Published in final edited form as:

Plast Reconstr Surg. 2014 February ; 133(2): 223–233. doi:10.1097/01.prs.0000436845.92623.9a.

Muscle-Sparing TRAM Flap Does Not Protect Breast Reconstruction from Post-Mastectomy Radiation Damage Compared to DIEP Flap

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Abstract

BACKGROUND—Radiation to free flaps following immediate breast reconstruction has been shown to compromise outcomes. We hypothesized that irradiated muscle-sparing free transverse rectus abdominis musculocutaneous (MS FTRAM) flaps experience less fat necrosis than irradiated deep inferior epigastric perforator (DIEP) flaps.

METHODS—We performed a retrospective study of all consecutive patients undergoing immediate, autologous, abdominal-based free flap breast reconstruction with MS FTRAM or DIEP flaps over a 10-year period at The University of Texas MD Anderson Cancer Center. Irradiated flaps (external-beam radiation therapy) after immediate breast reconstruction were compared to non-irradiated flaps. Logistic regression analysis was used to identify potential associations between patient, tumor, and reconstructive characteristics and surgical outcomes.

RESULTS—A total of 625 flaps were included in the analysis: 40 (6.4%) irradiated vs. 585 (93.6%) non-irradiated. Mean follow-up for the irradiated vs. non-irradiated flaps was 60.0 months and 48.5 months, respectively ($p=0.02$). Overall complication rates were similar for both the irradiated and non-irradiated flaps. Irradiated flaps (i.e., both DIEP and MS FTRAM flaps) developed fat necrosis at a significantly higher rate (22.5%) than the non-irradiated flaps (9.2%; $p=0.009$). There were no differences in fat necrosis rates between the DIEP and MS FTRAM flaps in both the irradiated and non-irradiated groups.

CONCLUSIONS—Both DIEP and MS FTRAM flap reconstructions had much higher rates of fat necrosis when irradiated. Contrary to our hypothesis, we found that immediate breast reconstruction with an MS FTRAM flap does not result in a lower rate of fat necrosis than reconstruction with a DIEP flap.

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Presented at the 8th Annual Association for Academic Surgery and Society of University Surgeons Academic Surgical Congress in New Orleans on February 6, 2013.

Financial Disclosure: Dr. Garvey is a consultant for LifeCell Corporation (Branchburg, NJ). None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

Products Mentioned: There are no commercial products mentioned in this manuscript.

INTRODUCTION

Postmastectomy radiation therapy (PMRT) has been shown to decrease the local recurrence and increase the overall survival rates of patients with breast cancer, even patients with early-stage breast cancer.^{1–7} However, PMRT can compromise the outcomes of immediate breast reconstructions that use abdominal-based free flaps such as deep inferior epigastric perforator (DIEP) flaps or muscle-sparing free transverse rectus abdominis musculocutaneous (MS FTRAM) flaps.^{6–14} Radiation therapy has been shown to cause fibrosis within the stroma of fat tissue where the blood vessels supply the adipose cells, which can result in cell death and subsequent fat necrosis. Fat necrosis and fibrosis in free flaps can lead to atrophy and contracture of the reconstructed breast and patient dissatisfaction (Figure 1).^{7–10,13–18}

The deleterious effects of PMRT on free flap breast reconstruction can be avoided by delaying the transfer of the free flap until after completion of the mastectomy and PMRT.^{9,19–23} In an effort to preserve the dimensions of the breast skin envelope, many surgeons place a tissue expander at the time of skin-sparing mastectomy in patients who will undergo PMRT and transfer the flap after completion of PMRT.^{20–25}

Other surgeons, however, have found a staged or delayed approach to free flap breast reconstruction to be onerous and costly and have advocated instead allowing the abdominal-based free flap to be irradiated. These surgeons have found the deleterious effects of PMRT to be acceptable and preferable to the delay in reconstruction and additional surgery required for the staged approach.^{6,12,26–30} Others have suggested that breast reconstruction with an MS FTRAM flap rather than a DIEP flap will avoid or decrease the deleterious effects of radiation because MS FTRAM flaps have a more robust blood supply.³¹ However, it is not known whether irradiated MS FTRAM flaps experience less fat necrosis and fibrosis than irradiated DIEP flaps. We hypothesized that immediate reconstruction using irradiated MS FTRAM flaps would be associated with fewer perfusion-related complications (i.e., fat necrosis) than immediate reconstruction using irradiated DIEP flaps.

PATIENTS AND METHODS

We retrospectively reviewed a prospectively maintained database of consecutive patients who underwent immediate abdominal-based free flap breast reconstructions performed by 26 reconstructive surgeons at The University of Texas MD Anderson Cancer Center between January 2000 and May 2011. The MD Anderson Institutional Review Board approved this study.

The flaps were classified as MS FTRAM or DIEP flaps.^{32–34} Our surgeons generally harvested DIEP and MS FTRAM flaps on either the medial or lateral DIEA branch through fascial incisions around the individual perforators using a fascia-sparing technique. DIEP flaps were raised by splitting the rectus abdominis muscle. MS FTRAM flaps were typically raised by harvesting a longitudinal section of muscle around the same-branch perforators or the section of muscle between medial and lateral branch perforators. The DIEP flaps were further classified according to the number of perforators. Single-perforator DIEP flaps were used only when the combined arterial and venous perforator diameter was >3 mm. Flaps harvested with perforators originating from either the medial or lateral branch of the deep inferior epigastric artery (DIEA) were classified as “Single DIEA Branch” flaps, while flaps harvested with perforators originating from both the medial and lateral branches of the DIEA were classified as “Both DIEA Branch” flaps.³⁵ The retrospective design of our study prevented an accurate description of the number of perforators in the MS FTRAM flaps, as our surgeons infrequently reported the number of perforators harvested in the MS FTRAM

operative reports, yet often reported the number of perforators harvested for the DIEP flaps. While it was impossible to accurately quantify perforator number when muscle was included, in general our MS FTRAM flaps do typically include more perforators than our DIEP flaps.

We included immediate DIEP and MS FTRAM reconstructions that were harvested as either “hemi-flaps” or “cross-midline flaps” and excluded “total flaps” (according to Holm perfusion zones as previously described).^{33,36} We also excluded patients with <6 months of postoperative follow-up, patients in whom the reconstruction was performed using a technique other than DIEP or MS FTRAM abdomen-based free flaps, and patients who underwent PMRT >10 months after free flap reconstruction (to exclude fat necrosis that may have resulted from decreased vascularity independent of the effects of radiation).

Our surgeons generally avoided immediate free flap breast reconstruction in patients who had a moderate (~ 20%) risk of requiring PMRT. However, some patients with a low preoperative risk of PMRT underwent immediate autologous breast reconstruction and were then found to have more extensive disease than predicted preoperatively and to require PMRT to the flaps. Thus, 40 of the patients included in the study underwent PMRT after immediate free flap breast reconstruction.

Patients were followed-up postoperatively with a clinical examination monthly for at least 6 months, every 3 to 6 months for 1 year, and then annually. Fat necrosis of the flap was defined as a palpable firm region ~ 1 cm in diameter that persisted more than 3 months postoperatively.^{33,37} The presence of fat necrosis of the flap was determined by clinical examination with radiographic or pathologic confirmation. Skin dehiscence was a separation of the incision ~ 0.5 cm. Delayed healing was defined as a wound requiring debridement and healing by secondary intention. Infection (cellulitis/abscess) was defined as erythema requiring treatment with intravenous or oral antibiotics with or without surgical intervention. Breast complications included only recipient site complications. Revisional surgery was defined as surgery needed to directly excise fat necrosis and revise the reconstructed breast.

Patient, treatment, and surgical outcome data were analyzed. The primary outcomes measured were the relationships between PMRT status and the occurrence of fat necrosis and the effects of DIEP vs. MS FTRAM harvest on the occurrence of fat necrosis with respect to PMRT.

Secondary outcome measures included the effects of PMRT on the rates of overall recipient site and flap complications. Recipient site complications were evaluated for each reconstructed breast and included the following: breast wound complications (infection, delayed healing, skin dehiscence, hematoma/seroma), mastectomy skin necrosis, perfusion-related complications (fat necrosis, partial flap necrosis), microvascular complications (arterial thrombosis, venous thrombosis), compromised integrity of the abdominal wall (bulge, hernia, umbilical necrosis), and abdominal wound complications (infection, delayed healing, skin dehiscence, hematoma/seroma).

When available, the ultrasound images of the flaps with fat necrosis were studied to determine the dimensions of the fat necrosis. We multiplied the height, width, and depth of the ultrasound-imaged fat necrosis to calculate a volume and then compared the mean fat necrosis volumes between the irradiated and non-irradiated DIEP and MS FTRAM flaps. To analyze the impact of flap volume on the effects of PMRT, the flaps were grouped into one of two groups (hemi-flaps or cross-midline flaps).

Statistical Analysis

We compared patient demographics and differences in outcomes between patients with irradiated and non-irradiated flaps using the Chi-squared test or Fisher's exact test for categorical variables and Student's t-test for continuous variables. To account for correlation between the flaps within the same patient, we compared the reconstruction characteristics between the two groups using the univariate and multivariate generalized estimating equation (GEE) model. The patient characteristic was included as an independent variable in the multivariable GEE model if the p-value was less than or equal to 0.25 in the univariate analysis. The final GEE model for each outcome was determined using a backward selection algorithm. A p-value of <0.05 was considered significant. The analyses were performed in SAS 9.2 (SAS Institute, Inc., Cary, NC). A senior staff biostatistician (Z.H.) performed all statistical analyses.

RESULTS

We included 625 flaps in 518 patients who met the inclusion criteria and had a mean follow-up duration of 49.1 ± 28.6 months. The mean patient age was 49.7 ± 9.2 years, and the mean length of hospitalization was 5.2 ± 1.5 days. Patients' characteristics were similar between the irradiated and non-irradiated study groups, with the exceptions of the patients in the non-irradiated group being older ($p=0.008$), having a higher mean body mass index ($p=0.04$), and undergoing more prior radiotherapy ($p=0.01$; Table 1). A higher percentage of patients with irradiated flaps required postoperative chemotherapy ($p<0.0001$). Mean follow-up was longer for the patients with irradiated flaps (60.0 vs. 48.5 months; $p=0.02$).

Approximately two-thirds of the reconstructions were MS FTRAM flaps ($N=396$, 63.4%) and one-third were DIEP flaps ($N=229$, 36.6%). More than one-half of the flaps were harvested as hemi-abdominal flaps ($N=361$, 57.8%) rather than cross-midline flaps ($N=228$, 36.5%). We were unable to classify 36 (5.8%) flaps as hemi-abdominal or cross-midline flaps from the operative reports. Table 2 demonstrates that the technical characteristics of the reconstructions were similar between the non-irradiated and irradiated groups with respect to the proportions of DIEP and MS FTRAM flaps, flap volumes, number of perforators, and number of DIEA branches harvested. The internal mammary vessels served as recipient vessels more often for the non-irradiated flaps (88.0%) than the irradiated flaps (70.0%; $p=0.001$).

Incidence of and Factors Associated with Fat Necrosis

We evaluated which factors were specifically associated with fat necrosis and how PMRT affected the incidence of fat necrosis. The overall fat necrosis rate was 10.2%. The rates of fat necrosis were similar for the DIEP (10.5%) and MS FTRAM (9.8%) flaps but were significantly higher for the irradiated than for the non-irradiated flaps (22.5% vs. 9.2%, respectively; $p=0.06$) (Table 3). Of the flaps that developed fat necrosis ($n=63$), 73.4% had fat necrosis that was confirmed either pathologically or radiographically. Ultrasound images of the flaps with fat necrosis were available for 23 flaps. The mean volume of the fat necrosis was similar in the irradiated ($n=7$) and non-irradiated ($n=16$) flaps (2.5 cm^3 versus 1.7 cm^3 , respectively; $p=0.9$).

Independent predictors of the development of fat necrosis in both univariate and multivariate logistic regression analyses were PMRT, a flap that included tissue across the midline (zone 3), the presence of at least one medical comorbidity, and preoperative chemotherapy (Table 3). Specifically, multivariate logistic regression analysis demonstrated that the odds of a flap developing fat necrosis were almost three times higher when the flap was subjected to radiation therapy ($OR=2.71$, 95% $CI=1.10-6.67$; $p=0.03$). Irradiated MS FTRAM flaps were

almost four times more likely to develop fat necrosis than MS FTRAM flaps that were not irradiated ($p=0.006$) (Table 4). We also observed a trend towards a higher fat necrosis rate among irradiated versus non-irradiated DIEP flaps; the rate was twice as high for the irradiated DIEP flaps, but the difference did not reach statistical significance.

We then analyzed whether irradiated MS FTRAM flaps experienced lower rates of fat necrosis in comparison to irradiated DIEP flaps (Table 5) and found that fat necrosis rates were actually higher for the irradiated MS FTRAM flaps (25.9%) than for the irradiated DIEP flaps (15.4%), although the percentages were statistically equivalent ($p=0.43$). Interestingly, the non-irradiated MS FTRAM and DIEP flaps also had equivalent rates of fat necrosis (8.7% vs. 10.2%, respectively; $p=0.55$).

Of the flaps that developed fat necrosis, a higher, yet statistically equivalent, percentage of the non-irradiated flaps required additional surgery to excise the fat necrosis compared with the irradiated flaps (48.1% vs. 22.2%, respectively; $p=0.12$). Subset analysis demonstrated this to be true for both the non-irradiated vs. irradiated MS FTRAM (43.8% vs. 28.6%, respectively; $p=0.43$) and DIEP (54.5% vs. 0%, respectively; $p=0.48$) groups.

Factors Affecting Overall Complication Rates

Overall complication rates were similar for the DIEP and MS FTRAM reconstructions (30.6% vs. 33.1%, respectively; $p=0.53$). Multivariate logistic regression analysis demonstrated that older age, higher body mass index, preoperative chemotherapy, bilateral reconstruction, 2 medical comorbidities, and use of the thoracodorsal vessels as recipient vessels were significant independent predictors of a higher overall complication rate (Table 6). Multivariate logistic regression analysis found preoperative chemotherapy, single DIEA branch harvest, and medical comorbidities to be significant independent predictors of flap complications (Table 7).

DISCUSSION

This study contains the largest patient cohort to date specifically evaluated to compare DIEP and MS FTRAM flap tolerance to PMRT. Contrary to our initial hypothesis that immediate breast reconstruction with an MS FTRAM flap would be more protective of the effects of PMRT than a DIEP flap, MS FTRAM flaps were not associated with a lower risk of fat necrosis from PMRT. Both flap types experienced high rates of fat necrosis when exposed to radiation therapy in comparison to non-irradiated flaps. Although radiation therapy had little effect on early flap recipient site wound healing complications, patients experienced an almost three-times higher incidence of fat necrosis when their flaps were exposed to PMRT.

Some studies evaluating immediate autologous tissue-based reconstruction before PMRT have reported reasonable rates of complications and satisfactory cosmetic outcomes.^{6,29,30,38} However, overall complication rates are often imprecisely defined, as reported overall complications may include complications at both the donor and recipient sites.³⁹ Even overall complication rates for only the recipient site are not significantly affected by PMRT, especially since radiation therapy is not typically begun until 1 or 2 months after the transfer of the microvascular flap. By that time, most early wound healing complications have already occurred; therefore, including wound healing complications and fat necrosis in the analysis of the effects of PMRT at the recipient site may confound the analysis and increase the likelihood of a β -error. In order to precisely demonstrate the effect of PMRT on free flap breast reconstruction, we included multiple subset analyses of both recipient site and donor site overall complications. We also analyzed the effect of radiation on fat necrosis rates alone. Similar to other studies, we found that radiation therapy to free flaps did not increase the overall complication rate at the recipient site or the flap donor site. However, our study

did demonstrate that fat necrosis was significantly increased in flaps that were irradiated. Based on our experience with managing irradiated flaps both in our own practice and presenting to us from outside reconstructive practices, we believe that the presence of fat necrosis in the setting of PMRT is not an isolated finding, but goes hand in hand with an overall volume loss of the flap secondary to radiation induced fibrosis. (Figure 1)

We attempted to evaluate whether the occurrence of fat necrosis affected the need to revise the reconstructed breast in patients who had received PMRT. Contradictory evidence exists regarding the need for corrective surgery after immediate breast reconstruction with autologous tissue and subsequent PMRT.^{6,14,15,40} We found no statistically significant difference in the need for reoperative surgery for fat necrosis between the irradiated and non-irradiated flaps. However, our surgeons typically avoid performing surgery in irradiated breast reconstructions whenever possible, given the well-documented poor wound healing characteristics of irradiated tissue.^{7–10,26} Thus, we believe that these observed rates of revisional surgery between irradiated and non-irradiated flaps reflect surgeon bias and should not underplay the consequences of PMRT to autologous free flaps.

Some authors have suggested that flaps should not be irradiated, not because of fat necrosis but because the presence of a reconstructed breast may compromise the design of the radiation fields, especially when treating the internal mammary lymph nodes, regardless of whether the breast was reconstructed with autologous tissue, an implant, or a combination.^{21,41,42} Some plastic surgeons have argued against the need to treat the internal mammary lymph nodes; however, emerging data may support their treatment in the near future. For example, the National Cancer Institute of Canada (NCIC) Clinical Trials Groups (CTG) MA-20 study randomized patients with one to three involved nodes to whole breast irradiation with or without regional nodal irradiation after segmental mastectomy and axillary lymphadenectomy.⁴³ Interim data from this study demonstrated that women receiving regional nodal irradiation experienced a greater than 30% relative improvement in disease-free survival, a 41% lower rate of regional recurrence, and a 36% lower rate of distant recurrence. These findings are likely to be similar in mastectomy patients, reinforcing the routine delivery of PMRT to the regional nodal basins, including the internal mammary chain, even in patients with a relatively low nodal burden. Nevertheless, at this point, in patients with advanced stages of breast cancer, immediate breast reconstruction has not been shown to adversely affect local recurrence or overall survival rates.^{6,23}

Although it has been shown to be oncologically safe to perform immediate breast reconstruction with autologous tissue prior to administration of PMRT, it predisposes patients to the development of a high incidence of fat necrosis, which typically presents as a palpable mass. Any lesion in the breast after breast cancer treatment can be a source of significant anxiety for a breast cancer patient because it may potentially represent a recurrent tumor. A breast lesion after an autologous breast reconstruction most often represents fat necrosis, but confirming the pathology of a breast mass after autologous reconstruction can be difficult and costly, subjecting patients to additional tests, procedures, and mental duress.⁴⁹ It is still unclear whether changes in technology and strategies for radiation delivery will lessen the damage to autologous flaps.^{45,50}

The fundamental mechanisms underlying radiation-induced fat necrosis remain poorly understood.^{18,44–46} Paradoxically, among the patients in this study who underwent PMRT, the fat necrosis risk was lower in patients with a DIEP flap than in those with an MS FTRAM flap. As oxygen markedly enhances the cytotoxic effects of radiation,^{47,48} it is plausible to hypothesize that differences in the oxygen environment of a DIEP flap may have affected radiation-related tissue damage. Alternatively, a “double-hit” mechanism might be involved whereby the flap experiences transient hypoperfusion followed by the

cytotoxic effects of radiation. However, proving such effects is beyond the scope of this study, and future research is thus clearly needed to improve our understanding of the pathophysiology of radiation-induced fat necrosis and to identify opportunities to improve both surgical and radiation approaches to mitigate this risk.

Our study was designed to quantify the incidence of fat necrosis in irradiated and non-irradiated DIEP and MS FTRAM flap reconstructions. The strengths of our study include the large number of breast reconstructions performed by multiple surgeons using similar techniques at a single center, careful study design to compare morbidity among breast reconstruction patients stratified by PMRT status, data obtained from a prospectively entered patient database, and regression analyses. Study limitations include its retrospective design, potential surgeon selection bias affecting the reconstruction choice, lack of a universally accepted standardized PMRT protocol, and lack of comparative aesthetic outcomes data. Specifically, a potential limitation with our study is that we assumed that there were perfusion differences between DIEP and MS FTRAM flaps when in fact there may not have been, especially in patients and perforators that are properly selected. Only a prospective, randomized study with postoperative radiologic and pathologic confirmation of fat necrosis can optimally assess the occurrence of fat necrosis after PMRT to an autologous, abdominal-based breast reconstruction. Furthermore, an accurate assessment of perfusion quality can only be achieved with a prospective study that employs measures to quantify perfusion quality with technology such as fluorescent angiography relative to precise measured volumes of the flap. Unfortunately the retrospective design of this study precluded perfusion assessment to this degree of accuracy.

CONCLUSIONS

In conclusion, this study reports a single center's 10-year experience, comparing outcomes between irradiated and non-irradiated DIEP and MS FTRAM flaps. The fat necrosis rates did not differ between the irradiated DIEP and MS FTRAM flaps, and all irradiated flaps had significantly higher fat necrosis rates than the non-irradiated flaps. Unless alternative types of radiation delivery can be developed that create less tissue damage, surgeons and oncologists should not underestimate the adverse consequences of contemporary radiation therapy for free flap breast reconstruction and should pursue reconstructive strategies that avoid direct irradiation of the flap rather than operating under the false assumption that the adverse effects can be mitigated by modifying flap design.

Acknowledgments

The authors wish to recognize former and current members of the Department of Plastic Surgery at The University of Texas MD Anderson Cancer Center for their support and/or contribution of patients to this series: Drs. David M. Adelman, Donald P. Baumann, David W. Chang, Melissa A. Crosby, Matthew M. Hanasono, Scott D. Oates, Gregory P. Reece, Jesse C. Selber, and Roman J. Skoracki, and former colleagues Drs. Bonnie J. Baldwin, Pierre M. Chevray, Mennen T. Gallas, Lior Heller, Stephen S. Kroll, Howard N. Langstein, Michael J. Miller, and Justin M. Sacks. The authors also thank Dawn Chalaire from The University of Texas MD Anderson Cancer Center, Department of Scientific Publications for assistance with scientific editing. Lastly, the authors would like to acknowledge the hard work and dedication of our fellows and residents who helped with these cases.

Financial Support: This research was supported in part by the National Institutes of Health through MD Anderson's Cancer Center Support Grant CA016672.

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Figure 1.

(a) Preoperative appearance of a patient before bilateral skin-sparing mastectomy and immediate MS FTRAM breast reconstruction, (b) Early postoperative appearance before receiving post-mastectomy radiation therapy to her right breast reconstruction, (c) Early appearance 4 months after completion of post-mastectomy radiation therapy to the patient's right breast reconstruction, (d) Late appearance 10 months after radiation demonstrating a firm, disfigured, atrophic, and asymmetric right breast reconstruction.

Table 1

Patient Characteristics by Study Group

	Total No. of Flaps (%) N=625 (518 Patients)	No. of Non-Irradiated Flaps (%) N=585 (478 Patients)	No. of Irradiated Flaps (%) N=40 (40 Patients)	P-value
Mean Age (years)	49.7 ± 9.2	49.9 ± 9.2	47.1 ± 9.2	0.008
Mean BMI (kg/m ²)	27.2 ± 4.7	27.3 ± 4.8	26.1 ± 4.3	0.04
Active Smoking	33 (6.4)	32 (6.7)	1 (2.5)	0.50
1 Medical Comorbidity	154 (29.7)	143 (29.9)	11 (27.5)	0.60
2 Medical Comorbidities	105 (20.3)	98 (20.5)	7 (17.5)	0.65
1 Prior Abdominal Surgery	317 (61.2)	294 (61.5)	23 (57.5)	0.62
Pre-op Chemotherapy	161 (31.1)	144 (30.1)	17 (42.5)	0.10
Post-op Chemotherapy	145 (28.0)	121 (25.3)	24 (60.0)	<0.0001
Pre-op Radiotherapy	97 (15.5)	96 (16.4)	1 (2.5)	0.01
Follow-up (months)	49.1 ± 28.6	48.5 ± 28.2	60.0 ± 32.9	0.02
Hospitalization (days)	5.3 ± 1.5	5.3 ± 1.6	5.1 ± 1.2	0.44

BMI, body mass index

Table 2

Reconstruction Characteristics by Study Group

	Total No. of Flaps (%) N=625 (518 Patients)	No. of Non-Irradiated Flaps (%) N=585 (478 Patients)	No. of Irradiated Flaps N=40 (40 Patients)	P-value
Flap Type				0.57
MS FTRAM	396 (63.4)	369 (63.1)	27 (67.5)	
DIEP	229 (36.6)	216 (36.9)	13 (32.5)	
Flap Design				0.71
Hemi-abdominal	361 (57.8)	340 (61.5)	21 (58.3)	
Cross-midline	228 (36.5)	213 (38.5)	15 (41.7)	
Number of Perforators				0.34
1	66 (10.6)	60 (13.3)	6 (18.2)	
2	135 (21.6)	130 (28.8)	5 (15.2)	
3	157 (25.1)	146 (32.4)	11 (33.3)	
4	126 (20.2)	115 (25.5)	11 (33.3)	
DIEA Branch Harvest				0.60
Single DIEA Branch	257 (41.1)	239 (40.9)	18 (45.0)	
Double DIEA Branch	368 (58.9)	346 (59.1)	22 (55.0)	
Recipient Vessels				0.001
Thoracodorsal Vessels	82 (13.1)	70 (12.0)	12 (30.0)	
Internal Mammary Vessels	541 (86.6)	513 (88.0)	28 (70.0)	
Side of Breast Reconstruction				0.09
Right	310 (49.6)	285 (48.7)	25 (62.5)	
Left	315 (50.4)	300 (51.3)	15 (37.5)	

MS FTRAM, muscle-sparing free transverse rectus abdominis musculocutaneous flap; DIEP, deep inferior epigastric perforator flap; DIEA, deep inferior epigastric artery

Table 3

Predictors of Fat Necrosis

	Univariate Logistic Regression		Multivariate Logistic Regression	
	Total No. of Flaps with Fat Necrosis (%) (N=63)	P-value	OR (95% CI)	P-value
Mean Age (years)	50.1 ± 8.5	0.49	-	-
Mean BMI (kg/m ²)	27.7 ± 5.1	0.48	-	-
Active Smoking	1 (2.4)	0.01	-	-
1 Medical Comorbidity	23 (12.5)	0.26	1.84 (0.98–3.44)	0.058
2 Medical Comorbidities	14 (10.6)	0.84	-	-
1 Prior Abdominal Surgery	35 (9.0)	0.28	-	-
Pre-op Chemotherapy	27 (13.6)	0.09	1.99 (1.05–3.75)	0.03
Post-op Chemotherapy	17 (10.1)	0.99	-	-
Pre-op Radiotherapy	12 (12.4)	0.48	-	-
Post-op Radiotherapy	9 (22.5)	0.06	2.71 (1.10–6.67)	0.03
Flap Type		0.80	-	-
MS FTRAM	39 (9.8)		-	-
DIEP	24 (10.5)		-	-
Bilateral Reconstruction	37 (12.3)	0.09	-	-
Flap Design		0.02	-	-
Hemi-abdominal	32 (14.0)		-	-
Cross-midline	27 (7.5)		-	-
Zone 3 Included with Flap	32 (14.0)	0.02	2.31 (1.25–4.28)	0.007
Number of Perforators		0.12	-	-
1	11 (16.7)		-	-
2	11 (8.1)		-	-
3	23 (14.6)		-	-
4	10 (7.9)		-	-
DIEA Branch Harvest		0.10	-	-
Double DIEA Branch	20 (7.8)		-	-
Single DIEA Branch	43 (11.7)		-	-
Recipient Vessels		0.12	-	-
Thoracodorsal Vessels	13 (15.9)		-	-
Internal Mammary Vessels	50 (9.2)		-	-
Side of Breast Reconstruction		0.61	-	-
Right	33 (10.6)		-	-
Left	30 (9.5)		-	-

OR, odds ratio; 95%CI, 95% confidence interval; BMI, body mass index; MS FTRAM, muscle-sparing free transverse rectus abdominis musculocutaneous flap; DIEP, deep inferior epigastric perforator flap; DIEA, deep inferior epigastric artery

Table 4

Effect of Radiation on Fat Necrosis by Flap Type

	Fat Necrosis		Univariate GEE Model	
	No	Yes	OR (95% CI)	P-value
Overall				
Non-irradiated	531 (90.8)	54 (9.2)	Ref.	-
Irradiated	31 (77.5)	9 (22.5)	2.85 (1.29–6.29)	0.009
MS FTRAM Flap				
Non-Irradiated	337 (91.3)	32 (8.7)	Ref.	-
Irradiated	20 (74.1)	7 (25.9)	3.68 (1.47–9.26)	0.006
DIEP Flap				
Non-Irradiated	194 (89.8)	22 (10.2)	Ref.	-
Irradiated	11 (84.6)	2 (15.4)	1.60 (0.33–7.74)	0.56

GEE, generalized estimating equation; OR, odds ratio; 95%CI, 95% confidence interval; MS FTRAM, muscle-sparing free transverse rectus abdominis musculocutaneous flap; DIEP, deep inferior epigastric perforator flap

Table 5

Effect of DIEP vs. MS FTRAM on Fat Necrosis by Radiation Status

	Fat Necrosis		P-value
	No	Yes	
Overall			0.80
MS FTRAM	357 (90.2)	39 (9.8)	
DIEP	205 (89.5)	24 (10.5)	
Irradiated Flaps			0.43
MS FTRAM	20 (74.1)	7 (25.9)	
DIEP	11 (84.6)	2 (15.4)	
Non-Irradiated Flaps			0.55
MS FTRAM	337 (91.3)	32 (8.7)	
DIEP	194 (89.8)	22 (10.2)	

MS FTRAM, muscle-sparing free transverse rectus abdominis musculocutaneous flap; DIEP, deep inferior epigastric perforator flap

Table 6**Predictors of Overall Complications**

	Univariate Logistic Regression		Multivariate Logistic Regression	
	Total No. of Patients with a Complication (%) (N=201)	P-value	OR (95% CI)	P-value
Mean Age (years)	50.7 ± 9.0	0.01	1.03 (1.01–1.06)	0.003
Mean BMI (kg/m ²)	28.2 ± 5.0	0.002	1.04 (1.01–1.09)	0.04
Active Smoking	13 (31.7)	0.96	-	-
1 Medical Comorbidity	74 (40.2)	0.01	-	-
2 Medical Comorbidities	55 (41.7)	0.02	1.51 (1.02–2.23)	0.04
1 Prior Abdominal Surgery	135 (34.5)	0.13	-	-
Pre-op Chemotherapy	81 (40.9)	0.005	1.80 (1.19–2.71)	0.005
Post-op Chemotherapy	42 (25.0)	0.02	-	-
Pre-op Radiotherapy	37 (38.1)	0.21	-	-
Post-op Radiotherapy	14 (35.0)	0.70	-	-
Flap Type		0.53	-	-
MS FTRAM	131 (33.1)		-	-
DIEP	70 (30.6)		-	-
Bilateral Reconstruction	121 (37.3)	0.008	1.54 (0.99–2.40)	0.057
Flap Design		0.03	-	-
Hemi-abdominal	130 (36.0)		-	-
Cross-midline	61 (26.8)		-	-
Number of Perforators		0.22	-	-
1	26 (39.4)		-	-
2	34 (25.2)		-	-
3	52 (33.1)		-	-
4	39 (31.0)		-	-
DIEA Branch Harvest		0.15	-	-
Single DIEA Branch	74 (28.8)		-	-
Double DIEA Branch	127 (34.5)		-	-
Recipient Vessels		0.20	1.69 (1.00–2.87)	0.05
Thoracodorsal Vessels	32 (39.0)		-	-
Internal Mammary Vessels	169 (31.2)		-	-
Side of Breast Reconstruction		0.23	-	-
Right	106 (34.2)		-	-
Left	95 (30.2)		-	-

OR, odds ratio; 95%CI, 95% confidence interval; BMI, body mass index; MS FTRAM, muscle-sparing free transverse rectus abdominis musculocutaneous flap; DIEP, deep inferior epigastric perforator flap; DIEA, deep inferior epigastric artery

Table 7**Predictors of Breast Flap Recipient Site Complications**

	Univariate Logistic Regression		Multivariate Logistic Regression	
	Total No. of Recipient Site Complications (%) (N=122)	P-value	OR (95% CI)	P-value
Mean Age (years)	50.1 ± 9.1	0.34	-	-
Mean BMI (kg/m ²)	28.0 ± 5.1	0.09	-	-
Active Smoking	3 (7.3)	0.01	-	-
1 Medical Comorbidity	55 (25.7)	0.01	1.71 (1.12–2.63)	0.01
2 Medical Comorbidities	27 (20.5)	0.78	-	-
1 Prior Abdominal Surgery	72 (18.4)	0.40	-	-
Pre-op Chemotherapy	49 (24.7)	0.05	1.65 (1.07–2.55)	0.02
Post-op Chemotherapy	29 (17.3)	0.36	-	-
Pre-op Radiotherapy	22 (22.7)	0.45	-	-
Post-op Radiotherapy	12 (30.0)	0.14	-	-
Flap Type		0.73	-	-
MS FTRAM	79 (19.9)		-	-
DIEP	43 (18.8)		-	-
Bilateral Reconstruction	63 (19.4)	0.96	-	-
Flap Design		0.45	-	-
Hemi-abdominal	49 (21.5)		-	-
Cross-midline	68 (18.8)		-	-
Number of Perforators		0.15	-	-
1	20 (30.3)		-	-
2	22 (16.3)		-	-
3	35 (22.3)		-	-
4	22 (17.5)		-	-
DIEA Branch Harvest		0.007	-	-
Double DIEA Branch	85 (23.1)		Ref.	-
Single DIEA Branch	37 (14.4)		1.63 (1.07–2.56)	0.02
Recipient Vessels		0.23	-	-
Thoracodorsal Vessels	21 (25.6)		-	-
Internal Mammary Vessels	101 (18.7)		-	-
Side of Breast Reconstruction		0.17	-	-
Right	67 (21.6)		-	-
Left	55 (17.5)		-	-

OR, odds ratio; 95%CI, 95% confidence interval; BMI, body mass index; MS FTRAM, muscle-sparing free transverse rectus abdominis musculocutaneous flap; DIEP, deep inferior epigastric perforator flap; DIEA, deep inferior epigastric artery