Estimation of Hemi-Abdominal-Based Free Flap Weight Using Two Computed Tomography-Derived Measurements

Nicolas Greige, MD, MSc[1] Bryce Liu, BS[1] David Nash, MD[1] Katie E. Weichman, MD[1] Joseph A. Ricci, MD[1]

[1] Division of Plastic and Reconstructive Surgery, Montefiore Medical Center, Albert Einstein College of Medicine; Bronx, New York

Address for correspondence Nicolas Greige, MD, MSc, Division of Plastic Surgery, Montefiore Medical Center, 1776 Eastchester Road, Suite 200, Bronx, NY 10461 (e-mail: ngreige94@gmail.com).

J Reconstr Microsurg 2022;38:549–554.

Abstract

Background Accurate flap weight estimation is crucial for preoperative planning in microsurgical breast reconstruction; however, current flap weight estimation methods are time consuming. It was our objective to develop a parsimonious and accurate formula for the estimation of abdominal-based free flap weight.

Methods Patients who underwent hemi-abdominal-based free tissue transfer for breast reconstruction at a single institution were retrospectively reviewed. Subcutaneous tissue thicknesses were measured on axial computed tomography angiograms at several predetermined points. Multivariable linear regression was used to generate the parsimonious flap weight estimation model. Split-sample validation was used to for internal validation.

Results A total of 132 patients (196 flaps) were analyzed, with a mean body mass index of 31.2 ± 4.0 kg/m^2 (range: 22.6–40.7). The mean intraoperative flap weight was 990 ± 344 g (range: 368–2,808). The full predictive model ($R^2 = 0.68$) estimated flap weight using the Eq. $91.3x + 36.4y + 6.2z - 1030.0$, where x is subcutaneous tissue thickness (cm) 5 cm lateral to midline at the level of the anterior superior iliac spine (ASIS), y is distance (cm) between the skin overlying each ASIS, and z is patient weight (kg). Two-thirds split-sample validation was performed using 131 flaps to build a model and the remaining 65 flaps for validation. Upon validation, we observed a median percent error of 10.2% (interquartile range [IQR]: 4.5–18.5) and a median absolute error of 108.6 g (IQR: 45.9–170.7).

Conclusion We developed and internally validated a simple and accurate formula for the preoperative estimation of hemi-abdominal-based free flap weight for breast reconstruction.

Keywords
- flap weight estimation
- DIEP
- TRAM
- breast reconstruction

Abdominal-based free tissue transfer is the most common method of autologous breast reconstruction in the United States.[1] To optimize clinical and aesthetic outcomes, preoperative planning is paramount. One such component of planning is the estimation of flap weight. The ability to accurately estimate flap weight serves to guide patient expectations and aid in achieving a symmetric reconstruction. Without preoperative planning, the anticipated size of the newly reconstructed breast may be unknown, and the need for a contralateral symmetry procedure may not be

received
June 21, 2021
accepted after revision
September 26, 2021
published online
November 24, 2021

Thieme Medical Publishers, Inc.,
333 Seventh Avenue, 18th Floor,
New York, NY 10001, USA

DOI https://doi.org/10.1055/s-0041-1740133.
ISSN 0743-684X.

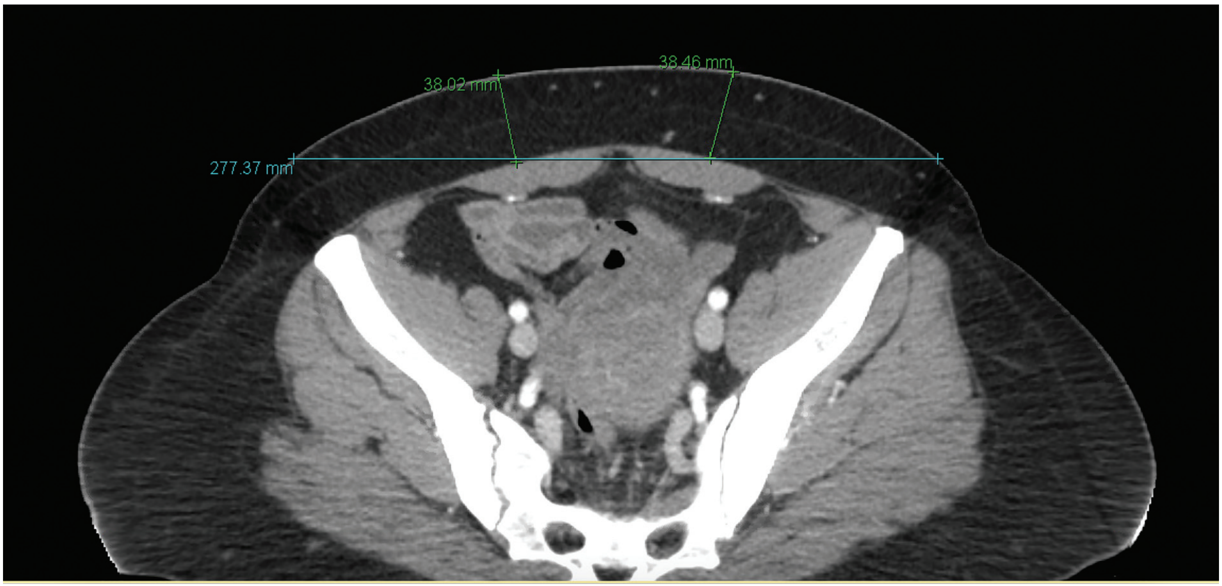

Fig. 1 Axial computed tomography angiography demonstrating subcutaneous thickness measurements (mm) 5 cm lateral to midline in the plane of the anterior superior iliac spine (ASIS), as well as cutaneous distance between each ASIS.

readily apparent. Additionally, accurate flap size estimation also guides decision making when performing conjoined flaps or four flap reconstructions to ensure an adequately voluminous breast mound. This estimate can mean the difference between turning to an alternative donor site or doing a stacked/conjoined flap. Furthermore, preoperative volumetric planning may reduce perfusion-related flap complications.[2]

Several flap weight and volume estimation methods have been previously described.[2–11] Although precise, these methods require a multitude of anthropomorphic measurements obtained using either caliper-based subcutaneous thickness, computed tomography angiography (CTA), magnetic resonance imaging, or three-dimensional photography. Given the necessity of utilizing multiple measurements to obtain an estimate, these methods are often time consuming and may be rendered cumbersome to perform.

CTA is a routine component of preoperative planning in autologous breast reconstruction and has been highlighted for improving operative efficiency.[12–15] Although the chief purpose of preoperative imaging is to discern perforator anatomy, it additionally offers insight into potential flap dimensions. It was our objective to determine the parsimonious flap weight estimation model utilizing preoperative imaging. We hypothesized that a prediction model utilizing measurements obtained from a single axial plane on CT scan could predict flap weight within ~10% of the actual flap weight.

Methods

A retrospective review of all patients who underwent abdominal-based free flaps for breast reconstruction between 2012 and 2020 at a single institution was conducted. Patients were included in the study if the flap was harvested as a hemi-abdominal flap (i.e., flaps extending beyond the midline were excluded), if there was a recent (within one year) preoperative CTA scan of the abdomen and pelvis available for review, and if flap weight was documented immediately after harvest and prior to any excision of excess tissue. Patient demographics and perioperative characteristics including age, body mass index (BMI), history of chemotherapy or radiotherapy, mastectomy technique, flap type, laterality, and extent of lymphadenectomy were collected.

Abdominal Wall Measurements

Subcutaneous tissue thicknesses were measured on each CTA scan by a single investigator (N.G.) at the following predetermined points: in the midline at the level of the anterior superior iliac spine (ASIS), 5 cm lateral to midline at the level of the ASIS, directly anterior to the ASIS, at the midline point equidistant from the xyphoid process and the umbilicus, and at the thickest overall point in the midline. Measurements were obtained on axial CT scan by drawing a line tangential to the abdominal wall at the point of interest and then measuring the thickness perpendicular to this tangent (►**Fig. 1**). Additionally, hip size was measured by drawing a line connecting the skin overlying each ASIS.

Flap Design

The flap is marked as an ellipse bound superiorly by the point ~1 cm above the umbilicus, inferiorly by the point ~5 cm above the pubis, and laterally by each ASIS. The cranial and caudal flap boundaries may be adjusted based on perforator location and abdominal wall soft tissue laxity, such that the abdomen may be closed primarily without excessive tension. For our standard hemi-abdominal flap, we do not extend our dissection past the midline (i.e., Hartrampf zone II is excluded from hemi-abdominal flap). Perforators are identified on preoperative CTA scan, location is verified using pencil Doppler, and preoperative marking of perforators is performed in the operating room.

Statistical Analysis

All analyses were computed using Stata Version 16.0 (StataCorp LLC, College Station, TX). The sample was randomly split for model building (two-thirds of the cohort) and model validation (one-third of the cohort) using a single iteration. A backward stepping multivariable linear regression analysis was performed to determine the parsimonious prediction formula using the larger of the split sample. All first-order interactions were evaluated, and none were found. All test assumptions were assessed, and violations of test assumptions were appropriately addressed. Given that flap weight prediction was modeled using each flap as its own individual observation, and that multiple linear regression does not account for the clustered nature of these data, we developed a mixed effects model to verify the robustness of our prediction model (not reported). The models were found to be quite similar and the within-subject variance was found to be great enough to continue with standard multiple linear regression analysis. After the parsimonious model was determined, the prediction formula was then validated on the remainder of the sample. Additionally, a model was built using the full sample to provide more precise coefficient estimates. Alpha was set at the 0.05 level.

Results

A total of 175 patients (259 flaps) were identified; however, 35 of these patients did not have a flap weight recorded prior to flap trimming, 2 patients underwent flaps extending beyond the midline, and 7 patients had CT scans performed over 1 year preoperatively; therefore, 132 patients (196 hemi-abdominal flaps) were analyzed. Operations were performed by five different surgeons. The mean age of the study population was 51.3 ± 9.4 years and the median BMI was 31.2 ± 4.0 kg/m^2 (►**Table 1**). The mean flap weight was 990 ± 344 g (range: 368–2808). One-hundred thirty-eight (70.4%) flaps were deep inferior epigastric perforator (DIEP) flaps, 14 (7.1%) were muscle sparing (MS)-0 transverse rectus abdominis myocutaneous (TRAM) flaps, and 44 (22.4%) were MS-1 or -2 TRAM flaps. Sixty-five (49.2%) patients underwent bilateral reconstruction and 23 (17.4%) underwent nipple-sparing mastectomy.

Abdominal-Based Flap Weight Estimation and Internal Validation

Flap weight was regressed on the aforementioned points along the abdominal wall in the larger of the split sample ($n = 131$). The parsimonious flap weight prediction formula was described by $99.8x + 32.4y + 4.5z - 810.9$, where x is subcutaneous tissue thickness (cm) 5 cm lateral to midline at the level of the ASIS, y is distance (cm) between the skin overlying each ASIS, and z is patient weight (kg) (►**Table 2**). For instance, a patient with a subcutaneous tissue thickness of 3.8 cm (x), a distance between the skin overlying each ASIS of 32.8 cm, and a weight of 110 kg (z) would have an estimated flap weight of 1,126 g with a 95% confidence interval of 1,037–1,222 g; the actual flap weight was 1,220 g. This model had a coefficient of determination (R^2) that equaled 0.67.

Table 1 Patient and flap characteristics

	Summary statistic ($n = 132$ patients, 196 flaps)
Age, y	51.3 ± 9.4
BMI, kg/m^2	31.2 ± 4.0
Neoadjuvant radiotherapy	56 (42.4)
Neoadjuvant chemotherapy	53 (40.2)
Bilateral reconstruction	65 (49.2)
Flap type	
DIEP	138 (70.4)
TRAM	58 (29.6)
Mastectomy technique	
Skin-sparing	109 (82.6)
Nipple-sparing	23 (17.4)
Lymphadenectomy	
None	26 (19.7)
Sentinel node biopsy	65 (49.2)
Axillary lymph node dissection	41 (31.1)
Flap weight, g	990 ± 344

Abbreviations: BMI, body mass index; DIEP, deep inferior epigastric perforator; SD, standard deviation; TRAM, transverse rectus abdominis myocutaneous.
Reported as mean ± SD or n (%).

Table 2 Linear regression for flap weight prediction in the split sample

Measurement	Regression coefficient (95% CI)
Subcutaneous thickness 5 cm lateral to midline, cm[a]	99.8 (55.7–144.0)
Distance between skin overlying each ASIS, cm	32.4 (18.0–46.8)
Weight, kg	45.0 (13.1–77.0)
Constant	−810.9 (−1113.5–−508.2)

Abbreviations: ASIS, anterior superior iliac spine; CI, confidence interval.
$R^2 = 0.67$, $n = 131$ flaps.
[a]Measured at the level of the ASIS.

The aforementioned model was then validated using the remaining 65 flaps in the sample. The median percent error (calculated as the absolute difference between estimated and actual flap weight divided by the latter) was 10.2% (interquartile range [IQR]: 4.5–18.5). The median absolute error was 108.6 g (IQR: 45.9–170.7).

To calculate increasingly precise flap weight estimates, an additional model was formulated using the entire sample ($n = 196$). This flap weight prediction formula was described by $91.3x + 36.4y + 6.2z - 1030.0$, where the variables are as

Table 3 Linear regression for flap weight prediction in the entire sample

Measurement	Regression coefficient (95% CI)
Subcutaneous thickness 5 cm lateral to midline, cm[a]	91.3 (56.2–126.3)
Distance between skin overlying each ASIS, cm	36.4 (25.2–47.5)
Weight, kg	61.2 (35.1–88.1)
Constant	−1030.0 (−1275.2–−784.8)

Abbreviations: ASIS, anterior superior iliac spine; CI, confidence interval.
$R^2 = 0.68$, $n = 196$ flaps.
[a]Measured at the level of the ASIS.

above (►**Table 3**). The R^2 equaled 0.68. This predictive model is published on our web-based calculator, which can be accessed at plasticsurgerycalc.com (►**Fig. 2**). Given the potential flap weight impact of rectus muscle inclusion, a sensitivity analysis was performed by generating a prediction model utilizing solely DIEP flaps. This model, with a sample size of 138 flaps, had an R^2 of 0.68 and a median percent error of 11.1% (IQR: 5.4–20.3).

Discussion

Our findings demonstrate that hemi-abdominal free flap weight can be estimated to ∼10% error using two measurements obtained from axial CT scan in the plane of the ASIS, in addition to patient weight. The aforementioned model utilizes subcutaneous tissue thickness 5 cm lateral to midline as well as the cutaneous distance between each ASIS. This model was internally validated using one-third of our sample, and the median percent error was 10.2%. Of note, the range of flap weights examined was 368 to 2,808 g, meaning the prediction model can be utilized over a wide array of flap sizes.

Current methods of flap weight and/or volume estimation, although accurate, are cumbersome and limited in their clinical applicability. For instance, ultrasonography has been utilized to estimate abdominal flap volume, a method that requires up to 30 minutes to complete.[5,7,9] Although ultrasonography has been described for preoperative perforator mapping, it is less commonly used than CTA and thus may not be a routine component of preoperative planning at most institutions.[13] Another method described by Woo et al, dubbed the "pinch test," is comprised of three paraumbilical abdominal thickness measurements obtained using a skin-

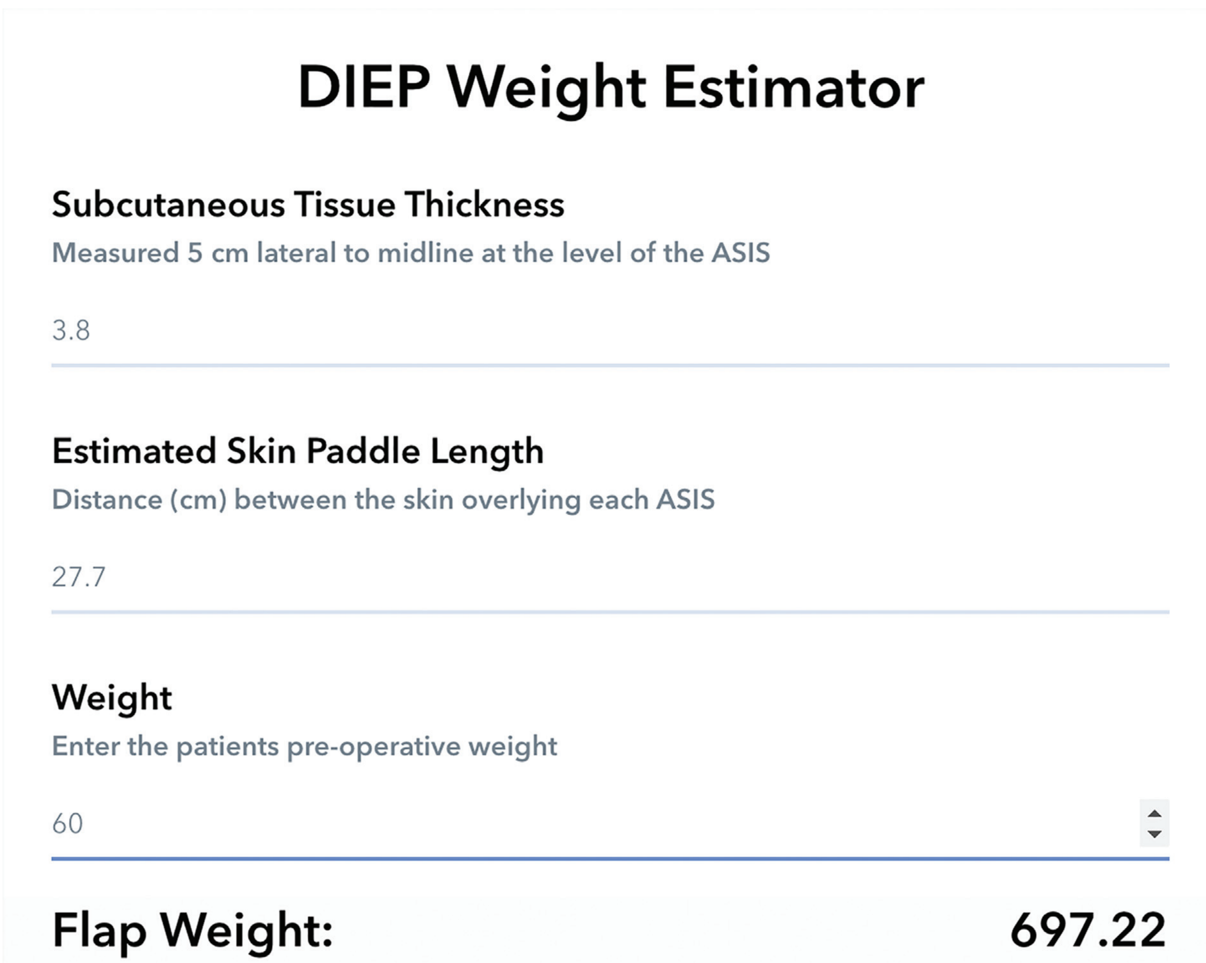

Fig. 2 Abdominal-based-free flap weight estimation calculator webpage, which can be accessed at plasticsurgerycalc.com. ASIS, anterior superior iliac spine; DIEP, deep inferior epigastric perforator.

fold caliper, in addition to flap height, flap width, and patient BMI.[11] Despite being useful when preoperative CTA is not available, the pinch test is particularly limited by interoperator variation in thickness measurements and relies heavily on consistent user technique.

Several studies have demonstrated shorter operative times when CTA is utilized, attributing these findings to enhanced understanding of perforator anatomy.[12,14–16] Given its established role in preoperative planning, as well as its cost-effectiveness, CTA remains the preferred flap weight estimation modality.[3] A predictive model by Woo et al was developed using BMI, flap height, flap width, and subcutaneous tissue thickness measured on CTA at three paraumbilical sites: 5 cm right, left, and inferior to the umbilicus.[10] This model yielded an absolute error of 7.7% with a mean flap weight of 680 g and range of 241 to 1,770 g. Although the aforementioned model was validated with an absolute error 2.5% less than our model, it is limited in its clinical applicability secondary to requiring three subcutaneous thickness measurements performed in multiple axial planes as well as flap height and width to be measured topographically during office visit. Additionally, it is valid over a narrow range of flap weight, limiting its generalizability. Another predictive model by Nanidis et al was developed using an isosceles triangle-based geometric formula requiring measurements obtained on CT scan in both the axial and sagittal planes.[6] The authors reported an absolute error of 6.8% with a mean flap weight of 657 g and a range of 300 to 1,290 g. Despite having a lesser percent error than our model, this study encounters many of the same qualms as the study by Woo et al, namely a cumbersome method and a narrow range of flap weights. Additionally, the sample size is small, with 17 flaps being utilized to build the model and 15 flaps for prospective validation. Of note, the aforementioned models predict the weight of the entire abdominal flap; therefore, direct comparison of prediction error with our model must be interpreted with caution. Lastly, several studies have described using CTA for three-dimensional flap volume estimation.[2,4,8] Although highly accurate, these methods are time consuming and software may not be easily accessible by most institutions. We describe a flap weight estimation method that utilizes just two-thickness measurements obtained from a single axial plane on CTA. Although this parsimonious approach favors ease of use over prediction accuracy, we maintain an acceptable median absolute error of ∼10%. This balance of accuracy and estimation efficiency provides an increasingly encouraging and user-friendly method.

Several abdominal wall measurements were considered during model development including the midline thickness at the level of the ASIS, midline thickness at the midpoint between the xiphoid process and umbilicus, thickest overall midline point, 5 cm lateral to midline at the level of the ASIS, and hip size at the level of the ASIS. Subcutaneous thickness 5 cm lateral to midline at the level of the ASIS was deemed to be the most predictive thickness measurement on the abdomen. We speculate that the midflap location of the ASIS contributed to this point's predictive strength. Additionally, the distribution of adiposity lateral to the midline is more representative of overall abdominal wall adiposity than subcutaneous thickness in the midline. Although a flap weight prediction formula utilizing just this measurement yielded a median absolute error of ∼12%, we felt that measuring hip size at the level of the ASIS added minimal additional time while increasing estimation accuracy.

We recognize several key limitations in our study. First, our model was validated both retrospectively and internally. Prospective, external validation is needed to support the accuracy and generalizability of our prediction method. Second, we only included patients who underwent hemi-abdominal free flaps and are therefore unable to comment on the prediction of other flap designs. Third, a single author measured all variables, which may limit generalizability. Fourth, we combined both DIEP and TRAM flap weight estimation into a single formula, which may contribute to the observed prediction variance. However, a sensitivity analysis was performed using only the 137 DIEP flaps in the study and demonstrated comparable prediction error; therefore, the decision was made to include both DIEP and TRAM flaps in a single formula. Fifth, we can only generalize our estimation to hemi-abdominal flaps, as the error of our prediction formula may be compounded if applied to the entire abdomen. Lastly, we excluded patients who underwent magnetic resonance angiography; therefore, our model cannot be extrapolated to patients imaged using this modality.

Nonetheless, our study encompasses a relatively large sample of hemi-abdominal free flaps performed by multiple surgeons. Given the wide range of flap weights, as well as our split sample validation method, we believe this study provides a reliable, validated, and streamlined method of estimating abdominal-based free flap weight for breast reconstruction.

Conclusion

Hemi-abdominal free flap weight can be estimated to ∼10% error using measurements obtained on CTA. Subcutaneous tissue thickness 5 cm from midline in the plane of the ASIS, hip size at the level of the ASIS, and patient weight were the only parameters needed to obtain an accurate flap weight estimation. This model is valid for flap weights in the range of 368 to 2,808 g.

Presented at
Northeastern Society of Plastic Surgeons Virtual Meeting, September 26th – 27th, 2020.

Conflicts of Interest and Source of Funding
None declared by all authors.

Acknowledgments
This study was supported by the NIH/National Center for Advancing Translational Science (NCATS) Einstein-Montefiore CTSA Grant Number UL1 TR001073.

References

1 Kamali P, Paul MA, Ibrahim AMS, et al. National and regional differences in 32,248 postmastectomy autologous breast reconstruction using the updated national inpatient survey. Ann Plast Surg 2017;78(06):717–722

2 Lee KT, Mun GH. Volumetric planning using computed tomographic angiography improves clinical outcomes in DIEP flap breast reconstruction. Plast Reconstr Surg 2016;137(05):771e–780e

3 Azzi AJ, Hilzenrat R, Viezel-Mathieu A, Hemmerling T, Gilardino M. A review of objective measurement of flap volume in reconstructive surgery. Plast Reconstr Surg Glob Open 2018;6(05):e1752

4 Eder M, Raith S, Jalali J, et al. Three-dimensional prediction of free-flap volume in autologous breast reconstruction by CT angiography imaging. Int J CARS 2014;9(04):541–549

5 Minn KW, Hong KY, Lee SW. Preoperative TRAM free flap volume estimation for breast reconstruction in lean patients. Ann Plast Surg 2010;64(04):397–401

6 Nanidis TG, Ridha H, Jallali N. The use of computed tomography for the estimation of DIEP flap weights in breast reconstruction: a simple mathematical formula. J Plast Reconstr Aesthet Surg 2014;67(10):1352–1356

7 Razzano S, Taylor R, Schonauer F, Figus A. How to assess the volume of a DIEP flap using a free online calculator: the DIEP V (volume) method. J Plast Reconstr Aesthet Surg 2018;71(10):1410–1416

8 Rosson GD, Shridharani SM, Magarakis M, et al. Three-dimensional computed tomographic angiography to predict weight and volume of deep inferior epigastric artery perforator flap for breast reconstruction. Microsurgery 2011;31(07):510–516

9 Taha AA, El Noman A, Mahboub TA, et al. Pre-operative predictive estimation of abdominal flap volume for breast reconstruction using ultrasound and an anthropometric method. Eur J Plast Surg 2018;41(06):653–662

10 Woo KJ, Kim EJ, Lee KT, Mun GH. A novel method to estimate the weight of the DIEP flap in breast reconstruction: DIEP-W, a simple calculation formula using paraumbilical flap thickness. J Reconstr Microsurg 2016;32(07):520–527

11 Woo KJ, Mun GH. Estimation of DIEP flap weight for breast reconstruction by the pinch test. Microsurgery 2017;37(07):786–792

12 Casey WJ III, Chew RT, Rebecca AM, Smith AA, Collins JM, Pockaj BA. Advantages of preoperative computed tomography in deep inferior epigastric artery perforator flap breast reconstruction. Plast Reconstr Surg 2009;123(04):1148–1155

13 Cina A, Salgarello M, Barone-Adesi L, Rinaldi P, Bonomo L. Planning breast reconstruction with deep inferior epigastric artery perforating vessels: multidetector CT angiography versus color Doppler US. Radiology 2010;255(03):979–987

14 Haddock NT, Dumestre DO, Teotia SS. Efficiency in DIEP flap breast reconstruction: the real benefit of computed tomographic angiography imaging. Plast Reconstr Surg 2020;146(04):719–723

15 Kim H, Lim SY, Pyon JK, Bang SI, Oh KS, Mun GH. Preoperative computed tomographic angiography of both donor and recipient sites for microsurgical breast reconstruction. Plast Reconstr Surg 2012;130(01):11e–20e

16 Tong WM, Dixon R, Ekis H, Halvorson EG. The impact of preoperative CT angiography on breast reconstruction with abdominal perforator flaps. Ann Plast Surg 2012;68(05):525–530

