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Anatomical features associated with venous congestion in DIEP flap using CT angiography with three-dimensional reconstruction

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ABSTRACT

Aim: Computed tomography angiography (CTA) using three-dimensional (3D) virtual reconstruction has been increasingly used in planning deep inferior epigastric artery perforator (DIEP) breast reconstruction. Although the most common complication associated with this surgery is diffuse venous congestion, its origin remains unclear. The aim of this study was to assess the anatomical characteristics of the anterior abdominal wall vessels that could predict venous congestion, using CTA with 3D virtual reconstruction. **Methods:** A retrospective case-control study was conducted and a total of 169 DIEP flaps were reviewed. An abdominal CTA with 3D virtual reconstruction was analyzed with regard to anatomical features of the abdominal wall vessels. Seven venous congestive cases were identified. For each case, 3 controls that had not exhibited any vascular complications were randomly selected. **Results:** The global venous congestion rate was 4.14%. No statistically significant differences were found between the groups' superficial inferior epigastric vein (SIEV) diameter (P = 0.915), number of branches of SIEV (P = 0.371), number of perforators per flap (P = 0.255), flap subcutaneous tissue thickness (P = 0.652), direct communications between SIEV-perforators (P = 0.418), and communications of both SIEVs across the abdominal midline (P = 0.371). **Conclusion:** The present study provided

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new information concerning the identification of the controversial anatomical features associated with venous congestion in DIEP flaps. CTA and 3D virtual reconstruction were useful tools for evaluating the abdominal wall anatomy and for planning DIEP breast surgery, but neither for predicting nor preventing the diffuse congestive phenomenon.

INTRODUCTION

Since the deep inferior epigastric artery perforator (DIEP) flap was used for the first time for breast reconstruction by Allen and Treece,[1] it has been adopted as the gold standard for autologous breast reconstruction, overtaking other popular autologous methods such as the latissimus dorsi flap and the transverse rectus abdominis myocutaneous flap. The amount of available tissue, the low abdominal morbidity, the ability of replacing like-for-like, and the good aesthetic results, are the most notable advantages of this technique that have contributed to its widespread use.[2] The success rate is high, with a flap loss rate under 3% according to the review by Lie *et al*.[3] on more than 17,000 DIEP flaps.

The main arterial inflow is provided by the deep inferior epigastric artery (DIEA), while the main venous drainage is provided by the superficial inferior epigastric vein (SIEV). Although the arterial component of the flap has been widely documented,[4,5] the venous system has not been as thoroughly studied. When a DIEP flap is dissected, a redirection of the venous outflow occurs from the dominant superficial system to the deep system. This redistribution could favor venous congestion in some of the flaps, leading to the most common vascular complication, the diffuse venous congestion of the DIEP flap, neither caused by pedicle-related issues (such as venous thrombosis or kinking) nor by technical errors (for example, deficient suture or avulsion of the pedicle).[6,7] This phenomenon is observed in 2-10.9% of cases[7-9] and it may cause partial or total flap loss if unsolved. In fact, up to 40% of total DIEP flap necrosis are associated with venous problems.[3] Paradoxically, the mechanisms behind this complication remain unclear and have not been clarified yet.

Several strategies exist to overcome such complication of DIEP flap diffuse venous congestion.[10-12] However, the origin remains to be elucidated. Some triggering factors have been proposed: diameter of the SIEV larger than 1.5 mm,[6,13] absence of communications of both SIEVs crossing the abdominal midline,[6,13] absence of direct communications by perforators between the SIEV and the deep inferior epigastric vein (DIEV),[6] number of perforators of the flap,[5] and subcutaneous tissue thickness.[14] Nevertheless, scarce evidence has been reported to date as only one study was able to refuse the correlation with the diameter of the SIEV,[8] and another one indicated a higher chance of congestion in DIEP flaps based on just one perforator without direct communication with the SIEV.[7]

The routine use of preoperative imaging to assess the microvascular anatomy of the anterior abdominal wall helps to achieve optimal outcomes.[15] Preoperative planning of DIEP flaps with computed tomographic angiography (CTA) followed by three-dimensional (3D) reconstruction has proved to be an effective technique to map the abdominal vascular anatomy, allowing a better tracking of the perforators, including their size, location and course, so as to shorten the operative time and number of complications.[16,17] On the other hand, little is known about the anatomical features related with the postoperative diffuse venous congestion and how new imaging technologies are able to identify aspects that can threaten the perfusion of the DIEP flap.

This study aimed to evaluate the anatomical features that could preoperatively predict the potential venous congestion of DIEP flaps, using 3D virtual reconstructions from CTA.

METHODS

This retrospective case-control study included 210 consecutive DIEP breast reconstructions in which a CTA was performed prior to surgery. These flaps were carried out consecutively by the same surgeon (D. Sicilia-Castro) in the Department of Plastic and Reconstructive Surgery of the Virgen del Rocio University Hospital in Seville, Spain, between January 2004 and January 2016. All patients were prophylactically administered low molecular weight heparin every 24 h postoperatively, in a dose of 40 mg of enoxaparin, and flaps were assessed clinically and with a hand-held Doppler probe hourly during the first 48 h, and every 2 h during the next 48 h. All patients signed informed consent to be included in the study.

Cases were defined as DIEP flaps preoperatively planned with CTA and 3D virtual reconstruction, which exhibited diffuse venous congestion intraoperatively after ligating the SIEV, not due to pedicle-related issues (venous thrombosis, twisting or kinking) or to technical failures (deficient suture or venous avulsion during manipulation). Controls were defined as DIEP flaps preoperatively planned with CTA and 3D virtual reconstruction, that did not exhibit previous nor other vascular complication, such as arteriovenous thrombosis or necrosis.

Thirty-seven reconstructions were excluded as the preoperative perforator mapping was performed with a hand-held Doppler probe. Four flaps that had exhibited vascular complications different to diffuse venous congestion (2 cases of intraoperative partial venous congestion related to abdominal midline scars, 1 case of intraoperative venous thrombosis, and 1 case of late venous thrombosis 6 days following the surgery) were discarded as well. The final sample group included data from 169 DIEP flaps. According to the inclusion criteria, 7 cases were identified as diffuse congestive flaps [Figure 1]. Due to the limited number of cases, 3 controls per case (21 controls) were selected by computer randomization, in an attempt to control the power of the study and to avoid selection bias.

Imaging procedures

The studies of CTA were carried out by a 16-detector-row computed tomography scanner (General Electric Light-Speed 16; General Electric Company, Fairfield, Conn.). The parameters followed by the CT scans were: 0.37 s rotational speed of the gantry, 0.63 mm collimator width slice thickness, and 1.37 helical detector pitch. The voltage of the X-ray tube was 120 kV and tube current was 250 to 300 mA. Prior to scanning, all patients received an intravenous administration of 100 mL of nonionic iodinated contrast medium at a concentration of 350 mg/mL (Omnipaque 350; GE Healthcare, Barcelona, Spain) into an antecubital vein.

Sections of 0.63 in width were obtained at an 0.5-mm interval from 4 cm above the umbilicus to the minor trochanter of the hip. The resulting set of images was automatically transferred to a computer workstation, which generated multiplanar reformatted images and 3D volume-rendered images. Data were stored as a Digital Imaging and Communications in Medicine (DICOM) compatible file on a CD-ROM to be uploaded to a personal computer with the AYRA® software (formerly known as VirSSPA®; Andalusian Health Department, Seville, Spain). The 3D reconstructions of the abdominal wall were generated using the DICOM files by means of the virtual reality AYRA® software. All the variables were assessed in these 3D virtual models.

Evaluation of the images

The preoperative 3D reconstruction of each case was retrieved by the same observer (A. Ruiz-Moya). The following anatomical variables were retrospectively analyzed in both groups: the existence of direct communications between the SIEV and the perforators of the flap [Figure 2], the existence of communications of both SIEVs across the abdominal midline [Figure 3], the 8-cm-diameter SIEV caudal to the most superior aspect of the iliac crests [Figure 4], the number of branches of the SIEV, the number of perforators included in each flap [Figure 5], and the flap subcutaneous tissue thickness at a point located

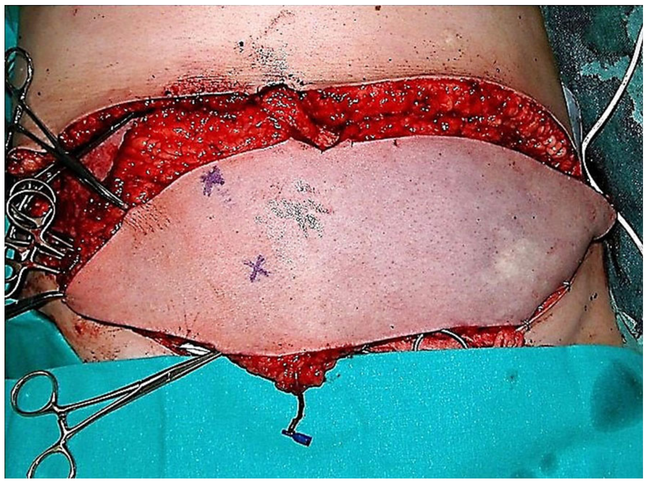

Figure 1: Deep inferior epigastric artery perforator flap exhibiting diffuse venous congestion

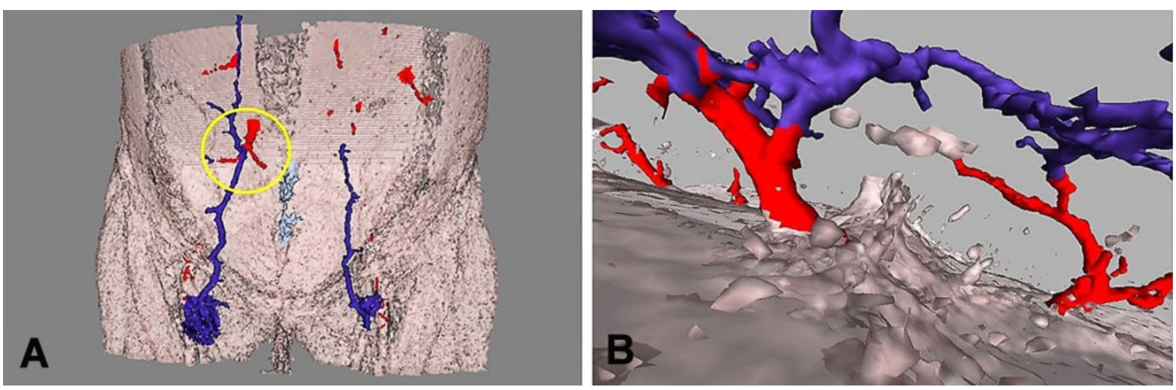

Figure 2: Three-dimensional abdominal wall reconstruction with AYRA software from computed tomography angiography images. (A) Point of assessment (circle) of direct communications between perforators (red) and superficial venous system (blue); (B) direct communications viewed from the abdominal wall

at the level of the most superior aspect of the iliac crests and at the midpoint of the rectus abdominis muscle width [Figure 6].

Statistical analysis

According to the small sample size, the quantitative variables were evaluated with the *U*-Mann-Whitney non-parametric test, and the qualitative variables with the Fisher exact test. For the statistical analysis, the IBM SPSS Statistics 19 package® (SPSS Inc. Chicago, IL) was used, considering significant differences when $P < 0.05$.

RESULTS

The global venous congestion rate was 4.14% (7 flaps). The mean age of case and control subjects was 50.1 years (range 38-58 years) and 49.1 years (range 35-64 years), respectively.

In the case group, direct communications between the DIEA and the SIEV through perforators were found in 57.14% of flaps (4 cases), direct communications of both SIEVs across the abdominal midline were found in 42.86% of flaps (3 cases), with a mean diameter of the SIEV of 3.04 mm (± 0.60 mm), a mean of 1.43 branches per SIEV, a mean of 1.86 (± 0.69) perforators nourishing each flap, and with an average flap subcutaneous tissue thickness of 3.56 cm (± 0.90 cm) [Table 1]. In every congestive flap, an additional venous anastomosis was performed, either to the second concomitant vein of the DIEA (5 cases) or to the cephalic vein (2 cases). After this salvage procedure, all of the 7 flaps overcame congestion and survived without necrosis. In the control group, direct communications between the DIEA and the SIEV through perforators were found in 38.10% of flaps (8 controls), direct communications of both SIEVs across the abdominal midline were found in 23.81% of flaps (5 controls), with a mean diameter of the SIEV of 3.08 mm (± 1.20 mm), a mean of 1.24 branches per SIEV, a mean of 2.24 (± 0.77) perforators nourishing each flap, and with a mean flap subcutaneous tissue thickness of 3.72 cm (± 0.83 cm) [Table 2]. No statistically significant differences were found between the two groups for any of the variables ($P > 0.05$) [Table 3].

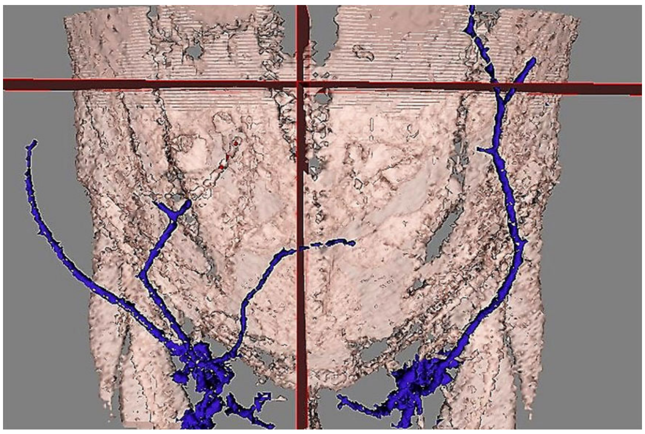

Figure 3: Three-dimensional abdominal wall reconstruction with AYRA software from computed tomography angiography images showing direct venous communication of the superficial inferior epigastric vein across the abdominal midline

DISCUSSION

The present study was not able to confirm any of the studied anatomical variables as predictive factors of venous congestion, despite being suggested in the literature.[5,6,13,14] The abdominal superficial venous dominance is one of the most extended and accepted (but not proved) hypothesis for explaining the diffuse congestion as a large diameter SIEV may denote dominance over the deep venous system.[6] Blondeel *et al*.[13] suggested that when this diameter is > 1.5 mm, the SIEV should be preserved for venous supercharging in case of congestion. However, in a study with CT angiography, Sadik *et al*.[8] did not find a correlation between the SIEV diameter and the venous dominance of the flap, concluding that the SIEV

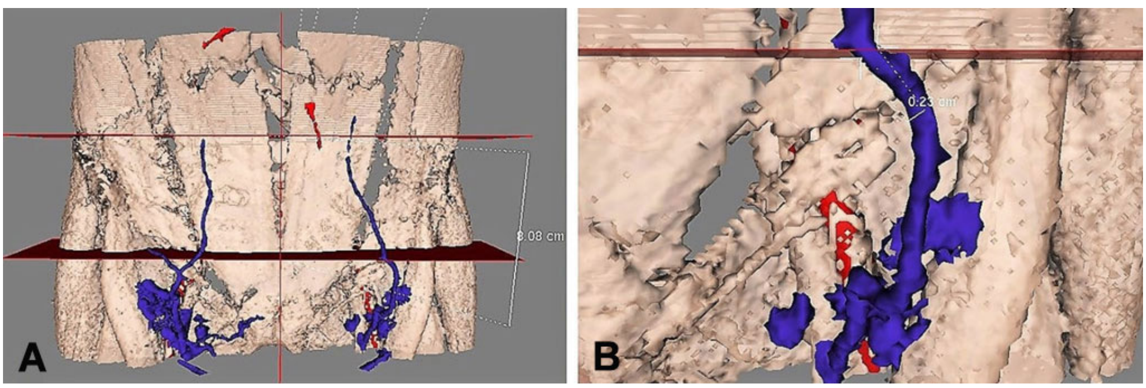

Figure 4: Three-dimensional abdominal wall reconstruction with AYRA software from computed tomography angiography images. (A) Horizontal plane 8 cm inferior to the horizontal plane connecting the iliac crests, marking level of measurement of the SIEV diameter; (B) measurement of the SIEV diameter. SIEV: superficial inferior epigastric vein

Table 1: Variables studied in case group

Case No.	Communication SIEV DIEA	Communication SIEV	Diameter of SIEV (mm)	Branches of SIEV	Perforators	Subcutaneous thickness (cm)	Age (years)
1	No	No	2.7	2	3	2.38	51
2	Yes	Yes	3.6	2	2	3.19	48
3	Yes	Yes	2.4	1	2	2.91	49
4	No	No	2.9	1	2	4.49	38
5	Yes	No	3.9	1	2	2.98	54
6	Yes	Yes	3.5	2	1	4.35	53
7	No	No	2.3	1	1	4.64	58

SIEV: superficial inferior epigastric vein; DIEA: deep inferior epigastric artery

Table 2: Variables studied in control group

Case No.	Communication SIEV DIEA	Communication SIEV	Diameter of SIEV (mm)	Branches of SIEV	Perforators	Subcutaneous thickness (cm)	Age (years)
1	Yes	No	3.4	1	3	3.98	58
2	No	No	3.0	1	3	2.72	54
3	No	No	3.7	2	2	5.00	39
4	Yes	No	2.7	1	2	4.14	57
5	No	No	4.5	1	3	4.66	41
6	No	No	1.7	1	2	3.70	64
7	Yes	No	2.6	1	3	2.69	51
8	No	No	3.1	1	2	4.50	35
9	No	No	2.1	1	3	3.27	40
10	No	Yes	2.4	2	2	3.50	50
11	Yes	Yes	3.5	1	2	3.70	51
12	Yes	No	3.6	2	2	4.42	47
13	No	No	3.1	1	2	3.70	57
14	Yes	No	3.3	2	1	4.27	50
15	No	No	2.7	1	4	2.20	60
16	Yes	Yes	3.9	1	2	3.57	37
17	No	No	5.2	1	2	3.40	52
18	No	No	2.1	1	1	5.49	36
19	Yes	Yes	6.2	1	2	2.99	59
20	No	Yes	3.0	2	1	3.57	50
21	No	No	2.5	1	3	2.64	44

SIEV: superficial inferior epigastric vein; DIEA: deep inferior epigastric artery

Table 3: Statistical analysis of variables between groups

Variables	Cases (*n* = 7)	Controls (*n* = 21)	Significance (*P*)	Difference and 95% CI
Diameter of SIEV (mm), mean ± SE	3.04 ± 0.63	3.08 ± 1.22	0.915	-0.04 (-1.04, 0.95)
Branches of SIEV (2 branches), *n* (%)	3 (42.86)	5 (23.81)	0.371	19.05 (21.90, 60.00)
Perforators per flap, mean ± SE	1.86 ± 0.69	2.24 ± 0.77	0.255	-0.38 (-1.05, 0.29)
Subcutaneous thickness (cm), mean ± SE	3.56 ± 0.90	3.72 ± 0.83	0.652	-0.16 (-0.92, -0.60)
Communication SIEV-perforators, *n* (%)	4 (57.14)	8 (38.10)	0.418	19.05 (-23.10, 61.20)
Communication SIEVs midline, *n* (%)	3 (42.86)	5 (23.81)	0.371	19.05 (-21.90, 60.00)

SIEV: superficial inferior epigastric vein; CI: confidence interval; SE: standard error

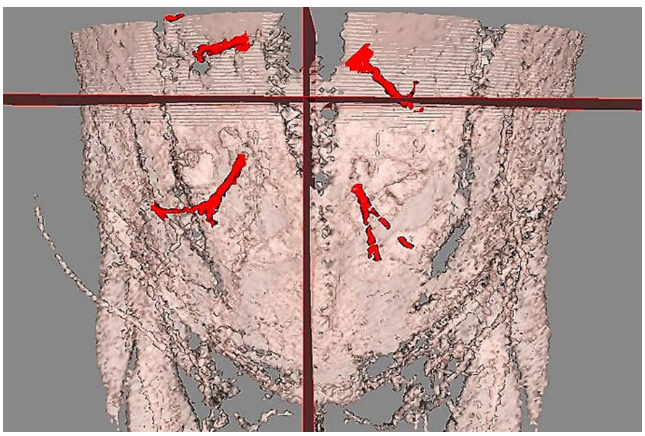

Figure 5: Three-dimensional abdominal wall reconstruction with AYRA software from computed tomography angiography images showing abdominal wall perforators

diameter was not useful for predicting congestion. This finding is consistent with the present study, as no statistically significant evidence (*P* = 0.91) was found when evaluating the SIEV diameter.

Another proposed feature in studies by Schaverien *et al*.,[4] Rozen *et al*.,[6] and Blondeel *et al*.[13] was the absence of direct venous communications of both SIEVs across the abdominal midline, that could favor congestion further this line. This hypothesis was not consistent with the results of our study, as no statistically significant evidence (*P* = 0.37) was found for this variable, being these communications more numerous in the case group than in the control group (48.86% *vs*. 23.81%).

Taking into account the redirection of the venous

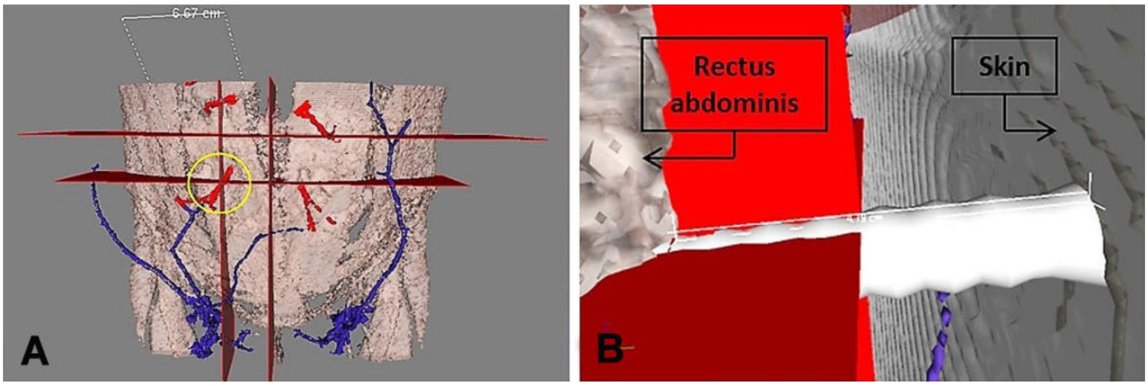

Figure 6: Three-dimensional abdominal wall reconstruction with AYRA software from computed tomography angiography images. (A) Point of measurement (circle) of flap subcutaneous tissue thickness, at the level of the iliac crests horizontally and at the midpoint of rectus abdominis width vertically; (B) measurement of flap subcutaneous tissue thickness

outflow from the superficial towards the deep system, several studies[6,7,11] have suggested that the absence of direct communications between the SIEV and the DIEV through venous perforators could favor congestion. However, statistically significant evidence was only reported by Schaverien *et al*.[7] using magnetic angioresonance, and only when a DIEP flap was dissected based on just one perforator without direct SIEV-DIEV communication. In fact, a larger proportion of these communications was found in the case group than in the control group (57.14% *vs*. 38.10%) in the present study, although statistically not significant ($P = 0.42$).

The number of perforators per flap is another controversial topic. Previous research has revealed that one medial row periumbilical perforator of appropriate caliber provides the best perfusion to the DIEP flap including Hartrampf's zone IV.[4,5] Nevertheless, from the point of view of venous perfusion, DIEP flaps sometimes exhibit a diminished drainage with an increased venous pressure. Douglas *et al*.[5] suggested that just one arterial perforator could provide the optimal perfusion, stating that with two arterial perforators the filling pressure could drop, decreasing the gradient and favoring congestion. For their part, Mohan *et al*.[18] found a non-significant four-fold congestion rate in DIEP flaps based on a single perforator compared to those based on multiple perforators. In the present study, no statistically significant evidence was found for the number of perforators per flap ($P = 0.25$).

The flap subcutaneous tissue thickness was another anatomical feature analyzed. Rubino *et al*.[19] demonstrated that bigger flaps intrinsically develop greater flow rates, and consequently, demand a higher drainage. Bast *et al*.[14] found a correlation between the suprascarpal fat pad thickness and the SIEV caliber, suggesting that thicker pads may show superficial drainage dominance. However, no evidence was reported supporting this hypothesis. Statistically significant evidence was neither found in the present study.

The number of branches of the SIEV was the last anatomical feature evaluated, with a mean of 1.43 for the case group and 1.24 for the control group. Unfortunately, no statistically significant evidence was found.

DIEP breast autologous reconstruction is recognized as a reliable procedure with excellent outcomes and low donor site morbidity.[3] Whereas success rates of over 95% have generally been reported, some flaps exhibit vascular complications and eventually fail.[3] The major complication that may arise is the diffuse venous congestion due to drainage insufficiency,[6,7] neither originated by venous thrombosis nor by technical failures. Finding predictive factors of congestion preoperatively would be extremely helpful for the surgeon. Using duplex ultrasonography, Figus *et al*.[20] reported that the identification of the dominant venous perforator of the flap entailed high possibilities of finding an arterial perforator of adequate caliber (93.5%), higher than the possibilities of finding a venous perforator of good caliber after the identification of the dominant arterial perforator (69.8%). Gravvanis *et al*.[21] compared two subgroups of breast reconstructions regarding vascular dissection: dominant arterial perforator-dissected versus dominant venous perforator-dissected DIEPs. A significant higher rate of venous congestion was found in the arterial perforator group. Laporta *et al*.[22] and Santanelli *et al*.[23] selected the type of perforators and their number for each flap depending on the diameter of the vein, and found that medial row perforators were a negative predictor for flap complications.

As previously stated, CTA is the gold standard technique for planning DIEP flap surgery. To our knowledge, the present study is the first to attempt to link the morphological characteristics of the abdominal wall vessels with DIEP venous congestion by CTA and 3D virtual reconstruction. Unfortunately, according to the results obtained, this method has not demonstrated clinical utility to predict venous congestion. We hypothesize that further than a single anatomical feature, a multifactorial origin leads to venous congestion. During the dissection of a DIEP flap, physiological adaptive changes can take place. The diversion of flow through different pathways or vasodilatation are among them.[15] Therefore, the pressure gradient between arterial perfusion and venous drainage is modified, resulting in an imbalance that may lead to venous congestion.

When a DIEP flap becomes congested, the main effective strategy for enhancing drainage outflow is the pressure relief by venous supercharging of the SIEV, whereas supercharging the second DIEV is less commonly performed.[24,25] This salvage procedure decreases venous pressure, increases pressure gradient and overcomes the venous congestion. Adding large caliber venous anastomosis in parallel decrease the risk of venous congestion, because of the ability to provide a superior drainage. One of the most popular modalities of venous supercharging is the anastomosis of the superficial epigastric vein to the cephalic vein. Other common strategies include the anastomosis of the SIEV to a second internal mammary vein, to an internal mammary perforator, or end-to-side to one of the DIEVs of the flap.[10,25,26] Less popular options include the anastomosis of the SIEV to the thoracoacromial vein, to the contralateral intermammary vein (which may need a vein graft), or to the toracodorsal vein (which may prevent the use of a latissimus dorsi as a rescue surgery in case the DIEP flap fails), among others. Notwithstanding, carrying out a second venous anastomosis is time-consuming, which represents the main drawback of this procedure, taking between 30 to 90 min.[26] The experience of the surgeon and the use of coupler devices may help to reduce this lapse of time. There is another potential drawback, specifically associated with the use of the cephalic vein, which is the possibility of triggering lymphedema in the upper extremity due to the impairment of the lymphatic drainage. Women who have received radiotherapy seem to be more likely to develop this phenomenon. However, the overall risk appears to be reasonably low, being able to consider the harvest of the cephalic vein a safe option.[25]

The systematic venous supercharging has been advocated to prevent the potential drainage insufficiency, after significant results experiencing less congestion.[26] However, a recent meta-analysis has failed to demonstrate the efficacy of the SIEV supercharging to reduce the flap-related complication rate.[9] Whereas venous supercharging has proved its capacity to rescue DIEP flaps that exhibit congestion and would eventually experience partial or total necrosis, the debate still continues about the convenience of supercharging every flap as a preventive strategy for minimizing perfusion-related complications.[9]

The present study has some limitations that should be considered. The low incidence of this phenomenon hinders prospective randomized controlled or prospective nonrandomized trials. Although the sample size is relatively small, this is one of the largest series specifically focused on congestive DIEP flaps reported to date. Further studies are needed to clarify the congestive phenomenon. Pressure gradient is of paramount importance, and its assessment along the flap could shed light on the subject. Larger sample sizes may also led to statistically significant differences when evaluating anatomical features.

In conclusion, this study provided new information to the literature concerning the identification of the anatomical features associated with venous congestion in DIEP flaps. No statistically significant differences were found between venous congestion of the flap and the suggested and accepted predisposing anatomical features. The congestive phenomenon is probably multifactorial, not being able to aim at any of them as the single cause. CTA was a useful tool for identifying the abdominal wall anatomy and planning DIEP breast surgery, but not for preventing the possible diffuse venous congestive phenomenon of this flap preoperatively.

DECLARATIONS

Authors' contributions

Concept design, manuscript preparation, data analysis and interpretation: A. Ruiz-Moya
Data analysis and interpretation: R.A. Lopez-Garcia
Case material's provide: D. Sicilia-Castro, T. Gomez-Cia
Manuscript preparation and review: P. Infante-Cossio

Financial support and sponsorship

None.

Conflicts of interest

There are no conflicts of interest.

Patient consent

All patients signed informed consent to be included in the study.

Ethics approval

The study was reviewed and approved by the Virgen del Rocio University Hospital Ethics Committee.

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