Free Tissue Breast Reconstruction

Rami Dibbs, BA¹ Jeff Trost, MD² Valerie DeGregorio, PA-C² Shayan Izaddoost, MD, PhD²

¹ Louisiana State University Health Science Center, New Orleans, Louisiana

² Division of Plastic Surgery, Baylor College of Medicine, Houston, Texas

Address for correspondence: Shayan Izaddoost, MD, PhD, Division of Plastic Surgery, Baylor College of Medicine, Jamail Specialty Care Center, Suite E6.100, 1977 Butler Blvd., Houston, Texas, 77030 (e-mail: shayani@bcm.edu).

Semin Plast Surg 2019;33:59–66.

Abstract

Keywords

- breast reconstruction
- free flap
- microsurgery
- DIEP
- abdominal-based reconstruction

Free tissue transfer serves as a modern workhorse for breast reconstruction. Advancements in microsurgical technique have allowed for the development of free flap procedures that produce an aesthetic breast while minimizing donor site morbidity. Here, the authors review the use of different free flap procedures for breast reconstruction with a focus on the preferred and most commonly used flap, the deep inferior epigastric perforator flap. Each flap has its advantages and drawbacks, and certain patient risk factors increase postoperative complications. Other techniques of breast reconstruction including pedicled flaps and adjunctive fat grafting are also briefly discussed.

Breast reconstruction has been thoroughly studied since the late 19th century as an opportunity to restore the natural appearance of the breasts following mastectomy. Free-tissue breast reconstruction was more recently investigated in 1979 by Hans Holmström to improve upon the shortcomings of implant-based and pedicled flap procedures.^{1,2} In this pioneering work, the rectus abdominis myocutaneous free flap was designed from the tissue removed from abdominoplasties.^{1–3} Hartrampf et al refined and popularized Holmström's technique to create the transverse rectus abdominis myocutaneous (TRAM) flap widely used today. This flap served as the framework that eventually gave rise to the free TRAM flap.^{1,2,4} Further modifications to abdominally-based free tissue flaps gave rise to the deep inferior epigastric perforator (DIEP) and superficial inferior epigastric artery (SIEA) flaps.

Advances in autologous reconstruction yielded a more natural look and texture as well as improved postoperative results including a decreased risk of hematoma, seroma, and cellulitis.⁵ However, donor site morbidity such as rectus bulging and hernia formation remained problematic, and flap failure rates as high as 2.4% have been reported.^{5–8} Advances in surgical technique and salvage protocols continue to improve outcomes. While the free flap provides better overall patient satisfaction than implant or pedicled flap techniques, all three remain cornerstone methods of breast reconstruction following mastectomy.⁹

Free Flap Procedures

Free tissue breast reconstruction has greatly evolved from its initial conception 40 years ago. Abdominal-based reconstruc-

tion provides the workhorse for free-flap breast reconstruction, though ingenuity in microsurgery has led to a growing number of unique donor sites. Pregnancy, a sparsity of abdominal tissue, or previous abdominal surgeries such as liposuction are among the contraindications for abdominally based breast reconstruction and lend toward the use of other donor sites.^{10–14} Goals for reconstruction are common among the different donor options and include tissue durability, a natural shape and feel, and minimal donor site morbidity.

Pioneered in 1993, gluteal-based free flaps such as the superior and inferior gluteal artery perforator flaps (SGAP and IGAP) were designed for minimal donor site morbidity and long pedicle length. SGAP flaps have the additional potential to be raised as a sensate flap as demonstrated by Blondeel in 1999.¹⁵ However, flap harvest can be tedious requiring a high level of surgical experience.^{10,16} While the SGAP is associated with little postoperative pain, it creates deformities in the buttock contour that are not seen with the IGAP procedure.^{10,11,17} Conversely, the IGAP flap is associated with more pain, especially upon sitting.¹⁰ A drawback of the operations is the requirement to turn the patient from the lateral decubitus position to the supine position intraoperatively; however, the flap is transferred from the ipsilateral side, allowing for simultaneous preparation of the donor and recipient sites.^{11,17}

Thigh-based free tissue options include the transverse and diagonal upper gracilis (TUG and DUG) and the profunda artery perforator (PAP) flaps. These utilize the profunda femoris arterial system as their blood supply.^{18,19} The TUG and DUG flaps offer a relative ease of shaping into the desired

rounded and elevated shape of the breast. Additionally, they can provide sensation to the reconstructed breast by coaptation of branches from the obturator nerve.^{12,18} Unlike abdominal-based flaps, the TUG and DUG flaps do not generally precipitate bulging or hernias at the donor site. However, the TUG flap requires a horizontal cut along the gluteal fold, producing greater tension at the donor site, increased wound healing complications, contouring deformities of the gluteal fold, and lymphedema at the donor site.¹⁸ The DUG flap avoids some of these complications by placing its incision along Langer's tension lines. This allows for a larger skin paddle, minimization of tension, and preservation of the lymphatics and gluteal fold.^{18,20}

The PAP flap has more recently been introduced in breast reconstruction. The profunda artery follows a reliable course through the adductor magnus muscle, simplifying the dissection of this perforator flap with greater operative exposure. The PAP flap also boasts a generous vascular pedicle length, can be contoured into a cosmetically-pleasing shape, and can incorporate branches of the posterior femoral cutaneous nerve to provide a sensate flap.^{12,18,21} Similar to the TUG flap, the PAP flap requires a transverse cut producing increased tension at the donor site. This limits the amount of tissue transferred and increases donor site morbidity including contour deformities and scar widening.^{18,21} However, unlike the TUG flap, lymphatics are avoided during the procedure, and lymphedema is not a significant concern.^{12,18,21} The PAP flap has recently become a significant, reliable alternative to abdominal-based free tissue reconstruction in patients with sparse abdominal tissue, or who exhibit other contraindications to its use.

Additional, albeit less commonly used flaps include the lumbar artery perforator (LAP) flap and lateral thigh perforator (LTP) flap. The LAP flap is based on vessels originating directly from the aorta at the level of L3 or L4 vertebrae. Lumbar fat closely mimics native breast tissue, but limited artery size often requires an interposition graft to the internal mammary vessels. Lower flap design may allow for concealment of scars within conventional underwear. The LTP flap is transversely designed between the anterior superior iliac spine and iliac tubercle and based off of the ascending branch of the lateral femoral circumflex vessels. Vasculature can be greatly variable in this region, and preoperative vascular imaging is recommended. Patients also often note a change in hip shape from convex to concave and must be considered in patients with curvy hips.

Abdomen-Based Flap Procedures

Abdominally based free flaps have been regarded as the most successful breast reconstruction options for women following mastectomy. They provide women with breasts that have a natural appearance and offer the best tissue quality.^{22,23} Over the historical course of its use, donor tissue harvest has progressed from the highly invasive pedicled TRAM (pTRAM) flap to the free TRAM (fTRAM) flap. Further attempts to minimize donor site morbidity subsequently led to the advent of muscle-sparing TRAM (msTRAM), the DIEP flap, and most recently the SIEA flap.^{22,24}

Abdominally based free tissue transfers are based off of the DIE artery system. This is in contrast to the pTRAM flap which is superiorly based and utilizes the superior epigastric vessels.²⁵ There is conflicting evidence regarding whether pTRAM flaps or fTRAM flaps are associated with increased postoperative complications. Some authors suggest that free tissue transfer increases the incidence of fat necrosis, wound dehiscence, and hematoma when compared to pedicled abdominal reconstruction.^{26–29}

The DIEP and SIEA flaps forgo the harvesting of muscle during the free flap procedure. However, while the DIEP flap does not utilize muscle, incision of the rectus fascia and dissection of the perforators through the muscle is essential to the operation. The SIEA flap, by leaving the rectus fascia intact, minimizes donor site complications postoperatively.²² The DIEP and SIEA flaps do not come without their drawbacks, as they are associated with increased risk for fat necrosis compared to the fTRAM and msTRAM flaps.^{22–24,30} Some authors, however, suggest that the risk of fat necrosis is more strongly associated with the number of perforators rather than the particular type of tissue transfer utilized. As fewer perforators (usually one or two) are present within the DIEP and SIEA flaps, they are more likely to undergo fat necrosis.²⁴ The smaller SIEA pedicle length and width also increase the risk of postoperative complications at the surgical anastomosis. In one study by Spiegel and Khan, it was demonstrated that SIEA flaps with a diameter of at least 1.5 mm were required to conduct the operation successfully with minimal flap loss.³¹ In another study by Park et al, it was determined that total flap loss for SIEA flaps was 4.8%.³² It is, therefore, imperative to recognize that each flap has its advantages and disadvantages when determining which tissue transfer is best suited for a particular patient.

DIEP Flap Reconstruction

DIEP Flap Anatomy

Successful DIEP flap breast reconstruction requires a detailed understanding of flap anatomy. The DIE artery arises from the external iliac artery deep to the inguinal ligament. It then courses superiorly between the transversalis fascia and the peritoneum before entering the posterior rectus abdominis muscle. After entering the rectus muscle, the artery variably branches into an average of five or so perforators, organized into lateral and medial rows, which will ultimately supply the abdominal skin. Lateral perforators tend to be larger in caliber and easier to dissect. However, medial perforators offer better blood supply to zones III and IV of the abdomen and must be carefully considered when this tissue is to be transferred with the flap.^{33,34} Abdominal-based flaps are indicated for patients with a body mass index (BMI) under 30, nonsmokers, and those who do not require postreconstruction radiation.^{35–37}

Patient Preparation

Preoperative planning is essential to successful reconstruction. Preoperative computed tomography (CT) can be used on patients with a history of abdominal surgery and has been

shown to decrease the time of flap dissection.³⁸ The patient is marked while standing in the preoperative area. Breast markings include the midline, inframammary folds, and breast pocket while the abdominal skin island is designed as a fusiform shape over the desired perforator determined by CT or preoperative Doppler. Usual anatomic landmarks for this skin island are the anterior superior iliac spines laterally, the umbilicus, and the suprapubic crease.

Free tissue breast reconstruction can be completed in either an immediate or delayed fashion. When immediate reconstruction is planned, the plastic surgery team can begin elevating the abdominal flap, while the breast surgeon proceeds with mastectomy. This can be more easily facilitated by turning the operating bed 180 degrees so that the patient's feet are closest to the anesthesiologist. A two-team approach continues following mastectomy or during delayed breast reconstruction for simultaneous dissection of the flap and recipient vessels.

Cardiac clearance is recommended for patients who have been on adriamycin and taxol-based chemotherapy as well as received herceptin. Radiation to the left chest wall can also yield cardiac sequelae. Care should be taken to time the procedure so as to allow for optimum healing after neoadjuvant chemotherapy.

Flap Elevation

The abdomen is incised along preoperative markings and dissection begun along the inferior border of the flap. Dissection is carried down to the fascia while taking care to identify the superficial inferior epigastric vein (SIEV). This is usually located in the inferomedial portion of the flap and should be dissected inferiorly from the pelvic tissue for an additional 4 to 6 cm of length prior to ligation (►Fig. 1). Throughout the remainder of the surgery, the SIEV remains an important tool in monitoring flap congestion. During inset, the SIEV can serve as a second venous anastomosis to improve overall venous drainage.

Flap elevation then proceeds from lateral to medial, identifying all perforators. Once lateral perforators are exposed, dissection can continue from a medial to lateral direction to

address the medial perforators. During perforator dissection, a handheld Doppler is a vital tool in assessing blood flow. Once a dominant perforator is identified, Acland clamps can be applied to superlative perforators to ensure adequate perfusion from the chosen vessel. The distal pedicle is then circumferentially exposed using scissors to incise the anterior rectus fascia in the direction of the underlying muscle fibers. Perforators can be hydro-dissected by the use of heparin with an olive tip needle. Dissection proceeds through the rectus fascia and muscle with fine scissors and bipolar electrocautery, isolating the DIE artery perforator to its origin from the external iliac artery. More adherent fibers are often found in proximity to side branches and motor nerves. Side branches should be ligated with surgical clips, while motor nerves are preserved. Medial row perforators exhibit a longer intramuscular course and may require more extensive dissection of the muscle. It is sometimes possible to capture multiple perforators from the same row (►Fig. 2); however, this must be balanced with the need for further tedious dissection and violation of the muscle and fascia. When identifying multiple perforators in the same row, it may be necessary to divide any intervening nerve branches. Capturing multiple perforators from different planes requires transection of intervening muscle fibers and should be avoided when possible. Once enough pedicle length is achieved and the recipient site prepared for transfer, the DIE vessels are clipped and flap freed from the abdomen (►Fig. 3).

Recipient Vessel Harvest

The internal mammary artery and vein (IMA/IMV) remain our recipient vessels of choice while the thoracodorsal vessels can also be used. Use of the thoracodorsal may preclude the use of the latissimus flap for reconstruction at a later date, although a latissimus flap based on the thoracodorsal branch to the serratus may still be possible. The breast pocket is dissected medially to the lateral sternum, taking care to identify and ligate any large perforators from the internal mammary system. The third rib is palpated

Fig. 1 Dissected superior inferior epigastric artery.

Fig. 2 Raised deep inferior epigastric perforator flap utilizing two perforators.

Fig. 3 Donor site after elevation of the deep inferior epigastric perforator flap.

and the pectoralis muscle overlying the rib is split parallel to its fibers. Perichondrium is then incised and circumferential dissection of the perichondrium from the underlying rib cartilage completed using a periosteal elevator. Once an area of about 1.5 cm of cartilage is exposed near to or abutting the sternum, a rongeur is used to carefully remove the cartilage. The anterior vessels are located immediately deep to posterior perichondrium. Bipolar electrocautery can be used to safely incise this remaining perichondrium and expose the vessels. Loupe magnification or the microscope are then used to dissect free the recipient vessels. Extra care must be taken when handling radiated tissues.

Flap Inset

Flap inset is more easily facilitated with contralateral free tissue transfer given the positioning of the vessels as well as positioning of the SIEV close to the internal mammary vessels in case of flap congestion. During the recipient vessel harvest, Acland clamps were placed on the anterograde IMA/IMV and the retrograde vessels were clipped. The vessels were divided and irrigated. Anastomosis begins with the artery which is handsewn using a 9-0 nylon suture in interrupted fashion. Venous couplers are then used for venous anastomoses. A 3 mm coupler can often be used. If vein size is less than 2 mm, a handsewn anastomosis may be recommended.³⁹

Acland clamps are released, and any anastomotic leaks immediately addressed with 9-0 nylon sutures. After initial inset, the SIEV can be reassessed to evaluate for venous congestion and the need for an additional venous anastomosis using this vessel. Following the completion of vascular anastomosis, the pedicle is carefully positioned to avoid kinking or excess pressure. Small amount of fat grafts cut from the abdominal tissue are used to pad and properly position the anastomosis site. The flap is then inset using 2-0 Vicryl sutures in interrupted fashion over two 19-French Blake drains.

Closure

The abdominal flap is elevated superiorly in the midline to the level of the xyphoid. The entire width of the abdominal flap needs not be elevated, as closure is accomplished by elevating a superiorly base abdominal flap only 5 cm wide. In patients with higher BMI, the risk of abdominal wound healing and complications increase with undermining of the flap. To further facilitate closure, the patient is flexed at the hips. Drains are brought out through the lateral abdominal wound. The umbilicus is brought out through a stab incision at the new umbilical site.

Postoperative Care

Certain protocols must be maintained postoperatively to ensure the safety and care for the patient. After placing the patient in a flexed beach chair position in the operating room, this positioning is kept for the duration of postoperative care to prevent tension on the abdominal wounds. Each patient also receives an abdominal binder and surgical bra with lateral Kerlix fluffs as a method to manage and alleviate symptoms of pain and reduce tension on inset of flaps. Additionally, movement of the patient from operating room bed to hospital bed is done with care to support flaps during turns and transfer.

Drain care is also essential beginning in the operating room and usually continues until seen in clinic for follow-up. High output from the abdominal wound should demonstrate a gradual decrease with time. Venous occlusion should be of concern if output is observed to be rising. Drains should be removed when output trends are less than 30cc within a 24-hour period or if clots are suspected in order to prevent hematoma formation.⁴⁰

It is routine practice at our institution to admit all flap patients to a nursing unit that allows frequent monitoring of vital signs and hourly flap checks. Tachycardia or hypertension may be the result of inadequately managed postoperative pain. Actively checking the patient for their comfort level can help avoid abnormal vital signs. Beta-blocker medications could provide an explanation for bradycardia. Patients with a mean arterial blood pressure below 60 mm Hg should be treated to prevent thrombosis and flap necrosis.⁴⁰ Maintaining an adequate urine output is important in assessing blood pressure. Patients should produce urine at a rate of 50 to 100 mL/hour. If the patient is producing less urine and is hypotensive, the administration of diuretics or pressors is not recommended; rather, adding volume or removing narcotics is suggested.⁴⁰

Postoperative flap monitoring is performed with a combination of clinical observation and handheld Doppler. Capillary refill time, temperature, swelling, and color of the flap should all be assessed immediately and frequently following surgery.⁴⁰⁻⁴³ For the first 24 hours after surgery, flap checks are performed hourly by nurses educated in the use of handheld Doppler. According to Kroll et al and Chen et al, while venous occlusion was deemed the most common cause of flap thrombosis and flap loss postoperatively, arterial thrombosis was more likely to occur during the first 24 hours.^{41,44,45} Prompt

diagnosis is imperative for flap salvage. If any abnormalities are observed, a surgeon should be notified quickly for further assessment.⁴⁰

Although handheld Dopplers remain a vital aspect of flap monitoring, their ability to detect abnormalities in flap perfusion is quite limited. It is difficult to assess whether the recipient vessel or vascular pedicle is abnormal externally.^{41,46} The use of an implantable Doppler may help address these concerns and allow for more accurate and continuous measurements.^{40,42,43,46} The ViOptix Tissue Oximeter (ViOptix, Inc.) is a newer flap monitoring method capable of measuring oxygen saturation using near-infrared spectroscopy with high sensitivity and specificity. In one study by Keller, no flap was lost out of 208 monitored breast flaps and all flaps with potential complications were detected prior to clinical symptoms using ViOptix.⁴⁷

Additional postoperative considerations include the gradual progression toward physical activity. Patients are asked to use "T-rex arms" for 3 to 4 weeks after surgery. In other words, avoidance of shoulder flexion and abduction helps prevent tension on the flap. Range of motion exercises begins once drains are removed in clinic. It is our practice to have patients stand up on postoperative day (POD) #1. This is accomplished with strict assistance to ensure the patient is maintaining a bent over position at the waist and not using their arms during the transition. Rather than returning to bed, the patients then spend the remainder of their hospital stay in a bedside recliner. We have found that this also maintains a beach chair position while resting and encourages transitioning between sitting and standing without the use of arms. Patients are asked to ambulate on POD#2. While standing up and walking, patients hold a pillowcase in front of them that contains their JP drains. This reduces clutter while walking as well as encourages a T-rex arm position while standing and walking. Pre- and postoperative DIEP flap photographs are demonstrated in ►Fig. 4.

Complications

While free flap breast reconstruction is relatively safe, certain risk factors greatly increase the potential for complications. In one study by Seidenstuecker et al, smoking was associated with nearly twice the risk of flap complications and triple the risk of donor site complications.³⁶ Additionally, obesity was associated with quadruple the risk for total flap complications.³⁶

Postreconstruction radiation has been linked to higher incidence of fat necrosis, hyperpigmentation, and skin contracture.^{35,48–50} Chemotherapy, however, has not significantly been associated with postoperative morbidity.^{51,52} Increasing age is also a risk factor.^{51,53} Lastly, there is conflicting evidence regarding the prevalence of complications with respect to immediate versus delayed reconstruction. In one study by Sullivan et al, there was no evidence to suggest a difference in complication rates between immediate and delayed reconstruction. In another study by Sanati-Mehrziy et al, immediate reconstruction was associated with increased complications.^{48,51,52,54}

Deep venous thrombosis (DVT) can be a catastrophic complication of free flap breast reconstruction. Rates of DVT following free tissue breast reconstruction are believed to be between less than 1 to 8%.^{55,56} Risk factors for DVT include prolonged surgery, positive *BRCA* status, greater age, high BMI, concurrent tamoxifen therapy, and delayed mobilization.^{56,57} Practices in DVT prophylaxis vary greatly among reconstructive breast surgeons, and most report noncompliance with American College of Chest Physicians (ACCP) guidelines.⁵⁸ Low-molecular weight heparin (LMWH) is often the prophylactic medication of choice and given daily to all patients throughout the course of admission. For patients with additional risk factors listed above, some surgeons have adapted postoperative protocols that include a full 2-week course of LMWH.⁵⁶

Fig. 4 (A) Preoperative and (B) postoperative photograph of deep inferior epigastric perforator flap breast reconstruction.

It is our practice to initiate sequential compression devices prior to induction of anesthesia. These remain on until the time of discharge. Lovenox (40 mg) is first given 6 to 8 hours after the end of ischemia time. It is then given daily for a total of 7 days. Our early mobilization protocols are also essential to the prevention of DVTs.

The most dreaded complication of free tissue breast reconstruction is flap loss. Intraoperatively, the anastomosis must be positioned without kinking, tension, or pressure. Excess pressure on the flap may occur from overzealous flap inset or from overly tight postoperative dressings. However, these preventative measures are not always sufficient to eliminating postoperative complications.⁴⁰

The decision to return to the operating room can be very difficult to make for the young surgeon or trainee. If a thrombus is suspected, re-exploration of the free flap should not be delayed.^{59–61} If an early thrombus (fresh clot) is observed, heparin should be administered and adjusted to maintain activated prothrombin time at 2 to 2.5 times normal levels with potential for a thrombectomy. If a late thrombus (established clot) is noted, heparin is similarly provided with thrombolytics (streptokinase or tissue plasminogen activator) and a thrombectomy. A number 2 Fogarty catheter can also be used for thrombectomy. Microvascular monitoring should be maintained for at least 3 days postoperatively to ensure quality care. If flap loss is inevitable, alternative options include a second free flap, a local flap, or delayed reconstruction.⁶⁰

Alternative Options for Breast Reconstruction

Alternative surgical options for breast reconstruction include implants, pedicled flaps, and adjunctive fat grafting. Implant-based breast reconstruction has been associated with higher postoperative complications. There is no surmounting evidence that indicates whether immediate or delayed reconstruction offers better outcomes.^{48,62,63} In one study by Fischer et al, implant-based reconstructions demonstrated a threefold increased risk for seroma and cellulitis compared to free flap reconstruction. Additionally, implant-based reconstruction was linked to capsular contraction, implant exposure, and infection.⁵ Asymmetry requiring contralateral breast reconstruction is also more common.⁵ With these additional surgical procedures, the cost associated with the implant-based model may surpass that of autologous flaps. However, while many studies have looked at the postoperative and cost benefits of autologous reconstruction, studies have shown conflicting evidence.^{5,62–64}

Pedicled flaps have served as effective alternatives when performing breast reconstruction surgery. The pTRAM and latissimus dorsi (LD) flap are both relatively common pedicled flaps transferred during breast reconstruction. As the pTRAM flap transfer requires removal of rectus abdominis muscle, donor site morbidity and longer hospital stays are the main limiting factors in its modern use.^{1,2,25,28} The LD flap is reliable and easy to harvest; however, flap volume is limited and of concern for patients who desire a relatively larger breast

augmentation.^{65–67} Therefore, LD reconstruction often requires a prosthesis in addition to the flap.⁶⁵ A modification of this technique, the extended LD myocutaneous flap, was introduced as a method to avoid use of the implant.⁶⁸ In addition to the LD muscle, scapular fat fascia is included for volume, taking care to keep the subdermal plexus of the back intact.⁶⁹ As this involves the transfer of whole muscle, fascia, and additional skin, there is a tradeoff between a larger breast size and increased donor site morbidity.^{66,68}

Fat grafting as an adjunct to pedicled flaps is a novel technique used for patients requiring breast reconstruction following mastectomy. Autologous fat grafting has the benefit of providing patients with increased breast augmentation and low donor site morbidity.^{66,70} Fat grafting has conventionally been used as a method for shaping the breasts appropriately after a delayed time following the index breast reconstruction.⁷¹ Recently, the LD flap has been performed in conjunction with immediate fat transfer to forgo the use of an implant.^{66,70–73} By avoiding prosthesis, patients are less likely to undergo postoperative complications and further procedures, which may additionally lower overall costs incurred by the patient.^{70,72}

Conclusion

There are numerous breast reconstruction procedures that can be performed post mastectomy. Free flap procedures should be highly considered as a primary surgical option when undergoing breast reconstruction as it demonstrates overall good postoperative outcomes and low donor site morbidity. Understanding the risks associated with autogenous flap transfers can be helpful for surgeons who may want to utilize an alternative procedure to minimize postoperative complications.

Financial Disclosure Statement

The authors have no financial disclosures.

Conflict of Interest

None declared.

References

- 1 Champaneria MC, Wong WW, Hill ME, Gupta SC. The evolution of breast reconstruction: a historical perspective. *World J Surg* 2012; 36(04):730–742
- 2 Uroskie TW, Colen LB. History of breast reconstruction. *Semin Plast Surg* 2004;18(02):65–69
- 3 Allen RJ, Treece P. Deep inferior epigastric perforator flap for breast reconstruction. *Ann Plast Surg* 1994;32(01):32–38
- 4 Hartrampf CR, Schefflan M, Black PW. Breast reconstruction with a transverse abdominal island flap. *Plast Reconstr Surg* 1982;69(02):216–225
- 5 Fischer JP, Nelson JA, Cleveland E, et al. Breast reconstruction modality outcome study: a comparison of expander/implants and free flaps in select patients. *Plast Reconstr Surg* 2013;131(05): 928–934
- 6 Vyas RM, Dickinson BP, Fastekjian JH, Watson JP, Dalio AL, Crisera CA. Risk factors for abdominal donor-site morbidity in free flap breast reconstruction. *Plast Reconstr Surg* 2008;121(05):1519–1526

- 7 Massenburg BB, Sanati-Mehrziy P, Ingargiola MJ, Rosa JH, Taub PJ. Flap failure and wound complications in autologous breast reconstruction: a national perspective. *Aesthetic Plast Surg* 2015;39(06):902–909
- 8 Selber JC, Angel Soto-Miranda M, Liu J, Robb G. The survival curve: factors impacting the outcome of free flap take-backs. *Plast Reconstr Surg* 2012;130(01):105–113
- 9 Yueh JH, Slavin SA, Adesiyun T, et al. Patient satisfaction in postmastectomy breast reconstruction: a comparative evaluation of DIEP, TRAM, latissimus flap, and implant techniques. *Plast Reconstr Surg* 2010;125(06):1585–1595
- 10 LoTempio MM, Allen RJ. Breast reconstruction with SGAP and IGAP flaps. *Plast Reconstr Surg* 2010;126(02):393–401
- 11 Granzow JW, Levine JL, Chiu ES, Allen RJ. Breast reconstruction with gluteal artery perforator flaps. *J Plast Reconstr Aesthet Surg* 2006;59(06):614–621
- 12 Allen RJ, Haddock NT, Ahn CY, Sadeghi A. Breast reconstruction with the profunda artery perforator flap. *Plast Reconstr Surg* 2012;129(01):16e–23e
- 13 Buntic RF, Horton KM, Brooks D, Althubaiti GA. Transverse upper gracilis flap as an alternative to abdominal tissue breast reconstruction: technique and modifications. *Plast Reconstr Surg* 2011;128(06):607e–613e
- 14 Wei FC, Suominen S, Cheng MH, Celik N, Lai YL. Anterolateral thigh flap for postmastectomy breast reconstruction. *Plast Reconstr Surg* 2002;110(01):82–88
- 15 Blondeel PN. The sensate free superior gluteal artery perforator (S-GAP) flap: a valuable alternative in autologous breast reconstruction. *Br J Plast Surg* 1999;52(03):185–193
- 16 Gagnon AR, Blondeel PN. Superior gluteal artery perforator flap. *Semin Plast Surg* 2006;20(02):79–88
- 17 Allen RJ, Levine JL, Granzow JW. The in-the-crease inferior gluteal artery perforator flap for breast reconstruction. *Plast Reconstr Surg* 2006;118(02):333–339
- 18 Dayan JH, Allen RJ Jr. Lower extremity free flaps for breast reconstruction. *Plast Reconstr Surg* 2017;140(5S) *Advances in Breast Reconstruction*, 55:775–865
- 19 Natoli NB, Wu LC. Vascular variations of the transverse upper gracilis flap in consideration for breast reconstruction. *Ann Plast Surg* 2015;74(05):528–531
- 20 Dayan E, Smith ML, Sultan M, Samson W, Dayan JH. The diagonal upper gracilis (DUG) flap: a safe and improved alternative to the TUG flap. *Plast Reconstr Surg* 2013;132(4S–1):33–34
- 21 Allen RJ Jr, Lee ZH, Mayo JL, Levine J, Ahn C, Allen RJ Sr. The profunda artery perforator flap experience for breast reconstruction. *Plast Reconstr Surg* 2016;138(05):968–975
- 22 Chevray PM. Update on breast reconstruction using free TRAM, DIEP, and SIEA flaps. *Semin Plast Surg* 2004;18(02):97–104
- 23 Wu LC, Bajaj A, Chang DW, Chevray PM. Comparison of donor-site morbidity of SIEA, DIEP, and muscle-sparing TRAM flaps for breast reconstruction. *Plast Reconstr Surg* 2008;122(03):702–709
- 24 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(05):1335–1341
- 25 Garvey PB, Buchel EW, Pockaj BA, et al. DIEP and pedicled TRAM flaps: a comparison of outcomes. *Plast Reconstr Surg* 2006;117(06):1711–1719, discussion 1720–1721
- 26 Golpanian S, Gerth DJ, Tashiro J, Thaller SR. Free versus pedicled TRAM flaps: cost utilization and complications. *Aesthetic Plast Surg* 2016;40(06):869–876
- 27 Gart MS, Smetona JT, Hanwright PJ, et al. Autologous options for postmastectomy breast reconstruction: a comparison of outcomes based on the American College of Surgeons National Surgical Quality Improvement Program. *J Am Coll Surg* 2013;216(02):229–238
- 28 Grotting JC, Urist MM, Maddox WA, Vasconez LO. Conventional TRAM flap versus free microsurgical TRAM flap for immediate breast reconstruction. *Plast Reconstr Surg* 1989;83(05):828–841, discussion 842–844
- 29 Elliott LF, Eskenazi L, Beegle PH Jr, Podres PE, Drazan L. Immediate TRAM flap breast reconstruction: 128 consecutive cases. *Plast Reconstr Surg* 1993;92(02):217–227
- 30 Bajaj AK, Chevray PM, Chang DW. Comparison of donor-site complications and functional outcomes in free muscle-sparing TRAM flap and free DIEP flap breast reconstruction. *Plast Reconstr Surg* 2006;117(03):737–746, discussion 747–750
- 31 Spiegel AJ, Khan FN. An intraoperative algorithm for use of the SIEA flap for breast reconstruction. *Plast Reconstr Surg* 2007;120(06):1450–1459
- 32 Park JE, Shenaq DS, Silva AK, Mhlaba JM, Song DH. Breast reconstruction with SIEA flaps: a single-institution experience with 145 free flaps. *Plast Reconstr Surg* 2016;137(06):1682–1689
- 33 Hamdi M, Rebecca A. The deep inferior epigastric artery perforator flap (DIEAP) in breast reconstruction. *Semin Plast Surg* 2006;20(02):95–102
- 34 El-Mrakby HH, Milner RH. The vascular anatomy of the lower anterior abdominal wall: a microdissection study on the deep inferior epigastric vessels and the perforator branches. *Plast Reconstr Surg* 2002;109(02):539–543, discussion 544–547
- 35 Albino FP, Koltz PF, Ling MN, Langstein HN. Irradiated autologous breast reconstructions: effects of patient factors and treatment variables. *Plast Reconstr Surg* 2010;126(01):12–16
- 36 Seidenstuecker K, Munder B, Mahajan AL, Richrath P, Behrendt P, Andree C. Morbidity of microsurgical breast reconstruction in patients with comorbid conditions. *Plast Reconstr Surg* 2011;127(03):1086–1092
- 37 Spear SL, Ducic I, Cuoco F, Taylor N. Effect of obesity on flap and donor-site complications in pedicled TRAM flap breast reconstruction. *Plast Reconstr Surg* 2007;119(03):788–795
- 38 Masia J, Larrañaga J, Clavero JA, Vives L, Pons G, Pons JM. The value of the multidetector row computed tomography for the preoperative planning of deep inferior epigastric artery perforator flap: our experience in 162 cases. *Ann Plast Surg* 2008;60(01):29–36
- 39 Broer PN, Weichman KE, Tanna N, et al. Venous coupler size in autologous breast reconstruction—does it matter? *Microsurgery* 2013;33(07):514–518
- 40 Bullocks JM, Hsu PW, Izaddoost SA, Hollier LH Jr. *Plastic Surgery Emergencies: Principles and Techniques*. New York: Thieme; 2017:229–237
- 41 Salgado CJ, Moran SL, Mardini S. Flap monitoring and patient management. *Plast Reconstr Surg* 2009;124(6, Suppl):e295–e302
- 42 Lohman RF, Langevin CJ, Bozkurt M, Kundu N, Djohan R. A prospective analysis of free flap monitoring techniques: physical examination, external Doppler, implantable Doppler, and tissue oximetry. *J Reconstr Microsurg* 2013;29(01):51–56
- 43 Smit JM, Zeebregts CJ, Acosta R, Werker PM. Advancements in free flap monitoring in the last decade: a critical review. *Plast Reconstr Surg* 2010;125(01):177–185
- 44 Kroll SS, Schusterman MA, Reece GP, et al. Timing of pedicle thrombosis and flap loss after free-tissue transfer. *Plast Reconstr Surg* 1996;98(07):1230–1233
- 45 Chen KT, Mardini S, Chuang DC, et al. Timing of presentation of the first signs of vascular compromise dictates the salvage outcome of free flap transfers. *Plast Reconstr Surg* 2007;120(01):187–195
- 46 Hosein RC, Cornejo A, Wang HT. Postoperative monitoring of free flap reconstruction: a comparison of external Doppler ultrasonography and the implantable Doppler probe. *Plast Surg (Oakv)* 2016;24(01):11–19
- 47 Keller A. A new diagnostic algorithm for early prediction of vascular compromise in 208 microsurgical flaps using tissue oxygen saturation measurements. *Ann Plast Surg* 2009;62(05):538–543
- 48 Sullivan SR, Fletcher DR, Isom CD, Isik FF. True incidence of all complications following immediate and delayed breast reconstruction. *Plast Reconstr Surg* 2008;122(01):19–28

- 49 Baumann DP, Crosby MA, Selber JC, et al. Optimal timing of delayed free lower abdominal flap breast reconstruction after postmastectomy radiation therapy. *Plast Reconstr Surg* 2011;127(03):1100–1106
- 50 Fracol ME, Basta MN, Nelson JA, et al. Bilateral free flap breast reconstruction after unilateral radiation: comparing intraoperative vascular complications and postoperative outcomes in radiated versus nonradiated breasts. *Ann Plast Surg* 2016;76(03):311–314
- 51 Wilkins EG, Hamill JB, Kim HM, et al. Complications in postmastectomy breast reconstruction: one-year outcomes of the mastectomy reconstruction outcomes consortium (MROC) study. *Ann Surg* 2018;267(01):164–170
- 52 Fischer JP, Sieber B, Nelson JA, et al. Comprehensive outcome and cost analysis of free tissue transfer for breast reconstruction: an experience with 1303 flaps. *Plast Reconstr Surg* 2013;131(02):195–203
- 53 McCarthy CM, Mehrara BJ, Riedel E, et al. Predicting complications following expander/implant breast reconstruction: an outcomes analysis based on preoperative clinical risk. *Plast Reconstr Surg* 2008;121(06):1886–1892
- 54 Sanati-Mehrziy P, Massenburg BB, Rozehnal JM, et al. A comparison of postoperative outcomes in immediate versus delayed reconstruction after mastectomy. *Eplasty* 2015;15:e44
- 55 Enajat M, Damen TH, Geenen A, Timman R, van der Hulst RR, Mureau MA. Pulmonary embolism after abdominal flap breast reconstruction: prediction and prevention. *Plast Reconstr Surg* 2013;131(06):1213–1222
- 56 McKean AR, Knox J, Harris P, Ramsey K, James S, Power KT. Audit of venous thromboembolism in DIEP free flap breast reconstruction. *J Plast Reconstr Aesthet Surg* 2017;70(07):970–972
- 57 Qiu CS, Jordan SW, Dorfman RG, Vu MM, Alghoul MS, Kim JYS. Surgical duration impacts venous thromboembolism risk in microsurgical breast reconstruction. *J Reconstr Microsurg* 2018;34(01):47–58
- 58 Pannucci CJ, Oppenheimer AJ, Wilkins EG. Practice patterns in venous thromboembolism prophylaxis: a survey of 606 reconstructive breast surgeons. *Ann Plast Surg* 2010;64(06):732–737
- 59 Baumeister S, Follmar KE, Zenn MR, Erdmann D, Levin LS. Strategy for reoperative free flaps after failure of a first flap. *Plast Reconstr Surg* 2008;122(03):962–971
- 60 Bui DT, Cordeiro PG, Hu QY, Disa JJ, Pusic A, Mehrara BJ. Free flap reexploration: indications, treatment, and outcomes in 1193 free flaps. *Plast Reconstr Surg* 2007;119(07):2092–2100
- 61 Khansa I, Chao AH, Taghizadeh M, Nagel T, Wang D, Tiwari P. A systematic approach to emergent breast free flap takeback: clinical outcomes, algorithm, and review of the literature. *Microsurgery* 2013;33(07):505–513
- 62 Francis SH, Ruberg RL, Stevenson KB, et al. Independent risk factors for infection in tissue expander breast reconstruction. *Plast Reconstr Surg* 2009;124(06):1790–1796
- 63 Alderman A, Gutowski K, Ahuja A, Gray D; Postmastectomy Expander Implant Breast Reconstruction Guideline Work Group. ASPS clinical practice guideline summary on breast reconstruction with expanders and implants. *Plast Reconstr Surg* 2014;134(04):648e–655e
- 64 Spear SL, Mardini S, Ganz JC. Resource cost comparison of implant-based breast reconstruction versus TRAM flap breast reconstruction. *Plast Reconstr Surg* 2003;112(01):101–105
- 65 Hammond DC. Latissimus dorsi flap breast reconstruction. *Plast Reconstr Surg* 2009;124(04):1055–1063
- 66 Santanelli di Pompeo F, Laporta R, Sorotos M, Pagnoni M, Falesiedi F, Longo B. Latissimus dorsi flap for total autologous immediate breast reconstruction without implants. *Plast Reconstr Surg* 2014;134(06):871e–879e
- 67 Economides JM, Song DH. Latissimus dorsi and immediate fat transfer (LIFT) for complete autologous breast reconstruction. *Plast Reconstr Surg Glob Open* 2018;6(01):e1656
- 68 Hokin JA, Silfverskiold KL. Breast reconstruction without an implant: results and complications using an extended latissimus dorsi flap. *Plast Reconstr Surg* 1987;79(01):58–66
- 69 Germann G, Steinau HU. Breast reconstruction with the extended latissimus dorsi flap. *Plast Reconstr Surg* 1996;97(03):519–526
- 70 Spear SL, Coles CN, Leung BK, Gitlin M, Parekh M, Macarios D. The safety, effectiveness, and efficiency of autologous fat grafting in breast surgery. *Plast Reconstr Surg Glob Open* 2016;4(08):e827
- 71 Kling RE, Mehrara BJ, Pusic AL, et al. Trends in autologous fat grafting to the breast: a national survey of the American society of plastic surgeons. *Plast Reconstr Surg* 2013;132(01):35–46
- 72 Thekkinkattil DK, Salhab M, McManus PL. Feasibility of autologous fat transfer for replacement of implant volume in complicated implant-assisted latissimus dorsi flap breast reconstruction. *Ann Plast Surg* 2015;74(04):397–402
- 73 Sinna R, Delay E, Garson S, Delaporte T, Tousoun G. Breast fat grafting (lipomodelling) after extended latissimus dorsi flap breast reconstruction: a preliminary report of 200 consecutive cases. *J Plast Reconstr Aesthet Surg* 2010;63(11):1769–1777