ORIGINAL ARTICLE

Breast

Microcirculatory Evaluation of the Abdominal Skin in Breast Reconstruction with Deep Inferior Epigastric Artery Perforator Flap

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Background: No studies have assessed the perfusion of the undermined abdominal skin in breast reconstruction with deep inferior epigastric artery perforator flap. A greater understanding of the procedure's impact on the perfusion of the abdominal skin can be valuable in predicting areas susceptible to necrosis.
Methods: Microcirculatory changes were monitored in the abdominal skin of 20 consecutive patients undergoing breast reconstruction with a deep inferior epigastric artery perforator flap. Quantitative mapping was performed with laser Doppler perfusion imaging at 7 set intervals. Measurements were taken and recorded within 4 standardized zones covering the skin between the xiphoid process and the upper incisional boundary of the flap (zones 1–4; cranial to caudal).
Results: Before commencing surgery, a significantly higher perfusion was registered in zones 3 and 4 when compared with zone 1. After undermining the abdominal skin, the perfusion in zones 1–3 increased significantly. After the abdominal closure, the perfusion dropped in all 4 zones and only the perfusion level in zone 1 remained significantly higher than preoperative mean. Postoperatively, the perfusion of each zone stabilized at a significantly higher level compared with preoperative values. No tissue necrosis was observed in any of the zones.
Conclusions: Although perforators are divided during undermining of the abdominal skin, there seems to be a reactive hyperemia that exceeds the blood supply delivered by the perforators. Thus, due to microcirculatory mechanisms, the undermining of the abdomen during the procedure does not seem to present any great risk of tissue necrosis. *(Plast Reconstr Surg Glob Open 2016;4:e616; doi: 10.1097/GOX.0000000000000602; Published online 10 February 2016.)*

The integument can be divided into vascular territories based on the arterial inflow. Each territory has a source artery, which supplies a certain block of skin and underlying structures. These composite units are called angiosomes or perforasomes.[1–3] Such vascular territories are interconnected either by true anastomotic vessels without change in caliber or by connections with reduced caliber called choke anastomotic vessels.[4–6] A substantial work has been conducted to map these units through ink injection, dissection, perforator mapping, and radiographic analysis in fresh cadavers.[7,8]

This knowledge is of major importance in terms of preoperative planning and establishing the surgical approach in perforator flap reconstructions.

At present, the deep inferior epigastric artery perforator (DIEAP) flap is the most commonly used perforator flap in breast reconstruction due to a wide array of advantages. The procedure does, however, have a detrimental impact on the structure and function of the abdominal wall.[9,10]

When harvesting the flap, one leaves behind a sizable abdominal donor defect. To close the defect, the integument cranial to the DIEAP flap has to be extensively undermined and mobilized. This process includes ligation of the perforators in the respective area. Both high tension and the loss of perforator vessels to the skin might reduce the local microcirculation and hereby pose a threat to the wound healing. Previously, it has been shown that comparable high tension when closing the wound can lead to reduced microcirculation[11,12] and poor wound healing.[13]

Most DIEAP surgeons have witnessed varying degrees of circulatory instability in the harvested flap, as well as the donor area throughout the postoperative phase. The purpose of this study was to perform a quantitative perfusion study of the undermined abdominal skin to obtain more knowledge on perfusion dynamics. Laser Doppler perfusion imaging (LDPI) was used to evaluate this.

PATIENTS AND METHODS

Study Design

In a prospective clinical study, microcirculatory changes in the undermined abdominal skin were evaluated applying LDPI in women undergoing breast reconstruction with a DIEAP flap. The study was registered and published in the ClinicalTrials.gov database (ID number: NCT0248184), and the research protocol was approved by the local Ethical Committee (REK Sør; reference no. S-07071a).

Patients

Twenty women consecutively undergoing secondary, unilateral breast reconstruction with a DIEAP flap were identified and recruited to participate in the study. The patients were informed about the risks and benefits and gave written consent before participation. All smokers stopped smoking 4 weeks before surgery. Patient details are listed in Table 1.

Surgery

A standard DIEAP flap procedure as described by Blondeel et al[14] was performed. Surgery was carried out at the donor and recipient area by 2 teams of plastic surgeons simultaneously. Only the largest perfora-

Table 1. Patient Details (N = 20)

Age at examination (yr)	53.5 (6.4)	(43.9–65.7)
BMI (kg/m²)	25.0 (2.8)	(21.6–30.9)
Coexisting conditions, n (%)		
None		15 (75)
Hypertension		1 (5)
Asthma		2 (10)
Other		2 (10)
Smoking, n (%)		3 (15)
Adjuvant therapy, n (%)		
Chemotherapy		8 (40)
Radiotherapy		9 (45)
Axillary node dissections, n (%)		9 (45)
Time between mastectomy and reconstruction (yr)	2.8 (2.3)	(0.5–11.8)

Data are described as means (SD) (min–max) or number of patients (%). BMI indicates body mass index; SD, standard deviation.

tors on one side were dissected from the level of the anterior rectus fascia to the entrance of the inferior epigastric vessels. The circulatory capacity of the largest perforators was tested by clamping remaining perforators for 15 minutes. If the chosen perforator(s) seemed to be satisfactory, transection of perforators was done, and the flap was transferred to the recipient area. Microanastomosis was performed end-to-end to the inframammary vessels in all cases.

Concurrent to the flap inseting, the donor defect was closed by the other team of surgeons. The undermining of the abdominal skin was performed to the level of xiphoid and along the costal margin. No infiltration was used, and no liposuction was done in the donor flap. Nor were any progressive tension sutures used to promote the adherence between the donor flap and the abdominal wall; however, the operating bed was jack-knifed to prevent tension.

The patients were returned to horizontal position before scans. Additionally, all postoperative measurements were completed in a horizontal position. Heating blankets were used intraoperatively to cover the lower extremities.

LDPI Measurements

LDPI is an extension of laser Doppler flowmetry and was developed to generate a color-coded perfusion image in a large area of skin.[15,16] LDPI has been increasingly used in skin research and the assessment of cutaneous microcirculation.[17] In plastic surgery, it has been used to evaluate the depth and healing of burn wounds,[18,19] and it has been proven to be an applicable, clinical tool in assessing and monitoring pressure sores, free flaps, and perforator flaps.[20–24]

An LDPI machine (PIM 3, Perimed AB, Järfälla, Sweden) was used to monitor the microcirculatory changes in the abdominal skin. The technique works by the emission of a laser beam, which is then scattered and partly absorbed by the tissue. Light hitting the moving blood cells undergoes a Doppler shift

(while light hitting static objects is unchanged). The magnitude of the frequency shift reflects the number and velocity of the blood cells in the area being studied, resulting in a quantitative measurement of cutaneous perfusion. The depth of the scans is 0.5–1 mm, depending on the tissue properties.[25]

Simultaneously, as the machine detects the reflected light, an internal mirror sequentially moves the laser beam stepwise between measurement points (perfusion sites). Detected light from different perfusion sites is then processed to create a color map of the scanned zones. In addition, a digital camera records a clinical photograph, which corresponds closely with the blood perfusion image.

In our clinical setup, 7 scans were performed: (1) preoperative; (2) after raising the flap; (3) after undermining; (4) after abdominal closure; (5) postoperative day 1 (POD1); (6) postoperative day 3 (POD3); and (7) postoperative day 7 (POD7).

The distance from the laser head to the skin was set at 35 cm, and the resolution was placed at a low range. All scans were performed perpendicular to the skin, under constant light, and temperature conditions (Fig. 1). The undermined abdominal skin was left undisturbed at least 10 minutes before each scan.

The perfusion was calculated using the software LDPI win 3.1.

Perfusion Zones

Four zones (zones 1–4; cranial to caudal) were used to evaluate the perfusion of the donor flap. The zones were standardized using 4 reference lines; A, a vertical line from the xiphoid process to the caudal boundary of the undermined skin; B, a horizontal line dividing A in 2 halves; C, a vertical line through the intersection of line B and the costal margin; D, a horizontal line parallel to the caudal boundary of the undermined skin (Fig. 2).

The zones were composed of 1 triangle (zone 1) and 3 rectangles (zones 2–4). The triangle had typically fewer perfusion sites compared with the remaining zones, with the smallest zone of 61 perfusion sites. All 4 zones were situated around the abdominal midline and did not include the outermost areas of the undermined skin—covering "zone 1" of the 3 vascular territories of the abdomen described by Huger.[26] This was done knowingly to only get measurements where the laser beam intersected the skin surface perpendicularly.

The zones described were not marked directly on the patient before commencing surgery. Alternatively, the perfusion zones were defined and demarked on the digital, clinical photograph using the software, which includes the necessary geometrical tools. The clinical photograph (intensity) when viewed in the software was directly correlated to the perfusion color map (perfusion), and the zones were automatically superimposed upon the latter (Fig. 2).

Statistical Analysis

Descriptive statistics are presented using means (SD) and number of patients (percentage) if not otherwise stated. Because of repeated and clustered measurements, we used linear mixed models with a random intercept. Separate statistical models for each of the 4 zones were conducted, and the 7 observation times (ie, preoperative to postoperative day 7) were assessed as a fixed factor. In addition, separate statistical models for each of the 7 observation times were conducted, and the 4 zones were then assessed as a fixed factor. All pair wise comparison in the statistical models was done with the Bonferroni correction. We accepted P values of less than 0.05 as statistical significance. IBM SPSS Statistics 21 (IBM, Armonk, NY) was used for statistical analysis.

RESULTS

No tissue necrosis, seromas, or hematomas were observed at the donor site following the abdominal closure.

Statistical data comparing the abdominal perfusion zones are listed in Table 2 and depicted in Figure 3. The results are reported briefly according to the time of measurement in the following text:
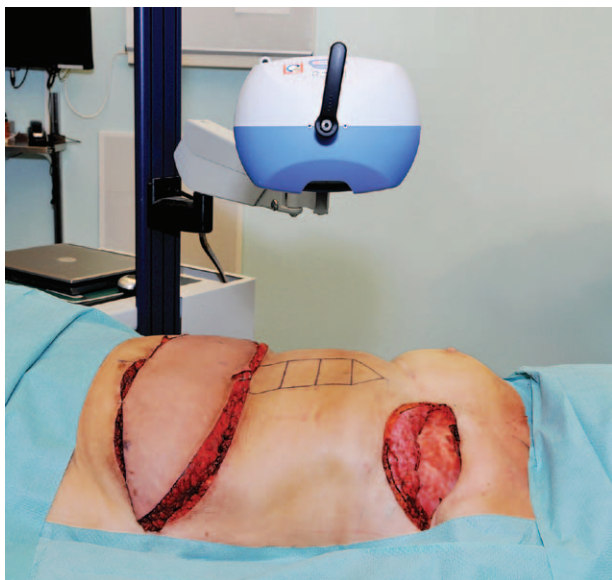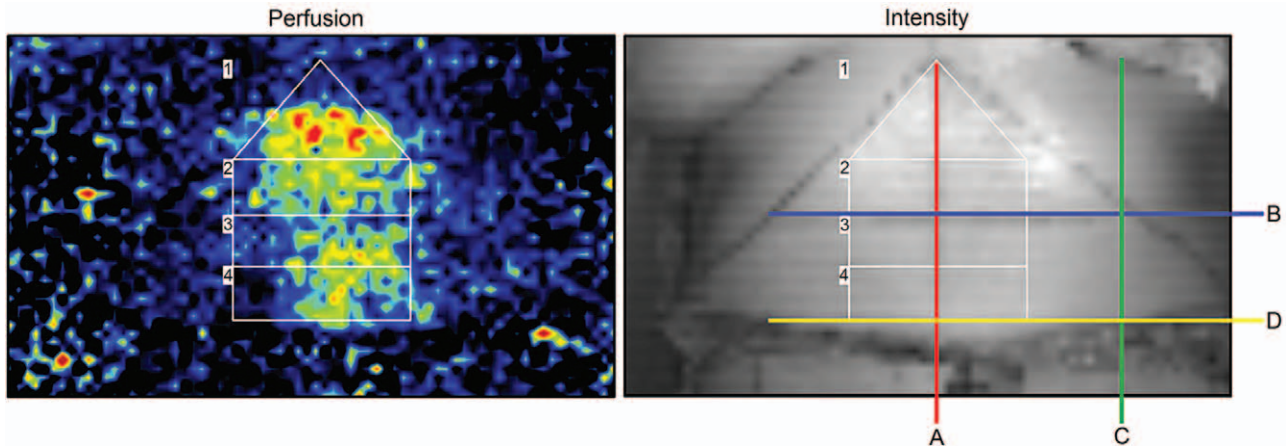

Fig. 1. Photograph taken intraoperatively after raising the flap that illustrates the clinical setup with the LDPI machine situated 35 cm above the abdomen. The 4 standardized zones are marked directly on the patient.

Fig. 2. "Intensity" showing the 4 standardized zones and reference lines marked on a grayscale version of the clinical photograph seen in the software used. Zones 1–4 made by the geometrical tools offered. "Perfusion" showing the 4 zones being automatically superimposed upon the color-coded LDPI perfusion map in the software.

Table 2. Microcirculatory Evaluation with Laser Doppler Perfusion Imaging of the Abdominal Zones 1–4 Shown in Mean Perfusion Units

		Preoperative	After Raising the Flap	After Undermining	After Abdominal Closure	POD1	POD3	POD7
Zone 1	Mean (SD)	37.2 (9.1)	46.8 (11.1)	88.7 (28.1)	52.5 (10.8)	70.2 (26.4)	58.9 (16.6)	61.2 (17.8)
	P value*	1	1	<0.01	0.04	<0.01	<0.01	<0.01
Zone 2	Mean (SD)	40.5 (11.1)	51.4 (12.8)	71.2 (20.6)	49.6 (12.3)	68.0 (15.1)	60.1 (18.1)	62.5 (16.9)
	P value†	0.34	0.13	<0.01	1.0	1.0	1.0	1.0
	P value*		0.09	<0.01	0.33	<0.01	<0.01	<0.01
Zone 3	Mean (SD)	42.1 (12.2)	51.9 (11.8)	59.0 (17.3)	45.3 (18.3)	66.7 (22.2)	64.8 (20.9)	69.4 (17.2)
	P value†	0.03	0.06	<0.01	0.26	1.0	0.99	0.22
	P value*		0.70	<0.01	1.0	<0.01	<0.01	<0.01
Zone 4	Mean (SD)	42.3 (10.2)	48.6 (9.9)	47.1 (15.7)	37.8 (12.3)	55.2 (17.5)	58.9 (15.4)	66.3 (14.0)
	P value†	0.03	1.0	<0.01	<0.01	<0.01	1.0	1.0
	P value*		1.0	1.0	1.0	0.01	<0.01	<0.01

Bold numbers qualify as significant. All P values are adjusted correspondingly to Bonferroni correction for pair wise comparisons. SD indicates standard deviation.
*P values comparing preoperative perfusion levels for each zone with perfusion levels at times indicated above.
†P values comparing perfusion levels of zone 1 with perfusion levels of zones 2–4.

1. Preoperative: Mean perfusion increased successively from zone 1 to zone 4. Zones 3 and 4 had significantly higher perfusion compared with zone 1.
2. After raising the flap: All zones had an increase of mean perfusion compared with preoperative mean, but none of these were significant. Zone 1 had insignificant perfusion compared with remaining zones.
3. After undermining: Zones 1–3 had a significant increase of mean perfusion compared with preoperative values (Fig. 4). Zone 4 had a decrease of perfusion compared with previous measurement, but the perfusion remained insignificant compared with the preoperative mean. Zone 1 had significantly higher perfusion compared with remaining zones.
4. After abdominal closure: All zones had a decrease of perfusion compared with previous measurement. Only zone 1 remained with a significantly higher perfusion compared with preoperative mean. Mean perfusion in zone 4 was significantly lower than zone 1.
5. POD1: All zones had an increase of perfusion compared with previous measurement, and all perfusion means were significantly higher compared with their preoperative mean. Only mean perfusion in zone 4 was significantly lower than zone 1.
6. POD3: Zones 1–3 had a decrease of perfusion compared with previous measurements, but the means were still significantly higher compared with their preoperative mean. Zone 4 had an increase of perfusion and remained significantly higher compared with preoperative mean. Zone 1 had insignificant perfusion mean compared with remaining zones.
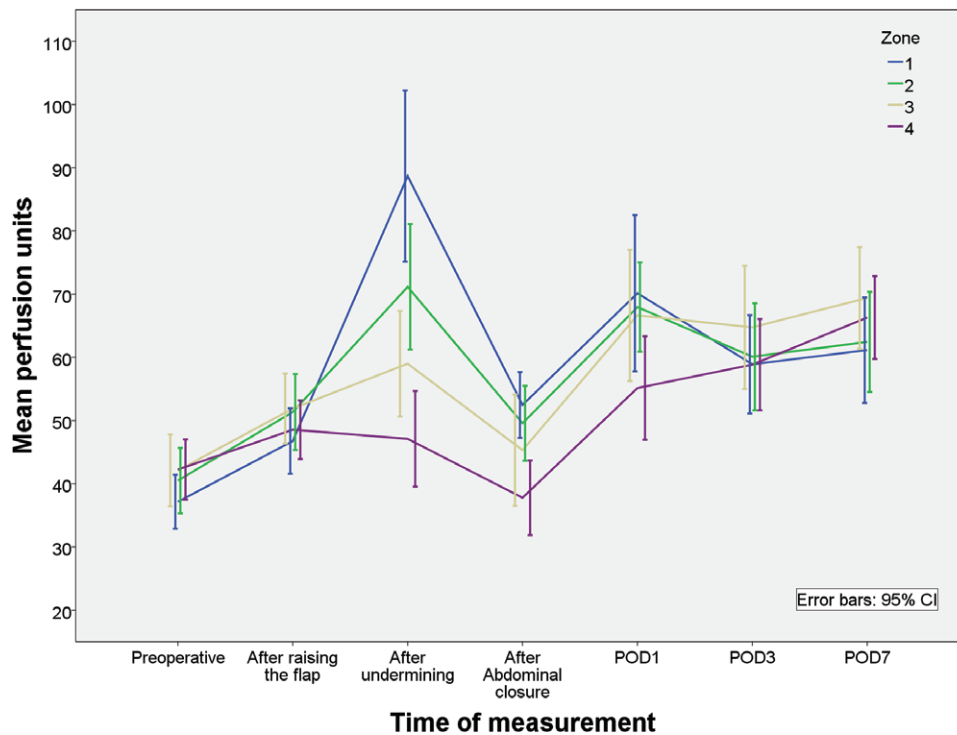
Fig. 3. Graph illustrating mean perfusion units for each zone at times indicated above. POD indicates postoperative day.
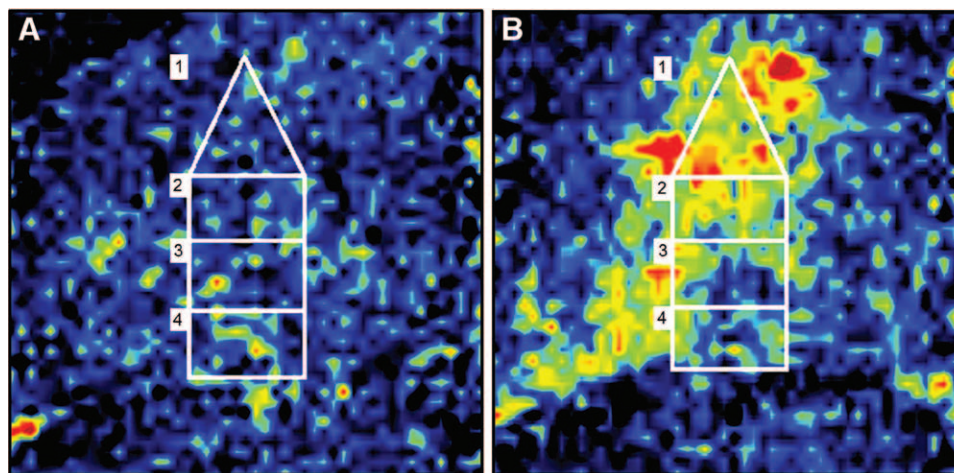

Fig. 4. Intraoperative perfusion maps with zones 1–4: after rising of the DIEAP flap (A) and after undermining of the abdominal skin (B).

7. POD7: All zones had an increase of perfusion compared with previous measurement, and all perfusion means were significantly higher compared with preoperative mean. Zone 1 had insignificant perfusion mean compared with remaining zones.

The highest individual perfusion mean was found after undermining in zones 1 and 2, and POD7 in zones 3 and 4. The lowest individual perfusion mean was found preoperatively for zones 1–3 and after abdominal closure for zone 4.

Zone 1 had both the highest (after undermining) and the lowest (preoperative) perfusion means of all measurements performed.

In terms of the standardized zones described above, the postsurgical location of umbilicus varied between patients. Seven of 20 (35%) patients was located in zone 3, 1 of 20 (5%) in zone 4 and 12 of 20 (60%) partly in both zones 3 and 4. The umbilicus had a higher number of perfusion units than the surrounding skin. Although the umbilicus had an impact on the zone's mean, we chose to not exclude

the umbilicus from the zonal perfusion mean (see Discussion section).

DISCUSSION

There is no prior research that addresses skin perfusion in the donor site in DIEAP flap breast reconstruction. The purpose of the study was to gain information on perfusion dynamics in the undermined abdominal skin by assessing the microvascular impact of the procedure.

It was observed that the postsurgical location of the umbilicus varied. The umbilicus had clearly a greater perfusion compared with adjacent areas. It was, nevertheless, included in the zones' mean perfusion. It was included based on 2 observations: (1) the umbilicus on the perfusion map was very irregular in terms of shape and perfusion level and had rarely a defined, outer border and (2) the perfusion maps often showed spots of higher perfusion surrounding the umbilicus. These observations made it, first of all, difficult to define, which perfusion areas that were related to the umbilicus and, thereby, should have been excluded. Second, it appeared in the postoperative phase as the umbilicus was improving the local perfusion, having spots of higher perfusion randomly spread in the most adjacent areas of the undermined abdominal skin. Thus, the umbilicus might be a factor kick-starting the local reperfusion and angiogenesis. Further investigations are needed to clarify the umbilicus' role in the undermined tissue.

Notably, our study uncovered several significant differences comparing the perfusion zones that were outlined in the clinical setup:

Significantly higher perfusion means were registered in zones 3 and 4 compared with zone 1 even before commencing surgery. Consistent with previous studies, this observation can be explained by the high occurrence of periumbilical perforators in these most caudal zones.[27,28]

After the undermining, we expected the perfusion to drop—especially in the zones being furthest away from underlying perforators (zones 3 and 4). These zones are to a greater extent provided by the subdermal plexus alone compared with more cranial zones. Although this seems logical, we did instead observe a significant increase of perfusion in zones 1–3 and only a minimal reduction in zone 4 after undermining (Fig. 4). The latter reduction was, moreover, insignificant compared with preoperative mean. In fact, the perfusion in none of the 4 zones dropped below the preoperative mean after the undermining.

An increase of perfusion in zones 1–3 could be explained by a reactive hyperemia—being more pronounced cranially in the donor flap; zone 1 had

significantly higher mean perfusion than zones 2–4 (Table 2).

The perfusion dropped rather dramatically in all zones after the abdominal closure. A comparable perfusion drop is described by Mayr et al[29] in their quantitative evaluation of perfusion changes in the abdominal wall after suturing of the abdominal flap during abdominoplasty. The observations are, additionally, in accordance with Barnhill et al,[11] who have previously shown that wound tension has a negative effect on the superficial dermal microvasculature and leads to reduced microcirculation.

Postoperatively, there was generally an increase and overall stabilization of perfusion in zones 1–4. Throughout the postoperative phase, all zones had a significantly higher perfusion compared with preoperative status. These consistently high postoperative perfusion measurements indicate a postoperative regeneration of vascular networks. Ribuffo et al[30] have evaluated this vascular buildup by the use of duplex scanning, verifying the growth of new vessels in the abdominal wall after radical abdominoplasty in 10 patients. The authors of the study describe that the initial reperfusion of the abdominal wall occurs mainly from regrowth of the intercostal vessels—most likely causing the significantly higher perfusion measurements in our postoperative data.

Our data illustrate that the perfusion of the donor flap gets increasingly better the more cranially you go from the harvested flap after the undermining. This stepwise decrease of perfusion in a cranial to caudal fashion lasts until the first postoperative day. The area just above the cranial incision of the donor defect (zone 4) is the most vulnerable in terms of low perfusion, especially after closure of the abdominal defect and the extra tension caused. Although several zonal differences like this were observed, it seems, however, like they do not have a clinical impact.

In summary, the material provides a greater understanding of the surgical impact of DIEAP flap reconstruction on abdominal skin perfusion. Our study did not find any contraindications of undermining larger areas of skin to achieve successful, surgical closure.

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