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Laser Speckle Contrast Imaging of the Blood Perfusion in Glabellar Flaps Used to Repair Medial Canthal Defects

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Background: The glabellar flap is a common technique for surgical repair after tumor excision in the medial canthal area. However, the outcome may be affected by partial flap necrosis. Little is known about the impact of surgery on blood perfusion and the postoperative course of reperfusion due to the absence of reliable and noninvasive perfusion monitoring techniques. The aim of this study was to use a modern imaging technique to assess blood perfusion in glabellar flaps.

Methods: Glabellar flaps were used to repair medial canthal defects following tumor excision in 7 patients. Blood perfusion was monitored using laser speckle contrast imaging: during surgery, immediately postoperatively (0 weeks), and at follow-up, 1, 3, and 6 weeks after surgery.

Results: Perfusion decreased gradually along the length of the flap, and reached a minimum 15 mm from the flap base. Perfusion in the proximal 20 mm of the flap was completely restored after 1 week, while the distal part of the flap was gradually reperfused over 6 weeks. Both the functional and esthetic surgical outcomes were excellent.

Conclusions: The rapid reperfusion of the glabellar flap may be explained by its connection to the vascular network via the flap pedicle. In flaps longer than 20 mm, the distal part can be considered a free skin transplant, and a combination of a glabellar flap and a free skin graft could then be considered.

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Reconstruction of the medial canthal region following tumor excision presents a challenge in maintaining the concavity of the canthus without distortion of the surrounding tissues, or the original eyebrow and eyelid contours and symmetry. Different surgical methods can be considered, such as laissez-faire, full-thickness skin grafting with or without a deep pericranial flap, a bilobed flap, or a rhomboid flap. However, the glabellar flap is a common choice because of it is a simple procedure in which excess skin from the lax glabellar skin region is advanced into the medial canthal defect, similarly to a V-Y flap.[1] A glabellar flap can also be extended inferiorly over the nose to repair defects of the middle and distal part of the nose.[2] Glabellar flaps have several advantages over a free full-thickness skin graft. Being a local skin flap, it will match the texture and color of the periorbital skin, it has its own blood supply, and the contraction on healing is less than in skin grafts,[3] all of which usually result in an excellent cosmetic result. However, there have been reports of both short-term and long-term problems associated with glabellar flap reconstructions, including lymphedema of the flap tip, necrosis of the tip or edges of the flap in the early postoperative period, undesirable scar formation, depression and fusion of the eyebrows, and contraction.[4] The planning of the flap is thus crucial, and many factors must be taken into consideration.

Successful flap reconstruction depends on understanding the vascular supply and the process of revascularization. When the glabellar flap technique was developed a century ago, it was based on empirical observations of clinical outcomes, because perfusion monitoring techniques were not available. Perfusion monitoring has recently been implemented in various reconstructive surgical procedures, but has not yet been described in the glabellar flap.

Conventional clinical methods of estimating blood flow include the assessment of temperature, color, and capillary refill, but are highly subjective and depend on the experience of the surgeon. Over the years, more objective techniques have been developed for perfusion monitoring of the skin; however, the use of these techniques has not become widespread in clinical practice due to a number of disadvantages. Fluorescein angiography is an invasive method, the dye causes discoloration, and it is not possible to repeat the measurements within 24 hours.[5,6] Thermal imaging has the advantage of being a noninvasive method; however, skin temperature is not solely dependent on perfusion.[7] Tissue oxygenation measurements using spectroscopic techniques lack the spatial information needed to identify heterogeneous changes in perfusion.[8] The need for reliable, fast, and noninvasive techniques to monitor perfusion in the entire surgical area has led to the introduction of laser-based techniques. Laser speckle contrast imaging (LSCI) is a noninvasive technique that has proven especially useful in clinical perfusion monitoring of free flaps, burns, and medium to large flap transfer in reconstructive surgery.[9–11]

In the present study, the authors used LSCI for intraoperative and postoperative perfusion monitoring in glabellar flap reconstruction in 7 patients following tumor excision in the medial canthal area. Improved knowledge of the perfusion and reperfusion of the flap may help reduce the risk of complications such as partial flap necrosis and poor cosmetic outcome.

METHODS

Ethics. The study was evaluated and approved by the ethics committee at Lund University, Sweden. It was carried out in accordance with the

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principles laid down in the Declaration of Helsinki as amended in 2008. All patients gave their fully informed consent.

Subjects. Seven patients with tissue defects in the medial canthal region after tumor removal (6 basal cell carcinomas and 1 squamous cell carcinoma) were included in the study. The patient characteristics are given in Table 1. Patients unable to provide informed consent, or who were physically or mentally unable to cooperate during the local anesthetic procedure, were excluded.

Surgical Procedure. Local infiltration anesthesia with 20 mg/mL lidocaine (Xylocaine, AstraZeneca, Södertälje, Sweden) was used. Epinephrine was not included in the local anesthetic, as it would have interfered with the perfusion measurements by causing transient vasoconstriction. No patient underwent surgery under general anesthesia. Modified glabellar flap procedures have been developed over the years; however, the "classical" procedure, as described, for example, by Collin,[1] was used in the present study (Fig. 1). An inverted V-shaped incision was made in the midline of the brow with 1 limb extending down to the defect. The flap was undermined in the subcutaneous plane, still attached to a pedicle across the nose. The median width of the base of the flap (i.e., the width of the bottom of the inverted V) was 17 mm (range 15–19 mm). The flap was then rotated about its pivotal point, that is, the medial canthus, and sutured into the defect. Thereafter, the brow defect was closed subcutaneously using 4-0 absorbable sutures (Vicryl, Ethicon, Somerville, NJ, U.S.A.). The skin was then sutured with a running 6 to 0 nonabsorbable nylon suture (Ethicon, Somerville, NJ, U.S.A.). Bipolar diathermy (25 W, KLS Martin ME102, KLS Martin, Tuttlingen, Germany) was used with caution, and diathermy at the base of the flap was avoided because repeated diathermy at the base of the flap has been found to significantly reduce blood perfusion.[12] No pressure dressing was applied. The superficial skin sutures were removed after 7 to 8 days. Surgery was carried out by 3 experienced, senior oculoplastic surgeons at the Department of Ophthalmology at the Skåne University Hospital in Lund, Sweden.

Laser Speckle Contrast Imaging. A PeriCam PSI NR System (Perimed AB, Stockholm, Sweden) was used for perfusion monitoring. An infrared 785 nm laser beam is dispersed over the skin region of interest by a diffuser. Dark and bright areas are created by random interference of the backscattered light, creating a speckle pattern.[13] The variation in this pattern caused by moving red blood cells is analyzed by the system software, allowing the blood perfusion to be measured in arbitrary units (perfusion units). The system is able to monitor perfusion in an area up to 24 × 24 cm, and the speckle pattern is recorded in real time (up to 100 images per second) with high resolution (100 μm/pixel). Perfusion was monitored at the following times:

1. during surgery, immediately after dissection of the glabellar flap,
2. after the flap had been sutured in place (denoted 0 weeks),
3. at follow-up at the clinic, after 6 to 8 days (denoted 1 week),
4. after 20 to 25 days (denoted 3 weeks), and
5. after 41 to 49 days (denoted 6 weeks) after surgery.

The variation in the follow-up times was due to logistic reasons.

TABLE 1. Patient characteristics

Number of men/women	2/5
Median age (range), years	77 (60–89)
No. patients using antihypertensive medication	4
No. patients with diabetes	4
No. patients with other cardiovascular diseases	2
No. patients using anticoagulant medication	2
No. patients using corticosteroid medication	0
No. smokers/former smokers (nonsmokers for the past 10 years)	2/2
No. patients treated with radiotherapy or previous surgery in the periorbital area	1

Calculations and Statistics. The perfusion in the glabellar flap was monitored along the length of the upper and lower parts of the flap and at a reference point in the flap base (see Fig. 1B). The perfusion along the flap is given as a percentage of the perfusion at the reference point and is presented as the median value and interquartile range. GraphPad Prism 9.0 (GraphPad Software Inc., San Diego, CA, U.S.A.) was used for calculations and statistical analysis. The Kruskal-Wallis test with Dunn's post hoc test for multiple comparisons was used for statistical analysis. Significance was defined as $p < 0.05$ ($p > 0.05$ not significant, n.s.).

RESULTS

Perioperative Blood Perfusion. Perfusion decreased along the length of the upper part of the flap, being 75% (interquartile range, 45%–85%) at 5 mm, 76% (39%–83%) at 10 mm, 46% (35%–67%) at 15 mm, and 47% (36%–49%) 20 mm from the base of the flap. A similar gradual decrease in perfusion was seen in the lower part of the flap. The results are shown in Figure 2. After rotation and suturing of the flap into place, a nonsignificant tendency towards a further decrease in perfusion was seen in the upper part of the flap (to 24% (20%–29%) at 14 mm, while no further decrease was seen in the lower part. Perfusion reached a minimum 14 mm from the flap base in the upper part of the sutured flaps and 15 mm from the base in the lower part of the sutured flaps. The values obtained at these positions were 26% (upper part) and 22% (lower part) and were assumed to reflect movement artifacts and not blood perfusion.

Reperfusion During Follow-up. One week after surgery, perfusion was completely restored in the proximal 20 mm of the upper part of the flap (93%, range 44%–126%) and did not differ significantly from the perfusion measured after 3 and 6 weeks (p = n.s.). However, the perfusion at 25 mm was still impaired 1 week after surgery (61% range 32%–89%). The distal part of the flap was thereafter gradually reperfused, being 73% (34%–88%) after 3 weeks and 91% (72%–122%) after 6 weeks. A similar pattern of reperfusion was seen in the lower part of the flap. Figure 3 shows a representative example of the glabella flap immediately after, and 6 weeks after, surgery, together with the corresponding perfusion images. The results for the whole group are shown in Figure 4.

Surgical Outcome. The flaps were viable in all patients and healed well. The flap skin sutures came loose in the distal part of the flap in 1 patient and the defect was allowed to heal by secondary intention. Both the functional and esthetic results were excellent. No hematomas were observed at postoperative clinical examination, and there were no artifacts in the LSCI signal indicating the presence of hematomas. However, 1 patient dropped out of the study after the 1-week follow-up due to the need for further surgery, as a residual tumor was found.

DISCUSSION

Knowledge of blood perfusion and revascularization is crucial in reconstructive surgery. This is the first study to investigate the reperfusion of glabellar flaps used to repair medial canthal defects. The perfusion in the glabellar flap was clearly impaired immediately postoperatively, especially so in the distal part of the flap. However, reperfusion of the flaps occurred quickly, and the proximal 20 mm of the flaps was fully reperfused within a week after surgery. This is in line with previous studies on other types of reconstructive flaps, where rapid

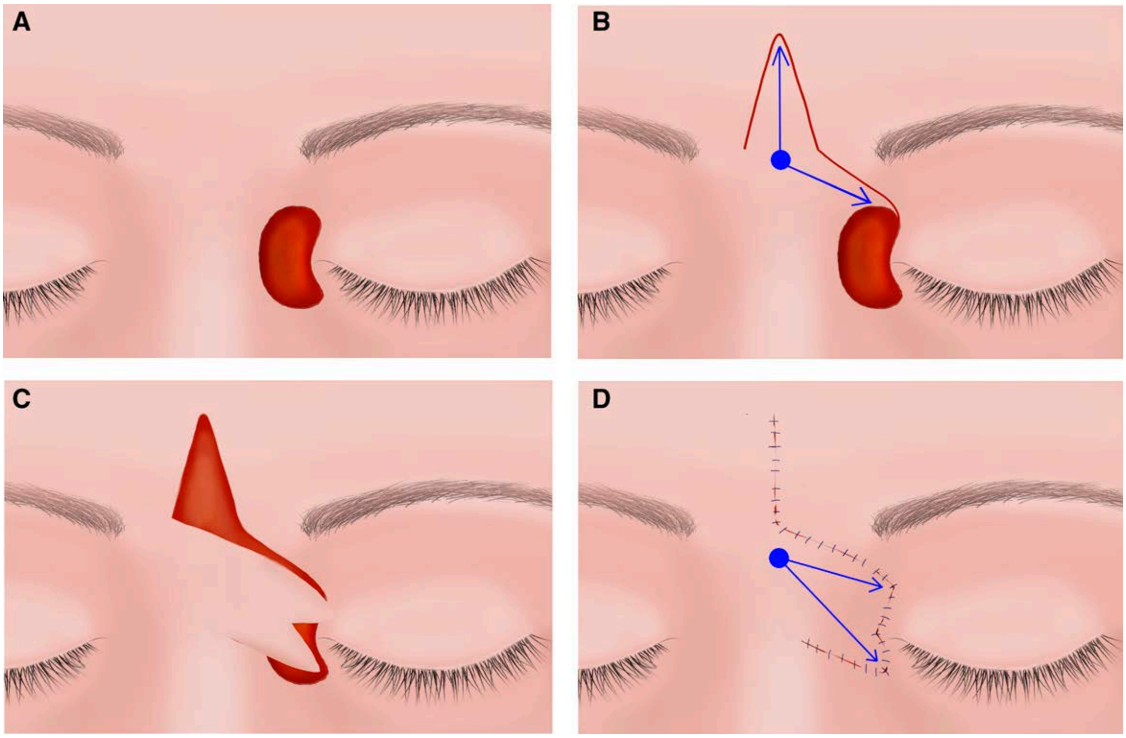

FIG. 1. Schematic illustration of the glabellar flap procedure. The flap is used to repair a medial canthal defect after tumor excision (**A**). The glabellar flap is first dissected from the midline of the brow with 1 limb extending down to the defect (**B**). The flap is then rotated about its base (**C**) and sutured into the defect, after which the glabellar defect is closed (**D**). LSCI was performed immediately after dissection, and after the flap had been sutured in place. Blood perfusion was measured along the length of the flap, in the upper and lower parts of the flap, as indicated by the blue arrows. Perfusion was then calculated as a percentage of the perfusion at a reference point in the flap base (blue dot). LSCI, laser speckle contrast imaging.

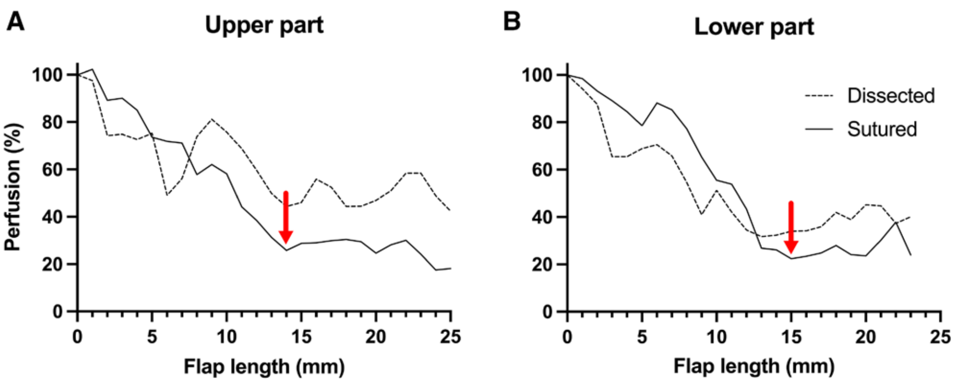

FIG. 2. Graphs showing the median blood perfusion in the 7 glabellar flaps as a percentage of the perfusion at the reference point, immediately after dissection, and after being rotated and sutured in place. Note the gradual decrease in perfusion along the length of the flaps, reaching a minimum at 14 and 15 mm, in the upper and lower parts of the sutured flaps, respectively (indicated by the red arrows).

reperfusion has been reported. In a recent LSCI study on the H-plasty procedure in the periocular region, the bipedicled flaps were found to be fully reperfused within 1 week of surgery.[14] In 1982, Young et al. studied the revascularization of pedicle skin flaps and new vascular connections between the distal viable region and the surrounding skin 3 to 4 days after surgery by injecting disulfine blue in a porcine model, and found that the whole flap had developed a collateral vascular supply after 7 to 10 days.[15] In 1985, Cumming et al. used laser Doppler and a dermofluorometer in a porcine model, and observed that the perfusion in a panniculus carnosus myocutaneous flap was adequate for survival without the pedicle 7 to 10 days after surgery.[16] Using animal models and ligation of the flap pedicle, Tsur et al. studied the revascularization of axial flaps, and found that it was sufficient to sustain flap survival after 6 to 7 days in rats, and after 4 to 5 days in pigs.[17] The rapid reperfusion of the proximal parts of the glabellar flap seen in the present study is presumably due to the vascular network connected to the flap via the pedicle, unlike a free skin graft, where reperfusion depends on angiogenesis throughout the graft. It is therefore not surprising that the reperfusion of glabellar flaps is more rapid.

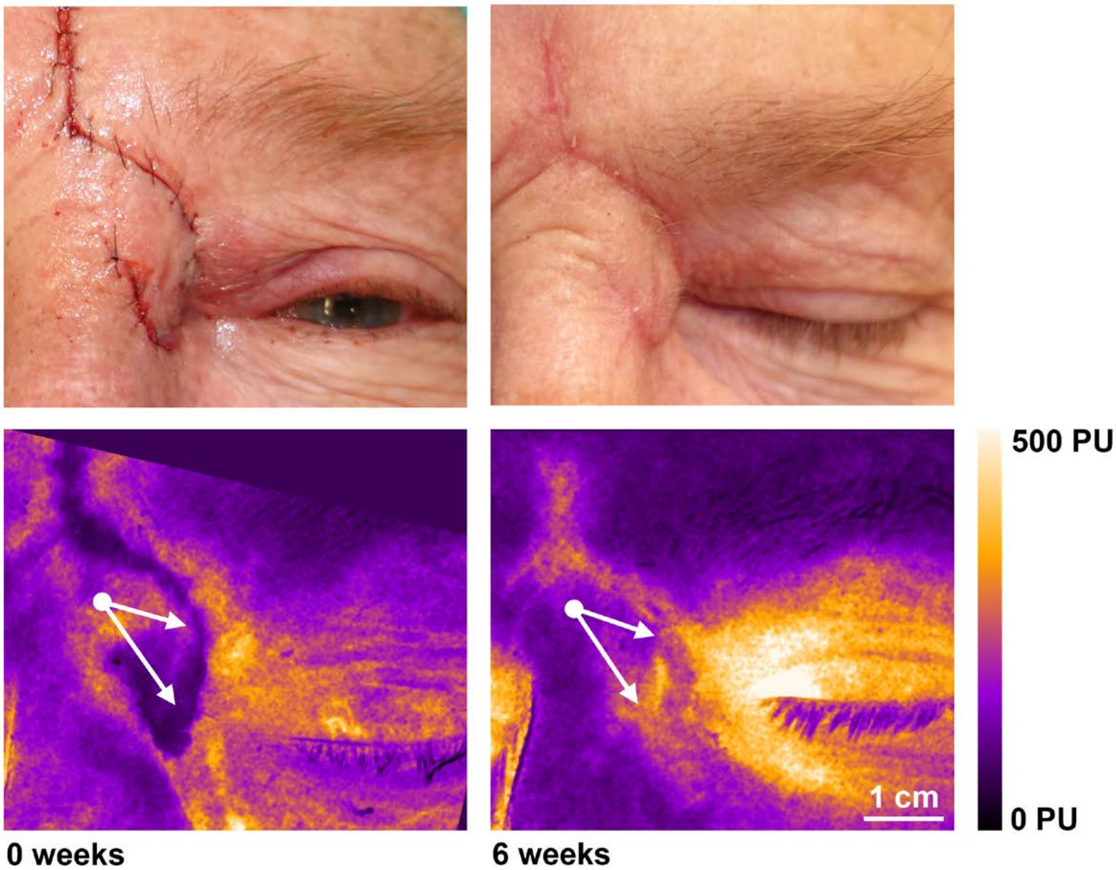

FIG. 3. Photographs and laser speckle contrast images of a glabellar flap immediately after surgery (0 weeks) and after 6 weeks (above). The LSCI recordings below show the variation in perfusion along the length of the upper and lower parts of the flap, as indicated by the white arrows. Note how the perfusion in the distal part of the flap is restored during healing. LSCI, laser speckle contrast imaging.

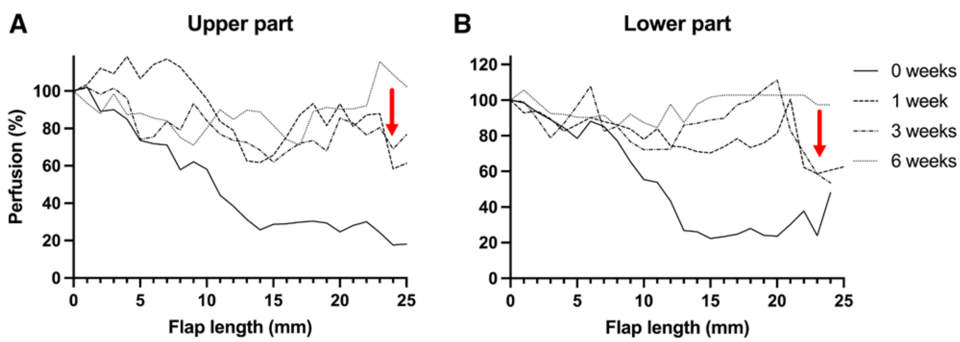

FIG. 4. Graphs showing the median blood perfusion in the upper and lower parts of the 7 glabellar flaps, immediately postoperatively (0 weeks), and at follow-up after 1, 3, and 6 weeks. It can be seen that complete reperfusion was achieved already after 1 week in the proximal 20 mm of the flaps, while reperfusion took longer in the distal parts of the flaps (red arrows).

In the present study, perfusion reached a minimum plateau in the distal parts of the glabellar flap, that is, ≥15 mm from the flap base. This is in line with a previous study by our group, in which it was shown that the perfusion in a human cutaneous upper eyelid flap was mainly preserved in the first 15 mm from the flap base, but very low beyond this.[12,18] Furthermore, 6 weeks was required for the distal tip of the glabellar flap, beyond 20 mm, to be reperfused. Reperfusion of the flap tip thus follows the same pattern as the revascularization of a free skin graft, and presumably depends on angiogenesis. Indeed, the authors have shown in previous studies that free full-thickness skin grafts in the periocular area require 7 weeks to become fully reperfused.[19,20]

Considering that the distal part of the flap does not seem to be perfused, the combination of a glabellar flap and a free full-thickness skin graft could be considered in cases where a long flap is required. The survival rate of free skin grafts in the well-perfused periocular area is known to be high, as shown in previous studies on free full-thickness skin grafts used on their own to cover defects,[19] or in combination with tarsoconjunctival flaps.[20] Indeed, it is common practice to combine a glabellar flap with other local flaps in cases of very large medial canthal defects, to reduce the length of the flap. For instance, in a case report from 2017, Ogino et al. used a glabellar flap, an upper eyelid myocutaneous advancement flap, and a cheek rotation flap to cover a medial canthal defect, while the donor site of the glabellar flap was covered by a Rintala flap.[21] In 2010, Chao et al. published a study on reconstruction using a combination of glabellar and orbicularis oculi myocutaneous advancement flaps.[22] To repair canthal defects that extend relatively inferiorly, a glabellar flap can be combined with a cheek rotation flap (i.e., Mustardé's cheek rotational flap).[23] An alternative method of reducing the length of the glabellar flap could be to combine a glabellar flap with a free skin graft. It would be of interest to investigate the effects of these types of combined surgical procedures on perfusion in future studies. The results of the present study suggest that combining a glabellar flap with a free skin graft could be considered in cases where the length of the required flap is greater than 15 mm.

The glabellar flap is a type of rotational advancement flap, where the flap is dissected from the forehead, and then rotated and stretched to cover the medial canthal defect. The results of this study show that the perfusion immediately after dissection was satisfactory over the full length of the glabellar flap, while after being sutured in place in the tissue defect, the perfusion had decreased slightly. It is well known from previous studies that manipulation of a flap impairs perfusion. In one of our previous studies on upper eyelid flaps using LSCI, the authors found that stretching a nonrotated flap had only a slight effect on perfusion, and simply rotating the flap by 90° had no significant effect on perfusion. However, the combination of rotation and stretching led to a significant reduction in perfusion.[18] This is in line with the results of our previous study on porcine eyelid flaps.[24] It, therefore, appears to be necessary to achieve a compromise between the length of the flap and the degree to which it must be rotated and stretched to cover a defect. The current study included only medial canthal defects, thus not extending much below the level of the eye. Glabellar flaps are sometimes used to repair defects of the middle and distal parts of the nose, requiring them to be extended further inferiorly over the nose. It is reasonable to assume that blood perfusion would be significantly affected in such cases, although this remains to be investigated in future studies.

As mentioned above, the authors have previously investigated the blood perfusion in other pedicle flaps from the eyelid, and found that the perfusion differed depending on the skin thickness and the underlying anatomy. Blood perfusion was found to be preserved to a greater extent distally in myocutaneous upper eyelid flaps containing orbicular muscle than in cutaneous flaps without orbicular muscle.[25] Perfusion was also found to be better preserved further distally in a full-thickness eyelid flap composed of both the anterior and posterior lamellae.[26] A glabellar flap consists of skin and subcutaneous fat in a region in which the skin is fairly thick compared with the upper eyelid skin. The region receives blood from the angular and supratrochlear arteries,[27] and LSCI monitoring of the skin microvascular blood perfusion shows that it is not as richly perfused as the upper eyelid. With this in mind, it can be concluded that perfusion depends on the flap thickness and the underlying muscular and vascular anatomy.

The median width of the base of the flap in the present study was 17 mm. It has previously been thought that the surviving length of a flap depends on its width.[28,29] However, this can be questioned. For example, Daniel and Williams found that increasing the width of random advancement flaps did not result in an increase in the length (mm) of the flap surviving.[30] In 2016, it was shown that hypoperfusion and oxygenation of random flaps could not be predicted by the ratio of the width to the length, but depended on the length and thickness of the flap.[31] In the present study, the width of the base of the flaps only varied slightly, between 15 and 19 mm, and the authors believe this had little effect on the perfusion, and it is thus more likely that the length of the flap was of greater importance for the perfusion at the tip of the flap.

There have been reports of problems in the short-term and long-term outcomes following glabellar flap reconstructions, including lymphedema of the flap tip, necrosis of the tip/edges of the flap in the early postoperative period, undesirable scar formation, depression and fusion of the eyebrows, and contraction.[4] The risk of such complications may increase if the postoperative perfusion is insufficient, leading to ischemia in the flap. The results of the present study indicate that the risk may increase when the flaps are longer than 20 mm. Poor microvascular status of the patient may also constitute a risk factor. It is well known that cardiovascular disease, diabetes mellitus, smoking,[32] and poor nutritional status[33] may influence the healing process, and therefore, most likely, reperfusion. However, no conclusions could be drawn regarding these factors in the present study due to the limited sample size. If it becomes possible in the future to monitor perfusion perioperatively in clinical practice, this may allow the surgical procedure to be tailored so as to avoid flap ischemia. This would hopefully reduce the risk of complications and improve surgical outcomes.

One major limitation of this study is the fact that perfusion was not monitored hourly in the immediate postoperative period. This means that it was not possible to determine whether the initial reduction in perfusion was due to the fact that the vessels were disrupted, or due to other surgical factors, such as surgical trauma, or temperature changes. Surgical vasospasm has been reported around the flap pedicle,[34] which may reduce the perfusion immediately postoperatively. However, it was not possible to monitor the blood flow for several hours after surgery as this would have meant keeping the patients at the clinic for an extended period.

In conclusion, the results of the present study suggest that glabellar flaps are reperfused quickly, and therefore provide an attractive alternative for the reconstruction of tissue defects in the medial canthal region. The major causes of glabellar flap necrosis are most likely a lack of surgical experience, inadequate planning, and careless flap dissection and/or raising. Rare cases of flap failure may be due to the flap being longer than that dictated by the microvascular status of the patient. In such cases, the glabellar flap should be shortened and combined, for example, with another myocutaneous advancement flap or a free graft. Perioperative LSCI monitoring may provide an attractive means of monitoring the perfusion of the flap during surgery and may make it possible to tailor the reconstructive procedure in each patient to avoid flap ischemia.

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