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Original Article

Forehead flap perfusion monitored by laser speckle contrast imaging: Importance of flap length and thickness

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Purpose: Forehead flaps are commonly used in oculoplastic surgery to cover defects after tumor excision. Blood perfusion is vital for flap survival. The aim of this study was to monitor the perfusion in forehead flaps and investigate the impact of flap length and thickness.

Methods: Nineteen forehead flaps in patients undergoing direct brow lift were studied. Perfusion was monitored using laser speckle contrast imaging, immediately after raising flaps consisting of epidermis, dermis, and subcutaneous tissue, and after removing the subcutaneous tissue resulting in a thin flap.

Results: Perfusion decreased gradually along the length, the mean value being 44% at 5 mm and 26% at 15 mm from the base, in thick flaps. Perfusion was significantly lower in thin flaps, being 13% when measured 15 mm from the flap base ($p < 0.0024$). Perfusion was better preserved in thick than in thin flaps. Very low perfusion was observed 16.7 mm (16.0–17.3 mm) from the base in thick flaps, and from 10.2 mm (9.8–10.6 mm) from the base in thin flaps ($p < 0.0001$).

Conclusions: Flap thickness is important in maintaining adequate blood perfusion and thus increasing the probability of flap survival.

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This may be particularly important in long flaps and in patients with impaired microcirculation.
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Introduction

Forehead flaps are sometimes used to cover defects after tumor excision in oculoplastic reconstructive surgery. Excess skin is often available above the eyebrows, especially in elderly patients with brow ptosis. This can be used for the reconstruction of large lower lid, upper lid, and lateral canthal defects, or to recruit vascularized tissue to anterior orbital defects.[1–5]

Flap thinning may be desirable to match the contour of the surrounding skin at the recipient site, in order to achieve better functionally and an aesthetically good outcome. This may be particularly important in the facial area, where a good aesthetic result is vital. Since the procedure of flap thinning is rather blind, there is a risk of damaging the vascular structures of the flap, thereby compromising perfusion.[6] Knowledge on how the perfusion is affected by thinning a flap is therefore important, particularly in patients with impaired microvascular flow. The effects of flap thinning on perfusion have been studied previously in upper eyelid flaps,[7] but to the best of our knowledge, not in forehead flaps where the skin has a different thickness and structure. The skin of the eyelid is unique because it is extremely thin and it lacks the subcutaneous fat layer.[8] The skin of the forehead more resembles the skin of the rest of the human body when it comes to thickness and structure.

Flap perfusion has historically been assessed by subjective clinical observations of skin temperature, turgor, color, and capillary refill time.[9] During recent years, more objective perfusion monitoring techniques have emerged. Laser speckle contrast imaging (LSCI) is a modern imaging technique that provides non-invasive, real-time visualization of the microvascular blood perfusion with high spatial resolution.[10] The surface of the area of tissue of interest is illuminated with near-infrared laser light, which penetrates into the tissue and interacts with the heterogeneous structure. The light that is scattered back out of the tissue generates a speckled pattern. Moving components within the tissue, i.e., blood cells, cause changes in the speckle pattern providing information on the relative change in perfusion in the imaged area. LSCI can be used intra-operatively, allowing investigations on how the design of flaps influences the perfusion. Such studies have been carried out in various oculoplastic reconstructive procedures, including upper eyelid flaps,[11] glabellar flaps,[12] H-procedures,[13] lower full-thickness eyelid flaps,[14] tarsoconjunctival flaps,[15,16] and switch flaps.[17]

To the best of our knowledge, this is the first study to monitor the perfusion in forehead flaps by LSCI. The aim of the study was to determine the importance of flap length and thickness on perfusion.

Methods

Ethics

The present study was performed in compliance with the World Medical Association Declaration of Helsinki regarding ethical principles for medical research involving human subjects, as amended in October 2013. All patients participating in the study gave their fully informed consent. The research protocol was approved by the Swedish Ethical Review Authority (2013/625).

Patients

Patients incapable of providing consent or who were physically or mentally unable to cooperate in the local anesthetic procedure were excluded. Patients who had undergone previous surgery, trauma,

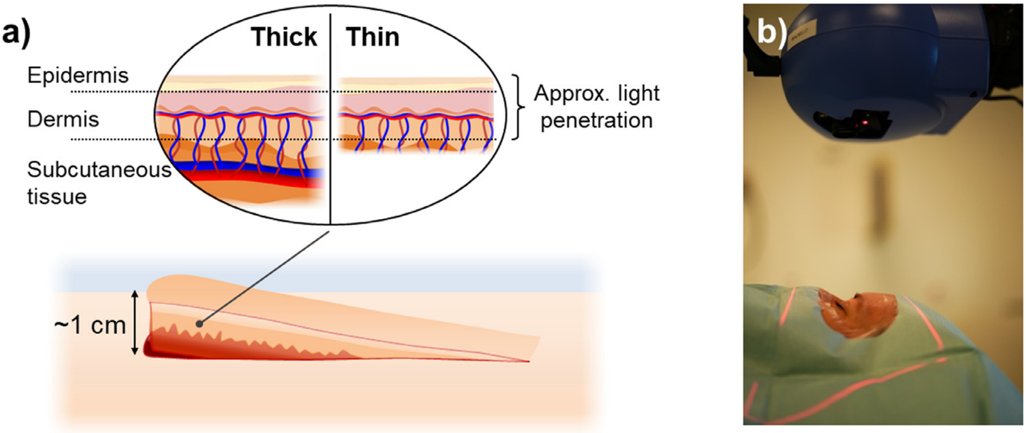

Figure 1. (a) Schematic illustrating the different tissue layers and vascular complexes in each flap type. (b) Photograph showing the measurement geometry with the LSCI instrument situated above the patient about to undergo reconstructive surgery.

or radiotherapy in this area were also excluded. Eleven patients, four women and seven men, with eyebrow ptosis were admitted to the Skåne University Hospital for a direct brow lift, two of whom underwent unilateral surgery. Indication for surgery was severe eyebrow dropping causing the skin of the upper eyelid to obstruct part of the vision field. Brow ptosis may be seen secondary to paralysis or weakness of the frontalis muscle or involuntary contraction of the orbicularis muscle, but it can also be due to mechanical downward pulling by, for an example, a malignant tumor.[18] In this study, only brow ptosis due to age-related degeneration of the skin and soft tissue were considered. Surgery was performed by the same experienced senior surgeon (first author, JB).

Movement, for example from heavy breathing or shivering, will result in artifacts. The left raised flap in one patient was excluded from the analysis as it was impossible to separate the perfusion signal from that due to motion artifacts. Nineteen of the twenty monitored flaps were included in the analysis. The patients had a median age of 68 (range 43–80) years, six were taking antihypertensive medication, four were taking anticoagulant medication, three had diabetes, three had cardiovascular disease, and there were no smokers.

Surgical procedure

A local anesthetic consisting of 20 mg/ml lidocaine without adrenalin (Xylocaine®, AstraZeneca, Södertälje, Sweden) was injected into the surgical area. The forehead flaps were raised as part of the direct brow lift procedure.[19] The superior border of the brow was marked as well as the excesses of skin and subcutaneous tissue to be resected as an ellipse above this border. An incision was made, but the skin located most medially to the ellipse was left intact. Dissection was carried out within the subcutaneous fat layer (Figure 1a). This resulted in medially anchored forehead flaps. The thick flaps were approximately 7 mm wide at the base (median, range 5–11 mm), 59 mm long (median, range 28–68 mm), and 3.5 mm thick (median, range 3–4.5 mm). Subcutaneous tissue was removed after the first measurement to obtain a thin flap consisting of the epidermis and dermis (Figure 2).

The position of the supraorbital nerve and vessels was identified by manually palpating the supraorbital notch before incision. In this area, perfusion is mainly based on the supraorbital and supratrochlear artery and their branches which pass through the frontal muscle. Dissection was not performed below the subcutaneous tissue, thereby minimizing the risk for interfering with these structures.

After the LSCI measurements the surgical procedure was completed by incision of the medial skin and removal of the flap. The edges were finally sutured in two layers together to draw up the brow.

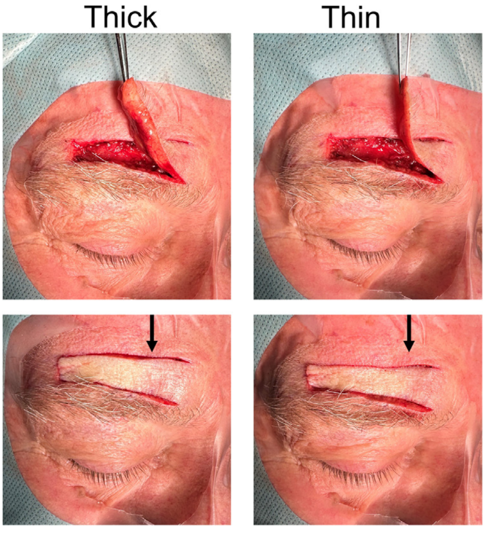

Figure 2. Intraoperative photographs of the surgical procedure. Perfusion was monitored using laser speckle contrast imaging, immediately after raising a thick flap (left panels) consisting of epidermis, dermis, and subcutaneous tissue, and after removing the subcutaneous tissue resulting in a thin flap (right panels). Note the gradual increase in pallor of the skin along the length of the flap, reflecting the retained perfusion in only the most proximal centimeter (arrows).

LSCI

Blood perfusion was monitored using a PeriCam LSCI instrument (PeriCam PSI NR System, Perimed AB, Stockholm, Sweden). The area of interest was illuminated by infrared laser light at a wavelength of 785 nm (Figure 1b). Dark and bright areas were created by interference of the light backscattered from moving particles in the illuminated area, producing a speckled pattern. This pattern was recorded in real time by a camera, at a rate of up to 100 images per second, and a spatial resolution of up to 100 μm/pixel. Perfusion was automatically calculated by the system by analyzing the variations in the speckle pattern. LSCI was used to monitor the perfusion first in the thick forehead flap and then in the thin flap.

Calculations and statistical analysis

Perfusion was determined along the flap length. While the LSCI measures blood perfusion in arbitrary units, called perfusion units, the perfusion in the flaps was calculated as a percentage of the perfusion at a reference point at the flap base. Significance was calculated using 2-way repeated measures analysis of variance and Šídák's multiple comparisons test with significance defined as $p < 0.05$. The decrease in perfusion along the flap length was calculated using nonlinear regression with 1-phase decay. Significance was defined as $p < 0.05$. All data analyses were performed using MATLAB (MathWorks Inc., Natick, MA), while statistical comparisons were made using GraphPad Prism 9.0 (GraphPad Software Inc., San Diego, CA, USA).

Results

Blood perfusion decreased gradually along the length of the flap, as shown in the representative example in Figure 3. Thinning of the flap resulted in a significant decrease in perfusion (Figure 3d). The mean decrease in the 19 thick flaps included in the analysis was 44% at 5 mm, 30% at 10 mm, 26% at 15 mm, and 20% at 20 mm from the flap base (Figure 4). The greatest difference in perfusion between thick and thin flaps was observed at 15 mm; being 26.0% of that at the reference point in

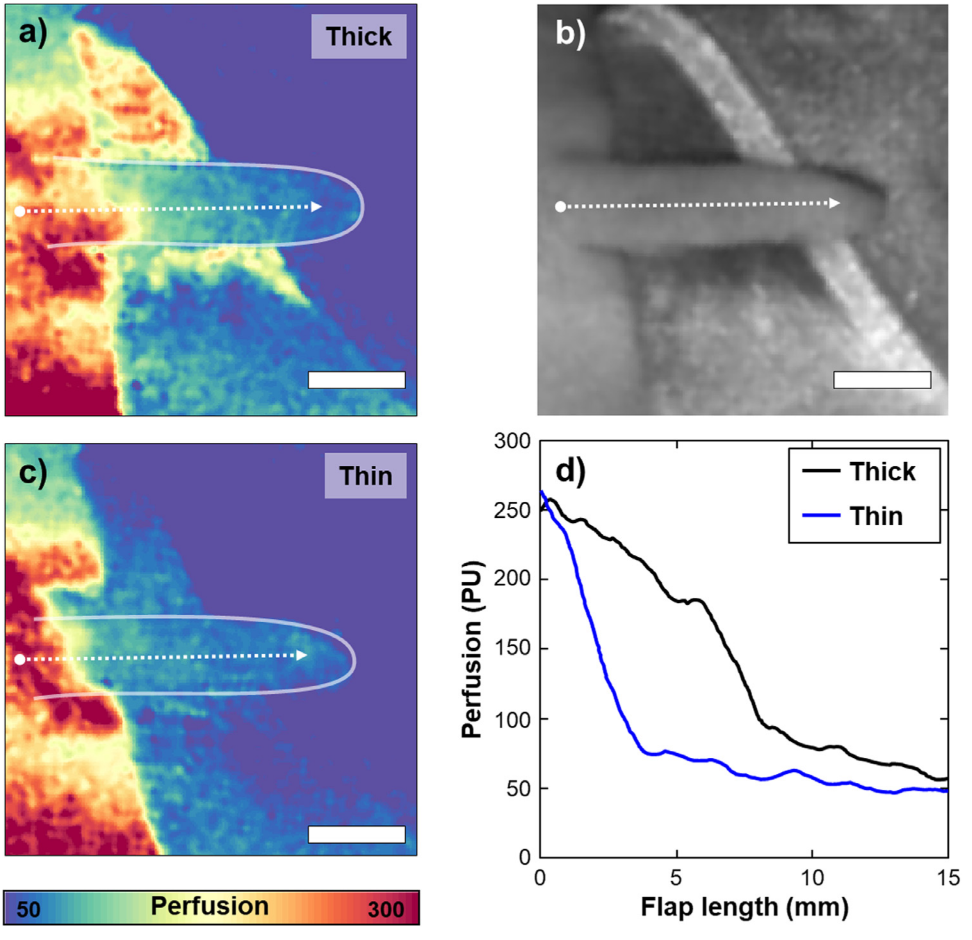

Figure 3. Representative examples of LSCI perfusion maps of a thick (a) and a thin (c) flap with its corresponding photo (b). Perfusion was calculated along the length of the flaps, as shown by the dashed arrows. The scale bar is 5 mm. The perfusion values obtained in these representative flaps are plotted in (d) showing the gradual decrease in perfusion over the length of the flap, and the significant decrease in perfusion upon thinning of the flap.

the thick flaps and 13.7% in the thin flaps ($p < 0.0001$). Furthermore, blood perfusion was preserved further along the flap in thick than in thin flaps. Very low perfusion was observed from 16.7 mm (16.0–17.3 mm) from the base in thick flaps, and from 10.2 mm (9.8–10.6 mm) from the base in thin flaps ($p < 0.0001$, Figure 4).

Discussion

The present study was performed to map the perfusion in forehead flaps. The results showed that perfusion decreased gradually from the base to the tip of the flap, and reached a minimum at 16.7 mm from the base of the thick flaps. A gradual decrease in perfusion along the length of the flap was seen in two of our previous studies on upper eyelid flaps in patients,[7,11] in which perfusion was very limited beyond the proximal 10.2 mm of the flaps. This could imply that a periorbital flap should not be longer than 10 mm in order not to risk necrosis and tip complications. The distal part of longer flaps will function as a free skin graft, and this may be an alternative when a long

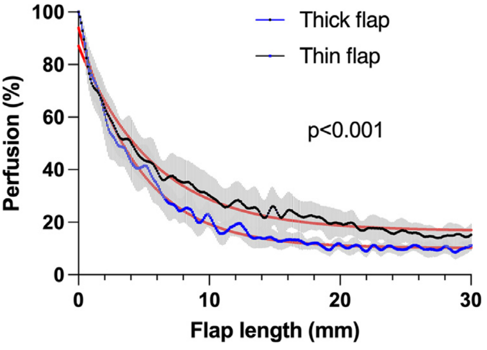

Figure 4. Mean perfusion along the thick and thin flaps. The solid black and blue lines represent the mean perfusion, and the shaded areas represent the 95% CIs. The red curves show the results of nonlinear regression analysis with 1-phase decay used to calculate the distance at which minimum perfusion was observed. This was 16.7 mm from the flap base for the thick flaps and 10.2 mm for the thin flaps.

flap is needed for reconstruction of a tissue defect. This knowledge about the deleterious effect of flap thinning is important for surgeons especially when dealing with patients with impaired microcirculation. In such individuals, flap thinning might be avoided and the subcutaneous plexus carefully spared.

After measuring the perfusion in the thick forehead flaps, composed of epidermis, dermis, and subcutaneous tissue, the subcutaneous tissue was removed to make thin flaps. Further LSCI measurements showed that the blood perfusion was significantly reduced in the thin flaps. These results are in line with the findings of a previous study on porcine flaps, in which we observed better perfusion and oxygenation in a thicker flap that was dissected down to the muscle fascia through the subcutaneous tissue, than in a thinner flap, dissected only through half the thickness of the subcutaneous tissue.[20] It is also in accordance with our previous study on the upper eyelid, in which perfusion was better preserved in myocutaneous flaps than in cutaneous flaps in which the orbicularis oculi muscle had been removed.[7]

In the present study, perfusion was preserved at a greater distance from the base in thick flaps than in thin flaps. The better perfusion in thick flaps is probably due to the vascular anatomy. The cutaneous microcirculation consists of a superficial dermal vascular plexus immediately underneath the epidermis and a deep dermal vascular plexus just above the subcutaneous plane. These plexuses are joined by ascending arterioles and descending venules. The deep dermal vascular plexus is preserved to a greater extent in the thicker flaps, resulting in better perfusion. Perfusion was retained in the proximal 16.7 mm of thick flaps, but only in the proximal 10.2 mm in thin flaps, indicating that flaps can be made longer if the subcutaneous tissue and its vasculature are included.

In this study, we created a model for examination of the perfusion in random flaps. Thus, the conclusions drawn from these findings may add to the general knowledge about random flaps used in reconstructive surgery. The study provides knowledge applicable to random flaps raised both in the periorbital area and the rest of the body. Flap thinning is often used and it is of importance for the surgeon to have knowledge about how flap thinning affects flap perfusion in order to be able to decide whether it is appropriate or if the risk of flap failure risk is impending. In future studies, it would be interesting to study specific random flaps, such as the Fricke flap, and to investigate flap survival in relation to perfusion and microvascular risk factors. In such a study, LSCI could easily be used to monitor the reperfusion of the flap in the postoperative period, in order to investigate the relation between flap perfusion and complications such as poor flap survival and the surgical outcome.

Another limitation of the present study is the small number of cases included. Subgroup analysis of some of the factors known to impair the microcirculation, such as diabetes or smoking, was not possible.

Conclusion

Perfusion was found to decrease gradually along the length of forehead flaps, and the results suggest that a thick flap containing epidermis, dermis, and subcutaneous tissue should not be longer than 17 mm in order to retain perfusion. Thinning of the flap by removal of the subcutaneous tissue significantly reduced the perfusion, and such a flap should not be longer than 10 mm to ensure perfusion. The distal part of longer flaps will function as a free skin graft, and this may be an alternative when designing a long flap.

Declaration of competing interest

None.

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Ethical approval statement

The study was approved by the Swedish Ethical Review Authority (2013/625).

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