



ELSEVIER



Review

Should free deep inferior epigastric artery perforator flaps be considered a quality indicator in breast reconstruction?



Ruth Tevlin, Derrick C. Wan, Arash Momeni*

Division of Plastic and Reconstructive Surgery, Hagey Laboratory for Pediatric Regenerative Medicine, Stanford University School of Medicine, 770 Welch Road, Suite 400, Stanford, Palo Alto, CA 94304, United States

Received 21 April 2019; accepted 18 August 2019

KEYWORDS

Breast reconstruction;
DIEP flap;
MS-TRAM flap;
Microsurgery;
Autologous
reconstruction

Summary Over the past several decades, technical advances in breast reconstruction have resulted in the development of flaps that are aimed at progressively decreasing abdominal wall morbidity. There is, however, ongoing controversy related to the superiority of deep inferior epigastric perforator (DIEP) flaps over muscle-sparing TRAM (MS-TRAM) flaps. Hence, the question remains unanswered as to which approach should be considered the standard of care, and more importantly, whether the rate of DIEP flap utilization should be considered a quality metric in breast reconstruction. In this review article, we examine the literature pertaining to abdominal free tissue transfer in breast reconstruction from both donor site and flap characteristics as well as the resultant complications and morbidity. The impact on the donor site remains a prevailing principle for autologous breast reconstruction; thus, must be adequately respected when classifying what is left behind following flap harvest. The most commonly used nomenclature is too simplistic. This, in turn, leads to inadequate incorporation of critical variables, such as degree of muscular preservation, fascial involvement, mesh implantation, and segmental nerve anatomy. Currently, there is insufficient evidence to support DIEP flap harvest as a quality indicator in breast reconstruction, as DIEP flap outcomes are not clearly superior when compared with MS-TRAM flaps.

© 2019 British Association of Plastic, Reconstructive and Aesthetic Surgeons. Published by Elsevier Ltd. All rights reserved.

* Corresponding author.

E-mail address: amomeni@stanford.edu (A. Momeni).

Contents

Introduction	1924
The introduction of abdominal free tissue transfer	1924
Evolution of abdominal free tissue transfer and classification systems	1924
Clinical outcomes	1925
Driving for excellence	1926
The importance of fascia preservation	1926
Abdominal closure - does mesh even the playing field?	1926
Continued uncertainty.....	1927
Conclusions.....	1927
Disclosures.....	1928
References.....	1928

Introduction

One in every eight women in the United States will develop breast cancer in their lifetime. Despite advances in oncologic treatment, mastectomy continues to play a major role in the treatment algorithm of breast cancer. Furthermore, the advent of genetic testing for risk stratification has resulted in an increasing number of women opting for prophylactic mastectomy.¹⁻⁴ Similarly, the frequency of contralateral prophylactic mastectomy is increasing dramatically.⁵ As a whole, an increasing number of reconstructive procedures are being performed annually worldwide.⁶⁻¹⁰ In the United States, an almost 40% increase in the number of breast reconstruction procedures has been noted since 2000.¹¹

The goals of reconstruction are best summarized by the acronym “5S”, that is, creation of breasts of appropriate size, shape, symmetry, softness, and (ideally) with sensation, thereby contributing to an improved quality of life, while minimizing donor-site morbidity.¹² In this regard, autologous reconstruction has been reported to be associated with superior long-term outcomes, with the abdomen being considered the ideal donor site.¹³⁻¹⁶ Over the past several decades, technical advances have resulted in the development of flaps that are associated with a progressive decrease in abdominal wall morbidity. This is best exemplified by the transition from pedicled transverse rectus abdominis musculocutaneous (TRAM) flaps to free deep inferior epigastric perforator (DIEP) and superficial inferior epigastric artery (SIEA) flaps.¹⁷⁻¹⁹ Despite the existing controversy related to the presence of any clinically meaningful difference between muscle-sparing TRAM (MS-TRAM) and DIEP flaps, free DIEP flaps are widely considered the gold standard in autologous breast reconstruction.²⁰ Hence, the question arises whether the DIEP flap should be considered a quality metric in autologous breast reconstruction and whether it being considered the gold standard reconstructive modality is justified.

The introduction of abdominal free tissue transfer

In 1979, Holmström introduced the concept of free abdominal tissue transfer for breast reconstruction.²¹ Interestingly, this predated the landmark contribution by Hartrampf and colleagues, who in 1982 introduced the pedicled TRAM flap

as an option for autologous breast reconstruction.¹⁷ This allowed the use of lower abdominal skin and subcutaneous tissue for creation of the breast “mound” while also providing a more esthetic donor-site closure. Paralleling an increasing understanding of vascular anatomy and physiology, several technical modifications were introduced to the pedicled TRAM flap. Notably, the delay principle, proposed by Moon and Taylor, led to an increased use of pedicled TRAM flaps in breast reconstruction in patients with increased risk of vascular complications.²² The pedicled TRAM, thus, became the workhorse of autologous breast reconstruction in the 1980s. Disadvantages, however, included a protracted recovery due to abdominal discomfort and potential for abdominal wall weakness and hernia formation.²³

Evolution of abdominal free tissue transfer and classification systems

The main focus following these early reports of autologous breast reconstruction was reduction in donor-site morbidity while preserving perfusion to the flap. In 1989, Koshima and Soeda first reported the ability to harvest the skin territory of the conventional TRAM flap (MS-0 TRAM) with preservation of the rectus abdominis muscle, thereby minimizing the risk of abdominal herniation.²⁴ Following this report, it was the experience of Allen and Treece that popularized the use of DIEP flaps (MS-3 TRAM) for breast reconstruction.¹⁹

A widely referenced classification of various abdominal flaps was presented in 2002 by Nahabedian et al.²⁵ In their study, the authors used the degree of rectus abdominis muscle preservation as the basis for their classification, thereby differentiating between muscle-sparing-0 (MS-0) (full width muscle harvest), MS-1 (preservation of the lateral muscle segment), MS-2 (preservation of lateral and medial segments), and MS-3 (preservation of the entire muscle [=DIEP]) (Table 1). Despite the merits of this classification system, its main limitation is that it does not consider numerous other parameters that are equally important when assessing donor-site morbidity. These include the length of intramuscular dissection, harvest of medial vs. lateral row perforators, extent of fascial preservation, preservation of neural innervation, and technique of fascial closure.

Expanding on Nahabedian’s classification, Lee et al. subclassified free DIEP (MS-3 TRAM) flaps according to nerve preservation (DIEP-1 preservation of all muscle and nerves

Table 1 Classification of muscle sparing.²⁵

Muscle-sparing technique	Definition (rectus abdominis)
MS-0	Full width, partial length
MS-1	Preservation of the lateral segment
MS-2	Preservation of the lateral and medial segments
MS-3	Preservation of the entire muscle

Reproduced from: Ref. 25.

Table 2 Classification of muscle and nerve sparing in DIEP flap reconstruction.²⁶

Technique	Definition
DIEP-1	Preservation of all muscle and nerves (1 perforator or septocutaneous perforator)
DIEP-2	Preservation of all muscles, sacrifice of segmental nerve (usually 2+ perforators in the same intramuscular septum)
DIEP-3	Preservation of lateral and medial muscles, sacrifice of segmental nerve, and division of central muscle (multiple rows of perforators, i.e., both medial and lateral rows)

Reproduced from: Ref. 26.

with one perforator or septocutaneous perforator; DIEP-2 segmental nerve sacrifice and minimal muscle sacrifice, which usually have 2 perforators in the same intramuscular septum; DIEP-3 perforator harvest from both the medial and lateral row, segmental nerve sacrifice, and central muscle sacrifice, which usually requires both medial and lateral perforator harvest) (Table 2). The authors reported a similar rate of abdominal bulge in the respective groups; however, they observed a higher rate of fat necrosis in DIEP-1 than DIEP-3 flaps.²⁶

A more comprehensive classification system that considers additional important parameters, that is, percentage and location of muscle harvest, type of fascial closure, mesh placement, and segmental nerve division, was introduced by Weissler et al. (Table 3).²⁷ The authors provide a

rationale for a more detailed scheme, as they propose that the previous Nahabedian²⁸ and Lee²⁶ formulations do not fully describe the anatomic variability of rectus abdominis flap harvest. Given the heterogeneity in flap dissection techniques and definitions, we must interpret surgical outcomes judiciously. Weissler et al. highlight that although the *location* of the muscle harvested (and concomitant muscle preserved) is important, *how much* of that muscle is preserved may also be an important factor. For a more complete description of heterogeneous harvest techniques, the authors consider the percentage of the muscle divided coupled with the location of the divided muscle.²⁹

Clinical outcomes

A general limitation of comparative analyses is the tremendous heterogeneity within the respective flap groups. One can justifiably state that “*Neither all DIEP flaps nor all MS-TRAM flaps are created equal.*” Importantly, it is critical to consider that harvest of a DIEP (MS-3 TRAM) flap can, in fact, be associated with a greater degree of rectus abdominis muscle injury than free MS-TRAM flap harvest.³⁰ Although the preservation of rectus abdominis muscle during abdominal flap harvest is intuitively a desirable goal, valid conclusions regarding the superiority of a particular surgical technique mandate objective assessment rather than a conceptual framework.

Important clinical outcome parameters following autologous breast reconstruction include the rate of flap loss, fat necrosis, abdominal bulge, and abdominal hernia. The former two are related to flap perfusion, whereas the latter two are reflective of donor-site morbidity. A critical question to ask then is whether, in the context of equivalent outcomes, a technically more complex procedure is warranted.

In addition to the technical heterogeneity, the lack of consensus regarding the measurement of certain outcome parameters minimizes our ability to compare the results of reported study. For example, the true rate of fat necrosis following autologous breast reconstruction remains unknown in large part due to varying definitions.³¹⁻³³ Although some studies use imaging modalities to identify fat necrosis, others use clinical criteria.³¹⁻³⁴ Additionally, approaches

Table 3 Abdominally based breast reconstruction donor-site classification system (MuFmN).²⁷

Muscle (Mu)	Fascia (F)	Mesh (m) ^b	Nerve (N)
Percentage of total muscle divided ^a	Width of muscle divided (cm)/total muscle width (cm)	F0: No primary closure of fascia	m: Mesh placement
Position of muscle divided ^c	L: Lateral M: Medial C: Central	F1: Primary closure of fascia	N0: No nerve injury N1: 1 segmental nerve division N2: >/= 2 segmental nerve division

Reproduced from: Ref. 27.

^a Documented as a percentage.

^b Documented as subscript “m”.

^c Documented as subscript preceding the percentage.

to determine postoperative abdominal wall weakness vary and include clinical examination, Electromyography (EMG) studies, as well as imaging modalities.³¹⁻³⁶ These and other limitations should be considered when, *for example*, claims regarding the superiority of DIEP (MS-3 TRAM) flap over MS-2 TRAM flaps are made.

Driving for excellence

The relative risks and benefits of free TRAM and free muscle-sparing TRAM flaps in comparison to the more technically challenging muscle-preserving procedures such as superficial or deep inferior epigastric artery perforators flaps remain a topic of debate in breast reconstruction. The proponents of the DIEP (MS-3 TRAM)/SIEA group believe that sparing the rectus muscle leads to less donor-site morbidity such as abdominal weakness, bulge, or hernia formation with little downside. The competing argument is that the blood supply to a DIEP (MS-3 TRAM) or SIEA flap may be less robust, thereby leading to increased flap complications.

Regarding the increased risk of abdominal morbidity with increasing degrees of muscle involvement with a MS-TRAM, is it over simplistic to simply examine the degree of muscle involvement as laid out in the MS-TRAM staging system? Perforating vessels display anatomic variability, and intraoperative decisions must balance flap perfusion with muscle or nerve sacrifice.

On review of the literature, there is no accepted consensus regarding whether the DIEP or MS-TRAM results in a better-quality breast reconstruction. There is justification of abdominal muscle strength preservation in the most polarized comparisons (pertaining to MS-0 TRAM versus DIEP [MS-3 TRAM] flaps rather than the more commonly questioned MS-2 TRAM versus DIEP). Blondeel noted a significant difference in abdominal wall strength at 1 year³⁷ (MS-0 TRAM versus MS-3 TRAM/DIEP), whereas Schaverien et al. did not find significant differences in functional activities as measured by the 36-item Short Form Health Survey Scores (MS-0 TRAM versus MS-3 TRAM/DIEP).³⁸

Butler and colleagues reviewed 234 DIEP flaps (MS-3 TRAM) in 202 patients and found that the number of perforators harvested significantly increased the risk of postoperative abdominal bulge/hernia formation.³⁹ In addition, using a single perforator from the lateral row or both rows was significantly more likely to result in hernia/bulge development than if a single medial perforator was harvested. These findings were corroborated by Hembd et al.⁴⁰ Furthermore, they found no difference in abdominal wall morbidity in the presence or absence of mesh closure. The authors recommended the use of a single medial row perforator with a favorable suprafascial course wherever possible.³⁹

The importance of fascia preservation

A further topic of discussion is whether muscle preservation is more important than fascial preservation. As it currently stands, the most commonly cited method of abdominal flap classification refers to the degree of muscle preservation.⁴¹ However, there are many occurrences where muscle preservation simply does not coincide with

fascia preservation. Weissler and colleagues pragmatically included this variability in their revised staging system and equated fascia preservation with the ability to close the fascia primarily.²⁷ This allows consideration of subtle implications of partial muscle-sparing - full fascial preservation vis-à-vis other permutations (full muscle-full fascial preservation or varying muscle-mesh closures). As muscle-sparing TRAM (MS-1/MS-2 TRAM) and DIEP (MS-3 TRAM) operations have evolved with more sophisticated anatomic understanding and surgical technique, so too should our classification systems evolve.

If DIEP (MS-3 TRAM) flaps are to be considered the gold standard quality marker of breast reconstruction based on superior abdominal strength and less abdominal morbidity, it is perplexing to see studies published that show no long-term difference in abdominal morbidity. A study by Uda and colleagues reported clinical and quantitative isokinetic comparison of abdominal morbidity and dynamics following DIEP versus muscle sparing free TRAM (MS-2 TRAM, fascial sparing, and primary fascial repair) breast reconstruction.³⁶ They showed that although there was a significant difference in abdominal morbidity at 3 months, at 6 months abdominal muscle function had recovered to preoperative levels in both groups. Furthermore, from a clinical perspective, these findings were consistent with the absence of a statistically significant difference in patient's postoperative abdominal pain and stiffness, activity level, and the incidence of bulging between the two groups at 6 months postoperatively. Furthermore, Nahabedian et al. also reported no difference in abdominal morbidity between patients undergoing DIEP (MS-3 TRAM) and muscle-sparing free TRAM (MS-2 TRAM, primary fascial closure where feasible) flap elevation.³⁵

So the central questions remains: when weighing up the abdominal morbidity of free abdominal tissue transfer (patient reported outcomes, physical therapy, quantitative measurement, EMG, and US) versus flap perfusion (flap loss and degree of fat necrosis), does the outcome following MS-2 TRAM compare favorably with the outcome following DIEP (MS-3 TRAM) breast reconstruction? Should reconstructive surgeons be driving to do the more complicated dissection with a goal of completing a DIEP flap, while also simultaneously sacrificing muscle integrity? Or simply take a cuff of muscle?

If we strive to take one step further and perform a SIEA flap, with complete fascia preservation, we would expect to see superior long-term donor-site-related outcomes. Interestingly, the UK National Mastectomy Breast Reconstructive Audit showed that although SIEA relative to DIEP (MS-3 TRAM) flaps demonstrated superior abdomen-specific BREAST-Q scores at 1 year, it was interesting to note that this difference was no longer seen at 2 years postoperatively.⁴² The temporary benefit of SIEA flap harvest, thus, has to be weighed against the increased rate of SIEA flap loss.^{43,44}

Abdominal closure - does mesh even the playing field?

How does the placement of mesh affect patient outcome? A 2010 study by Wan et al. showed that there was about

11.3% of postoperative abdominal bulge or hernia following free TRAM or muscle sparing TRAM (details of the degree of muscle sparing were not included in the manuscript) and that the risk reduced to 5.1% following the incorporation of polypropylene mesh into fascial repair in comparison to 3.1% hernia or bulge risk in patients undergoing DIEP reconstruction over a 5-year period.⁴⁵ Chang et al. found an increased rate of hernia formation in DIEP reconstruction versus MS-TRAM reporting the following rates of hernia formation: free TRAM (9.9%), MS-TRAM (3.9%) (fascia-sparing MS-TRAM facilitating primary closure where feasible; degree of MS-TRAM was not included in the results), and DIEP (5.9%). The authors demonstrated that the use of mesh for fascial closure reduced the odds of occurrence of bulge/hernia by 70% compared with primary fascial closure. Their study also emphasized that the harvest of more fascia was significantly associated with the need for mesh.⁴⁶ Regarding bilateral reconstruction with abdominal tissue, Chun et al. showed no significant difference in the rates of abdominal bulges or hernia in patients undergoing bilateral pedicled TRAM versus DIEP free tissue transfer⁴⁷ with primary closure of the abdominal fascial defect without the use of mesh.

Regarding the increased risk of infection associated with the use of mesh, Sotelo-Leon demonstrated that the risk of bulging and herniation is decreased in patients receiving mesh⁴⁸ but did not see an increased risk of wound infection associated with the use of mesh, and instead noted that a patient's elevated body mass index, as well as tension of closure, and other comorbidities are more likely causes of superficial wound complications.

Obesity as an independent risk factor for hernia formation must be addressed as a further confounder of surgical outcomes. It is well described that obesity is associated with higher rates of mastectomy skin flap necrosis, flap complications, and abdominal wall donor-site complications in comparison to nonobese patients.⁴⁹⁻⁵² The historic teaching includes as many perforators as possible in the flaps of obese patients; thus, historic philosophy favors MS-0 TRAM over DIEP (MS-3 TRAM) or SIEA flaps.⁵³ There is, however, some mounting evidence to suggest that DIEP and SIEA flaps are safe and reliable in the obese patient. Garvey et al. found no difference in rates of flap loss or fat necrosis among obese, overweight, or normal-weight patients that underwent DIEP flap reconstruction.⁵² Ochoa et al. found that although obesity predisposed DIEP flap patients to delayed wound healing of both the flap and the donor site, the overall flap complications were not significantly different in the obese compared to the normal-weight patients.⁵⁴ Zhong et al. compared MS-0 TRAM flaps to DIEP flaps in obese patients and found no statistically significant difference in rates of flap loss or fat necrosis,⁵⁵ instead highlighted a greater risk of abdominal donor-site complications in MS-0 TRAM flaps compared to DIEP flaps. Hence, although it is still advised that all patients planning to have DIEP or SIEA flaps should have a BMI of less than 30 to avoid a higher risk of complications, this is becoming less of a hard and fast rule.⁵³ Furthermore, Modarressi showed no significant correlation between BMI of 25-35 kg/m² or abdominal wall thickness and postoperative complications of the donor site or DIEP flap.⁵⁶ The notion that obesity represents a contraindication to autologous microsurgical

breast reconstruction is no longer supported by the literature.⁵⁷ There is a paucity of studies that directly compares the outcomes following TRAM (MS-0, MS-1, or MS-2 TRAM) versus DIEP (MS-3 TRAM) in obese versus nonobese patient cohorts, however, indicating that there is further work to be done.

Continued uncertainty

In the setting of this continued uncertainty, the American Society of Plastic Surgeons commissioned a multi-stakeholder Work Group to develop recommendations for autologous breast reconstruction with abdominal flaps.¹⁹ Following a systematic literature review, the group was unable to agree upon a gold standard, instead they urged reconstructive surgeons to consider the patient's preferences and risk factors, the setting in which the surgeon works (academic versus community practice), resources available, and the surgeon's technical expertise. Although strong opinions exist among surgeons, there is no evidence supporting the superiority of DIEP versus MS-2 TRAM flaps. Thus, DIEP flaps should not be considered a quality marker in breast reconstruction. The goal should be to perform breast reconstruction with the flap that has the most robust perfusion and least amount of donor-site morbidity. The patient's individual anatomy rather than surgeon's desire should determine the flap choice.

Conclusions

The designation of the type of flap harvested in autologous breast reconstruction does not reflect the donor-site morbidity associated with it, as tremendous heterogeneity exists even within the same flap classification. Importantly, harvest of a MS-TRAM flap, in fact, can be associated with less donor-site morbidity than a DIEP (MS-3 TRAM) flap harvest. There is insufficient evidence to support DIEP flap harvest as a quality indicator in breast reconstruction because DIEP flap outcomes are not clearly superior relative to MS-TRAM flaps. This review highlights the need for a more refined outcome metric of quality, including incidences of donor site morbidity (bulge, hernia, and functional implications); flap complications (viability, take back rates, fat necrosis rates, and secondary revision rates); process measures (including duration of surgery, inpatient stay, time off work/activity, and time until discharge from secondary follow-up); and patient-reported outcome measures. The data presented call for the accrual of standardized datasets to guide evidence-based reconstructive practice. Perhaps the best approach may not be as simplistic as MS-TRAM versus DIEP; however, it may be the technique that the individual surgeon can safely deliver in a specific clinical setting. The goal should be to harvest a well-perfused flap with the least amount of muscle *and* fascial sacrifice determined by the individual patient's anatomy. It is important to remember, however, that we have a paramount duty to our patients, which is to do as little harm as possible. If a well-perfused single-perforator flap with no muscle/nerve damage can be raised in a safe and timely manner, then this should be our aim.

Disclosures

Dr. Momeni is a consultant for Allergan, AxoGen, Sientra, and Stryker. None of the authors have any conflicts of interest to disclose relevant to the content of the manuscript. No payment was received for this article.

References

- D'Alonzo M, et al. Satisfaction and impact on quality of life of clinical and instrumental surveillance and prophylactic surgery in BRCA-mutation carriers. *Clin Breast Cancer* 2018.
- Krontiras H, Farmer M, Whatley J. Breast cancer genetics and indications for prophylactic mastectomy. *Surg Clin North Am* 2018;**98**:677-85.
- Liede A, et al. Risk-reducing mastectomy rates in the US: a closer examination of the Angelina Jolie effect. *Breast Cancer Res Treat* 2018;**171**:435-42.
- Salibian AA, Frey JD, Choi M, Karp NS. BRCA mutations in the young, high-risk female population: genetic testing, management of prophylactic therapies, and implications for plastic surgeons. *Plast Reconstr Surg* 2018;**141**:1341-50.
- You Q, et al. Factors associated with the increasing trend of contralateral prophylactic mastectomy among patients with ductal carcinoma in situ: analysis of surveillance, epidemiology, and end results data. *Breast* 2018;**40**:147-55.
- Hong KY, Son Y, Chang H, Jin US. Trends in breast reconstruction: implications for the National Health Insurance Service. *Arch Plast Surg* 2018;**45**:239-45.
- Barnow A, et al. Breast reconstruction among commercially insured women with breast cancer in the United States. *Ann Plast Surg* 2018;**81**:220-7.
- Epstein S, et al. Racial disparities in postmastectomy breast reconstruction: national trends in utilization from 2005 to 2014. *Cancer* 2018;**124**:2774-84.
- O'Halloran N, et al. Trends in breast reconstruction practices in a specialized breast tertiary referral centre. *BJS open* 2017;**1**:148-57.
- Pollom EL, et al. Rising rates of bilateral mastectomy with reconstruction following neoadjuvant chemotherapy. *Int J Cancer* 2018;**143**(12):3262-72.
- ASPS. 2016 Reconstructive plastic surgery statistics. <https://d2wirczt3b6wjw.cloudfront.net/News/Statistics/2016/reconstructive-procedure-trends-2016.pdf> (2016).
- Zhou A, Ducic I, Momeni A. Sensory restoration of breast reconstruction - the search for the ideal approach continues. *J Surg Oncol* 2018;**118**:780-92.
- Liu C, et al. Quality of life and patient satisfaction after microsurgical abdominal flap versus staged expander/implant breast reconstruction: a critical study of unilateral immediate breast reconstruction using patient-reported outcomes instrument breast-q. *Breast Cancer Res Treat* 2014;**146**:117-26.
- Momeni A, Kim RY, Heier M, Bannasch H, Stark GB. Abdominal wall strength: a matched-pair analysis comparing muscle-sparing tram flap donor-site morbidity with the effects of abdominoplasty. *Plast Reconstr Surg* 2010;**126**:1454-9.
- Alderman AK, Kuhn LE, Lowery JC, Wilkins EG. Does patient satisfaction with breast reconstruction change over time? two-year results of the michigan breast reconstruction outcomes study. *J Am Coll Surg* 2007;**204**:7-12.
- Hu ES, et al. Patient-reported aesthetic satisfaction with breast reconstruction during the long-term survivorship period. *Plast Reconstr Surg* 2009;**124**:1-8.
- Hartrampf CR, Schefflan M, Black PW. Breast reconstruction with a transverse abdominal island flap. *Plast Reconstr Surg* 1982;**69**:216-25.
- Grotting JC. The free abdominoplasty flap for immediate breast reconstruction. *Ann Plast Surg* 1991;**27**:351-4.
- Allen RJ, Treece P. Deep inferior epigastric perforator flap for breast reconstruction. *Ann Plast Surg* 1994;**32**:32-8.
- Healy C, Allen RJ Sr. The evolution of perforator flap breast reconstruction: twenty years after the first DIEP flap. *J Reconstr Microsurg* 2014;**30**:121-5.
- Holmstrom H. The free abdominoplasty flap and its use in breast reconstruction. An experimental study and clinical case report. *Scand J Plast Reconstr Surg* 1979;**13**:423-7.
- Moon HK, Taylor GI. The vascular anatomy of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. *Plast Reconstr Surg* 1988;**82**:815-32.
- Knox AD, et al. Comparison of outcomes following autologous breast reconstruction using the diep and pedicled tram flaps: a 12-Year clinical retrospective study and literature review. *Plast Reconstr Surg* 2016;**138**:16-28.
- Koshima I, Soeda S. Inferior epigastric artery skin flaps without rectus abdominis muscle. *Br J Plast Surg* 1989;**42**:645-8.
- Nahabedian MY, Momen B, Galdino G, Manson PN. Breast reconstruction with the free TRAM or DIEP flap: patient selection, choice of flap, and outcome. *Plast Reconstr Surg* 2002;**110**:466-75 discussion 476-467.
- Lee BT, Chen C, Nguyen MD, Lin SJ, Tobias AM. A new classification system for muscle and nerve preservation in DIEP flap breast reconstruction. *Microsurgery* 2010;**30**:85-90.
- Weissler JM, Albino FP, Carney MJ, Wu LC. Revisiting the abdominal donor site: introducing a novel nomenclature for autologous breast reconstruction. *Plast Reconstr Surg* 2017;**140**:1110-18.
- Nahabedian MY, Dooley W, Singh N, Manson PN. Contour abnormalities of the abdomen after breast reconstruction with abdominal flaps: the role of muscle preservation. *Plast Reconstr Surg* 2002;**109**:91-101.
- Kim JYS. Discussion: revisiting the abdominal donor site: introducing a novel nomenclature for autologous breast reconstruction. *Plast Reconstr Surg* 2017;**140**:1119-20.
- Selber JC, Serletti JM. The deep inferior epigastric perforator flap: myth and reality. *Plast Reconstr Surg* 2010;**125**:50-8.
- Kroll SS. Fat necrosis in free transverse rectus abdominis musculocutaneous and deep inferior epigastric perforator flaps. *Plast Reconstr Surg* 2000;**106**:576-83.
- Baumann DP, Lin HY, Chevray PM. Perforator number predicts fat necrosis in a prospective analysis of breast reconstruction with free TRAM, DIEP, and SIEA flaps. *Plast Reconstr Surg* 2010;**125**:1335-41.
- Kamali P, et al. Medial row perforators are associated with higher rates of fat necrosis in bilateral diep flap breast reconstruction. *Plast Reconstr Surg* 2017;**140**:19-24.
- Lee KT, Eom Y, Jeon BJ, Mun GH. Vertical spacing of perforators in deep inferior epigastric perforator flap breast reconstruction can affect the outcomes. *Plast Reconstr Surg* 2018;**142**:319-29.
- Nahabedian MY, Tsangaris T, Momen B. Breast reconstruction with the diep flap or the muscle-sparing (MS-2) free tram flap: is there a difference. *Plast Reconstr Surg* 2005;**115**:436-44 discussion 445-436.
- Uda H, et al. Clinical and quantitative isokinetic comparison of abdominal morbidity and dynamics following diep versus muscle-sparing free tram flap breast reconstruction. *Plast Reconstr Surg* 2017;**140**:1101-9.
- Blondeel N, et al. The donor site morbidity of free DIEP flaps and free TRAM flaps for breast reconstruction. *Br J Plast Surg* 1997;**50**:322-30.
- Schaverien MV, Perks AG, McCulley SJ. Comparison of outcomes and donor-site morbidity in unilateral free TRAM versus DIEP flap breast reconstruction. *J Plast Reconstr Aesthetic Surg JPRAS* 2007;**60**:1219-24.

39. Butler DP, et al. Factors that predict deep inferior epigastric perforator flap donor site hernia and bulge. *J Plast Surg Hand Surg* 2018;1-5.
40. Hembd A, Teotia SS, Zhu H, Haddock NT. Optimizing perforator selection: a multivariable analysis of predictors for fat necrosis and abdominal morbidity in diep flap breast reconstruction. *Plast Reconstr Surg* 2018;142:583-92.
41. Nahabedian MY, Manson PN. Contour abnormalities of the abdomen after transverse rectus abdominis muscle flap breast reconstruction: a multifactorial analysis. *Plast Reconstr Surg* 2002;109:81-7 discussion 88-90.
42. Erdmann-Sager J, et al. Complications and patient-reported outcomes after abdominally based breast reconstruction: results of the mastectomy reconstruction outcomes consortium study. *Plast Reconstr Surg* 2018;141:271-81.
43. Selber JC, et al. A head-to-head comparison between the muscle-sparing free tram and the siea flaps: is the rate of flap loss worth the gain in abdominal wall function. *Plast Reconstr Surg* 2008;122:348-55.
44. Sarik JR, Bank J, Wu LC, Serletti JM. Superficial inferior epigastric artery: learning curve versus reality. *Plast Reconstr Surg* 2016;137 1e-6e.
45. Wan DC, et al. Inclusion of mesh in donor-site repair of free TRAM and muscle-sparing free TRAM flaps yields rates of abdominal complications comparable to those of DIEP flap reconstruction. *Plast Reconstr Surg* 2010;126:367-74.
46. Chang EI, et al. Comprehensive analysis of donor-site morbidity in abdominally based free flap breast reconstruction. *Plast Reconstr Surg* 2013;132:1383-91.
47. Chun YS, et al. Comparison of morbidity, functional outcome, and satisfaction following bilateral TRAM versus bilateral DIEP flap breast reconstruction. *Plast Reconstr Surg* 2010;126:1133-41.
48. Leon DS, Nazerali R, Lee GK. Using mesh to reinforce the abdominal wall in abdominal free flaps for breast reconstruction: is there a benefit? What are the risks. *Ann Plast Surg* 2018;80:S295-8.
49. Chang DW, et al. Effect of obesity on flap and donor-site complications in free transverse rectus abdominis myocutaneous flap breast reconstruction. *Plast Reconstr Surg* 2000;105:1640-8.
50. Lee KT, Mun GH. Effects of obesity on postoperative complications after breast reconstruction using free muscle-sparing transverse rectus abdominis myocutaneous, deep inferior epigastric perforator, and superficial inferior epigastric artery flap: a systematic review and meta-analysis. *Ann Plast Surg* 2016;76:576-84.
51. Lundberg J, et al. When is the deep inferior epigastric artery flap indicated for breast reconstruction in patients not treated with radiotherapy. *Ann Plast Surg* 2014;73:105-13.
52. Garvey PB, Buchel EW, Pockaj BA, Gray RJ, Samson TD. The deep inferior epigastric perforator flap for breast reconstruction in overweight and obese patients. *Plast Reconstr Surg* 2005;115:447-57.
53. Butler PD, Wu LC. Abdominal perforator vs. muscle sparing flaps for breast reconstruction. *Gland Surg* 2015;4:212-21.
54. Ochoa O, Chrysopoulo M, Nastala C, Ledoux P, Pisano S. Abdominal wall stability and flap complications after deep inferior epigastric perforator flap breast reconstruction: does body mass index make a difference? Analysis of 418 patients and 639 flaps. *Plast Reconstr Surg* 2012;130 21e-33e.
55. Zhong T, et al. Using propensity score analysis to compare major complications between DIEP and free muscle-sparing TRAM flap breast reconstructions. *Plast Reconstr Surg* 2014;133:774-82.
56. Modarressi A, Muller CT, Montet X, Ruegg EM, Pittet-Cuenod B. DIEP flap for breast reconstruction: is abdominal fat thickness associated with post-operative complications? *J Plast Reconstr Aesthetic Surg JPRAS* 2017;70:1068-75.
57. Momeni A, Ahdoot MA, Kim RY, Leroux E, Galaiya DJ, Lee GK. Should we continue to consider obesity a relative contraindication for autologous microsurgical breast reconstruction. *J Plast Reconstr Aesthet Surg* 2012;65:420-5.