) within 24 hours to  $4.46^{\circ}\text{C}$  (14.9%) after 5–7 days of NP.

The skin temperature dynamics in the cool area of patients in Group 2 showed a positive trend when exposed to local NP continuously for a period of 5–7 days. The mean value increased from  $31.65^{\circ}\text{C}$  (3.76) before the NP system placement to  $33.07^{\circ}\text{C}$  (2.24) after 5–7 days upon the system removal ( $p = 0.286$  Wilcoxon signed rank test). The value increment within this period was  $1.42^{\circ}\text{C}$  or 4.5%, resulting in a «levelling» (reduction of differences) effect on temperature curves in the cool and warm areas (Fig. 4).

Thus, mean skin temperature in the cool area after applying the NP system for 5–7 days in 20 study participants increased by an average from  $30.85^{\circ}\text{C}$  (3.69) to  $33.64^{\circ}\text{C}$  (2.37). i.e., by  $2.79^{\circ}\text{C}$  (95% CI  $1.13–4.45^{\circ}\text{C}$ ) ( $p = 0.005$  Wilcoxon rank

Table 1. Skin temperature measurement results in 3 selected areas before the application of the NP system (n = 20), °C

| Parameter                      | Minimum–Maximum | M ± SD       | 95 % CI        | p*    |
|--------------------------------|-----------------|--------------|----------------|-------|
| Point 1                        | 27.0–38.6       | 32.74 ± 3.24 | 31.23–34.25    |       |
| Point 2                        | 28.4–38.3       | 32.97 ± 3.09 | 31.52–34.41    |       |
| Point 3                        | 25.0–36.1       | 30.85 ± 3.69 | 29.12–32.58    |       |
| Value difference in the points |                 |              |                |       |
| Point 2 – Point 1              | -0.5... +2.0    | 0.23 ± 0.51  | +0.01... +0.46 | 0.695 |
| Point 3 – Point 1              | -0.5... -3.3    | -1.89 ± 0.82 | -2.27... -1.51 | 0.093 |
| Point 3 – Point 2              | -0.7... -4.0    | -2.12 ± 0.90 | -2.54... -1.69 | 0.066 |

Note. \* Level of significance of the differences between the points was defined using Mann–Whitney U-test.

Table 2. Every day skin temperature measurement results in the selected areas during the application of the NP system (n = 9), °C (M ± SD)

| Parameter        | Before NPWT  | 1st day       | 2nd day        | 3rd day        | 4th day       | 5–7th day      |
|------------------|--------------|---------------|----------------|----------------|---------------|----------------|
| Point 1          | 31.82 ± 3.23 | 33.60 ± 2.35  | 34.70 ± 2.21** | 34.57 ± 3.06** | 34.23 ± 2.19* | 34.64 ± 2.60*  |
| Point 2          | 32.18 ± 3.13 | 33.58 ± 2.13  | 34.92 ± 2.01** | 34.69 ± 2.88** | 34.31 ± 1.94* | 34.70 ± 2.35*  |
| Point 3          | 29.87 ± 3.56 | 32.96 ± 2.44* | 34.39 ± 1.98** | 34.37 ± 3.12** | 33.91 ± 2.05* | 34.33 ± 2.47** |
| P <sub>1–2</sub> | 0.691        | 0.965         | 0.825          | 0.791          | 0.965         | 0.965          |
| P <sub>1–3</sub> | 0.233        | 0.536         | 0.659          | 0.791          | 0.536         | 0.566          |
| P <sub>2–3</sub> | 0.185        | 0.427         | 0.330          | 0.627          | 0.659         | 0.659          |

Note. P<sub>1–2</sub>, P<sub>1–3</sub>, P<sub>2–3</sub> — level of significance of the differences between the points (P) was defined using Mann–Whitney U-test; \* p < 0.05; \*\* p < 0.01 as compared to basic value in the corresponding point (Wilcoxon signed rank test).

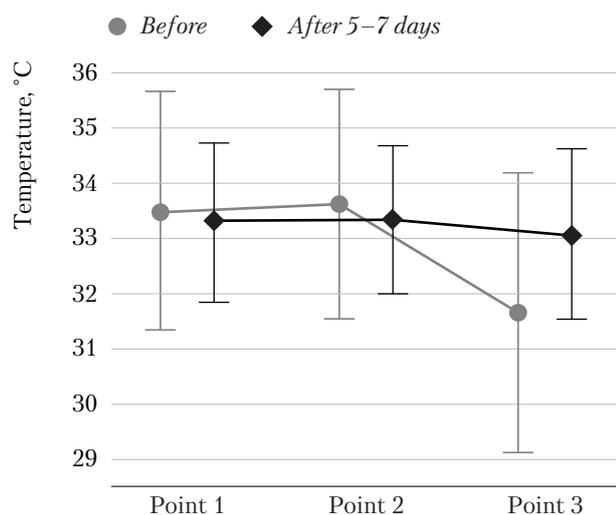


Figure 4. **Mean value trend in skin temperature measurement in the selected areas after using the NP system for 5–7 days (n = 11)**

sum test). The performance gap between Point 1 and Point 3 decreased to  $-0.26^{\circ}\text{C}$  (95 % CI  $-0.39...-0.12^{\circ}\text{C}$ ) at  $p = 0.561$  (Mann-Whitney U-test). The gap between Point 2 and Point 3 decreased to  $-0.35^{\circ}\text{C}$  (95 % CI  $-0.48...-0.17^{\circ}\text{C}$ ) at  $p = 0.626$  (Mann-Whitney U-test).

After the NP application at the donor sites, all patients had reconstructive surgeries to cover defects using free or local flaps. After reconstruction, all flaps survived, and only in one case did we have a non-critical complication in the form of partial necrosis of the flap (5 %).

A prior study conducted at our department revealed that in 13 to 40 % of cases, patients who met the same inclusion criteria but did not receive the NP therapy experienced complications, including ischemia and venous congestion, which resulted in partial necrosis of flaps [4, 6].

## Clinical case

On admission to our centre, a female patient presented with a persistent work-related injury from 1982 was treated according to the NPWT treatment programme for wounds directly within the preoperative stage (Fig. 5). We planned free transfer of the ALT flap with microvascular anastomosis formation (Fig. 6).

Thermographic study was done, perforator exit points and cool areas were defined, and outcome analysis was made (Fig. 7). A cutaneous NP system was applied in the cool areas. 5 days later, we noted changes in the temperature curve, a temperature rise directly in the perforator exit points, and a thermal gap transition into positive values (Fig. 8). The

patient was discharged with recovery, the postoperative period was smooth. The result 2 months after ALT-free flap surgery presented on Fig. 9.

## Discussion

In all cases, after cutaneous NP treatment programme application, we detected a temperature rise in the cool areas. 24 hours after the application of the NPA system, the temperature difference between perforator exit points and the area between perforators decreased. This fact evidences improved microcirculation in the skin between perforators, which implies functional improvement of anastomoses between perforators and possible opening of «choke» anastomoses. This ultimately leads to the optimisation of the blood supply at the flap donor site.

Other authors have also confirmed the possibility of cutaneous NP influence on skin microcirculation. There are reports of experimental studies [2, 11]. In a report of preoperative external NP therapy, Morykwas et al. found a 21 % increase in flap survival in random pattern flaps that were treated with external NP in a pig model [10]. Similarly, Rhodius et al. found



Figure 5. **The wound on the left leg after an injury 39 years ago**



Figure 6. **Marking the ALT perforator flap on the right thigh. The green dots mark the perforator exit points, which were found using Doppler**

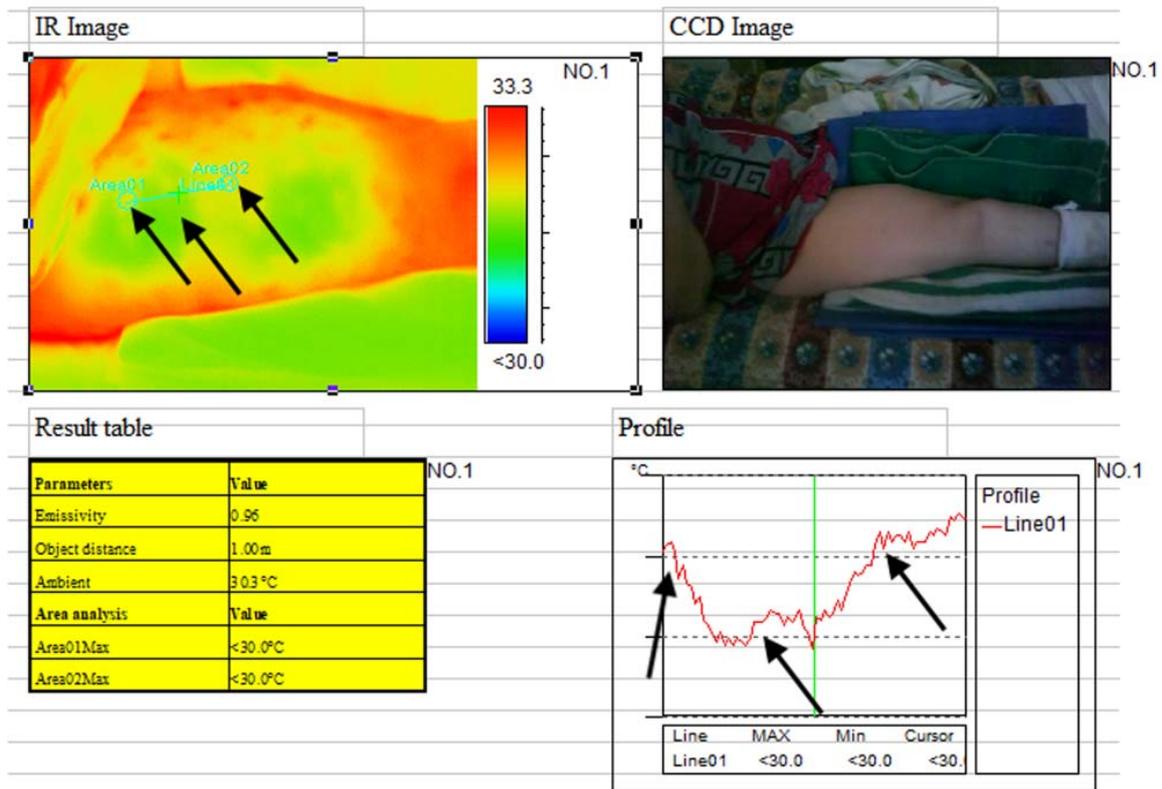


Figure 7. Thermography analysis report. Before NP. The arrows point to the places where the temperature was measured at the exit of the perforators and in the cold zone between them. The temperature corresponding to these points on the chart

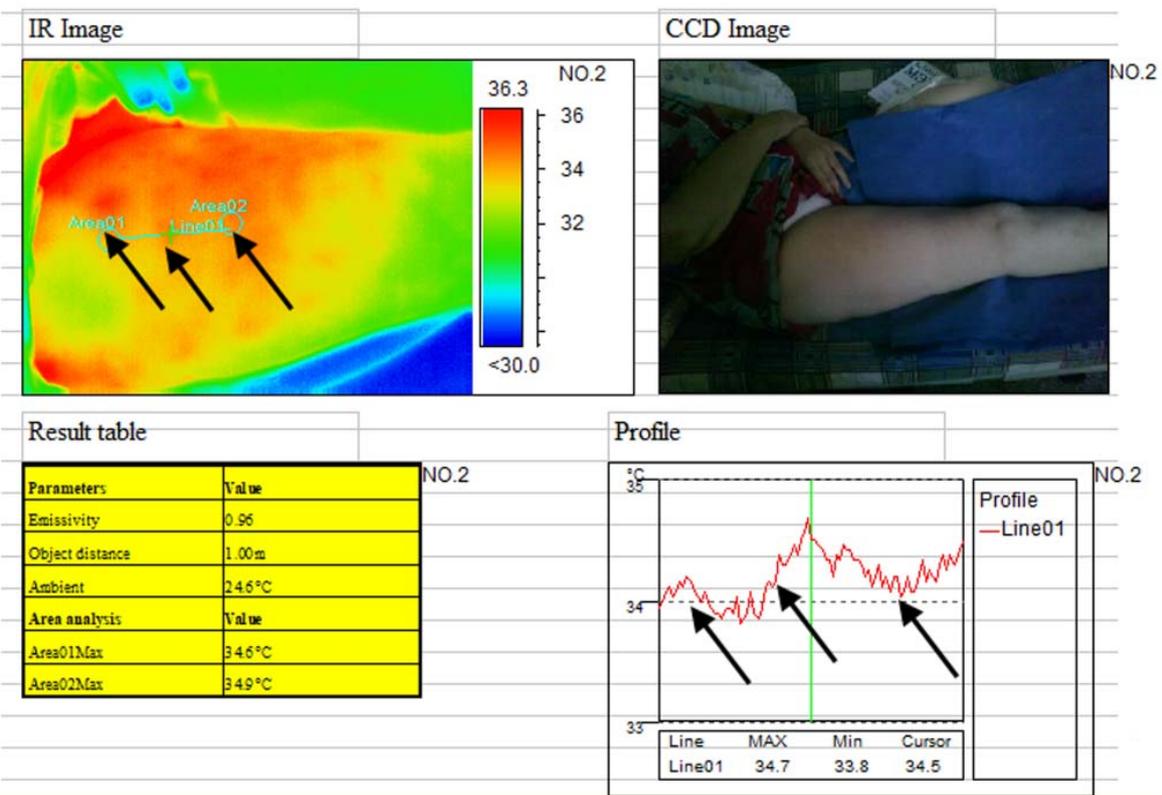


Figure 8. Thermography analysis report. 5 days after NP. The arrows point to the places where the temperature was measured at the exit of the perforators and in the cold zone between them. The temperature corresponding to these points on the chart



Figure 9. **The result 2 months after ALT-free flap surgery**

a 37 % increase in vessel density and a 27 % increase in flap survival in random pattern flaps performed in a diabetic murine mode [12]. Other authors have reported similar findings of increased vascularity, and improved blood supply and flap survival in animal models when treated with external NP [3, 22]. There have already been reports on the preparation of the donor area of the flap using NP, both in the clinic and in studies on healthy volunteers [7, 9].

However, due to the small number of observations, the results of the study did not show a statistically significant difference between the selected points in the cool and warm areas, both at the beginning of the study and during the first days of the NP system application. In our opinion, by making a number of observations and comparing them to treatment efficacy outcomes in patients with persistent wounds, we will be able to not only obtain solid statistically significant results but also answer questions related to:

- selection of the optimal temperature difference between the cool and warm areas on the skin to define the advisability of preoperative preparation with the NP application;
- calculation of the optimal length of preoperative preparation with NP;
- justification of the need (rationale) for everyday control of process dynamics;
- assessment of correlations between preoperative NP preparation treatment efficiency and other factors.

## Conclusions

The findings obtained from thermography analysis suggest that the application of NP has the potential to enhance blood circulation in the intended donor area. Therefore, it is plausible to discuss the possibility of improved microcirculation in the skin and the beneficial effect of local cutaneous NP application on the state of anastomoses between perforators.

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## DECLARATION OF INTERESTS

None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

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## ETHICS APPROVAL

The patient's treatment was conducted in strict adherence to the principles outlined in the Helsinki Declaration.

The administration of treatment was not connected with any of the ongoing clinical trials.

## AUTHORS CONTRIBUTIONS

P.O. Badiul: idea of the research; thermal image analysis; surgery; writing the manuscript; scientific literature review; S.V. Sliesarenko: idea of the research; surgery; writing the manuscript; administrative and material support; O.I. Rudenko: performing the practical part of the study; thermal image analysis; writing the manuscript; scientific literature review.

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## Оптимізація кровопостачання шкіри донорської ділянки за допомогою нашкірного негативного тиску

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Перфораторні клапті є дуже популярним методом у реконструктивній хірургії. Однак, попри те що перфораторні клапті дають добрі естетичні результати, часто їх застосування пов'язане з ускладненнями у вигляді порушення перфузії переміщених тканин.

**Мета** — визначити можливість оптимізації кровопостачання шкіри донорської ділянки за допомогою використання нашкірного негативного тиску.

**Матеріали та методи.** Дослідження проведене у період з 2019 до 2021 р. із залученням 20 осіб з глибокими рановими дефектами, які потрібно було вкрити клаптями. Запропоноване донорське місце є предметом дослідження методом динамічної термографії до та після використання пов'язки з негативним тиском (НТ).

**Результати.** Результати вимірювання температури у двох вибраних теплих точках перфоранта і точці в холодній зоні між перфорантами перед використанням НТ свідчили про постійну тенденцію до зниження температури в холодній зоні в середньому на  $-1,89^{\circ}\text{C}$  та  $-2,12^{\circ}\text{C}$  порівняно з теплими точками. Тренд-аналіз температури шкіри під впливом локального НТ зі щоденним збором даних виявив значне зменшення відмінностей між значеннями в холодній зоні й теплих точках вже після першого дня використання системи нашкірного НТ. «Вирівнювання» температурних кривих було пов'язане з підвищенням температури як у холодній зоні, так і в місцях виходу перфорантів.

**Висновки.** Результати аналізу термографії свідчили про тенденцію до оптимізації кровопостачання запланованої донорської зони під впливом нашкірного НТ, тому можна говорити про можливість поліпшення мікроциркуляції в шкірі та позитивний вплив застосування локального нашкірного НТ на стан анастомозів між перфорантами.

**Ключові слова:** нашкірний негативний тиск, перфораторні клапті, анастомози між перфорантами, термографія.

### FOR CITATION

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