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ARTICLE

The influence of venous system patterns on DIEP flap viability for breast reconstruction

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ABSTRACT

A deep inferior epigastric artery perforator (DIEP) flap has unique variations in the anatomy of the vascular supply, and this idea has been adapted to the venous system. Venous system patterns, including connections between the superficial and deep inferior epigastric vein (SDC) or connections of the superficial inferior epigastric vein across the midline-crossing linking veins (MCLV), have gradually become recognized as a cause of fat necrosis and induration due to venous congestion. Therefore, it is important to select patients who are appropriate for transplantation by evaluating blood flow in the flap based on these patterns. The subjects were 52 consecutive patients who underwent DIEP flap breast reconstruction. Relationships of fat necrosis and induration of a transplanted flap and venous system patterns (presence of SDC on the contralateral side: cSDC or MCLV, direction and diameter of perforator vein) in the flap were investigated. Logistic regression and univariate and multivariate analyses were used to identify predictors of fat necrosis and induration of the flap. Fat necrosis and induration were detected in 17.4 and 34.8% of cases, respectively. These incidences were significantly linked to the absence of cSDC and MCLV patterns in the flap. Patients without a cSDC or MCLV pattern had harder fat tissue in Zone II, especially in the distal portion. These results suggest that the absence of a cSDC or MCLV pattern causes complications such as fat necrosis and induration in a transplanted flap. If neither pattern is detected before surgery, improvement of venous drainage is recommended.

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Introduction

The deep inferior epigastric artery perforator (the DIEP) flap has become a mainstay for autologous breast reconstruction after total breast mastectomy [1–6]. In particular, harvesting of a DIEP flap with a single perforator has led to a safer, more expeditious method with muscular and fascial preservation that is applicable in many cases [4–6]. Despite this utility, the relatively high risk of venous congestion and subsequent complications, including fat necrosis and induration, remain as challenges because the DIEP flap has unique variations in the anatomy of the vascular supply, especially for venous return [4,7]. Latent complications such as fat induration and necrosis may be directly related to the extent of venous congestion, including in Hartrampf perfusion Zone II because theoretically, the region across the midline is a non-physiologic environment [7].

Dominant venous drainage to the lower abdominal panniculus may be provided through the superficial inferior epigastric vein (SIEV) rather than the deep inferior epigastric vein (DIEV). However, after flap elevation, the condition of the flap changes as the whole venous outflow is directed through the venae comitantes of the used perforators into the DIEV [8,9]. The relationships of connections between the superficial and deep inferior epigastric vein systems (superficial-to-deep connection: SDC) and those of the superficial inferior epigastric vein across the midline of the flap (midline-crossing linking vessels: MCLV) with venous congestion has been examined in several recent studies, and the effects of vascular anatomy patterns, including the size, direction and bifurcation points of the most dominant perforator vein in the flap, on the incidence of fat necrosis and stiffness in individual regions of the flap are also of interest [1–4,7,10]. Some studies have suggested that the direction and bifurcation points of the most dominant perforator vessel influence blood circulation in the flap [11,12].

Recent developments in imaging technology have widened the application range for diagnosis and study of anatomy. Computed tomographic angiography (CTA) provides improved preoperative information on the individual venous pattern, such as SDC and MCLV, and patterns of the dominant perforator vein [13–15]. This permits planning of how to maximize flap perfusion during flap harvest for safety, as well as avoidance of impairment of vascular dynamics during flap inset.

In the current study, we assessed the relationship between presurgical venous pattern analysis using CTA and outcomes related to the occurrence of venous compromises, such as fat necrosis or induration. Our findings have implications for the reduction of the incidence of venous congestion and its clinical sequelae, such as complete or partial flap failure, and for venous salvage procedures.

Materials and methods

A retrospective study of a clinical series was carried out in 52 patients who underwent preoperative CTA before single dominant

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Supplemental data for this article can be accessed here.

medial perforator DIEP flap elevation at Kyoto Prefectural University of Medicine from August 2014 to May 2018. Patient demographics and operative data were obtained from hospital records. Cases with a transplanted flap weight of >600 g and a history of midline abdominal incision were excluded from the study because these factors are likely to affect complications related to venous congestion [16]. In all cases, blood flow in all regions of Zones I and III and almost all regions of Zone II was shown by intraoperative indocyanine green (ICG) imaging, and thus these zones were used for transplantation. All Zone II regions were used in the area where blood flow was confirmed by ICG imaging, but Zone IV was not used even if blood flow is observed because we believe that a double-pedicled free flap is required when raising a DIEP flap that is close to the total flap including Zone IV (Figure 1(a)). Zone classification was based on Hartrampf's concept of zones of perfusion.

The diameter, direction, and bifurcation points of the most dominant perforator vein, and the presence or absence of an SDC on the contralateral side (cSDC) or MCLV pattern in the flap were determined using preoperative CTA. As previously described [17–20], the scan range was limited to the tissue used intraoperatively and thus spanned from the pubic symphysis to 4 cm above the level of the umbilicus. An intravenous iodinated solution (Omnipaque (iohexol); GE Healthcare, Waukesha, WI, USA) was injected as a contrast agent at 24.0 mg/kg/s for 25 s. Subsequent imaging was performed with a 64-slice CT scanner (Definition; Siemens Healthcare), including venous return (delay) phase filling and resolution of the cutaneous vasculature. Three-dimensional images were generated using a volume-rendering technique, which allowed the acquisition of clear and accurate images of venous return patterns.

The patterns of the direction and bifurcation points of the most dominant perforator vein in the flap are divided into two types (Figure 1(a)). To determine the blood vessel diameter for a perforator, the widths of blood vessels, including arteries and veins at the level of flow into fat tissue on the fascia, were measured using a micro-measure. cSDC and MCLVs in the lower abdominal region were identified (Figure 2). Zones I–III were further classified into the proximal, middle, and distal parts to measure fat stiffness objectively in 9 regions in total, using real-time ultrasound SWE (LOGIQ E9, GE Healthcare) and a 9L linear (4–9 MHz) probe [21.22] (Figure 1(a)). Measurements were performed three times and the mean stiffness was determined. The stiffness of subcutaneous fat located at a site 5 cm from the umbilicus on the cranial side was used as a control. Fat necrosis and induration in the transplanted flap were diagnosed 6 months after the operation. With reference to the definition by Peeters et al., fat necrosis was defined as any palpable firmness, nodule, or mass greater than approximately 3 cm in diameter that was present 6 months after surgery (Figure 3(a)) [23].

Fat induration was defined as palpation of a nodule or hard mass based on an optimal cut-off value of fat tissue of ≥60 kPa for significant fat induration using SWE at 6 months after the operation [21] (Figure 3(b)). Based on these measurements, the effects on fat necrosis and induration of vascular anatomy patterns such as the size, direction and bifurcation points of the most dominant perforator vein within the flap were examined.

Statistical analysis

Statistical analysis was performed by paired *t*-test for comparison of fat stiffness of Zone II regions of flaps with and without cSDC or MCLV patterns. Multivariate regression analysis was used to examine the effects of cSDC or MCLV and the number and location of perforators on fat stiffness, using a mixed model analysis with random effects with $p < 0.05$ considered to be significant. All

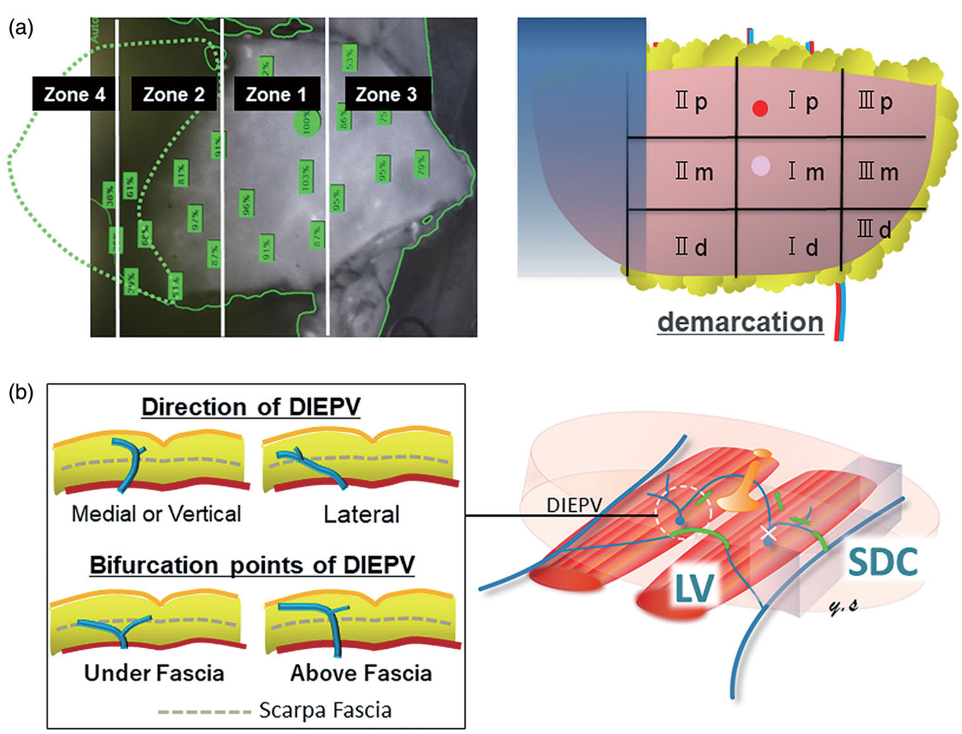

Figure 1. Schematic diagrams of anatomy patterns defined in a DIEP flap. (a) Venous anatomy patterns of the lower abdominal wall. The illustration shows images of cSDC and MCLV patterns, and classification of patterns of the direction and bifurcation points of the most dominant perforator vein within the flap. (b) Intraoperative indocyanine green (ICG) imaging and perforator perfusion zones divided into 9 regions. Zones I–III were further classified into proximal, middle, and distal parts to measure fat stiffness objectively in the 9 regions.

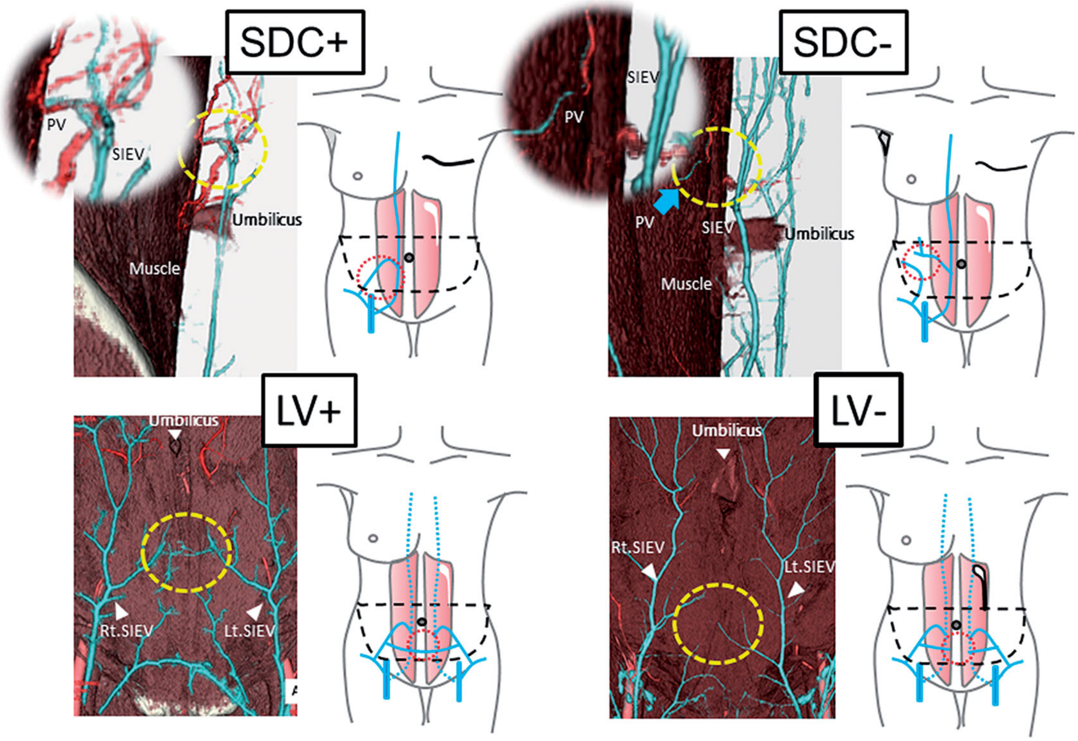

Figure 2. Identification of cSDC and MCLV patterns. Three-dimensional CT images processed using a volume-rendering technique allowed the cSDC and MCLV patterns to be distinguished.

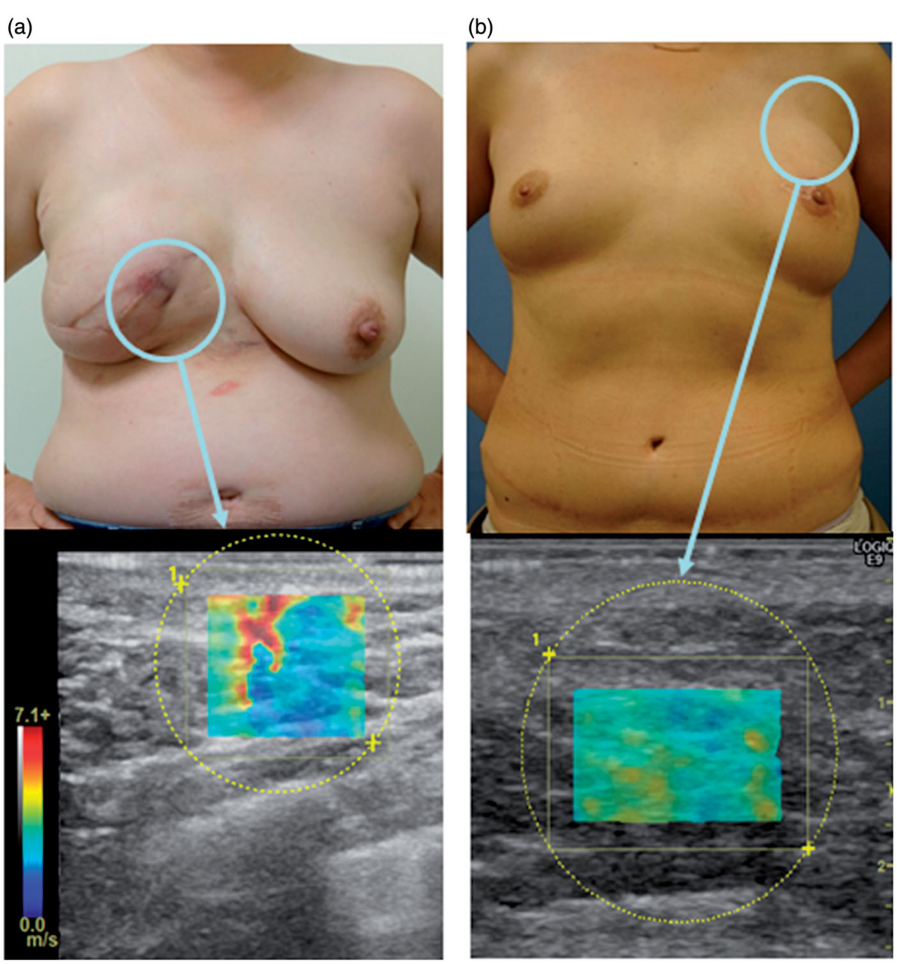

Figure 3. Clinical findings of fat necrosis and induration in part of a flap. (a) A palpable nodule was detected in an area of the right reconstructed breast. (b) Fat stiffness measured by shear wave elastograpy was >60 KPa.

Table 1. Background of patients.

	Variables	Patterns	n (%)
Dependent variables	Fat induration	+	18 (34.8)
		–	34 (65.2)
	Fat necrosis	+	9 (17.4)
		–	43 (82.6)
Independent variables	Superficial-to-deep connection (SDC)	+	39 (75.0)
		–	13 (25.0)
	Linking Vessels (LVs)	+	31 (59.6)
		–	21 (40.4)
	Bifurcation point	Under fascia	32 (61.5)
		Above fascia	20 (38.5)
	Direction	Medial or vertical	32 (61.5)
		Lateral	20 (38.5)
	Perforator diameter (1 mm)	>2 mm	16 (30.7)
		<2 mm	36 (69.3)

Prevalences of fat induration and necrosis are shown as dependent variables and venous patterns as independent variables for statistical analysis.

Table 2. Relationships of fat induration and fat necrosis with venous patterns in logistic regression models.

	Fat induration		Fat necrosis	
Item	Univariate	Multivariate	Univariate	Multivariate
SCD (+/–)	0.08 (0.02–0.35)	0.05 (0.01–0.32)	0.18 (0.03–0.84)	0.20 (0.04–1.09)
Linking vessels (+/–)	0.18 (0.05–0.62)	0.19 (0.04–0.87)	0.14 (0.03–0.75)	0.16 (0.03–0.98)
Branch (under/above fascia)	0.48 (0.15–1.54)	0.46 (0.10–2.07)	0.43 (0.10–1.84)	0.45 (0.09–2.41)
Direction (direct/lateral)	0.97 (0.30–3.14)	0.55 (0.09–3.41)	1.31 (0.29–5.95)	1.40 (0.24–8.34)
Perforator diameter (1 mm)	1.72 (0.53–5.53)	2.64 (0.46–15.3)	1.37 (0.32–5.85)	1.08 (0.22–5.42)

Data are shown as odds ratios (95% CI).
The presence of a cSDC or MCLV pattern was associated with a significantly lower risk of fat induration and necrosis.

calculations were performed using JMP® Pro 12.1 and SAS 9.4 (SAS Institute, Cary, NC, USA).

Results

The average age and BMI of the 52 subjects without augmentation of the venous drainage system were 50.8 ± 9.2 years old and 22.9 ± 1.8 kg/m^2. The average flap weight was 371.0 ± 81.3 g. A summary of the preoperative venous pattern analysis using CTA is shown in Table 1. The prevalence of fat induration and necrosis were 34.8 and 17.4%, respectively, in our clinical series in DIEP flaps for autologous breast reconstruction (Table 1). Univariate regression analyses revealed that the presence of a cSDC or MCLV pattern was associated with a significantly lower risk of fat induration and necrosis (Table 2). Similarly, multivariate regression analysis after adjusting for confounding factors showed the same results, except for the relationship between the presence of a cSDC pattern and fat necrosis (Table 2). Measurement of the DIEP flap using ultrasound showed significantly higher fat tissue stiffness in cases without a cSDC or MCLV pattern in all zones, including the means for all zones, compared with that in cases with a cSDC or MCLV pattern (Table 2). In comparisons within each zone, this tendency was more strongly apparent in distal regions of Zone II (Figure 4).

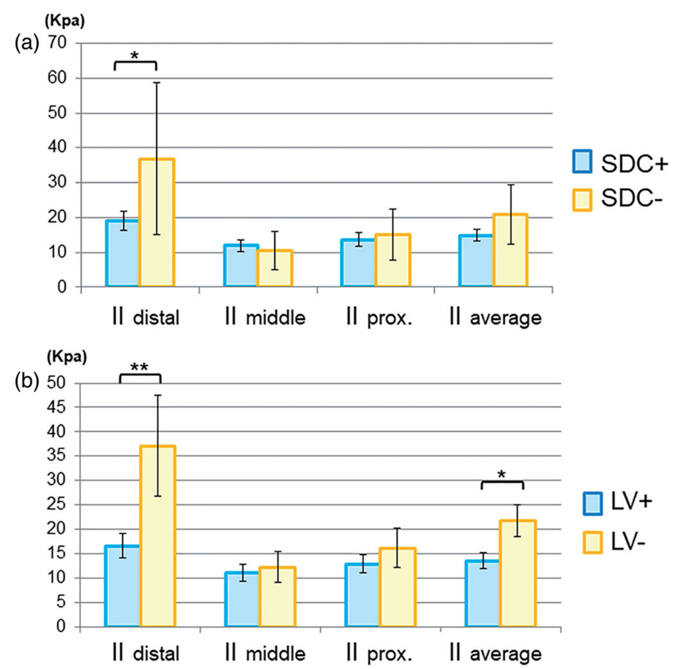

Figure 4. Measurement of fat tissue stiffness in Zone II. Fat tissue stiffness in the DIEP flap determined using ultrasound showed that fat tissue in patients with a cSDC (a) or MCLV (b) pattern was significantly lower than that in patients without one of these patterns, especially in the distal portion of the flap.

Discussion

The incidence of venous congestion was reported to be up to 27% in a large series of DIEP flap breast reconstructions and the etiology of this condition is not fully understood [3,6,24–27]. Reduction of this complication is the key to success for safer and more efficient breast reconstruction using a DIEP flap. At our hospital, we routinely confirm blood flow in the flap by ICG imaging during surgery and we check fat necrosis and induration postoperatively in transplanted tissues by palpation and measuring the stiffness of the tissues objectively, as in the current study. DIEP flaps based on a single dominant perforator generally have more unstable blood flow than those based on multiple perforators. In our clinical experience, there were no cases in which it was necessary to secure an additional arterial inflow tract, except for cases with all Zone II or cases with abdominal midline scars or large-sized flaps. Current results show that postoperative fat necrosis and induration are more frequent than previously reported, even when only optimal regions based on ICG imaging are used. ICG imaging of blood flow may indicate a region covered by arteries, but does not always show safe venous return. Several recent studies have highlighted the presence of an SDC or MCLV pattern and predicted that they might have a relationship with venous problems in raising a DIEP flap [1,4,7,28]. In 2010, Schaverien et al. focused on SDC as a significant contributory factor in venous congestion [28], and in 2016, Kurlander et al. proposed that a device should be used to avoid venous congestion [7]. Advances in imaging, particularly CTA, have facilitated preoperative perforator identification, allowing for improved flap design and shorter operating times. CTA has similar accuracy to that of MRA, although MRA has the advantage of avoidance of ionizing radiation, and generally MR contrast agents are better tolerated [20].

We routinely use preoperative CTA for DIEP flap vascular imaging to identify the presence of systems for venous drainage. Our current results are consistent with those from two previous studies that have shown a lack of an MCLV pattern in 36 and 13% of clinical cases [1,10]. Both of these studies postulated the midline crossover as a cause of venous problems. In the current study, we focused on cSDC in the Zone II region for the analysis because many fat necroses are known to be found in the deep subcutaneous tissue beneath the scarpa fascia in Zone II, which implies the importance of the cSDC that connects the superficial venous system and the deep venous system on the other side [29–31]. Objective evaluation of postoperative fat induration in a reconstructed breast with a DIEP flap was performed using ultrasound SWE, which allows non-invasive quantification of tissue softness [21,22]. We introduce a new concept in further classifying Zones I–III into detailed parts to measure the fat stiffness of a transplanted flap objectively, using real-time ultrasound shear wave elastography (SWE). This method provides details of the stiffness of deep fat that could not be previously determined and let us know latent fat necrosis and fat induration more precisely. Our results show the significant risk of fat necrosis and induration due to the absence of a cSDC or MCLV pattern in a cohort of patients defined as intermediately obese. The results also show that cSDC and MCLV patterns are strongly associated with postoperative venous drainage in a transplanted DIEP flap, whereas the diameter, direction, and bifurcation point of the dominant perforator vein is less important in this respect.

Several approaches can be used to avoid postoperative venous complications such as fat necrosis and induration. We preferentially select medial row perforators in DIEP flap harvest because these have some advantages. Schaverien et al. showed that venae comitantes with direct venous connections to the SIEV were significantly more likely to be found in a medial row than in lateral row perforators, which is consistent with our clinical experience. Furthermore, the selection of medial row perforators may have other advantages of adequate perfusion of zone IV [4] and avoidance of damage to motor nerves to the rectus abdominal muscle [4,32]. Laungani et al. showed that conservation of an intact dermis and its subdermal plexus has a critical role in overall flap perfusion through recruitment of indirect linking vessels [33]. Accordingly, when an MCLV pattern cannot be found, the skin paddle should be removed by cautious deepithelialization of the flap using a cold blade, rather than a cautery, to remove the skin, while retaining the integrity of the dermis.

The relationship between the caliber of the SIEV and perforator vein can be used to predict if the DIEP flap is superficial venous system dominant or deep system dominant. Based on our clinical experience and limited data, there is also a negative correlation between the caliber of the SIEV and the perforator vein (data not shown). Consequently, if the SIEV diameter is large and the perforator vein diameter is small, care should be taken in the procedure. A large caliber SIEV before flap elevation may also suggest that the flap is superficially dominant and requires super drainage [8,27].

The efficacy of super drainage using a SIEV for augmenting flap perfusion and reducing complications has been shown in several anatomical and imaging studies [34–39]. The results of this study suggest the significance of preoperative CTA confirmation of individual cSDC and MCLV anatomy to prevent fat necrosis and induration in the contralateral side (Zone II) of the flap. If MCLV is seen but cSDC is not present, a perforator vein leading to the deep fat layer on the contralateral side (Zone II) needs to be drained by additional venous anastomosis. Conversely, if cSDC is seen but MCLV is not present, super drainage via contralateral SIEV should be effective. If both are not seen, a complete solution is difficult, but either of super drainage procedures shown above may be useful (Refer to Supplementary Figures).

One limitation of the current study is the relatively small sample size and the focus on Zone II regions of a DIEP flap based on a single perforator from a medial row DIEA. However, consideration of two or more perforators would greatly complicate the study design and interpretation. Moreover, the criteria for judging the presence or absence of a cSDC or MCLV pattern are not clear-cut and are likely to depend on image acquisition conditions to some extent. A novel imaging method, ferumoxytol-enhanced MRA, has recently been introduced as a modality that provides a detailed view of the abdominal wall venous system [4,7,20,40]. Influences on the stiffness of a DIEP flap other than venous congestion also need to be considered. Our previous study indicated that the transplanted flap size might be involved in fat necrosis or induration [16]. However, multivariate regression analysis in the current study showed that the influence of the flap weight was small after excluding cases with a transplanted flap of weight >600 g (data not shown). Thus, further examination of causal factors is necessary.

In summary, we conclude that latent complications such as fat induration and necrosis occur at definite rates and are probably caused by flap venous congestion. We draw this conclusion because we used only the parts of the flap where we confirmed that arterial blood flow was good using ICG imaging. Our results suggest that inadequate communication between the chosen perforator venae comitantes and the SIEV or hypoplasia could explain the diffuse venous congestion seen in some DIEP flaps. An improved understanding of the venous anatomy of abdominal flaps preoperatively can play an important role in operative planning and execution.

Conclusion

Venous congestion is a significant obstacle for successful breast reconstruction with a DIEP flap. We have identified risk factors for venous congestion of a DIEP flap among patient background and anatomical features. The absence of patterns of cSDC or MCLV across the midline of the lower abdominal region is associated with a significantly increased risk of postoperative fat necrosis and induration. Early diagnosis and management, preferably at the time of the initial operation, offers the best chance for flap survival.

Ethical approval

The study was approved by the KPUM Institutional Review Board and was conducted in accordance with the ethical standards of the Institutional and National Research Committees. All procedures performed in studies involving human participants were in accordance with the ethical standards of Institutional and/or National Research Committees and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all subjects.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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