Efficacy of superficial inferior epigastric vein superdrainage in TRAM and DIEP flap: An Indocyanine green angiography study of 68 cases

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Abstract
This study aimed to evaluate the efficacy of venous augmentation using superficial inferior epigastric vein (SIEV) in transverse rectus abdominis musculocutaneous (TRAM) and deep inferior epigastric artery perforator (DIEP) flap. A retrospective review was performed of 62 free TRAM and 6 DIEP unilateral breast reconstructions from September 2017 to July 2022. Intraoperative indocyanine green angiography was performed with the SIEV contralateral to the pedicle clamped and declamped for 20 min. The ratio of hypoperfused area was calculated and compared quantitatively. The preoperative computed tomography angiography was reviewed to measure the SIEV diameter and number of midline-crossing medial branches. Sixty-two percent (42/68 cases) resulted in perfusion improvement after SIEV superdrainage (Group 1), whereas 29.4 percent (20/68 cases) resulted in sustained (Group 2) and 8.8 percent (6/68 cases) in aggravated perfusion (Group3). The mean number of midline-crossing branches (p = 0.002) and mean difference in the diameter of bilateral SIEVs (p = 0.039) were significantly greater in Group 1 compared to the other groups. Superdrainage using the contralateral SIEV in TRAM/DIEP flap is recommended when there are more than 2 midline-crossing medial branches of SIEV and when the caliber of draining vein is greater than that of the pedicle side.

Introduction
The free transverse rectus abdominis musculocutaneous (TRAM) or deep inferior epigastric perforator (DIEP) flap is one of the preferred methods for autologous breast reconstruction because of its natural-looking aesthetic results and relatively low complication rates [1–3]. Despite improvements in microsurgical techniques, venous congestion continues to be the most frequently encountered cause of flap failure in TRAM/DIEP flaps, accounting for 5–27% of the incidence [4–8]. While venous complications are often associated with microsurgical problems, some develop without microsurgical errors in pedicle anastomosis, which are assumed to be associated with ineffective venous structures [9, 10]. Although venous problems constitute the most common vascular complication and pose a greater limitation on flap viability, little has been published regarding the mechanism of venous outflow in the TRAM/DIEP flap.

As reported by Carramenha et al., the superficial inferior epigastric vein (SIEV) is the largest vein that drains the DIEP/TRAM flap, suggesting that dominant venous drainage preferentially occurs through the superficial venous system [11]. However, SIEVs on both sides are interrupted when the flap is harvested. The venous outflow of the contralateral side of the flap, the most commonly congested zones, is redirected from the superficial system of the contralateral side to the pedicle side through midline-crossing branches and to the deep system through the perforator vena comitantes [5, 10, 12]. Poor venous connections across the midline or between the deep and superficial systems may disturb this redistribution, which could result in venous congestion without pedicle-related problems [13–18].

Much effort has been made to prevent such complication, and various strategies for salvage of flaps with intraoperative venous congestion, including turbocharging or supercharging with the additional anastomosis of SIEV or accompanying deep inferior epigastric comitantes, have been introduced [19–35]. The benefits of superdrainage on augmenting flap perfusion and reducing congestive failures have been demonstrated in previous literatures [19–21, 36, 37]. However, debates as to whether superdrainage can actually prevent all congestion-related complications and reduce overall flap loss are still ongoing in clinical series [6, 38, 39].

This study aimed to evaluate the clinical efficacy of venous augmentation using SIEV for the salvage or prevention of intraoperative venous congestion in the TRAM/DIEP flap, and to investigate the contributing factors that may have discouraged the effect of superdrainage. This may lead to a better understanding of the mechanism of venous congestion in the TRAM/DIEP flap and provide guidance for the surgical planning of venous salvaging.

Results
Patient and flap-related characteristics

A total of 68 flaps from 68 patients were included: 42 (61.76%) in Group 1 (> 3% decrease in the hypoperfused area), 20 (29.41%) in Group 2 (changes ranging from − 3 to 3%), and 6 (8.82%) in Group 3 (> 3% increase in the hypoperfused area) (Table 1, Supplementary information file 1). The patient-related characteristics included the following: age (51.91 ± 8.68 years); body mass index (24.57 ± 3.79); previous abdominal surgery (25 patients [36.76%]); and diabetes mellitus or hyperlipidemia (12 patients [17.65%]). The flap-related characteristics included the following: 37 (54.41%) muscle sparing-1 TRAM, 25 (36.76%) muscle sparing-2 TRAM, and 6 (8.82%) DIEP flaps, weight of 842.87 ± 336.08 g, width (311.85 ± 27.48 mm), height (156.06 ± 14.64 mm), and thickness (30.06 ± 7.72 mm). There were no significant differences in all patient-related and flap-related characteristics between groups 1, 2, and 3.
Table 1
Patient and Surgical characteristics* (n = 68)

<table>
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<tr>
<th></th>
<th>Total</th>
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<th>Group2</th>
<th>Group3</th>
<th>p-value†</th>
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<td>Mean</td>
<td>%</td>
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<td>61.76</td>
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<td></td>
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<tr>
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<td>37</td>
<td>54.41</td>
<td>17</td>
<td>40.48</td>
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<tr>
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<td>31</td>
<td>45.59</td>
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<td>50.00</td>
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<td>Flap weight, mean g (SD)</td>
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<td>7.72</td>
<td>29.91</td>
<td>56.91</td>
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*Data are expressed as no. (%).
Three-way comparison between Group 1,2,3; p values were calculated with a one-way analysis of variance (continuous variables) or with chi-square or Fisher exact test (categorical variables) with Bonferroni correction.

Quantitative analysis of hypoperfused areas in indocyanine green (ICG) angiography

The mean difference in the hypoperfused area ratio was significantly greater in Group 1 (10.62 ± 0.38), followed by Group 2 (0.30 ± 0.02) and 3 (-5.82 ± 0.03) (p < 0.001) (Table 2).

<table>
<thead>
<tr>
<th>Table 2</th>
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<td>Number of medial branches of SIEV, mean (SD)</td>
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<td>SIEV diameter on superdrainage side, mean mm (SD)</td>
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<td>SIEV diameter on pedicle side, mean mm (SD)</td>
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<td>SIEV diameter difference, mean mm (SD)</td>
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</table>

Quantitative analysis of SIEV measurement in CT angiography

There was a significant difference in the number of midline-crossing medial branches of the SIEV, with 3.24 ± 2.04, 2.05 ± 1.63, 1.67 ± 1.47 for Group 1, 2, 3, respectively (p = 0.002). There were three cases (4.41%) with no visible medial branches (two in Group 1, one in Group 2). The mean diameter of SIEV on the superdrainage side was greatest in Group 1 (2.85 ± 0.55), followed by Group 2 (2.83 ± 0.70) and Group 3 (2.73 ± 0.65), whereas the diameter of SIEV on the pedicle side was greatest in Group 3 (3.15 ± 0.40), followed by Group 2 (2.78 ± 0.49) and Group 1 (2.72 ± 0.61), although these results were not significant. The mean diameter difference of bilateral SIEVs was significantly greater in Group 1 (0.13 ± 0.16) than in Group 2 (0.05 ± 0.32) and Group 3 (-0.42 ± 0.50) (p = 0.039).

Discussion

Recent studies have identified that venous congestion without microsurgical failure is due to the insufficient superficial venous outflow via the deep venous system in TRAM/DIEP flap [19, 20]. To resolve this problem, many authors have offered varying means of augmenting or supercharging the venous drainage of congested or compromised flaps and have recommended the use of SIEV [19–27]. Although there is a known benefit of such salvaging procedure in reducing the risk of flap congestion, a consensus regarding the reproduciability of superdrainage effect in individual cases does not exist.

In this study, although the majority (61.76%, Group 1) resulted in improvement of flap perfusion after augmenting venous drainage through the contralateral SIEV, 29.41% (Group 2) remained almost the same and 8.82% (Group 3) even showed a decrease in perfusion, with a significant difference in the flap perfusion change between the three groups (p = 0 < 0.001). Considering that the arterial inflow of the flap remained constant before and after declamping the SIEV, the change in the hypoperfused area on ICG angiography may be attributable to the effects of superdrainage. The increased efficiency of
venous drainage by contralateral SIEV augmentation helps increase the arterial pressure of the flap, resulting in better overall perfusion (Fig. 1). In a previous intraoperative ICG angiography study of 52 DIEP flaps, 9.6% showed intraoperative venous congestion, all of which resolved after removing the vascular clamps of the SIEVs [40]. This is in contrast to the results of our study, in which almost 40% of the cases resulted in unexpected outcomes with a decreased or sustained level of perfusion.

The improvement in flap perfusion showed significant correlation with a greater number of medial branches of the SIEV that interconnected the bilateral superficial systems (3.24, Group 1; 2.05, Group 2; 1.67, Group 3; p = 0.002). Most of the hypoperfused areas were observed on the contralateral side of the flap. Venous drainage of the contralateral flap is known to pass through the fine midline-crossing networks, join the ipsilateral SIEV, and gain access to the deep system through the venae comitantes of perforators [12, 14–16]. However, a number of anatomical and imaging studies have demonstrated the absence of direct venous communications of bilateral SIEVs across the midline in 6–36% of cases, in which venous congestion could be favored further the midline [5, 10, 13, 17]. In the current study, 4.41% of patients showed no visible midline-crossing medial branches, and flaps with less than two visible medial branches of SIEV on preoperative CT angiography resulted in aggravated overall perfusion after SIEV superdrainage (Group 3). In such cases, the drainage capacity of the infraumbilical venous networks might still be limited even with the SIEV superdrainage because of the limited function in midline crossing, which could be responsible for the failure to improve perfusion.

The effect of SIEV drainage on perfusion improvement also showed significant positive correlations with a greater diameter of SIEV on the superdraining side than on the pedicle side (p = 0.039). Previous literature suggests that large-caliber superficial veins and small venous perforator veins are associated with dominant superficial venous drainage and suggests the augmentation of venous drainage with a secondary superficial vein [5, 7]. A SIEV greater than 1.5 mm in diameter is known to be the dominant vein, and a perforating vein greater than 1 mm in diameter is the dominant deep inferior epigastric vein perforator [10, 41]. However, there are contrasting opinions that the SIEV diameter may not be an absolute predictor of venous congestion. Some recent studies have shown no direct correlation between vessel diameters in the superficial and deep inferior epigastric systems and venous congestion [42–44]. In the current study, the diameter of the SIEV on both sides did not show any correlation with venous congestion. However, how much larger the diameter of the SIEV on the superdraining side than on the pedicle side was significantly associated with a better venous superdrainage effect. This shows that venous dominance may differ on each side of the flap, and the relative caliber of SIEV of the superdrainage side, not the absolute caliber, can be a predictor of superficial venous dominance on that side of the flap. For example, the side with a relatively larger SIEV would be superficial-dominant, whereas the other side would be deep-dominant, and the use of a larger SIEV as an augmentation route would benefit the venous drainage.

The venous dominance of each side of the flap should be assessed by performing routine preoperative computed tomography angiography (CTA), and the flap pedicle should be better selected from the deep-dominant side. Intraoperative venous congestion is evaluated using ICG angiography, and superdrainage through the contralateral SIEV should be considered in congestive cases. However, if there are fewer than two midline-crossing medial branches of the SIEV or the diameter of the SIEV is smaller than the counter side, the effect of superdrainage would be questionable. In other words, superdrainage through the contralateral SIEV is recommended when its caliber is relatively greater than that of the pedicle side, and when there are more than two midline-crossing superficial branches.

There are some limitations to consider for this study. First, there were challenges in accurately assessing the imaging, which include the following: area of flap hypoperfusion, number of medial branches of the SIEV, and diameter of the SIEV. Radiographic measurements are potentially unreliable because of their small size and limited image resolution. To minimize such bias, all imaging studies were performed using a single CTA and ICG angiography modality in a standardized manner, and the data were collected by a single surgeon. Second, despite the wide understanding that the significant contributing factors implicated in the causality of venous compromise include not only the degree of midline crossover or the caliber of SIEVs, but also the inclusion of perforator venae comitantes that directly connect with SIEV and
the caliber of venous perforators, these were not considered in the current study [38–40]. As mentioned earlier, due to technical problems, the communication between the perforator venae comitantes and SIEV, or the caliber of the perforator veins, was not assessed. Further studies including these factors using better-equipped imaging modalities are needed. Finally, due to the retrospective nature of the study, there was no control group and the sample size was relatively small. Prospective studies with larger samples may lead to a better understanding of the mechanism of super-drainage of the TRAM/DIEP flap. The pathophysiology of venous congestion in TRAM/DIEP flaps is likely multifactorial and requires further research.

Ultimately, planning venous drainage requires the optimization of numerous anatomical factors, such as identification of the superficial venous dominant side, selection of the best pedicle, and inclusion of SIEV as a complementary drainage route. Identifying the features of draining veins through preoperative and intraoperative imaging studies is important for planning optimal venous drainage. Superdrainage using the contralateral SIEV in TRAM/DIEP flap is recommended when the SIEV caliber is relatively larger than the counter side and when there are more than 2 midline-crossing medial branches of SIEV.

**Methods**

- **Study design**

A retrospective review was performed on patients who underwent TRAM or DIEP flaps for unilateral breast reconstruction between September 2017 and July 2022. Patients with vertical abdominal scars, body mass index greater than 35, history of cardiovascular disease, and current smokers were excluded. All enrolled patients underwent preoperative CTA and intraoperative ICG angiography. This study was conducted in accordance with the principles of the Declaration of Helsinki and under the approval of institutional review board at of Seoul National University Hospital Biomedical Research Institute (IRB 2206-048-1330). Informed consents were waived from the IRB of Seoul National University Hospital Biomedical Research Institute due to the retrospective design.

- **Flap harvest and perfusion assessment**

Free muscle-sparing 1 TRAM, muscle-sparing 2 TRAM, DIEP flaps were elevated using a standard approach, saving the SIEV on the contralateral side of the pedicle. The following parameters were measured: weight, width, height, and thickness at the umbilical level.

Before ligation of the deep inferior epigastric pedicles, ICG dye (2.5 mg/cc, 4cc) was intravenously injected and angiography (Fluobeam 800 System, FLUOPTICS®-BHT-Bât 52 – 7, Parvis Louis Néel, CS 20050, 38040 Grenoble Cedex 9, France) was performed in a standardized setting with the flap’s contralateral SIEV clamped. Real-time movement of the fluorescent substance was monitored and recorded. After 3 min of recording, the hypoperfused zones were indicated by relatively lower grayscale areas. The boundaries were confirmed using a built-in analysis software (FluoSoftTM®), which showed the relative perfusion values of each area. A second ICG angiography was performed 20 min after declamping the SIEV using the same process.

- **Quantitative analysis of hypoperfused areas in ICG angiography**

The ratio of the hypoperfused area to the total flap area suggested by the ICG angiography was quantitatively calculated using ImageJ Version 1.53n (Wayne Rasband, National Institute of Mental Health, Bethesda, Maryland, USA). The change in the hypoperfused area ratio between the first and second ICG angiographies was used to quantify the change in flap perfusion after SIEV drainage. Flaps with > 3% decrease in the hypoperfused area were classified as Group 1, those with changes ranging from −3 to 3% were classified as Group 2, and those with >3% increase were classified as Group 3 (Fig. 2).
Quantitative analysis of SIEV measurement in CT angiography

In the preoperative CTA, the mean diameter of the SIEV, measured at three points (level of the umbilicus, pubic symphysis, and midpoint of the line connecting the two points), was calculated for each side. The difference in the SIEV diameter between the contralateral and ipsilateral sides of the pedicle was calculated. The number of midline-crossing medial branches of SIEVs was also evaluated (Fig. 3).

Statistical analysis

Data were analyzed using IBM SPSS version 23.0 (IBM Corp., Armonk, N.Y., USA). Descriptive statistics were expressed as mean (± SD) and as numbers (percentages). Three-way comparisons were performed between Groups 1, 2, and 3. The p-values were calculated with a one-way analysis of variance for continuous variables, or with chi-square or Fisher's exact test for categorical variables with Bonferroni correction. Differences were considered statistically significant at P < 0.05.

Declarations

Data Availability

All data generated or analyzed during this study are included in this published article as a Supplementary information file 1.

Acknowledgements

None.

Author contributions

C.H. conceived the experiment, Y.Z., H.Y., S.M. conducted the experiment, Y.Z. and H.Y. analyzed the results and wrote the manuscript. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

References


Figures
Figure 1

Schematic illustrations of venous outflow of free TRAM/DIEP flap.

When a free TRAM/DIEP flap is harvested, SIEVs on both sides are interrupted, and the superficial venous outflow redirects from the contralateral side to the pedicle side through midline-crossing branches and to the deep system through the perforator vena comitantes (left). As the contralateral SIEV is declamped, the infraumbilical venous outflow is distributed to both the deep system of the pedicle side and the superficial system of the contralateral side (right).
Figure 2

Captured images at 3 minutes during first (left) and second ICG angiography (right). The red lines indicate the boundaries of hypoperfused area. Flaps with >3% decrease of hypoperfused area were classified as Group 1 (upper), those with change ranging from -3 to 3% were classified as Group 2 (middle), and those with >3% increase were classified as Group 3 (lower).
Figure 3
The infraumbilical medial branches of the SIEV are visible in the preoperative CTA.

**Supplementary Files**
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- [Supplementary information file 1.xlsx](#)