Estimation of Profunda Artery Perforator Flap Weight Using Preoperative Computed Tomography Angiography

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Abstract

Background Given the relatively small size of thigh-based flaps and the possible necessity for a multiflap reconstruction, it is imperative to arrive at an accurate estimation of flap weight during preoperative planning. It was our objective to develop a novel technique for the preoperative estimation of profunda artery perforator (PAP) flap weight.

Methods All patients that underwent transverse PAP flap breast reconstruction at two institutions were retrospectively reviewed. Subcutaneous tissue thicknesses were measured on axial computed tomography angiography scans at several predetermined points. The distance from the inferior gluteal crease to the PAP was also recorded. Linear regression was used to estimate flap weight.

Results A total of 18 patients (32 flaps) were analyzed. The median intraoperative flap weight was 299 g (interquartile range [IQR]: 235 – 408). The parsimonious model ($R^2 = 0.80$) estimated flap weight using the Eq. $77.9x + 33.8y + 43.4z - 254.3$, where x is subcutaneous tissue thickness (cm) at the lateral border of long head of the biceps femoris at a level 4.5 cm caudal to the inferior gluteal fold, y is distance (cm) from the inferior gluteal fold to the dominant PAP, and z has a value of 1 if the patient was scanned in the supine position or 0 if prone. The aforementioned formula yielded a median estimated flap weight of 305 g (IQR: 234–402) and a median percent error of 10.5% (IQR: 6.1–16.2).

Conclusion The authors demonstrate a simple and accurate formula for the preoperative estimation of transverse PAP flap weight for breast reconstruction.

Keywords
► PAP flap
► flap weight estimation
► predictive model

The preponderance of autologous breast reconstruction is abdominally based.[1] Certain patient characteristics, however, may preclude the use of an abdominal donor site. For instance, those with relatively low subcutaneous abdominal adiposity, poor abdominal perforators, previous abdominally-based reconstruction, or a history of abdominoplasty are not suitable candidates for abdominal free tissue transfer. In such cases, reconstructive surgeons may utilize alternative donor sites including the upper thigh and buttocks.

The profunda artery perforator (PAP) flap has become an increasingly popular free tissue option since Allen first described its use in breast reconstruction in 2010.[2] Early adopters of the PAP flap have championed its reliable anatomy, low donor site morbidity, versatility, and comparable success rate to abdominally based free flaps.[3–6] However, PAP flap reconstructions are limited by the relatively small amount of tissue available in the posterior thigh as compared with the abdomen. For example, a systematic review of 12

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studies and 516 flaps demonstrates an average PAP flap weight of 360 g as compared with an average abdominally based flap weight of 638 g found in another study.[6,7] To surmount this potential shortcoming and better match native breast size, multiple PAP flaps may be inset in a stacked fashion.[8,9]

In select patients, the relative paucity of posterior thigh tissue in relation to the amount of tissue necessary to achieve a symmetric breast reconstruction may tip the scales toward a multiflap reconstruction. It is for this reason that arriving at an accurate estimation of flap weight preoperatively is of paramount importance in surgical planning. Several methods have been described for flap weight estimation in abdominally based free flaps; however, no such studies exist for PAP flaps.[10,11] Our objective was to develop a technique for the preoperative estimation of PAP flap weight. Given that preoperative angiography is routinely performed in autologous breast reconstruction, we hypothesized that subcutaneous tissue thicknesses and perforator location, as measured on preoperative computed tomography angiography (CTA) scans, could be used to accurately estimate flap weight.[12–15]

Additionally, we sought to investigate the association between flap weight and PAP flap postoperative complications. Current literature suggests that flap weight may be greater in patients with donor site wound dehiscence; however, there has yet to be a study evaluating the association between flap weight and recipient site complications.[16] It was our secondary objective to further elucidate these associations.

Methods

A retrospective review of all patients that underwent PAP flap breast reconstruction between 2014 and 2019 at two institutions was conducted. Patients were included in the study if they underwent a transverse PAP flap reconstruction (i.e., vertical and tri-lobed PAP flap techniques were excluded), had a preoperative CTA scan available for review, and had documented flap weight immediate after harvest and prior to any excision of excess tissue. Patient demographics and perioperative characteristics including age, body mass index, smoking status, history of chemotherapy or radiotherapy, mastectomy technique, laterality and timing of reconstruction, extent of lymphadenectomy, and operative time, as well as postoperative outcomes including donor site dehiscence/delayed wound healing, hematoma, fat necrosis, mastectomy flap necrosis, infection, seroma, and flap loss were recorded.

Preoperative Planning and Surgical Technique

Our flaps were harvested utilizing the technique described by Allen et al in 2012.[17] As part of preoperative planning, all patients had a CTA of the pelvis and lower extremity for the evaluation of the PAP. In the preoperative holding area, these perforators are then marked on the skin based on measurements from known landmarks taken from CT imaging. The flap is then designed in a transverse elliptical fashion. The flap design is adjusted as necessary to capture the dominant perforator, but generally the superior aspect of the flap is marked 1 cm caudal to the gluteal fold, while the inferior aspect is ~7 cm below the superior marking. The lateral border of the flap is marked at the lateral extent of the inferior gluteal fold and the medial border is marked over the posterior border of the adductor longus. The flap is harvested with the patient in supine frog-leg position. The anterior incisions are made and dissection is carried down to the adductor longus fascia and then continues in a suprafascial plane until the gracilis is encountered. At this point, the gracilis fascia is incised and posteriorly directed dissection continues in subfascial plane. In a similar fashion, the adductor magnus fascia is also incised and flap elevation continued in a subfascial plan until identification of the perforator(s). Intramuscular (or septal) perforator dissection then proceeds until arrival at its origin off of the profunda artery. Following preparation of the recipient vessels in the chest, the flap is harvested.

Upper Thigh Measurements

Subcutaneous tissue thicknesses were measured on each CTA scan by a single investigator (N.G.) at the following predetermined points: the lateral border of the long head of biceps femoris, the junction of adductor magnus and gracilis, and the posterior border of sartorius. These measurements were recorded both in the plane where the dominant PAP pierced the deep fascia and 4.5 cm caudal to the gluteal fold (►**Fig. 1**). The latter plane was chosen as the average midpoint of the flap assuming a standard flap height of 7 cm that began 1 cm inferior to the inferior gluteal fold and terminated 8 cm inferior to the gluteal fold. The distance from the inferior gluteal fold to where the dominant PAP pierced the deep fascia was also recorded. The dominant perforator was identified based on vessel diameter, intramuscular course, and perforator row, with a preference for large vessels with a short intramuscular course (or septocutaneous, if present) and a medial location.

Statistical Analysis

All analyses were computed using Stata Version 16.0 (StataCorp LLC, College Station, TX). Bivariate analyses were performed using Fischer's exact test or Mann–Whitney U test. A forward stepping multiple linear regression analysis was performed to determine the parsimonious prediction formula. 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 proceed with standard multiple linear regression analysis. Alpha was set at the 0.05 level, and statistical power was set at the 0.80 level.

Results

A total of 29 patients were identified; however, 8 of these patients did not have preoperative imaging available for

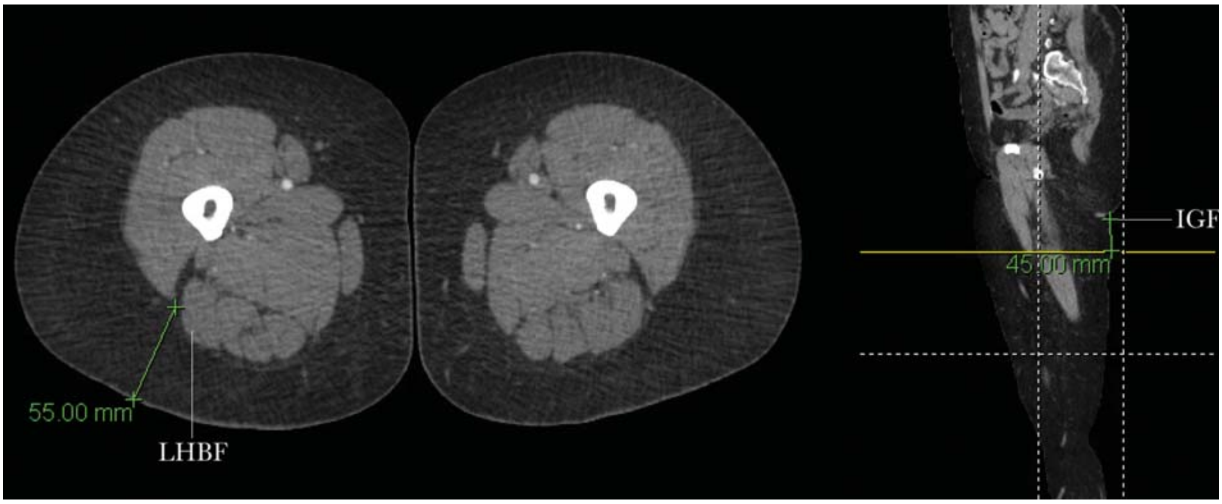

Fig. 1 Axial (left) and sagittal (right) images of a supine-positioned computed tomography angiography scan of a patient with a subcutaneous tissue thickness of 5.5 cm at the lateral border of the long head of the biceps femoris (LHBF) at the level 4.5 cm caudal to the inferior gluteal fold (IGF). The right-sided profunda artery perforator flap had an estimated weight of 471 g and an actual weight of 440 g.

review, 1 patient did not have a recorded flap weight, 1 patient underwent a tri-lobed PAP flap reconstruction, and 1 patient underwent a vertical PAP flap reconstruction; therefore, 18 patients (32 flaps used to reconstruct 23 breasts) were analyzed. Operations were performed by three different surgeons. The median age of the study population was 47 years (interquartile range [IQR]: 42–53) and the median body mass index was 25.4 kg/m^2 (IQR: 21.9–31.5) (►**Table 1**). The median flap weight was 299 g (IQR: 235–408, range: 188–539).

Table 1 Patient, perioperative, and flap characteristics

	Summary statistic
Age, y	47 (42–53)
BMI, kg/m^2	25.4 (21.9–31.5)
Smoking	
Never	14 (77.8)
Former	3 (16.7)
Current	1 (5.6)
Preoperative chemotherapy	11 (61.1)
Preoperative radiotherapy	3 (13.0)
Bilateral reconstruction	6 (33.3)
Stacked reconstruction	9 (39.1)
Delayed reconstruction	7 (30.4)
Nipple-sparing mastectomy	14 (60.9)
Lymphadenectomy	
None	8 (34.8)
Sentinel node biopsy	11 (47.8)
ALND	4 (17.4)
Flap weight	
Measured, g	299 (235–408)
Estimated, g	305 (234–402)
Percent error[a]	10.5 (6.1–16.2)
Operative time, h	9.0 (8.0–10.0)

Abbreviations: ALND, axillary lymph node dissection; BMI, body mass index; IQR, interquartile range.
$n = 18$ patients, 23 breasts, 32 flaps.
Note: Reported as median (IQR) or n(%).
[a]Absolute difference between estimated and actual flap weight divided by actual flap weight.

PAP Flap Weight Estimation Formula

Flap weight was regressed on subcutaneous thigh thickness measurements at the aforementioned points. The parsimonious flap weight prediction formula was described by $77.9x + 33.8y + 43.4z - 254.3$, where x is subcutaneous tissue thickness (cm) at the lateral border of long head of the biceps femoris at a level 4.5 cm caudal to the inferior gluteal fold, y is distance (cm) from the inferior gluteal fold to the dominant PAP, and z has a value of 1 if the patient was scanned in the supine position or 0 if prone (►**Table 2**). For instance, a patient with a subcutaneous tissue thickness of 5.8 cm (x), a distance from gluteal fold to perforator of 2.5 cm, and a CT scan performed in the prone position ($z = 0$) would have an estimated PAP flap weight of 282 g with a 95% confidence interval of 237 to 327 g; the actual flap weight was 313 g. For ease of calculation, readers are encouraged to visit our webpage (►**Fig. 2**).

The aforementioned model resulted in an R^2 of 0.80, meaning that it predicted 80% of the variance in flap weight. The median estimated flap weight was 305 g (IQR: 234–402). The median percent error between actual and estimated flap weight was calculated as the absolute difference between estimated and actual flap weight divided by actual flap weight and was 10.5% (IQR: 6.1–16.2).

Complication Analysis by Flap Weight

Donor site complications were analyzed by individual flap and recipient site complications were analyzed by individual breast. Upper tertiles of either flap weight or total reconstructed breast weight were compared with combined lower tertiles of their respective free tissue weights (►**Table 3**). With respect to donor site complications, 2e observed an

Table 2 Linear regression for flap weight prediction

	Regression coefficient (95% CI)
Subcutaneous thickness lateral to LHBF, cm[a]	77.9 (62.0–93.8)
Distance from IGF to dominant perforator, cm	33.8 (20.9–46.7)
Supine position during CTA scan (reference: prone)	43.4 (7.5–79.3)
Constant	−254.3 (−377.0 to −131.7)

Abbreviations: CI, confidence interval; CTA, computed tomography angiography; IGF, inferior gluteal fold; LHBF, long head of biceps femoris.
Note: $R^2 = 0.80$, $n = 32$ flaps.
[a]Measured at the level 4.5 cm caudal to the IGF.

increased frequency of combined delayed wound healing and wound dehiscence (30.0 vs. 18.2%, $p = 0.65$, power $= 0.09$) and a decreased frequency of thigh hematoma (0.0 vs. 13.6%, $p = 0.53$, power $= 0.13$) in larger flaps as compared with smaller flaps, although these findings were not statistically significant and were underpowered. With respect to recipient site complications, heavier reconstructed breasts, as compared with smaller breast reconstructions, had a decreased frequency of fat necrosis (0.0 vs. 18.8%, $p = 0.53$, power $= 0.13$) and an increased frequency of both hematoma (28.6 vs. 0.0%, $p = 0.08$, power $= 0.58$) and mastectomy flap necrosis (14.3 vs. 6.3%, $p = 0.53$, power $= 0.13$), although these findings were not statistically significant and were underpowered. We did not observe any PAP flap loss, seroma, or infection.

Table 3 Complication analysis by upper versus combined lower tertiles of flap weight (upper) and reconstructed breast weight (lower)

	Upper tertile	Lower tertile	*p*–Value
Donor site ($n = 32$)	≥ 381 g ($n = 10$)	< 381 g ($n = 22$)	
Delayed wound healing/wound dehiscence	3 (30.0)	4 (18.2)	0.65
Hematoma	0 (0.0)	3 (13.6)	0.53
Recipient site ($n = 23$)	≥ 488 g ($n = 7$)	< 488 g ($n = 16$)	
Fat necrosis	0 (0.0)	3 (18.8)	0.53
Hematoma	2 (28.6)	0 (0.0)	0.08
Mastectomy flap necrosis	1 (14.3)	1 (6.3)	0.53

Note: Reported as *n* (%).

Discussion

Our work demonstrates that PAP flap weight can be preoperatively estimated over a wide range of flap weights using

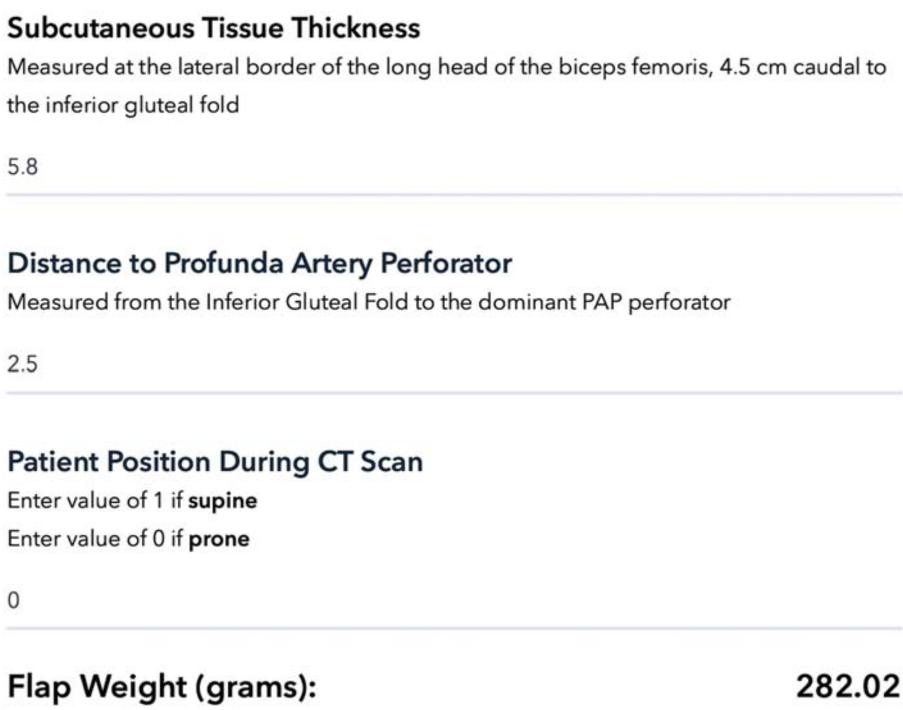

Fig. 2 Profunda artery perforator (PAP) flap weight calculator webpage for a patient with an estimated PAP flap weight of 282 g and an actual flap weight of 313 g (https://dwnash12.wixsite.com/website/post/profunda-artery-perforator-flap-weight-estimator).

CTA scans. Subcutaneous tissue thickness, PAP location, and patient position during CTA scan all significantly contribute to arriving at an accurate estimation of transverse PAP flap weight. The utility of possessing an accurate PAP flap weight prediction model is multifaceted. Given the anatomic location of this flap, as well as variation in perforator location, it is difficult to predict flap weight by way of physical examination. Inaccurate flap weight estimation may result in unanticipated increases in operative time in an effort to achieve a symmetrical reconstruction. Overestimation of flap size may warrant augmentation of the reconstruction with harvest of an additional flap, placement of an implant underneath the flap, or commit the patient to another stage in their reconstruction. It may also contribute to additional donor site complications as surgeons may bevel more in an attempt to avoid performing a stacked reconstruction leading to an unintended degree of tension on the eventual closure. Conversely, underestimation of flap (or flaps, when stacked) weight results in additional flap trimming, a maneuver that increases operative time and complication rate. Precise estimation of flap weight serves to enhance preoperative planning and streamline intraoperative decision-making.

We believe that subcutaneous tissue thickness, PAP location, and patient position during CTA scan all contribute to accurate flap weight estimation for difference reasons. Subcutaneous tissue thickness at the border of the long head of the biceps femoris serves as an overall representation of flap thickness. It is our impression that the lateral location of this thickness measurement allows for minimal distortion secondary to patient positioning during imaging; therefore, it better represents overall flap thickness than subcutaneous tissue thickness measured at other anatomic landmarks. The distance from inferior gluteal fold to where the dominant PAP pierces the deep fascia is paramount to determining flap height. Although the standard transverse PAP flap markings anticipate a flap height of 7 cm, it is not infrequently that this height may be adjusted to incorporate a perforator that resides caudal to the standard inferior flap border.[17] Finally, patient position (supine or prone) during imaging has an impact on measured subcutaneous tissue thickness. Patients imaged in the supine position have decreased posterior thigh thickness measurements as compared with those imaged in the prone position secondary to compression of subcutaneous tissue at the interface with the CTA table.

To our knowledge, this is the first study to demonstrate that PAP flap weight can be preoperatively estimated using CTA measurements. Previous studies, however, have employed CTA in the estimation of deep inferior epigastric perforator (DIEP) flap weight. Woo et al utilized a similar approach to create a DIEP flap estimation formula that predicted flap weight with an absolute error of 7.7% and an R^2 of 0.93, which is more accurate than our absolute error of 10.5% and R^2 of 0.80.[11] The authors used a sample size of 100 flaps to develop their prediction formula, which suggests that we may be able to arrive at a more accurate estimation of PAP flap weight by increasing the size of our study. Additionally, PAP flap weight may be inherently more difficult to estimate than DIEP flap weight given the variability associated with perforator location. The amount of fat beveling performed also contributes increased variability in PAP flap weight, as beveling comprises a greater percentage of PAP flap weight than DIEP flap weight. Another study by Nanidis et al described a geometric formula for the estimation of DIEP flap weight using CTA, which was associated with an absolute error of 6.8%.[10] In our experience, a geometric-based formula is difficult to implement for the estimation of PAP flap weight given the potential association between perforator location and flap height. Additionally, this method of flap weight estimation requires the conversion of volume to weight and assumes a constant interpatient flap density. Given that free tissue transfer for breast reconstruction is primarily adipose tissue by weight, and adipose tissue density has been demonstrated to vary, we deemed it most appropriate to directly estimate flap weight using multiple linear regression.[18]

We examined the association between flap weight and postoperative complications; however, our analysis was largely underpowered. We did find that heavier reconstructions were more frequently complicated by breast hematoma than smaller reconstructions with a trend toward significance. This association was likely confounded by stacked reconstruction, as both hematomas occurred in breasts that were reconstructed using stacked flaps. Additionally, we observed an increased frequency of donor site wound dehiscence/delayed wound healing in larger flaps. Although not statistically significant, this finding is consistent with results from a study by Cho et al in 2019 who reported that PAP flap donor sites complicated by wound dehiscence had an average flap weight 70 g greater than uncomplicated donor sites.[16] Further studies are needed to adequately analyze these relationships.

These findings are limited by small sample size. As previously mentioned, we feel that increasing the number of flaps included in the study would lead to a more accurate and precise PAP flap weight estimation formula. Additionally, this study is limited by its retrospective design and lack of internal and external validation methods; further studies are required to validate this prediction model. We also acknowledge the potential limitations stemming from a single author having measured all variables introduced into the model, namely that it may reduce the generalizability of our findings. Finally, we did not include patients who were imaged with magnetic resonance angiography (MRA). This limits the generalizability of our estimation model, as we are unable to comment on its utility in patients who are imaged using MRA.

Conclusion

We describe an accurate, novel, and simple method for the preoperative estimation of transverse PAP flap weight in breast reconstruction using CTA. Our prediction model consists of two measurements, namely subcutaneous tissue thickness and PAP location, as well as noting the patient position during CTA. The strengths of our study are highlighted by a multi-surgeon and multi-institution experience, a wide range of flap weights, and a three-variable prediction formula that estimated PAP flap weight to within 10% error.

Note

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Conflicts of Interest

None declared.

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 Allen RJ. Lateral Thigh Perforator Flap Live Surgery Performed. 13th International Course on Perforator Flaps. Mexico City, Mexico. 2010
3 Dayan JH, Allen RJ Jr. Lower extremity free flaps for breast reconstruction. Plast Reconstr Surg 2017;140(5S Advances in Breast Reconstruction):77S–86S
4 Haddock N, Nagarkar P, Teotia SS. Versatility of the profunda artery perforator flap: creative uses in breast reconstruction. Plast Reconstr Surg 2017;139(03):606e–612e
5 Haddock NT, Gassman A, Cho MJ, Teotia SS. 101 Consecutive profunda artery perforator flaps in breast reconstruction: lessons learned with our early experience. Plast Reconstr Surg 2017;140 (02):229–239
6 Qian B, Xiong L, Li J, et al. A systematic review and meta-analysis on microsurgical safety and efficacy of profunda artery perforator flap in breast reconstruction. J Oncol 2019;2019:9506720
7 Lam G, Weichman KE, Reavey PL, et al. Analysis of flap weight and postoperative complications based on flap weight in patients undergoing microsurgical breast reconstruction. J Reconstr Microsurg 2017;33(03):186–193
8 Haddock NT, Cho MJ, Gassman A, Teotia SS. Stacked profunda artery perforator flap for breast reconstruction in failed or unavailable deep inferior epigastric perforator flap. Plast Reconstr Surg 2019;143(03):488e–494e
9 Tessler O, Guste J, Bartow MJ, et al. Stacked lateral thigh perforator flap as a novel option for autologous breast reconstruction. Plast Reconstr Surg 2019;143(06):1601–1604
10 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
11 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
12 Agrawal MD, Thimmappa ND, Vasile JV, et al. Autologous breast reconstruction: preoperative magnetic resonance angiography for perforator flap vessel mapping. J Reconstr Microsurg 2015;31 (01):1–11
13 Mohan AT, Zhu L, Sur YJ, et al. Application of posterior thigh three-dimensional profunda artery perforator perforasomes in refining next-generation flap designs: transverse, vertical, and S-shaped profunda artery perforator flaps. Plast Reconstr Surg 2017;139 (04):834e–845e
14 Saad A, Sadeghi A, Allen RJ. The anatomic basis of the profunda femoris artery perforator flap: a new option for autologous breast reconstruction–a cadaveric and computer tomography angiogram study. J Reconstr Microsurg 2012;28(06):381–386
15 Vasile JV, Levine JL. Magnetic resonance angiography in perforator flap breast reconstruction. Gland Surg 2016;5(02):197–211
16 Cho MJ, Teotia SS, Haddock NT. Classification and management of donor-site wound complications in the profunda artery perforator flap for breast reconstruction. J Reconstr Microsurg 2020;36 (02):110–115
17 Allen RJ, Haddock NT, Ahn CY, Sadeghi A. Breast reconstruction with the profunda artery perforator flap. Plast Reconstr Surg 2012;129(01):16e–23e
18 van der Pot WJ, Kreulen M, Melis P, Hage JJ. Specific volume of female subcutaneous abdominal tissue as a reference in autologous breast reconstruction. J Reconstr Microsurg 2010;26(03):185–188