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Cosmetic

Impact on Abdominal Skin Perfusion following Abdominoplasty

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Background: Wound healing problems following abdominoplasty may be a result of impaired tissue perfusion. This study evaluated the impact a standard abdominoplasty may have on abdominal skin perfusion.

Methods: A standard abdominoplasty was performed in 16 patients. Dynamic infrared thermography (DIRT) using a mild and a stronger cold challenge was performed pre-, intra-, and postoperatively on day 1, 2, and in week 6. The abdomen was divided into Huger's vascular zones. A two-tailed *t* test was used to evaluate differences in mean temperature between zones. Statistical significance was defined as $P < 0.05$.

Results: Two patients suffered wound healing problems. Abdominal skin perfusion showed a hyperaemic state on day 1, day 2, and week 6, postoperatively. Hotspots in zones I and II had all disappeared at the end of surgery and on day 1, except in the cranial part of zone I. Hotspots reappeared in zones I and II during day 2. A statistically significant difference between zones I and II was seen on day 1 and 2, with zone II being cooler. This difference had disappeared in week 6 for the mild cold challenge but not for the stronger cold challenge.

Conclusions: A standard abdominoplasty has a significant impact on abdominal skin perfusion. The skin perfusion is a dynamic process with a gradual improvement over time. The strongest effect was seen in zone II near the lower transverse incision line, where skin perfusion was the least. Such may contribute to impaired wound healing at this site. *(Plast Reconstr Surg Glob Open 2021;8:e3343; doi: 10.1097/GOX.0000000000003343; Published online 26 January 2021.)*

INTRODUCTION

Abdominoplasty is one of the most commonly performed cosmetic surgical procedures. Nevertheless, abdominoplasty is associated with a higher complication rate than other aesthetic procedures, and it has the highest readmission rate of the 5 most common outpatient cosmetic procedures.[1,2] One of the main risks of abdominoplasty is delayed wound healing at the lower transverse suture line, which can have a negative impact on the aesthetic outcome, cause emotional stress to the patient, and increase health care costs.[1,3,4]

Abdominoplasty requires undermining of a large skin-fat flap that has a random-pattern blood supply.[5] Complications like wound dehiscence, skin necrosis, and wound infection can be related to decreased perfusion of this flap and are inherent to the surgical technique. As adequate blood perfusion is crucial for normal wound healing, a better understanding of abdominal skin perfusion after abdominoplasty may contribute to reducing wound healing problems.

Infra-red (IR) measurements of skin surface temperature provide indirect information on skin perfusion. Studies have shown a good correlation between thermographic results and laser Doppler flowmetry, and between thermographic results and skin perfusion monitored with indocyanine green fluorescence video angiography and isotope perfusion.[6–10] Dynamic infrared thermography (DIRT) is based on the relationship between skin perfusion and the change in rate and pattern of skin surface temperature following a transient thermal challenge.[11] Its value in monitoring flap perfusion and in preoperative perforator mapping has been reported in a number of

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studies.[12–15] The purpose of the present study was to determine the impact abdominoplasty may have on postoperative abdominal skin perfusion as monitored with DIRT.

MATERIALS AND METHODS

This prospective clinical study was approved by the regional ethical committee, and the principles outlined in the Declaration of Helsinki were followed. Only patients scheduled for a standard abdominoplasty who were nonsmokers or had stopped smoking at least 3 months before surgery and had no abdominal scar were included. All patients consented for participation in writing. None of the patients had significant co-morbidities or had obesity.

The operations were performed in general anesthesia and by the same surgeon. All patients were kept normothermic, and all intravenous fluids were at body temperature. Due to the vasoconstrictive effect of epinephrine, the procedure was performed without the use of local anaesthesia and liposuction. A standard abdominoplasty with a lower transverse incision was used in all patients. The skin incision was carried down to the fascia. The abdominal flap (including Scarpa's fascia) was elevated in the midline close to the xyphoid after isolating the umbilicus. Laterally, undermining was performed up to the costal margin. The abdominal flap was pulled down, and excess skin and subcutaneous tissue was resected. The umbilicus was transposed and the transverse wound was closed with minimal tension in layers. No quilting sutures were used. The wound was closed over 2 suction drains.

DIRT was performed in the same supine position on the day before surgery, intraoperatively and postoperatively on day 1 and 2, and in week 6. An IR camera (FLIR S645, FLIR Systems, FLIR Systems AB, Boston, Mass.) (accuracy 0.01°C) was positioned over the exposed abdomen. Thermal emissivity was set to 0.98, and the accuracy of the camera was regularly checked against a black body with a traceable temperature source (Model IR-2103/301, Infrared Systems Development Corp., Winter Park, Fla.). IR images were taken at regular intervals to register the rate and pattern of rewarming of the skin for 3 minutes after a mild cold challenge. Images were electronically stored and then processed using an image analysis software (ThermaCAM Researcher Pro 2.8 SR-1; FLIR Systems AB, Boston, Mass.).

The pre- and postoperative images were taken in a dedicated laboratory [room temperature: (22 ± 0.5)°C] before and during rewarming following a cold challenge after an acclimatization period of 10 minutes with the abdominal wall exposed. Two types of mild cold challenges (A and B) were used. Type A thermal challenge involved blowing air at room temperature over the skin surface for 2 minutes with a desktop fan. Type B thermal challenge involved washing the abdomen evenly for 1 minute with gauze soaked in saline with a temperature of 22°C. Before taking the IR images, all excess liquid was removed by drying the skin quickly with a compress. The intraoperative examination was performed with the patient in general anaesthesia before and at the end of surgery, with room temperature set at 22°C. Types A and B were used pre- and postoperatively, whereas type B was used only intraoperatively for reasons of sterility. For the purposes of analysis, the abdomen was divided into Huger's vascular zones, but the right zone III was labeled IIIA and the left was labeled IIIB (Figs. 1 and 2). All patients were their own control. A qualitative analysis of the change of pattern and rate of rewarming of hotspots within each zone was made and compared with the results from the other zones. For quantitative analysis, the mean skin temperature was calculated for each zone in the pre- and postoperative phase before cooling, at the end cooling, and at 1, 2, and 3 minutes rewarming. A two-tailed t test for paired variables and 1 degree of freedom was used to see if there was a difference in mean zone temperature between IIIA and IIIB at precooling, end cooling, and at 1, 2, and 3 minutes rewarming for the pre- and postoperative phase. Then differences among zones I, II, and III were calculated for the pre-, intra-, and postoperative examinations. In addition,

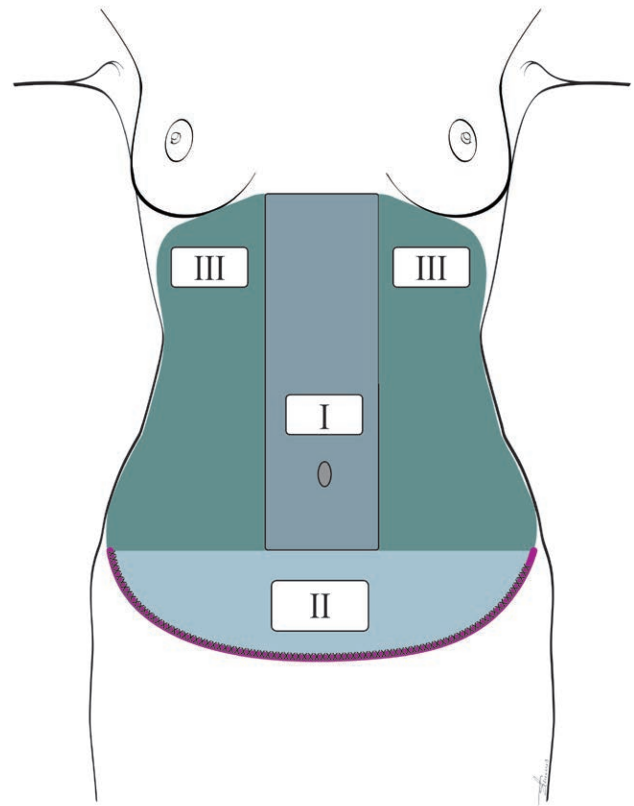

Fig. 1. Illustration of Huger's vascular zones of the abdominal wall. Zone I is primarily supplied by the arcade formed by the superior epigastric and inferior epigastric vessels and ranges from the xiphoid to the transverse line connecting both anterosuperior iliac spines. It lies in between the lateral borders of the rectus abdominis muscles. Zone II receives its blood supply from the superficial epigastric, superficial circumflex iliac, and inferior epigastric vessels. This zone II is the area defined superiorly by a line connecting both anterosuperior iliac spines and inferiorly by the groin and pubic creases. Zone III is supplied by segmental intercostal, subcostal, and lumbar vessels. This zone comprises the lateral abdomen and flanks. The Huger zones are composed of angiosomes of the source vessels incorporated in each zone.

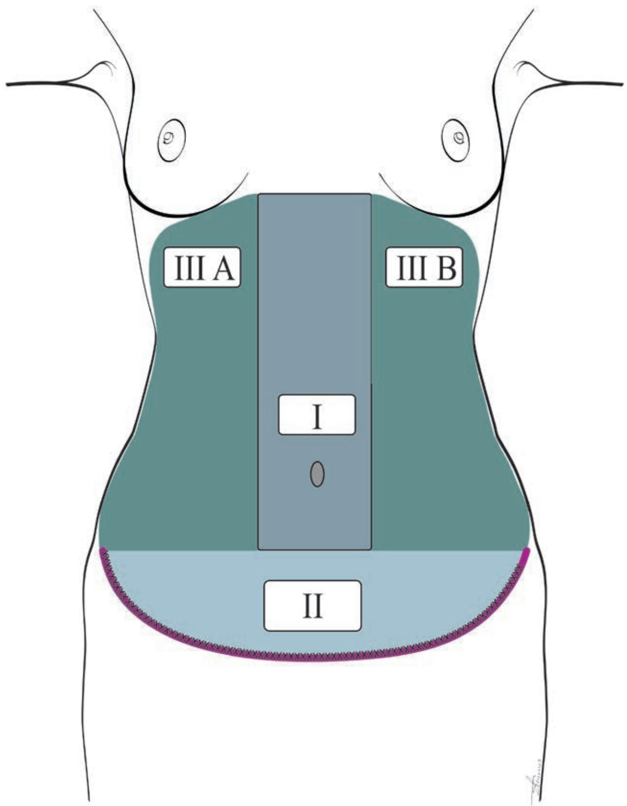

Fig. 2. The authors' modification of Huger's zones for the standard abdominoplasty in which zone III on the left side is numbered IIIA, and on the right side, IIIB.

the mean temperature of all zones together at 3 minutes rewarming was calculated for the day before surgery and for day 1, 2, and week 6 postoperatively. Statistical significance was defined as $P < 0.05$.

RESULTS

A total of 16 patients (12 women and 4 men), mean age 42 years (range 22–64), and mean BMI 25.4 kg/m^2 (range 19.7–28.4) were included in the study. Wound healing problems occurred in 2 of the 16 patients and were all located at the centre of the lower transverse suture line. Both patients had a small wound dehiscence and minor fat necrosis. Both wounds healed with daily wound care after a minor wound revision at the outpatient department.

Qualitative Analysis

Qualitative analysis of the pre-, intra, and postoperative DIRT examinations showed a large variability in patterns of hotspots among patients and between the right and the left side of a patient. In all patients, a similar effect on abdominal skin perfusion could be seen irrespective of the cold challenges used. The preoperative pattern of hotspots for zone III did not change intra- and postoperatively. Also, in the cranial part of zone I, hotspots stayed clearly visible. In the remaining of zone I and in zone II, hotspots became less visible or had disappeared at the end of surgery and on the first postoperative day. This effect was most pronounced for zone II. All zones showed a hyperaemic state intra- and postoperatively. Hotspots in zone III and in the cranial part of zone I showed an increase in the rate of rewarming at the end of surgery and on day 1. On day 2, hotspots reappeared in zones I and II. At the same time, the hyperaemic state and the rate of rewarming of hotspots decreased in zone III. At week 6, the overall rate of rewarming at the hot spots had decreased (Fig. 3).

Quantitative Analysis

In general, the quantitative results reflected the qualitative findings. The pre, intra-, and postoperative DIRT examinations revealed no statistical significance in mean zone temperature between zones III A and III B at 3 minutes rewarming for both types of cold challenges. Preoperatively, there was a statistically significant difference in mean zone temperature between zones I and II for both cold challenges, with zone I being warmer. This difference was also seen at the end of surgery, and on postoperative day 1 and 2. However, in week 6 this statistical difference had disappeared for type A cold challenge, but not for type B (Fig. 4). Preoperatively there was no statistical difference in mean zone temperature between zones I and III. Only on day 1, there was a statistically significant difference in mean zone temperature between zones I and III when using the type B cold challenge, with zone III being cooler. Otherwise there was no statistical difference between zones I and III. There was a statistical difference between zones II and III preoperatively and on day 1 for both types of cold challenges, with zone II being cooler. This difference disappeared on postoperative day 2 (Tables 1 and 2). The mean skin temperature of all zones combined showed a postoperative hyperemia that was statistically significant until week 6 (Fig. 5).

DISCUSSION

This study shows that a standard abdominoplasty causes considerable changes in abdominal skin perfusion. The qualitative results showed a change in the pattern of hotspots. Patterns of hotspots on IR images of the abdominal skin have been previously described.[11,13–15] Heat radiation from the skin is registered with an IR camera showing a higher IR emission at the hotspots. These hotspots are associated with locations where perforators, transporting warm blood to the skin, are in connection with the subdermal plexus. These hotspots have been related to the locations of arterial Doppler sounds and the vascular anatomy of perforators on computed tomography angiography.[13,15] True and "choke" anastomoses have also been visualized with DIRT.[16]

Closure of a standard abdominoplasty involves undermining of skin and subcutaneous tissue in the midline close to the xiphoid, creating a large random pattern abdominoplasty flap. The postoperative changes in abdominal skin perfusion may be explained using Huger's vascular zones and the angiosome theory.[17,18] Huger zones are composed of angiosomes of the source vessels incorporated in each zone. It is important to realize that although the

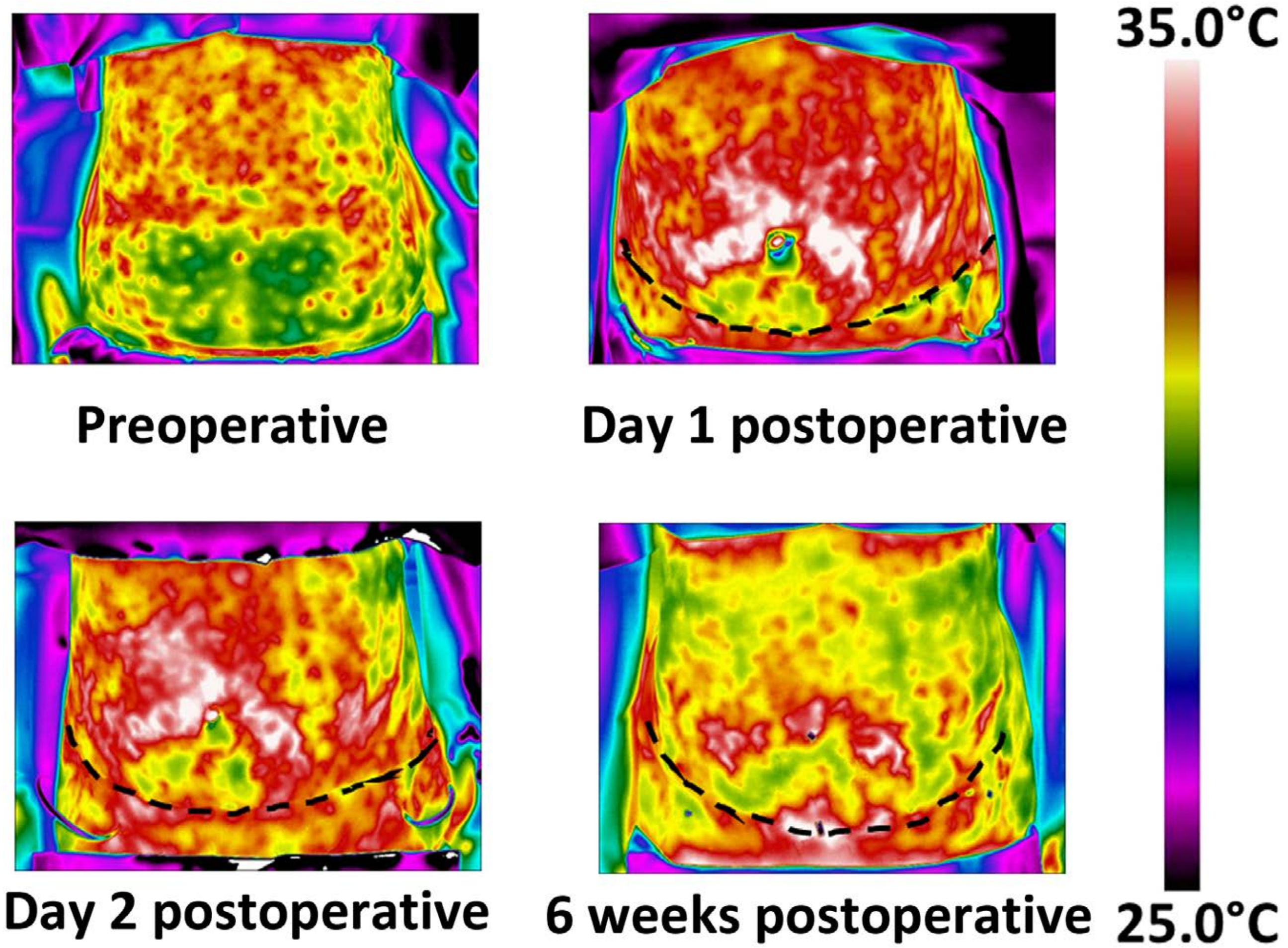

Fig. 3. Thermal images of an abdomen before surgery and on day 1, day 2, and in week 6. The thermal images are taken at the end of a 3-minute rewarming period following a 2-minute period of convective cooling with a desktop fan. This sequence shows clearly the postoperative hyperaemic state and the dynamics in abdominal skin perfusion after a standard abdominoplasty.

anatomical landmarks for the division in Huger's zones remain unchanged, closure in an abdominoplasty results in an inferior-medial advancement of the abdominoplasty flap. In a standard abdominoplasty, zone II is largely resected. The superficial inferior epigastric and superficial circumflex iliac arteries as well as perforators of the deep inferior epigastric arteries are cut and sealed and do not perfuse the remaining part of zone II. Before surgery, zone I relies on the angiosomes of the paired superior epigastric-inferior epigastric systems, for its blood supply. During surgery, zone I is undermined in the midline close to the xiphoid and, as a result, the number of hotspots becomes drastically reduced. The return of hotspots in zones I and II can be explained with the angiosome concept. While some perforators in the cranial part of zone I are still perfused by the superior epigastric artery (SEA) and therewith producing hotspots, the remaining of the angiosomes in zones I and II are no longer perfused by their source vessels. Reperfusion of the abdominoplasty flap must come from perforators of the SEAs near the costal margin and xyphoid, and from source vessels of the adjacent angiosomes—that is, the intercostal, subcostal, and lumbar arteries that normally perfuse zone III.

This situation is comparable to that seen in the delay phenomenon of flaps. Dahr and Taylor reported on the anatomic changes that occur at the level of the reduced-calibre choke vessels between adjacent vascular territories of a pedicled flap.[19] Their study on the delay phenomenon showed an initial vasoconstriction of choke vessels, which lasted for up to 3 hours. Between 3 and 24 hours, the choke vessels returned to a diameter comparable to the control and, thereafter, underwent progressive sequential dilation that was most dramatic between 48 and 72 hours. With the opening of choke vessels, the adjacent angiosomes become reperfused. Other studies support their findings.[20,21] Our results show a reappearance of hotspots in the angiosomes incorporated in Huger's vascular zones I and II during the postoperative period. The existing vascular structures within these angiosomes become reperfused from the adjacent angiosomes. This dynamic process of reperfusion with reappearances of hotspots in adjacent angiosomes was also seen in a DIRT study on the postoperative reperfusion of DIEP and SIEA flaps.[22]

Further support for the reperfusion of zones I and II from the adjacent angiosomes can be found in the

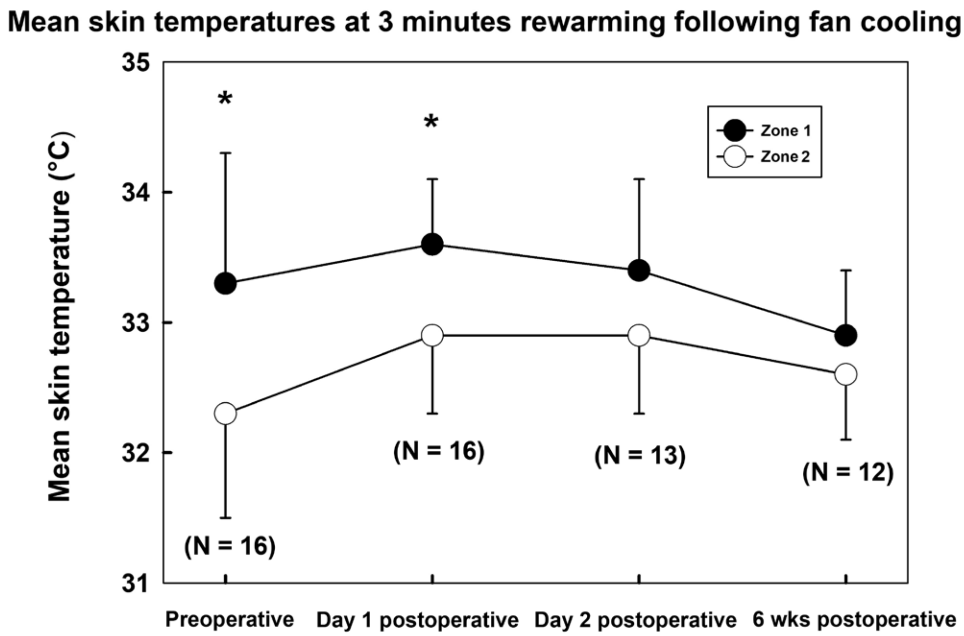

Fig. 4. Mean skin temperatures ± SD at 3 different time points after surgery in zones I and II. Each data point is from the third minute of rewarming following a 2-minute period of convective cooling with a desktop fan.

Table 1. *t*-Test (2-tailed, One Degree of Freedom) Statistical Comparison (*P* ≤ 0.05) of Average Skin Temperature within Zone II versus Zone III during the Third Minute of Recovery following a Cold Challenge Either with Saline Washing or with Fanning

	Washing Protocol	Fanning Protocol
Preoperative	≤0.05 (n = 16)	≤0.05 (n = 16)
Postoperative	≤0.05 (n = 16)	NA
1-day recovery	≤0.05 (n = 16)	≤0.05 (n = 16)
2-day recovery	ns (n = 14)	ns (n = 14)
6-weeks recovery	ns (n = 12)	ns (n = 12)

n, number of patients; NA, not applicable (unable to use desktop fan in operation room); ns, not statistically significant.

Table 2. *t*-Test (2-tailed, One Degree of Freedom) Statistical Comparison (*P* ≤ 0.05) of Average Skin Temperature within Zone I versus Zone II during the Third Minute of Recovery following a Cold Challenge Either with Saline Washing or with Fanning

	Washing Protocol	Fanning Protocol
Preoperative	≤0.05 (n = 16)	≤0.05 (n = 16)
Postoperative	≤0.05 (n = 16)	NA
1-day recovery	≤0.05 (n = 16)	≤0.05 (n = 16)
2-day recovery	≤0.05 (n = 14)	≤0.05 (n = 14)
6-weeks recovery	≤0.05 (n = 12)	ns (n = 12)

n, number of patients; NA, not applicable (unable to use desktop fan in operation room); ns, not statistically significant.

change in direction of the rewarming pattern seen with DIRT. The intercostal, subcostal, and lumbar arteries follow the nerves and their dermatomes which have a nearly transverse course.[18,23] The closure in an abdominoplasty results in skin advancement in an inferior-medial direction. The direction in the postoperative rewarming

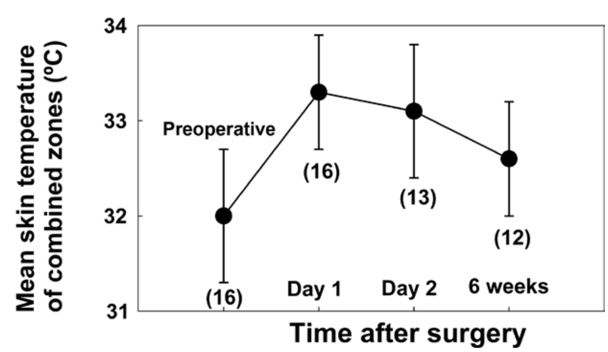

Fig. 5. Mean combined skin temperature of zones I, II, and III before (pre-op) and after surgery—1 day after surgery (Day 1), 2 Days after surgery (Day 2), and 6 weeks after surgery (6 weeks)—with the respective number of patients shown in parentheses. Error bars are SDs. The measurements were made at the end of a 3-min rewarming period following a 2-min period of fan cooling. The postoperative hyperaemia becomes less over time.

pattern changed compared with that in the preoperative DIRT. Postoperatively, rewarming started laterally and proceeded inferiorly and medially.

Another interesting finding is the mean zone temperature in zone I compared with zone III on day 1. Preoperatively, the mean zone temperatures of zone I and III showed no statistically significant difference. But on day 1 and only for type B cold challenge, there is a statistically significant difference between zone I and zone III, with zone I being warmer. One would expect that the undermining of zone I would result in a mean zone temperature of zone I that is lower compared with that of zone III. Before surgery, zone I receives its dominant blood supply from the paired superior and inferior epigastric systems.

These source vessels are connected with each other just above the umbilicus by a watershed zone.[18] These dominant source vessels have a robust blood supply that allows the raising of a pedicled transverse rectus abdominis musculocutaneous flap (TRAM) and a reverse TRAM flap on, respectively, the SEA and deep inferior epigastric artery (DIEA) and comitant veins.[24,25] The pedicled TRAM flap can even be raised on the costomarginal artery in case of a lesion of the SEA, indicating the robust blood supply of this vessel.[26] Undermining in an abdominoplasty proceeds frequently close to the xiphoid, but laterally the undermining is limited to preserve blood supply to the abdominoplasty flap by preserving perforators in the lateral upper part of zone I. The SEA is a continuation of the internal mammary artery (IMA). A study on the impact of unilateral IMA harvest in free abdominal flap breast reconstruction showed that the abdominoplasty flap became significantly less perfused on the side where the IMA is harvested compared with that on the contralateral side.[27] Such observation indicates that the IMA, and therewith the SEA, contribute significantly to abdominal skin perfusion. Smith and Smith spared 1 or 2 perforator vessels from the SEA in a standard abdominoplasty and attributed their low complication rate to better perfusion of the abdominoplasty flap.[28] Postoperatively, all zones showed a hyperaemia during day 1, 2, and at 6 weeks. The hyperaemia has been attributed to the denervation of the flap, which causes a relaxation of sympathetic tone in the vessels wall.[25] The denervation is most pronounced in zone I due to the undermining, and less pronounced in zone III because this zone is hardly undermined. This may be a possible explanation why zone I is warmer on day 1 compared with zone III. The difference is only statistically significant for the stronger type B cold challenge.

Postoperatively, the mean zone temperature of zone I is statistically higher than that of zone II on day 1 and 2 for both types of cold challenges. An anatomic cadaveric study on perforasomes of the upper abdomen revealed that perforators arising from the SEA can perfuse a large skin flap.[29] However, a vertical subcostal superior epigastric artery perforator flap design reaching supraumbilically would include the neighboring deep inferior epigastric artery angiosome.[30] The SEA angiosome and deep inferior epigastric artery angiosome are separated by a watershed zone.[18] This watershed zone with choke vessels may have an impact on the reperfusion of the distal part of the flap and predispose it for impaired perfusion.

In an abdominoplasty, the abdominoplasty flap is stretched and part of zone I becomes the central part of zone II, whereas the lateral part of zone II is built up by zone III. Although the angiosomes in zone III and the remaining perforasomes of the remaining perforators from SEA contribute to perfusion of the new zone II, the long distance may lead to impaired perfusion of the central part of zone II near the lower transverse suture line. Tension along the suture line may further contribute to an increased risk for wound healing problems.

Wound healing problems following abdominoplasty occur usually in zone II at the centre of the lower transverse incision line. Our postoperative results show a statistical difference in mean zone temperature between zone I and II and between zones II and III, with zone II being colder on day 1 for both cold challenges. However, zone I was also significantly warmer than zone II on day 2 and even for the type B cold challenge in week 6. This reduced perfusion in zone II could be a cause of the high rate of wound healing problems in a standard abdominoplasty.[2,3] Mayr et al evaluated skin perfusion during abdominoplasty using indocyanine green fluorescence angiography intraoperatively.[5] Similar to our results, they found a significant impairment in skin perfusion in the new zone II intraoperatively. In our study, skin perfusion was not only monitored intraoperatively but also monitored postoperatively. Our results show a rapid improvement in skin perfusion during the first postoperative day, which could be the reason why wound healing problems after abdominoplasty are often minor and can easily be dealt with at the outpatient clinic. The limitations of our study are the relatively low number of patients. However, all patients were their own control, and statistical significance obtained showed that zone II was temporarily the least perfused zone. Another limitation is that thermography only provides indirect information on skin perfusion, even though studies have shown a good correlation between the results obtained with thermography and laser Doppler flowmetry, between thermography and indocyanine green fluorescence video angiography, and between thermography and isotope perfusion.[12–14]

CONCLUSIONS

This study provides, for the first time, scientific information on postoperative perfusion in abdominal skin after a standard abdominoplasty. DIRT showed in vivo the reperfusion of the abdominoplasty flap over time as a dynamic process with a rapid improvement in skin perfusion during the first postoperative days. The reperfusion is quite like that seen in the delay phenomenon.

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