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Laser Speckle Flowgraphy Can Support Intraoperative Assessment of Deep Inferior Epigastric Perforator Flap Blood Flow With Indocyanine Green

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Background: Accurately evaluating cutaneous blood flow during the elevation of a deep inferior epigastric perforator (DIEP) flap may reduce postoperative complications in breast reconstruction surgery. This study examined whether laser speckle flowgraphy (LSFG) could be used to help objectively identify the safe areas of DIEP flaps.

Methods: Forty-eight patients who underwent unilateral breast reconstruction with a DIEP flap at Shinshu University Hospital between 2020 and 2024 were prospectively studied. During flap elevation, skin blood flow throughout the flap was measured using LSFG and compared with results obtained by indocyanine green (ICG) angiography. The cohort was also divided according to the number and location of perforators, and an intergroup comparison was performed according to LSFG readings.

Results: In all subjects, relative LSFG blood flow in zones 2 (89.1%) and 3 (87.9%) was comparable, whereas blood flow in zone 4 (72.8%) was significantly lower than in those areas (both $P < 0.001$). In the lateral row group, blood flow in zone 2 tended to be lower and in zone 3 tended to be higher than in the medial row group (zone 2: 82.6% versus 89.5%, zone 3: 93.6% versus 86.8%). LSFG values did not differ significantly in relation to perforator number. LSFG-determined blood flow in the stained side of the ICG-determined staining border was significantly higher than in the nonstained side (80.6% versus 71.4%, $P < 0.001$).

Conclusions: LSFG enables objective, noninvasive evaluation of safety margins in DIEP flaps that may support ICG angiography. Safe zones may vary depending on the location of the selected perforator. *(Plast Reconstr Surg Glob Open 2025;13:e6627; doi: 10.1097/GOX.0000000000006627; Published online 20 March 2025.)*

INTRODUCTION

The deep inferior epigastric perforator (DIEP) flap is a popular and widespread technique in autologous breast reconstruction.[1,2] However, DIEP flaps carry a risk of postoperative complications in the form of partial necrosis and fat necrosis.[2,3] Aberrant flap blood flow is involved in both of these adverse events.

Various blood flow monitoring methods have been reported for the DIEP flap.[4–9] For instance, the use of intraoperative indocyanine green (ICG) angiography can help reduce postoperative fat necrosis.[8,9] Although ICG is a simple, low-cost, and safe means of estimating skin blood flow, issues arise in the timing of measurements after contrast agent injection and how to evaluate brightness.

A more objective and easier method than ICG angiography for evaluating DIEP flaps intraoperatively has not yet been established. We recently reported on the quantitative determination of skin blood flow in the ischemic lower leg in humans and abdominal flaps in rats using laser speckle flowgraphy (LSFG).[10–12] LSFG is designed to irradiate near-infrared light on an object and count the amount of light reflected back. This amount is dependent on the velocity of erythrocyte movement, which correlates with blood flow.[13] As far as we know, no studies have addressed skin blood flow in perforator flaps with LSFG.

This investigation evaluated intraoperative blood flow in DIEP flaps using LSFG and compared those findings with ICG angiography. We sought to objectively quantify blood flow in DIEP flaps using LSFG to estimate the areas of adequate perfusion.

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MATERIALS AND METHODS

A prospective observational study to evaluate skin blood flow in DIEP flaps for breast reconstruction was performed at a single center from January 2020 to May 2024. The inclusion criteria included unilateral breast cancer, at least 1 perforator confirmed by preoperative contrast-enhanced computed tomography, and the selection of breast reconstruction with a DIEP flap. The exclusion criteria included bilateral breast cancer, prophylactic resection, and patient refusal to participate in the study. A total of 52 consecutive patients who underwent breast reconstruction with a DIEP flap after total mastectomy for breast cancer were potentially eligible for the study. Although both ICG and LSFG were performed during each surgery, we ultimately deferred to ICG for clinical decision-making, with LSFG analysis afterward.

First, the demographic data, number and location of perforators, and postoperative outcomes and complications were recorded. Next, the skin blood flow of the DIEP flap connected to the supplying vessels was evaluated using LSFG. Based on perforator location, regions of interest (ROIs) were set as zones 1–4 (Fig. 1A). The blood flow values of zones 2–4 were calculated as ratios based on zone 1. The measurements of each zone were further analyzed by dividing the groups into medial row, lateral row, and both row branches of the deep inferior epigastric artery as well as into groups with 1 and 2+ perforators. Third, the stained area by ICG was marked at 2 minutes after intravenous injection of 2 mL ICG. Two additional ROIs were set on the stained side furthest from the perforator and distally adjacent to it (Fig. 1B, C). The ratio of blood flow of those ROIs were calculated based on the LSFG reading of zone 1. Surgically, the flap area stained with ICG was used as the transplant tissue, with the area with poor ICG staining excised.

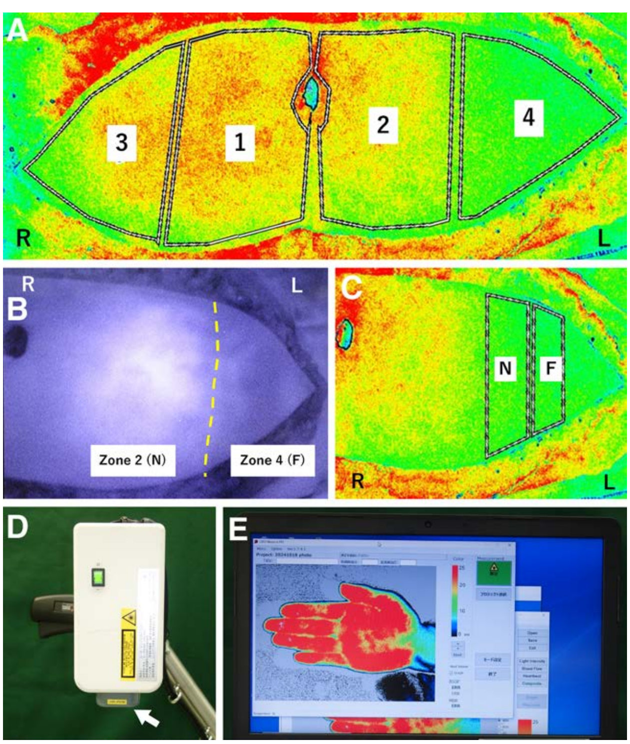

Fig. 1. DIEP flap under 2-dimensional mapping by LSFG and ICG angiography. A, DIEP flap including a medial row perforator on the right side. The flap was divided into 4 zones. B, Left half of the DIEP flap. Zone 2 was enhanced by ICG, whereas most of zone 4 was not. The yellow dotted line indicates the ICG staining border. C, A staining border in LSFG was set based on ICG angiography. ROIs were determined on the near and far sides of the perforator, with the staining border between them. D, LSFG irradiates near-infrared light to the object and captures the reflected light. Arrow indicates the irradiation and capture port. E, A laptop computer shows the LSFG measurement results as a pseudocolor image. 1–4, zones 1–4; F, far side; L, left side; N, near side; R, right side.

Takeaways

Question: Can laser speckle flowgraphy (LSFG) help objectively identify the safe area of deep inferior epigastric perforator (DIEP) flaps?

Findings: We assessed DIEP skin flap blood flow readings obtained by LSFG. Skin blood flow in zones 2, 3, and 4 was 89%, 88%, and 73%, respectively, compared with zone 1. We observed an approximately 9% LSFG difference across the safety border determined by indocyanine green angiography.

Meaning: LSFG results in DIEP flaps support indocyanine green angiography, with LSFG providing noninvasive, objective numerical evaluation.

Due to the anonymous nature of the data, the requirement for informed consent was waived, and an opt-out document was posted on the hospital website. The study protocol was approved by the institutional review board of Shinshu University Medical School Hospital (no. 6016).

Data are presented as the mean (interquartile range) and compared using paired *t* tests and the Bonferroni test. Statistical significance was set at a *P* value of less than 0.05. All statistical analyses were performed using IBM SPSS version 23.0 software (IBM Corp., NY).

LSFG Device

LSFG (Fig. 1D) irradiates the skin with a near-infrared laser (830 nm wavelength) from a distance of 24 cm, and a charge-coupled device camera captures the reflected light.[14] LSFG is a noncontact device that measures the relative moving speed of erythrocytes 1–2 mm under the skin.[15] The results are displayed on a monitor in pseudocolor (Fig. 1E), with warm colors for high skin blood flow areas and cool colors for low skin blood flow areas, expressed as a 2-dimensional map (Fig. 1A). The details of LSFG are described in our previous article.[12]

ICG Fluorescence

In this study, 2.5 mg/mL of ICG solution (Diagnogreen 25 mg, Daiichi Sankyo Co., Ltd, Japan) was injected into the peripheral vein. ICG fluorescence was observed using a photodynamic eye camera (PDE camera, Hamamatsu Photonics K. K., Japan).

Table 1. Patient Characteristics

n	48
Age, y (mean)	50.8 ± 6.6 (36–69)
BMI, kg/m² (mean)	23.1 ± 3.4 (17.2–34.2)
Ventromedial operation scar	6/48 (12.5%)
Hypertension	3/48 (6.3%)
Hyperlipidemia	4/48 (8.3%)
Smoking habit: present	2/48 (4.2%)
Past	13/48 (27%)
Reconstruction side (right)	22/48 (46%)
Perforator in the DIEP flap	
Location (right)	25/48 (52%)
Number: 1	18/48 (37.5%)
2+	30/48 (62.5%)
Medial row	35/48 (73%)
Lateral row	7/48 (14.5%)
Both rows	6/48 (12.5%)

BMI, body mass index.

Table 2. Postoperative Complications

Total flap necrosis	0/48
Partial flap necrosis	2/48 (4.2%)
Fat necrosis	3/48 (6.3%)
Dehiscence	2/48 (4.2%)
Reoperation	4/48 (8.3%)
Seroma in donor site	8/48 (16.7%)

RESULTS

After application of the exclusion criteria, 48 patients were analyzed in this study. The background characteristics of the patients and perforator details of DIEP flaps are presented in Table 1. The mean age was 50.8 (range, 36–69) years, and mean body mass index was 23.1 (range, 17.2–34.2) kg/m². A surgical scar was present in the midline of the abdomen in 6 (12.5%) cases. Regarding the number of perforators in the DIEP flap, 18 (37.5%) cases included 1 and 30 (62.5%) cases contained 2+ perforators. Concerning the branch of the deep inferior epigastric artery in the DIEP flap, 35 (73%) cases included the medial row, 7 (14.5%) cases included the lateral row, and 6 (12.5%) cases included both rows.

The postoperative complications are summarized in Table 2. There were no cases of total flap necrosis. We observed partial flap necrosis in 2 (4.2%) cases and fat necrosis in 3 (6.3%) cases. Reoperation was needed in 4 (8.3%) cases due to a hematoma in the donor site (1 case), partial flap necrosis (1 case), and dehiscence in the donor site (2 cases). Seroma in the donor site required aspiration in 8 (16.7%) cases.

With regard to LSFG readings, blood flow in zone 4 (72.8% ± 11.6%) was significantly lower than in zone 2 (89.1% ± 10.5%) and zone 3 (87.9% ± 9.9%) (both $P < 0.001$) (Fig. 2), with no remarkable difference between zones 2 and 3 ($P = 1.00$). LSFG readings in the medial row group were 89.5%, 86.8%, 73.3% in zones 2–4, respectively (Fig. 3A). These values were 82.6%, 93.6%, and 68.6% in the lateral row group (Fig. 3B) and 94.2%, 87.4%, and 75.2% in the both rows group. Thus, blood flow tended to be higher in zone 2 but lower in zone 3 in the medial group versus the lateral group. LSFG results in zones 2, 3, and 4 were 90.0%, 86.3%, and 73.9% in the 1 perforator group and 89.4%, 87.3%, and 71.4% in the 2+ perforator group, respectively, with no significant differences for any zone (nonpaired t test; zone 2: $P = 0.423$, zone 3: $P = 0.303$, zone 4: $P = 0.237$).

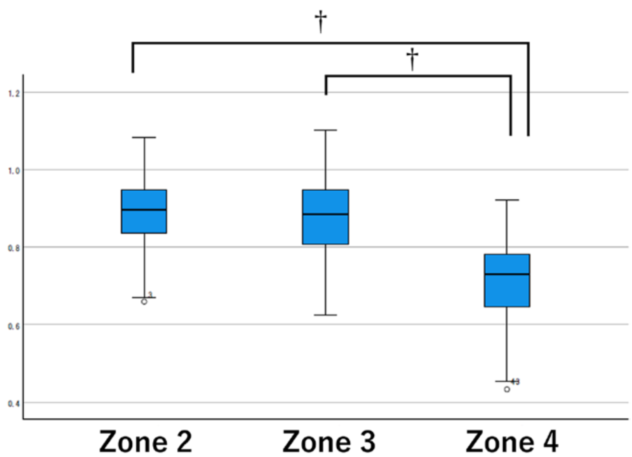

Fig. 2. LSFG readings for each Zone. No significant difference was seen between zone 2 (89.1% ± 10.5%) and zone 3 (87.9% ± 9.9%). Blood flow in zone 4 (72.8% ± 11.6%) was significantly lower than in zones 2 and 3 (both †$P < 0.001$).

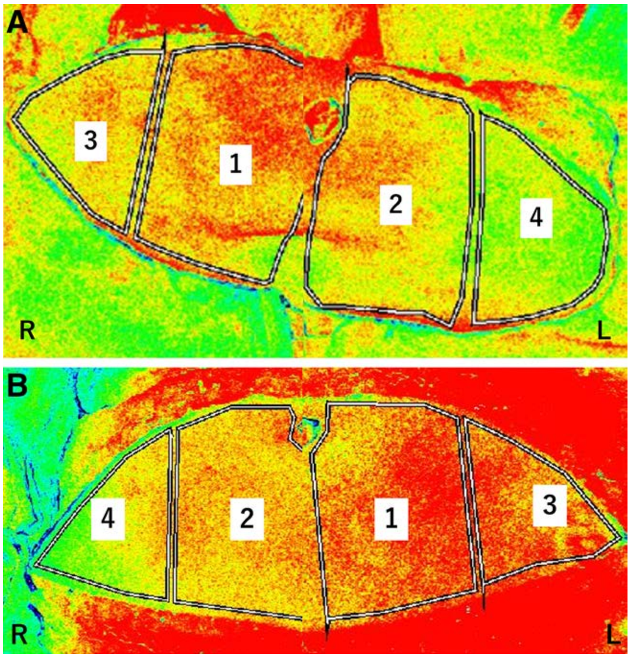

Fig. 3. DIEP flap under 2-dimensional mapping by LSFG. A, Medial row perforator group. The medial row perforator was located on the right side. Warm colors were displayed over a wide range in zones 1, 2, and 3. Cool colors were displayed in zone 4. B, Lateral row perforator group. Zone 3 displayed a larger range of warm colors compared with zone 2. 1–4, zones 1–4; L, left side; R, right side.

Next, the stained area of the DIEP flap was marked at 2 minutes after intravenous ICG injection (Fig. 4A, B). The staining border was set in LSFG zone 2 in 16 cases, in zone 3 in 6 cases, and in zone 4 in 32 cases. Using this border

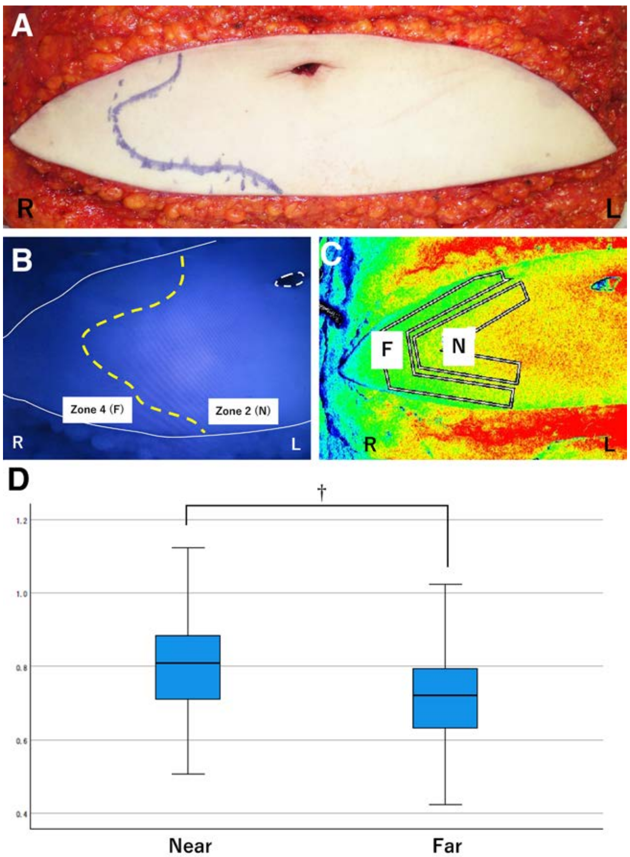

Fig. 4. Comparisons between LSFG and ICG angiography. A, The patient's DIEP flap included a medial row perforator on the left side. A blue line was marked according to ICG angiography at 2 minutes after the injection of ICG. B, Right half of the DIEP flap. Most of zone 2 was enhanced by ICG, whereas most of zone 4 was not. The white line indicates the skin edge of the DIEP flap. The white dotted circle indicates the umbilicus. The yellow dotted line indicates the ICG staining border. C, Measurement results by LSFG displayed in 2-dimensional mapping. ROIs were set on the near and far sides of the perforator location using a staining line based on ICG angiography. D, LSFG results of the near and far sides of the perforator based on ICG staining. Blood flow in the far side was significantly lower than in the near side (71.4% ± 12.0% vs 80.6 ± 12.0%, †$P < 0.001$). F, far side; L, left side; N, near side; R, right side.

line, the ROIs were set on the near and far sides of the perforator (Fig. 4C). LSFG readings in the far side were significantly lower than in the near side (71.4% ± 12.0% versus 80.6% ± 12.0%, $P < 0.001$) (Fig. 4D).

DISCUSSION

This study investigated intraoperative skin blood flow in DIEP flaps objectively and noninvasively using LSFG in relation to ICG angiography. According to LSFG readings, zones 2 and 3 demonstrated approximately 90% of the skin blood flow of zone 1, with zone 4 exhibiting approximately 70% of zone 1 skin blood flow. On the basis of ICG determination of a safety border, LSFG values on the stained side were 9% and significantly higher than on the nonstained side, which demonstrated good agreement.

It has been reported that zones 1, 2, and half of 3 of a DIEP flap can be used safely when using a single perforator in the medial row.[16] However, this may vary when the surgeon uses a lateral row perforator or if the patient has surgical scars on the abdomen. In this study, zones 2 and 3 of the DIEP flap demonstrated LSFG readings approaching those of zone 1. The medial row group tended to have lower blood flow in zone 3 compared with the lateral row group. Although no significant difference in blood flow was observed in relation to the number of perforators, multiple perforators are considered desirable to reduce the risk of postoperative complications.[17] As flap loss might occur as a result of poor blood flow,[18] obtaining objective numeric blood flow values in each zone could be useful to determine which ones should be used as transplanted tissue or resected.

ICG angiography is a simple and widespread method to determine the safety area of the DIEP flap for each patient.[19] The intraoperative use of ICG can reduce postoperative fat necrosis,[8,9] but there remains no standardized method of assessment.[19] ICG angiography has the disadvantages of a low true-positive rate for detecting flap compromise[20] and unsuitability in patients with a contrast agent allergy or liver disease.[21] LSFG has the potential to avoid such problems and may be considered in cases of allergy, liver disease, and renal failure. Moreover, LSFG circumvents the subjective nature of ICG angiography by being expressed as objective values.

We earlier reported that skin flaps in rats showing LSFG blood flow of 80% or less would become necrotic.[12] In the present study, zones 2 and 3 were well above this threshold, indicating that those areas would be safe. However, ICG stained weakly in the lateral areas of zone 2 or 3 in some cases. As there were individual differences in the location and course of the selected perforator within the DIEP flap, some areas in these zones might not have been stained with ICG. Further subdivision of existing zones may help clarify LSFG readings. Nevertheless, the ICG-stained side displayed a mean 80.6% blood supply, whereas just distal to the staining line showed a mean 71.4% blood supply. In this study, we resected the part of the DIEP flap that was not stained by ICG angiography at 2 minutes after injection. This resected area tended to correspond to LSFG readings of 80% or less. Postoperative fat necrosis frequency was comparable to that of a previous report using ICG (our study: 6.3% versus Hembd et al.[9]: 8.5%), which suggested that LSFG readings could indicate adequate perfusion areas accurately and provide supportive numerical values for the simple and sensitive ICG angiography method.

LSFG has the advantage that it can be used repeatedly in a short time while being noninvasive and objective. The 2-dimensional mapping by LSFG is also helpful when determining ROIs because it is easy to distinguish the border between warm and cool colors for judging the safe area of a DIEP flap. Moreover, the device operation method is simple by setting the distance between the camera and the object and pushing a button on a laptop computer. On the other hand, the disadvantages of LSFG include the results being presented as relative values that cannot be directly compared with other objects. Physiological movements, such as respiratory fluctuations, tremor at rest, and spasms, may also affect results. Furthermore, readings may change when the distance between the camera and object is not constant due to the object's shape. Future validation of LSFG to intraoperatively estimate flap blood flow will enable even trainees and nurses with little experience in skin flap surgery to make better judgments.

LIMITATIONS

The number of subjects in this study was small. Because we focused on Asian DIEP flaps, it is uncertain whether similar results can be obtained with other skin tones or flaps. In this investigation, areas stained by ICG at 2 minutes after injection were selected for clinical decision-making. Although these regions exhibited blood flow of 80% or less on LSFG as in our preliminary animal experiments,[12] further research is needed to determine the correlation of blood flow and surgical outcomes. Finally, the measurements were taken of the skin, not the fat area, and no clear cutoff was identified. To determine safety cutoffs, it will be necessary to clarify the range of tissue actually transplanted and compare the results of LSFG and postoperative complications.

CONCLUSIONS

LSFG enables objective, noninvasive evaluation of safety margins in DIEP flaps that may help quantify the results of ICG angiography. Further studies are warranted on the precise cutoff values of LSFG readings towards predicting safe areas of DIEP flaps in breast reconstruction surgery.

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DISCLOSURES

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