OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Reconstructive

# Influence of VAC Therapy on Perfusion and Edema of Gracilis Flaps: Prospective Case-control Study

Anian Kuenlen, MD, MHBA*
Karl Waked, MD†
Michael Eisenburger, MD, MHBA*
Alan Oramary, MD*
Abeer Alsherawi, MD*
Milomir Ninkovic, MD, PhD*

**Background:** The gracilis muscle flap is a popular choice in reconstructive surgery to repair soft tissue defects or for functional restoration. Little is known on the influence of postoperative application of VAC (vacuum-assisted closure; Kinetic Concepts Inc., San Antonio, Tex.) therapy on perfusion and postoperative flap edema of free gracilis muscle flaps.

**Methods:** In total, 26 patients with soft tissue defects of lower extremity underwent gracilis muscle flap reconstruction. The study group (VAC, n = 13) was supplied with postoperative negative pressure therapy as a dressing; the control group (NVAC, n = 13) was supplied with conventional fat gauze dressing. Postoperative measurements of micro- and macroperfusion were performed intraoperatively, on postoperative day (POD) 3 and POD 5. Flap edema measurement was performed intraoperatively, on POD 5 and 2 weeks after operation.

**Results:** The VAC group showed significantly better macroflow during intraoperative VAC treatment, as well on POD 3 and POD 5. Venous outflow was also better with lower hemoglobin levels. Microflow was better in the NVAC group with higher measured oxygen levels. All gracilis muscle flaps of the VAC group showed significantly less flap edema compared with the control group.

**Conclusions:** VAC application on free gracilis muscle flaps leads to significantly less postoperative flap edema, improved arterial macroflow, and improved venous outflow. VAC therapy can be used without any danger for patient's safety, as flap survival is not endangered, and presents an easy to handle and pleasant dressing regimen for nursing staff and patients. *(Plast Reconstr Surg Glob Open 2023; 11:e4964; doi: 10.1097/GOX.0000000000004964; Published online 28 April 2023.)*

## INTRODUCTION

Vacuum-assisted closure (VAC) therapy can be used to improve wound healing, reduce wound secretions, and lower bacterial load, therefore guaranteeing a safer wound environment.[1,2] Furthermore, VAC treatment may reduce postoperative flap edema, leading to better flap macro- and microcirculation.[3] It reduces ischemia/reperfusion-associated inflammatory response of free-transplanted tissue, and reduced interstitial edema leads to a reduced number of apoptotic cells in free-transplanted tissue.[4] All these benefits lead to an improved functional and aesthetic outcome with shorter hospital stays and more satisfied patients.

Most publications on VAC therapy focus on wound conditioning through wound cleaning, generation of granulation tissue, induction of neo-angiogenesis, approximation of wound margins, and reduction of interstitial edema.[1,2,5–10] In addition, some reports discuss the use of VAC therapy to fix split-thickness skin grafts on free muscle flaps.[11–17]

In 2018, Chim et al applied VAC on free transplanted muscle flaps of lower extremity to study the effect of VAC therapy on postoperative flap edema. Their results showed that immediate application of VAC on free muscle flaps of lower extremity did not compromise flap survival nor overall outcomes and resulted in decreased flap thickness and a better aesthetic outcome.[3] The aim of this study was to investigate effects of the VAC therapy on micro- and macroperfusion of free gracilis muscle flaps to better evaluate its use and potential benefits. Lack of data regarding micro- and macrocirculation, flap edema, and therapeutic outcomes may be a possible explanation for its limited use in free flap surgery.

*From the *Department of Plastic, Reconstructive, Hand and Burn Surgery - Bogenhausen Academic Hospital, Munich, Germany; and †Department of Plastic and Reconstructive Surgery, Brussels University Hospital, Vrije Universiteit Brussel (VUB), Brussels, Belgium.*

*Received for publication January 25, 2023; accepted March 9, 2023.*



DOI: 10.1097/GOX.0000000000004964

Disclosure statements are at the end of this article, following the correspondence information.

## MATERIALS AND METHODS

A prospective, randomized, single center study was conducted at Munich Hospital Bogenhausen (Germany). Before conducting the study, ethical approval was obtained through the federal chamber of Bavarian physicians (ethic proposal number: 14087). The study was planned and conducted in accordance with the World Medical Association Declaration of Helsinki (June 1964) and subsequent amendments.

This prospective case-control study focused on patients with a soft tissue defect of the lower extremity, requiring free flap surgery to cover the defect. Inclusion criteria were patients with a soft tissue defect of the lower extremity who were planned for a free gracilis muscle flap with split-thickness skin graft, minimum age of 18 years, American Society of Anesthesiologists classification of I or II, and international normalized ratio within normal range of 0.9–1.2. Exclusion criteria were patients who were not fit to undergo general anesthesia, patients with any form of coagulopathy, patients under ongoing chemotherapy, and patients diagnosed with diabetes mellitus. Smoking, arterial hypertension, and hypercholesteremia were not seen as exclusion criteria. However, because there has only been one clinical study on this association regimen to date, these high-risk patients were excluded in order not to endanger patient safety.[3] An informed consent was obtained of every included patient.

All included patients received either VAC therapy on gracilis muscle flap immediately after flap transfer and placement of skin graft (study group = the VAC group) or were treated with conventional dressings, consisting of fat gauzes with absorbing dressings (control group = the NVAC group). VAC therapy settings were 125 mm Hg, continuous pressure.

Because none of the studies conducted on this subject provided any information about the ideal applied VAC pressure, 125 mm Hg was set after no critical signs of ischemia of muscle flaps were detected in initial test runs.

Both the removal of the VAC dressing of the study group and change of fat gauze of the control group on postoperative day (POD) 4 and POD 14 were carried out in patient's bed with help of intravenously administered analgesic medication.

### Clinical Analysis

In all included patients, the following parameters were measured:

***1. Arterial Macrocirculation:***

Macrocirculation was measured with an implantable Cook-Swartz Doppler probe (Cook Medical, Bloomington, USA). Cook-Swartz Doppler probe was applied next to arterial pedicle using fibrin glue. Measurements took place intraoperatively before VAC placement, during first VAC activation, after VAC activation, on POD 3, and on POD 5. Sensitivity of Cook Medical Probe was measured at 100% in a 2015 study by Frost et al.[18]

> **Takeaways**
>
> **Question:** What influence does vacuum-assisted closure therapy have on micro- and macroperfusion and postoperative flap edema in lower leg reconstructions using free gracilis transfer?
>
> **Findings:** Vacuum-assisted closure application to free gracilis flaps significantly improves macroperfusion and results in significantly less postoperative flap edema. Improved microperfusion is also evident.
>
> **Meaning:** Vacuum-assisted closure can be easily applied to free gracilis muscle flaps postoperatively without endangering the flap.

***2. Venous Microcirculation:***

Microcirculation was measured by an O2C laser Doppler and tissue spectrometry (LEA Medical Technique cooperation, Gießen, Germany). With help of O2C device, blood flow conditions in tissues can be displayed in a noninvasive manner using laser Doppler spectroscopy and tissue spectrometry. The recorded measurement parameters include information on blood flow and oxygen levels as well as capillary-venous saturation of hemoglobin, relative blood flow, blood flow speed, and current blood filling of microvessels.

The O2C device consists of a computer and a measuring probe, which has a laser Doppler and a white light source. Both signals are emitted by the probe and reflected back to the corpuscular blood components. The above values can be calculated using the reflected signals.

The O2C probe was put in place directly on the split thickness skin graft of all flaps by suturing the probe into the flap. Probe was removed on POD 5. A study carried out in 2002 regarding the variance of the O2C measuring system showed a variance of 5%.[19]

***3. Flap Edema:***

Flap edema was measured by using a 3D scan D Spider (RSI 3-D Systems, Oberusel, Germany). All gracilis flaps were marked by using anchor points, made of sutures or plaster strips. Volume of each flap was calculated by analyzing changes in relative position between anchor points individually within the flap (Fig. 1). All measurements of postoperative flap edema in both control and study groups were carried out immediately postoperatively without any wound dressing, as well as at POD 5 and POD 14.

Measurement of postoperative flap edema was validated by meticulously making sure when applying flap markings that those markings with suture material or with Steristrips are located at anatomical sites that have as little mobility as possible (bony prominences, such as malleoli med. and lat., calcaneus). It was also always ensured that flaps of the control group were always wrapped only with fat gauze and a large compress and were therefore not exposed to any manipulation of the wound. Additional perioperative measurements were analyzed, including ischemia time, type of arterial anastomosis, and venous anastomosis.

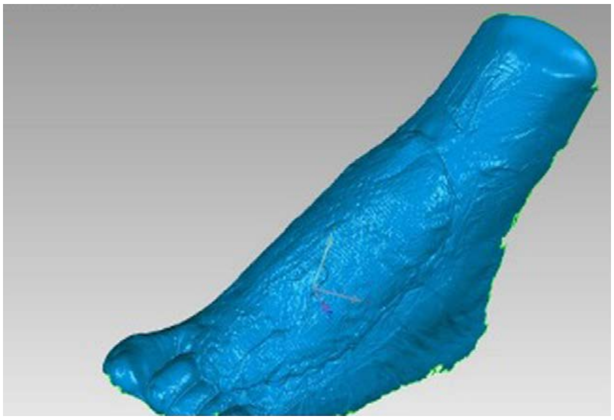

**Fig. 1.** Scanned lower left leg. Flap edema measurement was performed intraoperatively, on POD 5 and 2 weeks after the operation. All three scans were projected on top of each other and flap edema was calculated.

## RESULTS

Average age of patients at the time of reconstruction was 50.4±18.9 years (Table 1). In total, 11 patients were women (42.3%) and 15 were men (57.7%). Sex, comorbidities, and smoking history were equally distributed between both groups.

Table 2 shows perioperative data. Ischemia time was similar between both the VAC and NVAC group with an overall mean ischemia time of 62.5±18.9 minutes. All micro-anastomoses were performed in an end-to-end fashion.

For reasons of standardization, care was always taken to ensure that flap inflow was anterograde. All flap locations were on the forefoot. Below that, an anatomical area was defined, which begins distal to both malleoli and extends to the toes.

In the control group, 11 flaps were anastomosed to two veins, whereas in the study group, 10 flaps were anastomosed to two veins. Remaining flaps (the control group: two flaps; the study group: three flaps) were placed on one vein for anatomical reasons. In the control group, 10 flaps were anastomosed to the deep vein system; in the study group, this was the case in nine flaps. Remaining flaps (the control group: three flaps, the study group: four flaps) were connected to the superficial venous system for anatomical reasons.

**Table 1. Patient Demographics**

| | Total | VAC | NVAC |
|---|---|---|---|
| No. patients | 26 | 13 | 13 |
| Men | 15 | 8 | 7 |
| Women | 11 | 5 | 6 |
| Mean age (y) | 50,4 | 51.5 | 49.3 |
| Comorbidities | | | |
| Diabetes mellitus | 4 | 2 | 2 |
| Arterial hypertension | 6 | 3 | 3 |
| Hypercholesterolemia | 1 | 0 | 1 |
| Active smokers | 4 | 2 | 2 |

VAC = the study group; NVAC = the control group.

**Table 2. Perioperative Data**

| | Total | VAC | NVAC |
|---|---|---|---|
| No. patients | 26 | 13 | 13 |
| Time of ischemia (min) | 62.5 | 63.9 | 61.2 |
| Type of anastomosis | | | |
| Arterial end-to-end | 26 | 13 | 13 |
| Venous end-to-end | 26 | 13 | 13 |
| Primary revision | 0 | 0 | 0 |
| Secondary revision | 2 | 1 | 1 |

No anastomosis revisions were required. Each study group had one patient in whom a small secondary revision was necessary, due to a wound healing disorder requiring a second piece of split-thickness graft.

### Macroperfusion

Arterial macroflow already showed significant changes during activation of VAC therapy (Table 3 and Fig. 2). During first VAC activation, there was a significant increase in macroflow, followed by a decrease immediately after VAC activation.

Furthermore, macroflow in the VAC group showed significant higher flow rates on POD 3 and POD 5, compared with the control group (Table 4 and Fig. 3). Macroflow increased day after day during the first 5 days postoperatively in the VAC group, when compared with a continuous decrease in macroflow in the NVAC group.

### Microperfusion

Regarding venous outflow, microperfusion analysis in both groups showed a nonsignificant decrease of oxygen

**Table 3. Measured Macroflow before VAC Activation, during the First VAC Activation and Immediately Post VAC Activation in the VAC Group**

| | Macroflow (cm/s) | *P* |
|---|---|---|
| Before VAC activation | 0.01 | 0.000 |
| During VAC activation | 0.05 | 0.104 |
| Immediately post VAC activation | 0.02 | 0.003 |

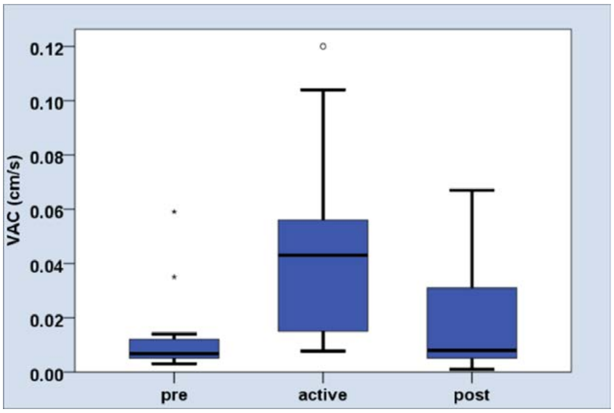


**Fig. 2.** Graphical representation of the macroflow before VAC activation, during first VAC activation, and immediately post VAC activation, in the VAC group.

**Table 4. Comparison of the Macroflow on POD 0, POD 3, and POD 5 between the VAC and NVAC Group**

| | | Macroflow POD 0 (cm/s) | Macroflow POD 3 (cm/s) | Macroflow POD 5 (cm/s) |
|---|---|---|---|---|
| Mean | **VAC** | 3.69 | 5.34 | 7.96 |
| | **NVAC** | 2.64 | 1.13 | 0.76 |
| SD | **VAC** | 5.65 | 5.24 | 8.05 |
| | **NVAC** | 2.62 | 1.25 | 0.91 |
| Median | **VAC** | 2.09 | 3.12 | 3.30 |
| | **NVAC** | 2.60 | 0.81 | 0.49 |
| Valid n | **VAC** | 13 | 13 | 13 |
| | **NVAC** | 13 | 13 | 13 |
| *P* | | 0.797 | 0.015 | <0.005 |

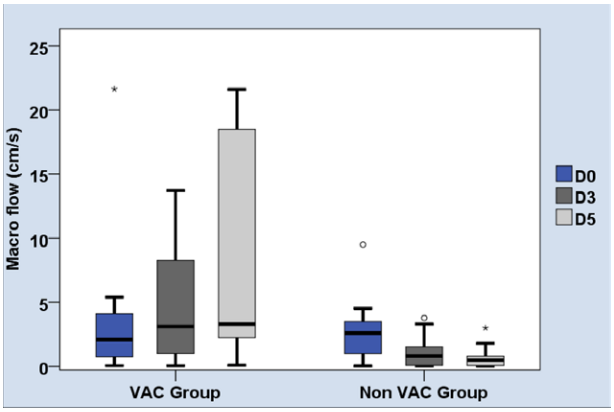


**Fig. 3.** Graphic representation of the comparison of the macroflow on POD 0, POD 3, and POD 5 between the VAC and NVAC group.

saturation from POD 0 to POD 3, as well as from POD 3 to POD 5, and overall, from POD 0 to POD 5 (Fig. 3 and Table 5). Initial decrease in oxygen saturation for the first 3 days postoperatively was higher in the VAC group, followed by a stronger decrease in oxygen saturation in the NVAC group in following days (POD 3 to POD 5, and overall, from POD 0 to POD 5). Venous hemoglobin levels on POD 3 and POD 5 showed nonsignificant higher levels in the NVAC group (Table 6 and Fig. 4).

### Flap Edema

Flap edema measurements in the VAC group showed a significant decrease of flap volume, compared with an increase of flap volume in the NVAC group over the course of the first five postoperative days, as well as during the first 14 days postoperatively (Table 7; Figs. 5–7)

### Wound Fluid Volume

Volume of wound fluid aspirated through VAC pump increased consistently from POD 0 to POD 14 (Table 8).

### Flap Mobility

In all gracilis flaps, adapted flap training was carried out on POD 6 using a flap dangling protocol. Because this study is designed as a pilot study, all postoperative edema measurements were only carried out in the first 14 postoperative days.

## DISCUSSION

In 2007, Machen et al showed that application of VAC therapy on free muscle flaps may lead to reduced postoperative flap edema without critical reduction of blood supply.[6] Similar findings were published in 2012, when Eisenhardt et al detected significant lower levels of inflammatory factors in muscle flaps treated with negative pressure wound therapy, as well as reduced flap edema.[4] Safety of VAC on free muscle flaps was again proven in 2018.[3] Postoperative flap edema was studied as well through sequential metric measurements.

In our study, we have analyzed postoperative flap edema by means of a 3D scan, which delivers a more objective and accurate result. We have proven that VAC treatment of free muscle flaps significantly reduces postoperative flap edema the first 14 days after surgery. Not only does this result in enhanced postoperative patient mobility, but final aesthetic aspect of the flap is improved

**Table 5. Oxygen Saturation of the VAC and NVAC Group of Δ POD 0–POD 3, Δ POD 3–POD 5, and Δ POD 0–POD 5**

| | | Δ SO2 POD 0–POD 3 | Δ SO2 POD 3–POD 5 | Δ SO2 POD 0–POD 5 |
|---|---|---|---|---|
| Mean | **VAC** | −3.70 | −1.18 | −4.88 |
| | **NVAC** | −2.99 | −8.18 | −10.46 |
| SD | **VAC** | 9.61 | 12.38 | 15.43 |
| | **NVAC** | 8.33 | 10.91 | 12.51 |
| Median | **VAC** | −0.93 | 1.53 | 1.07 |
| | **NVAC** | 0.00 | −5.80 | −10.80 |
| Valid n | **VAC** | 13 | 13 | 13 |
| | **NVAC** | 13 | 13 | 13 |
| Asympt. significance (two-tailed) | | 0.626 | 0.106 | 0.158 |

**Table 6. Venous Hemoglobin Levels on POD 0, POD 3, and POD 5 in the VAC and NVAC Group**

| | | rHb POD 0 | rHb POD 3 | rHb POD 5 |
|---|---|---|---|---|
| Mean | VAC | 52.78 | 52.74 | 67.11 |
| | NVAC | 68.39 | 62.36 | 80.58 |
| SD | VAC | 16.45 | 15.97 | 21.58 |
| | NVAC | 34.89 | 24.57 | 37.84 |
| Median | VAC | 54.40 | 53.53 | 66.40 |
| | NVAC | 57.87 | 56.07 | 61.60 |
| Valid n | VAC | 13 | 13 | 13 |
| | NVAC | 13 | 13 | 13 |
| *P* | | 0.228 | 0.270 | 0.555 |

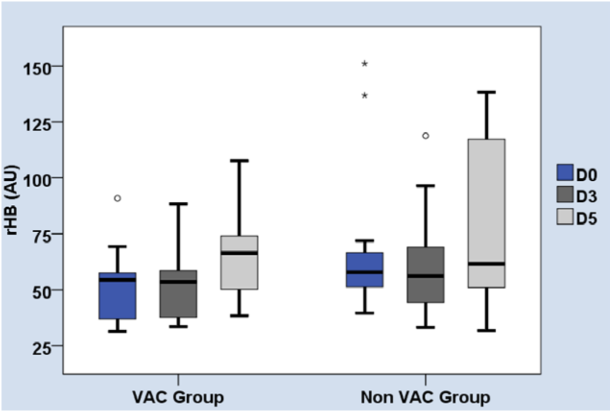


**Fig. 4.** Hemoglobin levels on POD 0, POD 3, and POD 5 of the study and control group.

as well, with lower need for additional surgery, mainly muscle flap thinning.[3,13] Furthermore, application of VAC on a skin grafted muscle flap reduces the number of dressing changes within the first five postoperative days, which both reduces workload of nursing staff, as well as discomfort and experienced pain by patients with every dressing change.

During initial intraoperative VAC activation, a significant increase in macroflow was measured by Doppler probe. This finding confirms that sudden, and sometimes worrisome, VAC aspiration does not threaten flap perfusion, nor poses an acute danger on flap survival. Moreover, macroflow continued to increase under VAC-therapy during the first 5 postoperative days, in contrast to a decrease of macroflow in the control group.

There are several theories on increase in macroflow, both intraoperatively and postoperatively, in the VAC group: during first VAC activation, acquired negative pressure may lead to a passive squeezing of venous capillary wound bed. This in turn may lead to a faster arterial inflow due to resulting flow gradient.[20]

In the early postoperative period, reduced intramuscular flap edema in the VAC group may reduce external compressive forces on arterioles and venules, thus inducing vasodilation with higher flow rates.[21] This may explain the continued increase in macroflow on POD 3 and POD 5, as reported in our study.

Interestingly enough, patients who received VAC treatment on their free flap showed a higher decrease of oxygen saturation during the first three postoperative days compared with NVAC patients. This phenomenon could be explained by reactive spastic vasoconstriction in the superficial part of the flap, resulting in reduced oxygen saturations.[22] However, it should be emphasized that there were no wound healing disorders or reduced adherence of split thickness skin grafts in the VAC group. Reduced oxygen levels therefore do not seem to have much relevance in terms of clinical outcome.

Another benefit of VAC application is resulting improved venous outflow, as shown by lower venous hemoglobin levels. The lower the venous hemoglobin level, the higher the venous outflow of the flap.[23] The VAC group showed lower hemoglobin levels on POD 0, POD 3, and POD 5, compared with the NVAC group. A possible explanation may be that flaps treated by conventional dressings develop a higher degree of intramuscular edema, which may lead to passive compression of venules and, thus, reduced venous outflow.

**Table 7. Flap Edema of the VAC and NVAC Group of Δ POD 0–POD 5, Δ POD 5–POD 14, and Δ POD 0–POD 14**

| | | Δ Flap Edema D 0–D5 ($mm^3$) | Δ Flap Edema D5–D14 ($mm^3$) | Δ Flap Edema D0–D14 ($mm^3$) |
|---|---|---|---|---|
| Mean | VAC | –29.23 | –53.54 | –82.77 |
| | NVAC | 95.20 | –45.92 | 49.29 |
| SD | VAC | 50.85 | 102.82 | 133.88 |
| | NVAC | 141.30 | 116.54 | 55.40 |
| Median | VAC | –7.83 | –27.53 | –33.27 |
| | NVAC | 44.10 | –1.79 | 38.81 |
| Valid n | VAC | 13 | 13 | 13 |
| | NVAC | 13 | 13 | 13 |
| Asympt. significance (two-tailed) | | 0.00 | 0.015 | 0.00 |

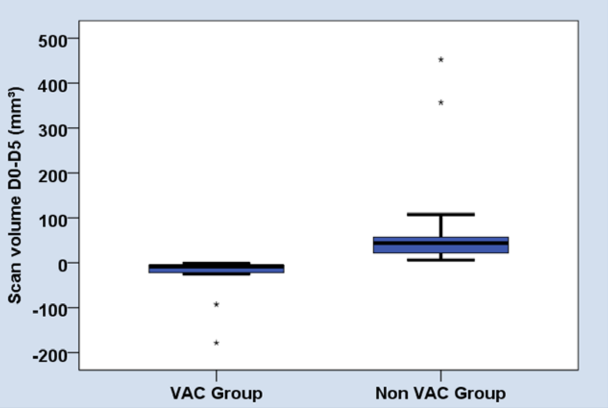


**Fig. 5.** Flap edema of the study and control group of Δ POD 0–POD 5.

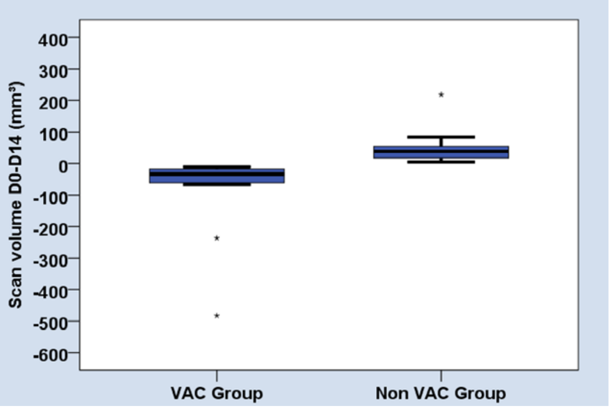


**Fig. 6.** Flap edema of the study and control group of Δ POD 0–POD 14.

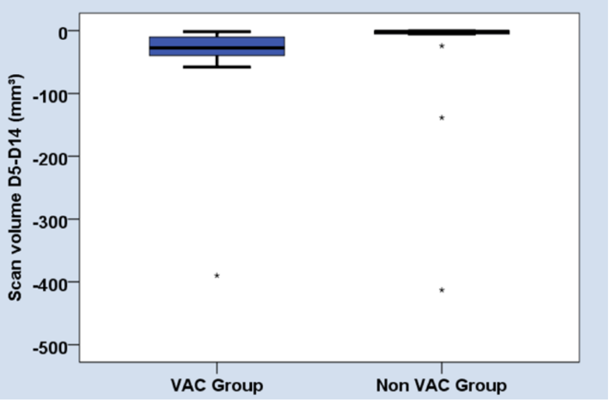


**Fig. 7.** Flap edema of the study and control group of Δ POD 5–POD 14.

Our study aimed to investigate whether VAC application on the free gracilis muscle flap and associated negative pressure may negatively influence the blood circulation. A negative effect of VAC application on flap microperfusion would be proven through reduced oxygen levels and increased venous hemoglobin levels because of venous stasis. Neither of those were found in our study. Furthermore, a reduction in micro-perfusion may lead to the so-called shunt phenomenon, characterized by reduced blood circulation in superficial flap layers (due to the negative VAC pressure) and reactive vasodilation in deeper flap layers.[24] This reactive flap autoregulation is caused by shifting hemodynamic pressures in the flap with subsequently changing hemodynamic features and potential influence on flap vascularization.[25] VAC application induces a vasoconstriction in superficial flap layer during early postoperative period, as seen by a reduced oxygen saturation in our study. Following the shunt phenomenon, this superficial vasoconstriction may induce a vasodilation in deeper flap layers, thus potentially leading to an enhanced blood supply with redistribution of blood from superficial to deep. Our statistical analysis shows that vascularization of free flaps in the VAC group is improved; however, an explanation based in the shunt phenomenon remains a hypothesis. The O2C probe used in this study has a measuring depth of 7 mm. Therefore, tissue layers deeper than 7 mm could not be detected for improved oxygen levels; this could be carried out in further studies by means of an ultrasound probe with power Doppler. In addition, it should be mentioned that all flaps in our study were only monitored for a period of 2 weeks after operation. No conclusions can therefore be drawn with regard to further clinical evolution and outcomes of free flaps. A longer follow-up time with measurements of deep microflow would be interesting to understand the complexity of intraflap vascularization in more detail.

We did not find any significant differences in flap survival or flap vascularization, when considering certain comorbidities, such as diabetes mellitus, arterial hypertension, or hypercholesterolemia. Furthermore, no significant differences were found between smokers and nonsmokers. A longer flap ischemia time also did not result in a degradation of flap outcome or vascularization.

**Table 8. VAC Aspirate in the VAC Group**

| | VAC Aspirate POD 0 (mL) | VAC Aspirate POD 3 (mL) | VAC Aspirate POD 5 (mL) |
|---|---|---|---|
| Mean | 6.15 | 160.00 | 244.62 |
| SD | 15.57 | 88.03 | 124.94 |
| Median | 0.00 | 210.00 | 310.00 |
| Valid n | 13 | 13 | 13 |

### Limitations of this Study

It should be noted that clinical postoperative period was 14 days, with some guidelines suggesting keeping VAC therapy on a wound bed for a maximum of 7 days. Thus, no statement could be made regarding flap edema after full mobilization of patients. Only a statement can be made regarding postoperative flap edema after flap dangling protocol, which was started on the sixth postoperative day. Likewise, statements regarding wound healing capabilities or ability to take a skin graft were only made in a postoperative period of 14 days. This certainly represents a limitation of our study and should therefore be investigated in another study with a larger patient population and a longer postoperative follow-up period.

Furthermore, in the control group, depending on wound secretion, fatty gauze and cotton swab dressing were changed at least once a day, whereas in the VAC group, first postoperative dressing change took place at POD 5.

Even if the exact workload of the nursing staff was not measured, it can be assumed that workload for patients in the study (VAC) group was less than in the control (NVAC) group in the first five postoperative days. Similarly, although no official postoperative pain evaluation score was conducted, the pain level of patients in the VAC group was lower than the pain level of patients in the control group, as every dressing change may cause pain due to mobilization of the leg and potential manipulation of the wound.

Because the postoperative study duration was only 2 weeks, we cannot conclude from this study if VAC therapy reduces the need for secondary surgical flap thinning. However, it can be assumed that this is the case since a reduction of swelling in the flap may lead to reduced fibrosis, which in turn leads to an increase in muscle atrophy, thus making the flap thinner. Although most of muscle flap is likely to atrophy from motor endplate transection, it can be hypothesized that reduced postoperative edema may aid this atrophic process.[26] However, this hypothesis should be further investigated in a further clinical study with a larger patient population.

The use of immediate VAC therapy in free muscle flaps is still limited. However, our study has proven that both macro- and microperfusion are enhanced thanks to VAC application, and flap edema is reduced, resulting in better functional and aesthetic outcomes.

The extent to which the application of VAC therapy can be applied to other muscle flaps could not be demonstrated in this study, but it can be assumed that this should also be applicable to other flaps such as latissimus dorsi flaps, as its safety in gracilis muscle flaps has been proven with this study. However, to be able to confirm this with certainty, a further study with other flap types (both muscle and fascio-cutaneous flaps) and a larger patient population should be carried out.

## CONCLUSIONS

The routine use of VAC therapy on free gracilis flaps leads to a significant reduction in postoperative flap edema, as well as an improvement in macro- and microflow. A clear recommendation for the use of VAC therapy on transferred gracilis muscle flap transfer to lower extremity can therefore be made. One might assume that other free muscle flaps that follow the same physiological principles may also benefit from VAC application. Despite the promising outcomes of this study, further research with longer follow-up times and a larger patient population with more critical clinical conditions is recommended to validate our findings.

***Anian S. Kuenlen, MD, MHBA***
Department of Plastic, Reconstructive, Hand and Burn Surgery
Bogenhausen Academic Hospital
Englschalkinger Street 77
81925 Munich, Germany
E-mail: a.kuenlen@hotmail.com
Instagram: @dr.kuenlen.plasticsurgery

## DISCLOSURE

*The authors have no financial interest to declare in relation to the content of this article.*

## REFERENCES

1. Xie SL, Guo GH, Min DH. Advances in the research of application of vacuum-assisted closure in wound healing and its mechanism. *Zhonghua Shao Shang Za Zhi.* 2017;33:397–400.
2. Mouës CM, Heule F, Hovius SER. A review of topical negative pressure therapy in wound healing: sufficient evidence? *Am J Surg.* 2011;201:544–546.
3. Chim H, Zoghbi Y, Nugent AG, et al. Immediate application of vacuum assisted closure dressing over free muscle flaps in the lower extremity does not compromise flap survival and results in decreased flap thickness. *Arch Plast Surg.* 2018;45:45–50.
4. Eisenhardt SU, Schmidt Y, Thiele JR, et al. Negative pressure wound therapy reduces the ischaemia/reperfusion-associated inflammatory response in free muscle flaps. *J Plast Reconstr Aesthet Surg.* 2012;65:640–649.
5. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg.* - Series A. 1976;58:453–458.
6. Machen S. Management of traumatic war wounds using vacuum-assisted closure dressings in an austere environment. *US Army Med Dep J.* 2007:17–23. PMID:
7. Saziye K, Mustafa C, Ilker U, et al. comparison of vacuum-assisted closure device and conservative treatment for fasciotomy wound healing in ischaemia-reperfusion syndrome: preliminary results*Int Wound J.* 2011;8:229–236.
8. Suliburk JW, Ware DN, Balogh Z, et al. Vacuum-assisted wound closure achieves early fascial closure of open abdomens after severe trauma. *J Trauma.* 2003;55:1155–1160.
9. Tan Y, Wang X, Li H, et al. The clinical efficacy of the vacuum-assisted closure therapy in the management of adult osteomyelitis. *Arch Orthop Trauma Surg.* 2011;131:255–259.
10. Yang CC, Chang DS, Webb LX. Vacuum-assisted closure for fasciotomy wounds following compartment syndrome of the leg. *J Surg Orthop Adv.* 2006;15:19–23.
11. Kamolz LP, Lumenta DB, Parvizi D, et al. Skin graft fixation in severe burns: use of topical negative pressure. *Ann Burns Fire Disasters.* 2014;27:141–145.
12. Nguyen TQ, Franczyk M, Lee JC, et al. Prospective randomized controlled trial comparing two methods of securing skin grafts using negative pressure wound therapy: vacuum-assisted closure and gauze suction. *J Burn Care Res.* 2015;36:324–328.
13. Bi H, Khan M, Li J, et al. Use of incisional negative pressure wound therapy in skin-containing free tissue transfer. *J Reconstr Microsurg.* 2018;34:200–205.
14. Nakayama Y, Soeda S. A new dressing method for free skin grafting in hands. *Ann Plast Surg.* 1991;26:499–502.
15. Nather A, Chionh SB, Han AYY, et al. Effectiveness of vacuum-assisted closure (VAC) therapy in the healing of chronic diabetic foot ulcers. *Ann Acad Med Singap.* 2010;39:353–358.
16. Webb LX. New techniques in wound management: vacuum-assisted wound closure. *J Am Acad Orthop Surg.* 2002;10:303–311.
17. Hanasono MM, Skoracki RJ. Securing skin grafts to microvascular free flaps using the vacuum-assisted closure (VAC) device. *Ann Plast Surg.* 2007;58:573–576.
18. Frost MW, Niumsawatt V, Rozen WM, et al. Direct comparison of postoperative monitoring of free flaps with

microdialysis, implantable cook-swartz Doppler probe, and clinical monitoring in 20 consecutive patients. *Microsurgery*. 2015;35:262–271.
19. Ghzanfari M. Reproducibility of non invasive blood flow measurement using laser doppler spectroscopy. *Phys Med Rehab Kuror*. 2002;12:330–336.
20. Sakarya AH, Do NTK, Huang YL, et al. Effect of degree of arterial inflow on a functioning free muscle transplantation in a rat gracilis model. *J Reconstr Microsurg*. 2020;36:458–465.
21. Chen SZ, Li J, Li XY, et al. Effects of vacuum-assisted closure on wound microcirculation: an experimental study. *Asian J Surg*. 2005;28:211–217.
22. Moellhoff N, Gernert C, Frank K, et al. The 72-hour microcirculation dynamics in viable free flap reconstructions. *J Reconstr Microsurg*. 2022;38:637–646.
23. Henton JMD, Simmons JMH, Hettiaratchy S, et al. Perfusion dynamics in lower limb reconstruction: investigating postoperative recovery and training using combined white light photospectroscopy and laser Doppler (O2C). *J Plast Reconstr Aesthet Surg*. 2015;68:1286–1292.
24. Rozen WM, Chubb D, Ashton MW, et al. images in plastic surgery: the anatomy of macrovascular arteriovenous shunts and implications for abdominal wall free flaps. *Ann Plast Surg*. 2011;67:99–100.
25. Kim JT, Kim CY, Kim YH. T-Anastomosis in microsurgical free flap reconstruction: an overview of clinical applications. *J Plast Reconstr Aesthet Surg*. 2008;61:1157–1163.
26. Brakenhielm E, González A, Díez J. Role of cardiac lymphatics in myocardial edema and fibrosis. *J Am Coll Cardiol*. 2020;76:735–744.