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Original Article

Semiautomatic Quantitative Assessment of DIEP Flap Volume and Thickness for Breast Reconstruction using CTA Data and Implications in Postoperative Complications

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ABSTRACT

Accurately assessing flap volume and thickness is a crucial aspect of breast reconstruction using the deep inferior epigastric perforator (DIEP) flap, especially in challenging cases such as thin or large-breasted women or bilateral reconstruction. To address this, we present an innovative image processing tool utilizing computed tomography angiography (CTA) to measure DIEP flap volume and thickness. Our approach incorporates an elliptical equation validated on DIEP reconstruction patients. Preoperative ab-

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dominal CTA images were obtained from 70 patients who underwent DIEP flap breast reconstruction at Hospital Universitari de Bellvitge from 2017 to 2021. The image processing tool was employed for preoperative quantification, utilizing elliptical approximations, to determine the volume to be harvested and assess the central thickness of the flap. Subsequently, a non-parametric statistical retrospective analysis was conducted to examine these parameters in relation to immediate complications. The mean maximum recruitable volume (MRV) was 1017.15 ± 325.51 cm³, with a mean thickness of 3.65 ± 1.14 cm. No significant correlation was found between postoperative complications and MRV or thickness values. The processing tool offers a reliable solution for accurately measuring the volume and thickness of the DIEP flap from CTA images, aiding surgeons in breast reconstruction decision-making. This innovative approach enhances surgical planning by addressing quantitative values of thickness and volume of the DIEP flap, which is critical for accurate flap assessment.

Introduction

Breast cancer is the most prevalent non-cutaneous cancer worldwide, according to the World Health Organization, with 7.8 million women diagnosed in the past 5 years. Surgery remains the cornerstone of treatment strategies. Mastectomy has dramatic psychological effects on women who undergo the procedure. The loss of a breast leads to feelings of asexuality, loss of self-image, and consequent depression.[1] Therefore, breast reconstruction should always be offered to patients, provided they desire it. It has been shown to have a profound positive impact on mental health and, subsequently, a better quality of life.[2,3]

Autologous reconstruction is considered the gold standard for breast reconstruction, especially in patients undergoing radiotherapy. Advances in surgical technique, such as the DIEP flap, allow tissue transfer without compromising muscle or other anatomical structure, except for skin and fatty tissue.[4] In most cases, the DIEP flap has proven to be the preferred technique for autologous breast reconstruction after mastectomy, because it offers a natural and permanent result with minimal morbidity in the donor area.[5] However, it requires significant microsurgical expertise. It involves meticulous dissection of the vessels within the rectus abdominis muscle.[6,7] The location, course and caliber of the perforators and the fat volume of tissue available for reconstruction are essential factors to consider when planning the surgery.

Computed tomography angiography (CTA) is a standard preoperative method for evaluating the abdominal vascular anatomy of the DIEP flap and the approximate estimation of its dimensions. This preoperative study technique allows the mapping of the perforators, which has been shown to enhance flap dissection efficiency, reduce surgical time and the risk of complications.[8–11] However, the information obtained from CTA is limited and requires a significant time by the radiologist. Also, conventional planning using CTA does not allow for an accurate assessment flap volume or thickness estimations. DIEP flap volume is typically estimated subjectively during the physical examination in the preoperative patient visit. DIEP volume is particularly important in relatively thin patients with large breasts or in patients requiring bilateral breast reconstruction with DIEP is indicated.[12] When the volume of the flap is insufficient, the aesthetic reconstruction result is compromised due to a lack of volume and shape.[13] In addition, the scar in the abdominal area can be too high or even develop dehiscence problems due to excessive tension. Recognizing in advance that the volume may be inadequate allows for potential modifications to the reconstructive strategy, such as considering alternative flap types or even breast implants or tissue expanders. Therefore, preoperative quantitative assessment of CTA data, such as predicted volume and thickness of the flap, can provide valuable information, ultimately leading to improved surgical outcomes and saving time for both radiologists and surgeons.

On another note, it is unclear whether obesity and body mass index (BMI) are related to a higher incidence of complications in DIEP flap surgery.[14–17] Quantitative assessment of the volume and thickness of DIEP flaps preoperatively could have prognostic interest. In addition, it is traditionally assumed that thicker flaps can be associated with insufficient venous drainage from the deep inferior epigastric vein (DIEV), usually used for vein anastomosis. There is no clear evidence to support these claims, although a correlation has been found between the thickness of the superficial fat pad and the dominance of the vein drainage of the flap.[18] Superficial venous dominance can lead to venous congestion and, eventually, flap necrosis. An additional vein anastomosis is performed if venous congestion is probable, usually using the superficial inferior epigastric vein (SIEV). Although efforts have been made to predict which flaps will need a SIEV additional anastomosis, a preoperative prediction tool is unavailable at present.[19–21] Again, quantitative assessment of CTA data could offer preoperative information about DIEP thickness, that could have prognostic value in future studies.

This study proposes a novel image processing tool that provides quantitative information on DIEP flap volume and thickness from CTA data. In addition, we performed a comparative analysis between DIEP volume, thickness and postoperative complications to establish possible correlations. This information could provide surgeons and radiologists with preoperative knowledge that might be useful in planning the procedure. This novel tool can also be useful in future work regarding the morphology and characteristics of DIEP flaps and enhance other studies related to the prediction of complications and morphology of the DIEP flap.

Materials & methods

Patients and dataset description

Patients who underwent DIEP flap reconstruction for breast cancer or prophylactic mastectomy due to high breast cancer genetic risk at the Hospital Universitari de Bellvitge (L'Hospitalet de Llobregat, Barcelona, Spain) between June 2017 and December 2021 were included in the study. Patients without preoperative CTA images were excluded. Demographic data, perioperative factors, and postoperative outcomes were retrospectively collected. Complications were considered using the following criteria: 1) wound dehiscence: cases that required more than 4 weeks to heal and/or needed negative pressure therapy and/or suturing. 2) Hematoma and seroma: cases that required aspiration by puncture, debridement or other surgical maneuvers. 3) Infection: cases with oral or intravenous antibiotic requirement, fever and/or local signs of wound infection. A total of 70 patients were included in the analysis, adhering to the ethical guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Hospital Universitari de Bellvitge, reference PR028/23.

CTA images were acquired using two different types of computed tomography (CT) scanners. The first scanner used was the Aquilion ONE CT (Canon), which obtained between 410 and 556 slices with a thickness of 1 mm or 2 mm, depending on the protocol used. The second scanner used was the LightSpeed VCT (GE Medical Systems), which obtained between 345 and 730 slices with a thickness of 1.25 mm and a spacing between slices of 0.625 mm or 1.25 mm. Intravenous contrast agent, Iomeprol, was administered at a total volume and flow rate of 100 to 120 ml (400 mg/ml) and 4 ml/s, respectively.

In all cases, a Wise pattern skin-sparing mastectomy was performed, except for prophylactic mastectomies, which were nipple-sparing mastectomies. Single-perforator DIEP flaps were harvested. Indocyanine green fluorescence angiography was performed after the vascular anastomosis with the internal mammary vessels was completed. The flap was trimmed based on the result of the angiography. Four plastic surgeons were involved in the operations. The surgery was performed by two teams, one performing the oncological resection, recipient vessels preparation, and microsurgical anastomosis, whereas the other was in charge of dissecting the DIEP flap and the abdominal closure.

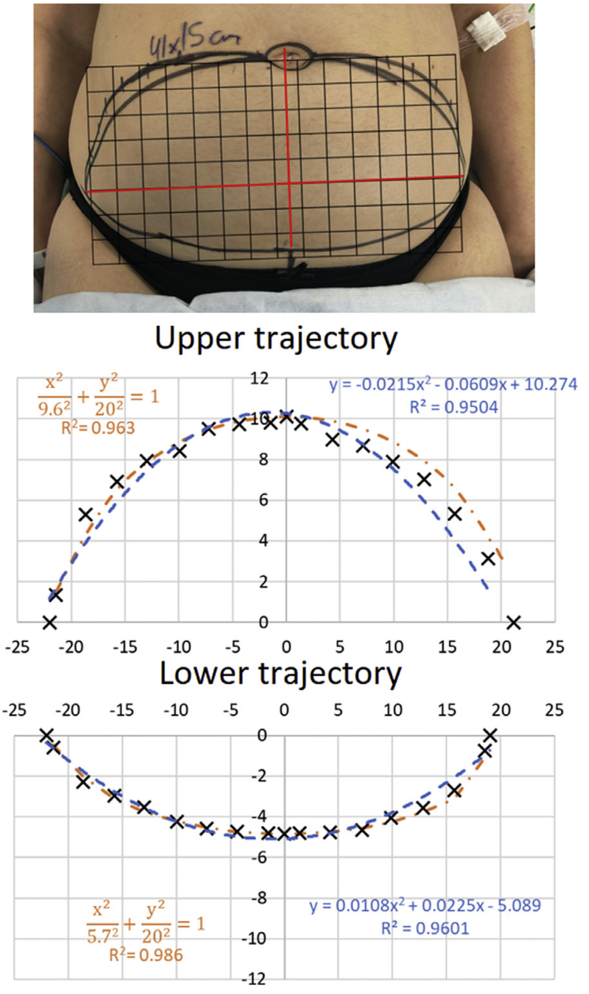

Figure 1. Approximation of flap section area using elliptic and quadratic equations in a patient with a flap trajectory defined with 15 cm height and 41 cm width.

Maximum recruitable volume (MRV) of DIEP flap determination based on image processing algorithm

As previously described in a recent conference paper, we developed a novel image processing algorithm to determine the MRV of the DIEP flap based on CTA images.[22] The best numerical approximation of the MRV was obtained using intraoperative measurements of the volume of DIEP flaps. The complete image processing algorithm and equations can be found in Annex 1. This method approximates the design of the DIEP flap to an elliptic trajectory in the coronal plane of the abdomen, as seen in Figure 1. As the design (projected trajectory) of the flap changes according to the characteristics of the patient, three reference points were needed for each individual case. The reference points were the inferior border of the umbilicus and both anterior superior iliac spines. These reference points were manually introduced by the surgeon and the trajectory of the desired DIEP flap was automatically calculated using an elliptic equation. By image processing methods described in Annex 1, the volume of fat above the abdominal wall was determined automatically and defined as the MRV of the flap.

Table 1
Patients, BMI, DIEP flap area and volume after being harvested.

Patient	BMI (kg/m^2)	Height × width (cm × cm)	Flap volume (cm^3)
A	31.25	15 × 38	1500
B	29.97	14.5 × 39	1300
C	33.46	15 × 41	1900
D	31.63	15 × 40	1500
E	19.00	10 × 28.5	300

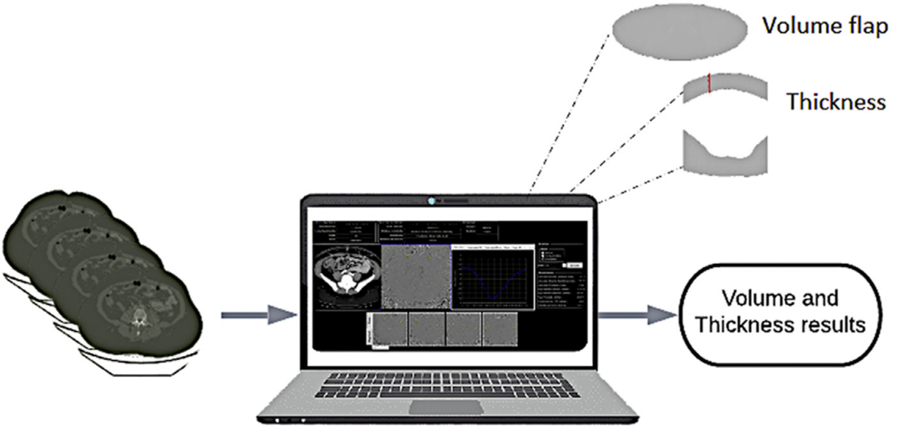

Figure 2. Schematic methodology of the analysis of DIEP flap volume and thickness.

We validated this image processing algorithm in five patients with intraoperative measurements, see Table 1. After the surgeon had designed the DIEP flap in the operating room, the height and width of the flap were recorded. After autonomizing but before trimming the flap, its volume was measured using the water displacement method by introducing the dissected flap into a graduated saline solution bucket. Using the height and width to define the limits of the elliptic trajectory of the algorithm, intraoperative volumes were compared with the calculated ones. The results showed that the elliptic equation could predict the measured DIEP MRV with an accuracy of 91.6% in the worst-case scenario. The results of this study can also be found in Annex 1. Figure 2 illustrates the methodology employed for determining the volume and thickness of the DIEP flap from the acquired CTA images.

Results

The demographic data, surgical timing (90% immediate, 10% delayed), mastectomy side (8.5% were bilateral), and dimensions of the designed flap prior to surgery are listed in Table 2. A total of 35.71% of the patients had received chemotherapy and 24.28% had received radiotherapy before the surgery. Mean flap dimensions were 38 ± 5.8 cm in height and 13.8 ± 2.2 cm in width. The average flap volume was 1,017.15 ± 325.51 cm^3 and the average thickness was 3.65 ± 1.14 cm. An additional vein anastomosis was required in 27.1% of the cases. Table 3 summarizes the postoperative outcomes, including complication rates. The flap survival rate was 91.5%, whereas flap loss accounted for 8.5%, primarily due to arterial thrombosis (7.1%). Breast wound dehiscence occurred in 7.14%, whereas abdominal wound dehiscence occurred in 8.57% of the cases. Infection occurred in 5.71%, hematoma 4.29% and seroma 5.71%. A least-square correlation analysis revealed a linear relationship ($R^2 = 0.753$) between volume and thickness (volume = 108.2 + 248.5x thickness). A strong association was found between BMI, volume and thickness, with a least-square correlation of 0.641. Figure 3 shows the linear correlation between the volume, thickness, and BMI. Table 4 presents the results obtained after

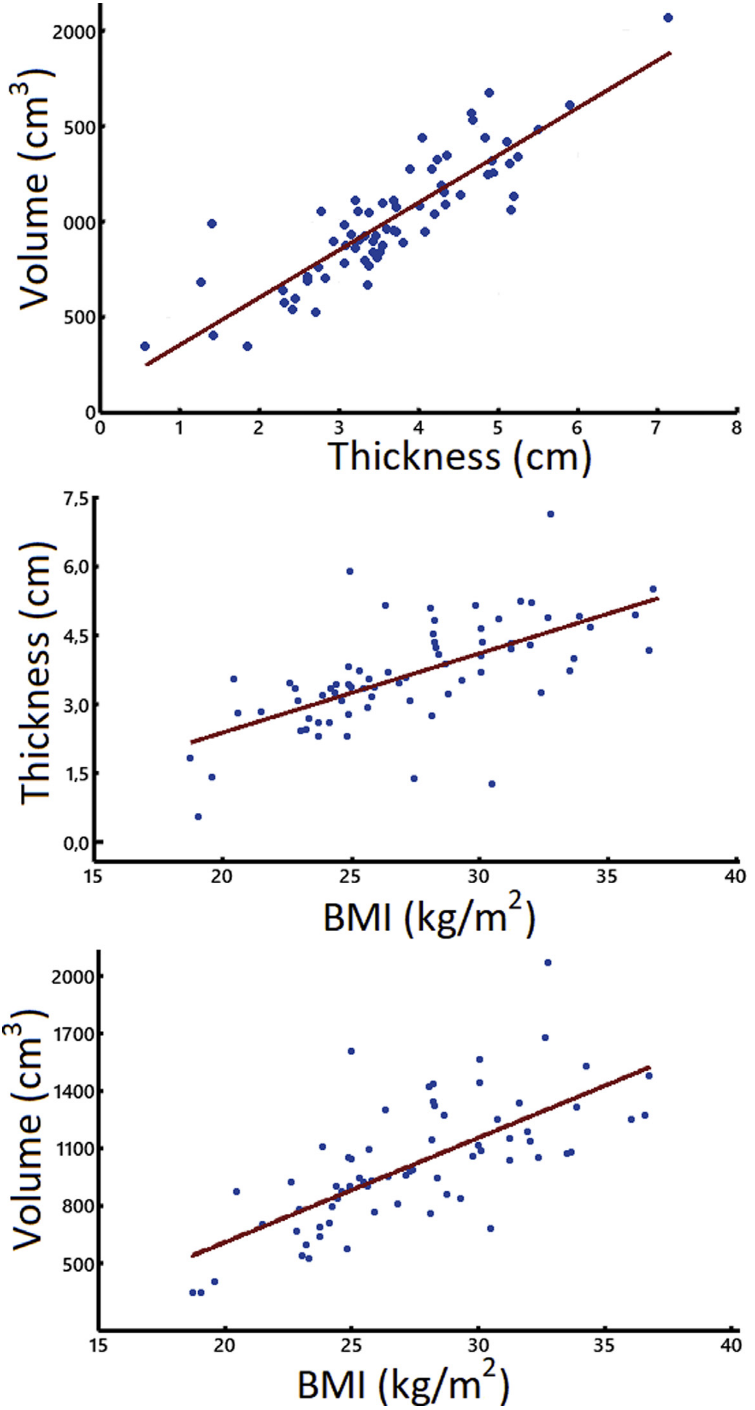

Figure 3. Linear regression of flap volume and thickness and BMI.

Table 2
Patient demographics and intraoperative variables.

Variable	Mean ± STD
Age (years)	51.7 ± 9.3
BMI (kg/m^2)	27.2 ± 4.4
Immediate/delayed	63 (90%)/7 (10%)
Previous CT	25 (35.71%)
Previous RT	17 (24.28%)
Breast side	48.5% (Left)/42.8 % (Right)/8.5% (Bilateral)
Planned flap*	38 ± 5.8 × 13.8 ± 2.2
Additional venous drainage	Yes (19, 27.1%) No (51, 72.9%)
Hospital stay (day)	5.6 ± 1.4

* The planned DIEP flap is defined by the total width [cm] and length [cm] of the flap design from the umbilicus. CT: Chemotherapy. RT: Radiotherapy

Table 3
Postoperative complications.

Breast dehiscence	5 (7, 14%)
Abdominal dehiscence	6 (8, 57%)
Infection	4 (5, 71%)
Hematoma	3 (4, 29%)
Seroma	4 (5, 71%)
Flap survival	Yes (64, 91.4%)
Arterial thrombosis	Yes (5, 7.1%)
Vein thrombosis	Yes (1, 1.4%)

Table 4
Statistical analysis of DIEP flap morphology and immediate postoperative complications.

Response	Factor	p-valor*
Volume	Breast dehiscence	0.198
	Abdominal dehiscence	0.401
	Infection	0.782
	Hematoma	0.187
	Seroma	0.637
	Arterial thrombosis	0.950
	Vein thrombosis	0.499
Thickness	Breast dehiscence	0.445
	Abdominal dehiscence	0.482
	Infection	0.633
	Hematoma	0.274
	Seroma	0.870
	Arterial thrombosis	0.902
	Vein thrombosis	0.522

* Kruskal-Wallis test was used to analyze the response and factor variables.

applying the Kruskal-Wallis test to determine if there was a significant statistical association between volume/thickness and postoperative complications. No significant association was found between the volume or thickness of the DIEP flap and the likelihood of experiencing wound dehiscence, hematoma, seroma, infection, arterial thrombosis, or venous thrombosis.

Discussion

Among the multiple options in autologous tissue transfer, the DIEP flap is the most commonly used (17% of all breast reconstructions in 2020[23]), mainly because of its capacity to provide enough soft tissue to mimic breast morphology while leading to minor donor site morbidity. Despite this, DIEP flap harvesting represents a complex surgical procedure and even with vast experience, the mean operative time reported in studies is at least 4 hours.[24] Preoperative CTA has proven to reduce total operative time, mainly because it helps identify and choose the best perforators before surgery.[25–27] Nevertheless, the surgeon can only infer data regarding the flap volume subjectively. In this study, we demonstrate the development of an image processing tool that predicts the MRV and thickness of the DIEP flap using CTA images. This tool aims to provide information before surgery to help the surgeon in preoperative planning and decision-making. Although validation and regulatory approval are required for clinical use, this software could be installed on a surgeon's computer, enabling comprehensive DIEP flap planning, analogous to conventional CT scanner software.

Little research has explored quantitative DIEP volume acquisition methods. Lee et al.[28] demonstrated that preoperative volumetric analysis of DIEP flaps using CTA data improves postoperative outcomes by reducing partial fat necrosis and overall complications when comparing different patient cohorts. Razzano et al.[29] proposed a simple yet practical DIEP flap volume approximation by measuring abdominal fat thickness with ultrasound and applying the truncated pyramid formula to obtain volumes of already trimmed DIEP flaps. Based on the CTA scan, the image processing tool proposed in this article predicts the MRV and thickness of a DIEP flap without the need for tedious manual segmentation or other types of time-consuming image processing. The information provided might be particularly helpful, especially for slim patients with little abdominal fat on physical examination or in cases of bilateral reconstruction. DIEP reconstruction in thin patients can lead to insufficient breast volume or high abdominal scars that cannot be easily hidden with underwear.[30] Thin patients are not traditionally offered bilateral DIEP reconstructions.[31] Especially in these cases, having quantitative data on the predicted flap could help determine more accurately if a DIEP reconstruction is the best option rather than relying solely on a physical examination.

The morphological data about DIEP flaps collected by the image processing tool were used to conduct a retrospective analysis. There are multiple studies regarding DIEP flap breast reconstruction outcomes in patients with high patients, and they have drawn disparate conclusions.[14-17,32-34] Moreover, patients with high BMI have more cardiovascular risk factors associated with a reduced capacity for wound healing.[35] As might be expected, our study found a statistically significant association between the volume/thickness of the DIEP flap and BMI, indicating that patients with higher BMI had higher volume flaps. Regarding postoperative complications, there was no statistically significant relationship between the volume/thickness of DIEP flaps and any of the complications studied. These results support the claims of some studies that there is no relationship between DIEP volume or thickness and complications.

Limitations of the study

This study has some other limitations. First, it should be noted that the volume measured with this tool represents the MRV of the flap before trimming and in setting. We are aware that the MRV differs from the real volume transferred to the breast, but it still might provide useful information to the surgeon prior to surgery. That is why we are working on a new tool that will enable us to trim the edges of the flap and calculate the predicted volume after trimming, which will more accurately approximate the final volume of the flap. Second, a relatively high flap failure rate has been found, with a predominance for arterial thrombosis rather than venous thrombosis. Although a more in-depth retrospective analysis is needed for confirmation, the high rate of patients who received neoadjuvant chemotherapy (35.71%) combined with the high prevalence of smoking (45%) in our study population may contribute to a higher failure rate than other studies. Regarding the lower rate of venous thrombosis compared to arterial thrombosis, we hypothesize that our tendency to favor superdrainage with SIEV veins, even in cases where its necessity is uncertain, could lead to lower venous congestion rates.

Conclusion

This study demonstrates the development of an image processing tool that allows quantitative analysis of DIEP flap MRV and thickness based on CTA images. This tool has been used to confirm that patients with higher BMI have higher volume DIEP flaps and has shown a significant correlation between volume and thickness and the rate of breast dehiscence. This image processing tool might be useful in the preoperative planning of DIEP breast reconstruction, but this needs to be analyzed in future studies.

Compliance with Ethical Standard

All patients were informed of the procedure and asked to sign a consent form to use their data for research purposes. The Ethics Committee of Hospital Universitari de Bellvitge approved this study, reference PR028/23, under the ethical standards laid down in the Declaration of Helsinki and its later amendments.

Conflict of Interest

All authors declare no financial tie or conflict of interest related directly or indirectly to the current work.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jpra.2024.10.003.

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