Inchauste. *Plast Aesthet Res* 2023;10:27
DOI: 10.20517/2347-9264.2022.139

Plastic and Aesthetic Research

Review

Open Access

Check for updates

Complications in microsurgical breast reconstruction: thrombosis prevention and management

Suzanne M. Inchauste

Department of Surgery, Division of Plastic and Reconstructive Surgery, University of Washington Medical Center, 1959 NE Pacific Street, Seattle, WA 98195, USA.

Correspondence to: Dr. Suzanne M. Inchauste, Department of Surgery, Division of Plastic and Reconstructive Surgery, University of Washington Medical Center, Seattle, WA 98195, USA. E-mail: sinchaus@uw.edu

How to cite this article: Inchauste SM. Complications in microsurgical breast reconstruction: thrombosis prevention and management. *Plast Aesthet Res* 2023;10:27. https://dx.doi.org/10.20517/2347-9264.2022.139

Received: 1 Dec 2022 **First Decision:** 14 Mar 2023 **Revised:** 18 Apr 2023 **Accepted:** 5 Jun 2023 **Published:** 12 Jun 2023

Academic Editor: Christine Hsu Rohde **Copy Editor:** Yanbing Bai **Production Editor:** Yanbing Bai

Abstract
Breast reconstruction is one of the largest components of plastic and reconstructive surgery. Autologous free flap breast reconstruction continues to grow due to exceptionally high flap success rates. It provides patients with a durable and natural reconstruction with high patient satisfaction. A patent microvascular anastomosis is a key component to a successful autologous free flap breast reconstruction. Thrombus within the vascular anastomosis or the distal flap microcirculation is the most common cause of flap failure. This review aims to discuss microsurgical techniques including atraumatic handling of vessels, appropriate magnification, suture styles, anastomotic techniques, recipient vessel selection, the role of anticoagulation and antiplatelet therapy used to minimize the risk of thrombotic events. When microvascular thrombus occurs, early reoperation and reperfusion is imperative to flap survival. This review will discuss specific maneuvers and intraoperative interventions to maximize flap salvage.

Keywords: Microsurgery, autologous free flap breast reconstruction, thrombosis, microsurgical anastomosis, thrombus prevention

© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, sharing, adaptation, distribution and reproduction in any medium or format, for any purpose, even commercially, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

INTRODUCTION

The first free tissue transfer by McLean and Buncke in 1972[1] was the birth of microsurgery. Autologous free flap breast reconstruction has gained popularity since it was first described in 1979[2]. In 1979, Holmström studied the vascular supply of abdominoplasty tissue using angiography and identified the superficial and deep inferior epigastric vascular systems. He then performed the first autologous free flap breast reconstruction using a free abdominoplasty flap in a patient with a prior radical mastectomy. Holmstrom designed the flap based on the dimensions of an abdominoplasty, umbilicus to pubic region and between the anterior superior iliac spines. Holmstrom visualized the perforators within the rectus abdominus muscle, piercing the anterior rectus sheath, and traveling into the abdominoplasty tissue. He raised the flap on these perforators, including the ipsilateral rectus muscle and vascular pedicle, transferring the flap 5 days later. Holmstrom completed the arterial anastomosis to the axillary artery, and the two venae comitans and the contralateral superficial inferior epigastric vein to the axillary and thoracodorsal veins. Improvements in microvascular free tissue transfer techniques over the past 50 years have made autologous free flap breast reconstruction widely accepted. After reading this review, the participant will gain knowledge about how to successfully perform a microvascular anastomosis. This review will discuss microsurgical techniques including atraumatic handling of vessels, appropriate magnification, suture styles, anastomotic techniques and the role of anticoagulants and antiplatelet therapy in minimizing the risk of thrombosis to improve any microsurgical anastomosis. It will specifically discuss autologous breast free flap recipient vessel selection, alternative options, and maneuvers to manage thrombotic complications.

PREVENTION

The percentage of women electing to have breast reconstruction after mastectomy continues to increase. Overall, autologous free flap breast reconstruction is less common than implant-based breast reconstruction. However, it has steadily increased and accounted for 23% of all breast reconstruction procedures in 2020[3]. Autologous microvascular free flap breast reconstruction continues to grow with advancements in technology, increasing experience and comfort of surgeons with microsurgery, expanding indications, and new donor sites such as lumbar artery perforator flaps[4] and omental fat-augmented free flap for breast reconstruction patients with inadequate abdominal or thigh tissue[5]. In addition, autologous free flap breast reconstruction has excellent patient-reported outcomes and satisfaction[6]. Autologous free flap breast reconstruction provides a durable, natural aesthetic reconstruction. Autologous free flap breast reconstruction has been associated with high satisfaction and lower long-term failure[6]. Drawbacks to autologous free flap breast reconstruction include a secondary donor site with associated donor site morbidity, longer surgery, and recovery with a higher risk of thromboembolic complications, and specialized operative instruments that can be expensive and not available at every site providing breast reconstruction. Implant-based reconstruction does not require specialized equipment, limits surgery to the breast only with shorter operative times and recovery, but has lower patient satisfaction, higher longer-term failure rates and thus more explant procedures[7]. Successful autologous free flap breast reconstruction requires appropriate patient selection, adequate preoperative planning, meticulous flap dissection, and patent microvascular anastomosis. Autologous free flap breast reconstruction has exceptionally high success rates ranging from 97%-99%, with flap failure most associated with a thrombus[8-14]. Patient selection, flap selection and design, and complete preoperative evaluation with appropriate imaging are important. The goal of this review is to discuss surgical techniques and maneuvers of microsurgery to maximize success.

Microsurgical technical points:

Excellent surgical technique is key to the success of any surgery; microsurgery is no exception. Meticulous dissection of the flap perforators, flap pedicle and recipient vessels is equally important. Autologous free flap breast reconstruction relies on the patency of very small vessels to be successful. Extreme care must be taken during vessel dissection to minimize tension on vessels and avoid avulsion or intimal injury. The same care is required during the preparation and handling of vessels during microvascular anastomosis.

Endothelium is the inner cellular lining of all vessels and constitutes the intima layer. The endothelium controls vascular relaxation and constriction[15]. Injury to the endothelium can result in vasospasm or constriction as well as platelet adherence and clot formation. Studies have shown that damage to the intima increases the risk of thrombus and flap loss[16]. It is important to minimize instrumentation to both the recipient and flap vessels, especially within the lumen of the vessel. The lumen of the vessels should be visualized under high magnification and carefully inspected for any tears or separation of the intima. This is especially critical when the patient has a history of radiation. Radiated vessels are more friable and prone to intimal injury. Prior radiation therapy is not a contraindication but awareness of the potential damage to recipient vessels is needed. Compared to implant-based reconstruction and immediate autologous free flap breast reconstruction in postmastectomy radiation patients, delayed autologous free flap breast reconstruction is associated with higher patient satisfaction, fewer revision surgeries and lower long-term complications[17]. If an intimal injury is seen, the vessel needs to be trimmed back until healthy, uninjured intima prior to proceeding with the anastomosis. Further dissection of the vessels may be needed to achieve appropriate exposure to healthy-appearing vasculature. In the setting of poor vessel quality, such as radiation damage or atherosclerotic disease, the use of alternative vessels or vein grafts may be warranted, as discussed below.

Once the vessel is trimmed back to a healthy lumen and appropriate length, the outside of the vessel is prepared. The vessels are separated, and surrounding fatty tissue removed. The outer layer of connective tissue surrounding a blood vessel is the tunica adventitia or tunica externa. Adventitia is comprised of collagen, elastic fibers, and perivascular nerves. The adventitia plays an important role in controlling lumen size through the regulation of the smooth muscle tone. Activation of sympathetic fibers within the adventitia causes vasoconstriction and lumen narrowing. Interruption of these sympathetic fibers within the adventitia leads to decreased activation of smooth muscle tone and vasodilation[18]. Limited resection of the adventitia around the artery during vessel preparation has been shown to reduce vascular tone and increase lumen size, and vascular flow during microvascular anastomosis[18]. Vasodilation and increased flow improve anastomotic patency and decrease thrombosis. Care must be taken to not over-resect the adventitia and weaken the vessel. Limited adventitiectomy around the circumference of the vessel edge with microscissors can provide the desired sympathectomy without compromising the vessel integrity.

Magnification:

Visualization is crucial to performing a successful microvascular anastomosis. It is critical to see all the structures of the vessel and suture placement. The use of surgical microscopes for appropriate visual magnification to perform microvascular anastomoses remains the predominant method. The magnification achievable with most operating microscopes is between 6× and 40×. More recent publications have shown microsurgical anastomoses performed with loupes magnification to be safe and effective for free flap breast reconstruction[10,19,20]. Loupes provided 3.5× to 5.5× magnification[20]. Small vessel diameters equal to 1.5 mm or less still require operative microscope magnification[20]. One must consider that the authors of most publications regarding loupes microsurgery are very experienced microsurgeons. Novice surgeons learning microsurgery may not have equivalent outcomes. The operative microscope allows for significantly better visualization with magnification twice to forty times as powerful as loupes. Newer operative microscopes are equipped with integrated near-infrared illumination systems that can be used to evaluate intraoperative flap perfusion and anastomotic patency[21]. Operative microscopes provide better visualization of vessel intima to evaluate damage or tears, management of small side branches, or dissection within fibrotic or radiated fields. This is especially important when first learning microsurgery.

Suture technique:

Now it is time to perform the vascular anastomosis. There has been debate regarding the ideal suture technique. Simple interrupted suture for microvascular anastomosis remains the gold standard, but numerous techniques have been described. The six most published suture techniques are simple interrupted, continuous, locking continuous, continuous horizontal, horizontal interrupted with eversion, and sleeve anastomoses[21]. Publications comparing anastomotic suture techniques have shown no difference in short and/or long-term patency rates. Each technique has been found to be successful if microsurgical principles of suture line eversion with direct intima-to-intima contact and minimal tension are maintained. The suture technique is less important than maintaining the above principles. Suture style depends more on surgeon preference and experience than the superiority of one technique over another.

Hand sewn versus coupler anastomosis:

Vascular anastomoses were historically handsewn with sutures. Nakayama first described a microvascular anastomotic coupling device in 1962[22]. Microvascular anastomotic coupling device (MACD) is a well-established alternative to hand-sewn venous anastomosis. The device has an interlocking ring-pin design to complete the anastomosis with reliable vessel eversion and intima-to-intima contact. The coupling device ring acts as a rigid stent and protects against vessel collapse. However, the rigid ring can act as a potential twisting or kinking point as well if not positioned appropriately. Hand-sewn venous anastomosis is technically demanding due to the thin, fragile nature of vein walls. Studies comparing venous anastomosis techniques (coupler versus hand sewn) show comparable revision and thrombosis rates[9,22,23] but do demonstrate shorter anastomosis times with the use of MACD[22,23]. The use of a coupling device to complete a venous anastomosis is successful in approximately 99% of attempts with a less than 1% conversion rate to hand-sewn anastomosis[23]. The shorter anastomosis time translates to shorter operative time and potential cost savings. A study compared the cost of disposable products and operating room time between hand-sewn venous anastomosis and MACD. This study demonstrated cost saving due to decreased operative time despite the higher disposable cost with MACD[24]. The use of a coupler device for venous anastomosis has been widely adopted as the standard.

Microsurgeons have reported the use of MACD for arterial anastomosis as well. Studies demonstrate anastomotic completion rates with MACD are lower with a higher conversion to hand-sewn anastomosis compared to venous anastomosis[25]. Vessel size mismatch, end-to-side anastomosis, thicker arterial wall, or nonpliable artery were the most common reasons surgeons reported for failure to complete an arterial anastomosis with a coupling device. The literature also describes intimal cracking or tearing during eversion onto the coupler ring pins as reasons for conversion as well[25]. The use of a coupling device for arterial anastomosis can be done, but proper vessel selection is critical. Successful arterial coupling requires adequate vessel size, minimal vessel size mismatch, and a pliable vessel that can be everted. Hand-sewn anastomosis remains the most popular technique for arterial anastomosis.

End-to-end versus end-to-side anastomosis:

End-to-end anastomosis remains the standard technique for microsurgical autologous free flap breast reconstruction. This is especially true in the case of more novice microsurgeons, as this provides the best visualization of the vessel lumen and most pedicle freedom. When end-to-end and end-to-side were compared, rates of anastomotic thrombosis and flap failure were not significantly different[26-28]. Surgeon preference and experience with each technique play a role in selection. End-to-end anastomosis does allow for more freedom of rotation with flap positioning and inset. End-to-side anastomosis can create a tether point at the anastomosis, which may be a point of possible avulsion injury. End-to-side can be technically more difficult but allows for continuity of the recipient vessel and maintains distal perfusion.

Some authors describe the use of end-to-side microvascular anastomosis when a significant vessel caliber mismatch exists. When SIEA flaps are used for autologous free flap breast reconstruction, the superficial inferior epigastric artery diameter is smaller, usually less than 1.5 mm. This can be less than 50% the diameter of recipient IM artery, creating a significant size mismatch. The use of either end-to-side microvascular anastomosis or the use of the thoracodorsal artery as an alternative for a better size match has been described[29].

Internal mammary perforators or end-to-side anastomoses have been described to preserve the internal mammary vessels[30-32]. The use of internal mammary perforators is limited by the size of the perforators and is found to be adequate in less than 10% of cases[32]. Internal mammary perforators have limited use due to their small size and risk of kinking, therefore, should be reserved for use by experienced microsurgeons. End-to-side anastomosis for the internal mammary vessels can be considered in cases when preservation of distal perfusion is desired, such as in patients with coronary artery disease. This allows preservation of the internal mammary artery for coronary artery bypass grafting[31,33].

Vessel selection:

One of the key elements of successful microvascular anastomosis is the appropriate selection of the recipient artery and vein. The thoracodorsal vessels were the first described recipient chest vessels for free flap breast reconstruction[34]. In early autologous free flap breast reconstruction, axillary lymph node dissection was more common, so surgeons routinely used thoracodorsal vessels due to the ease of access within the operative field. Innovations in breast cancer surgery meant more sentinel lymph node biopsy and less frequent axillary lymph node dissection. This influenced a change in recipient vessel selection to the internal mammary (IM) vessels. By contrast, thoracodorsal vessels had a higher rate of conversion compared to internal mammary vessels in autologous free flap breast reconstruction patients[35]. History of axillary lymph node dissection and preoperative radiation were significantly associated with thoracodorsal vessel conversion[35].

Currently, the internal mammary vessels are the predominant recipient vessel of choice due to their larger size, need for shorter pedicle length, better access for microvascular anastomosis and more central placement of the flap in the breast pocket[35-38]. The use of internal mammary vessels has also been advocated because it preserves the thoracodorsal vessels as a backup option for recipient vessels in salvage reconstruction or pedicled myocutaneous latissimus dorsi flap. Dissection of internal mammary vessels does have some special considerations. It often requires removal of a small segment of rib cartilage for adequate exposure. During this dissection, there is potential for pneumothorax, given that only a thin layer of pleura exists between the IM vessels and the lung. Chest wall movement with respiration and radiation fibrosis can make recipient vessel exposure and microvascular anastomosis more challenging. The IM vessels have been found to be the largest at the third intercostal space, which is the most common access point.

 Inchauste. *Plast Aesthet Res* 2023;10:27 | https://dx.doi.org/10.20517/2347-9264.2022.139

Studies have shown that size of the right and left internal mammary arteries did not differ significantly[39]. However, studies have shown left internal mammary vein is significantly smaller than the right[39]. The left internal mammary vein has been shown to have higher rates of thrombosis, venous thrombosis-related flap loss, and higher rates of conversion to an alternate vein compared to the right internal mammary vein[39]. Studies have shown higher rates of venous thrombosis associated with smaller vein diameters.

If a small caliber vein is seen, the first step is to dissect the vessel more proximal to look for a larger caliber. Consideration should be taken if the recipient vein diameter is less than 2 mm, particularly in delayed reconstruction in an irradiated chest, to look for an alternate recipient vessel. Alternate recipient vessels include the vena comitans, retrograde IM vein, contralateral IM vein, or thoracodorsal vein. Other alternative recipient venous outflow options include cephalic vein transposition[40]. Cephalic vein transposition (CVT) is used more frequently in patients undergoing delayed reconstruction and with a history of radiation[40]. CVT can be used as an alternative for the primary recipient vessel or to supplement flap venous insufficiency. Contralateral internal mammary vessels are another option in the setting of unilateral reconstruction [Figure 1], which requires adequate pedicle length or vein graft in flaps with shorter pedicles such as a transverse upper gracilis flap (TUG). Adequate dissection is needed to avoid kinking the vessel and one should appropriately line the course of the pedicle with adipose tissue to prevent compression from the underlying sternum. Thoracodorsal vessels were the original recipient vessel choice of free flap breast reconstruction and are often considered a reliable alternative vessel choice when the IM vessels are not usable, but it does require a longer pedicle. The use of the thoracodorsal vein as an alternative recipient vessel when the IMA anastomosis is patent may require a long vein graft. It can also potentially limit the use of a pedicled latissimus dorsi myocutaneous flap for salvage reconstruction. The thoracodorsal vessels may not be usable in up to a third of all patients with a history of axillary lymphadenectomy and radiation[35].

Venous insufficiency:

After the primary microvascular anastomosis, the flap can demonstrate venous outflow insufficiency with hyperemic appearance of the flap skin and dark red bleeding from the edges. If the flap demonstrates venous congestion, the first step is a complete evaluation of the arterial and venous anastomosis for patency. If the anastomoses are patented, the next step is to augment the venous drainage of flaps with additional venous anastomosis. If the recipient vein is small and the concern is inadequate deep venous flow, the primary option is augmentation of the deep venous system by completing a second venous anastomosis to the other vena comitans of the deep venous system of the flap to IM vena comitans, retrograde IM vein or an alternate vein.

It is rare to develop intraoperative venous congestion in the setting of patent adequate deep venous anastomosis, as this occurs less than 1% of the time[41]. This is most commonly due to superficial dominant venous drainage of the flap [Figure 2]. Most surgeons routinely dissect the superficial inferior epigastric vein at a length of 5-8 cm during DIEP flap harvest. In the setting of flap venous congestion, if the SIEV is engorged and congestion improves with drainage of the superficial system, then augmenting the venous outflow with a separate venous anastomosis to the SIEV is necessary. A second recipient vein such as second IMV, retrograde IMV, internal mammary or intercostal perforator, lateral thoracic vein, thoracoacromial vein, external jugular, cephalic vein transposition, thoracodorsal vein or to a proximally dissected vena comitans of the flap with and without vein graft has all been described[40-43]. Early recognition of flap venous insufficiency at the time of primary reconstruction with intraoperative correction has shown exceptional intraoperative salvage rates[41].

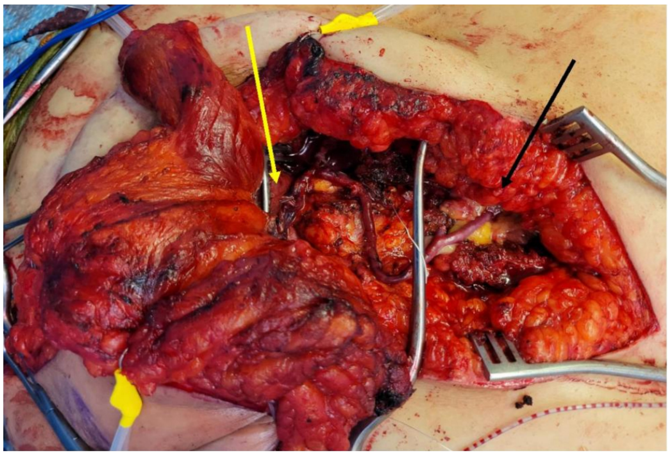

Figure 1. TUG flap with vein graft to the contralateral IM artery. The patient had a history of a failed DIEP flap. Yellow arrow points to the anastomosis of TUG artery to the vein graft. Black arrow points to the anastomosis of the vein graft to contralateral IMA. IM: internal mammary; DIEP: deep inferior epigastric perforator; IMA: internal mammary artery.

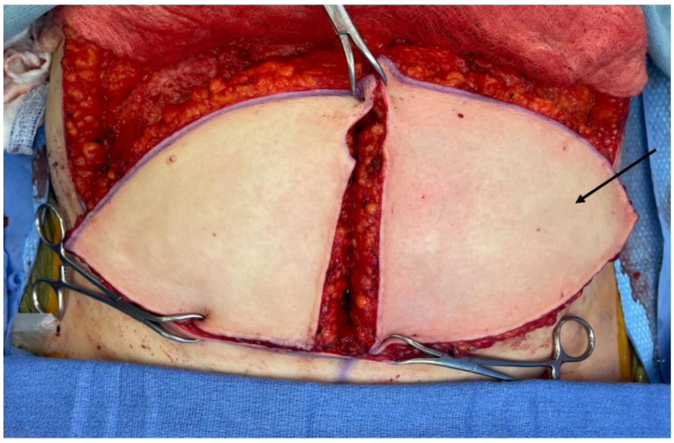

Figure 2. Arrow pointing to the left hemiabdomen in a bilateral DIEP with superficial dominant venous system. The left hemiabdomen demonstrated mild hyperemia compared to the right hemiabdomen prior to microvascular anastomosis. A second venous anastomosis to the SIEV was done at the initial microsurgical anastomosis. DIEP: deep inferior epigastric perforator; SIEV: superficial inferior epigastic vein.

Vein grafts:

If a vein graft is needed for a second venous anastomosis, several vein graft donor sites have been described. One must consider vessel size match, donor site morbidity, and ease of donor site access within the surgical field. The contralateral SIEV [Figure 3] or superficial circumflex iliac vein can be used, particularly in the setting of unilateral reconstruction. These vessels are within the abdominal sterile field, easy to access and harvest, and have a good vessel size match. Other options include the dorsal foot veins. They are easy to access, can be prepped quickly without disrupting the chest and abdominal field, and have adequate size match. Superficial veins in the forearm have been described in a similar way. It is important when harvesting a vein graft to ligate all the side branches and mark the proximal end to orient the direction of flow.

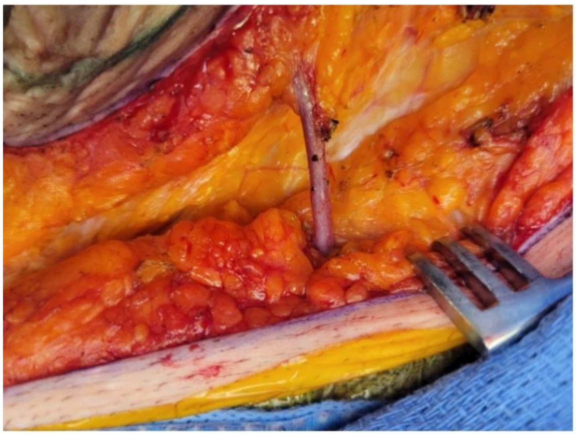

Figure 3. SIEV dissected 8 cm to length during DIEP flap elevation. DIEP: deep inferior epigastric perforator; SIEV: superficial inferior epigastic vein.

Vein grafts can be used to increase pedicle length for either the arterial or venous anastomosis, augment flap venous outflow with a second venous anastomosis through either the deep or superficial system, or during flap salvage. Vein grafts are more commonly used during primary reconstruction to troubleshoot intraoperative concerns[40]. For example, if the recipient or flap vessels have scar or fibrosis, then cutting back the vessels to more healthy tissue may shorten the vessel length resulting in the need for a vein graft. If the primary recipient vessels are insufficient and pedicle length is needed to access alternative recipient vessels, a vein graft may also be required [Figure 1]. If a second venous anastomosis is needed to augment flap venous drainage, a vein graft may be needed to perform the second venous anastomosis. Vein grafts can be used during flap salvage to restore flow after thrombosis or avulsion injury as well. Studies have shown that primary reconstruction with the use of vein graft has success rates as high as 95%, but there are significantly higher rates of thrombosis compared to primary reconstruction without vein graft[44]. Longer vein grafts are associated with higher rates of thrombosis and failure[45]. Vein grafts are an important tool in one's armamentarium when confronted with difficult microsurgical free flap reconstructions but are associated with higher rates of thrombosis and flap failure.

Once the free flap surgery is complete, postoperative flap monitoring protocols that are diligent, rigorous, and timely are essential for successful free flap breast reconstruction. The first and most important flap monitoring system is the physical exam. Flap assessment evaluating the skin color, temperature, turgor, capillary refill, and bleeding with pinprick is the gold standard. Any signs of concern such as pale flap color, cool to the touch, absent capillary refill or blood on pinprick are concerns for an arterial or inflow thrombosis. Brisk capillary refill, hyperemic or purple skin color, swollen or boggy turgor, or brisk dark red blood with pinprick are physical exam findings consistent with venous congestion or venous thrombosis [Figure 4]. Monitoring systems including acoustic Doppler sonography, implantable Doppler devices, and continuous near-infrared spectroscopy that complement physical exam can prompt early detection of vascular compromise and facilitate expeditious return to the operating room. Studies have shown higher salvage rates with a shorter time from detection of compromise and return to the operating room with the use of a monitoring system in addition to serial physical exams[46].

Anticoagulation:

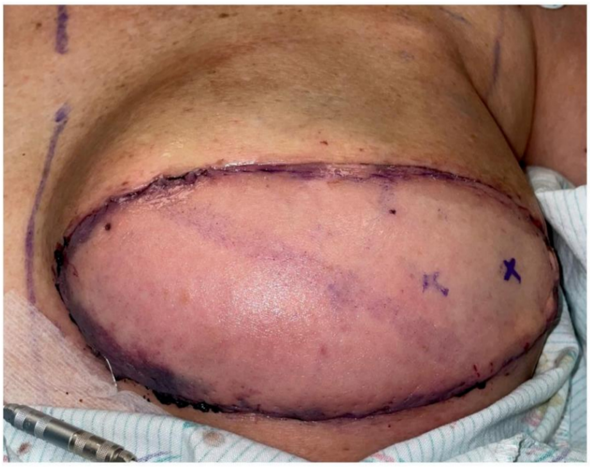

Figure 4. Left breast DIEP flap venous congestion seen on post operative. Please change to left breast DIEP flap with venous congeston on post operative day 2. DIEP: deep inferior epigastric perforator.

Medications to prevent and treat thrombus have been given to patients for decades. One of the oldest and most widely used anticoagulants is heparin[47]. McLean discovered heparin in 1916, but its clinical inception was not until 1935[47]. Heparin activates antithrombin III which inhibits thrombin, thus preventing conversion of fibrinogen to fibrin and inhibiting clot propagation. Heparin aids in the migration of endothelial cells while increasing negative charge, disturbs the fibrin lattice, and prevents platelet binding[16]. Heparin is an effective treatment for both arterial and venous thrombosis.

Heparin can be used locally as an irrigation solution or given to the patient as a systemic anticoagulant during microsurgery. Most microsurgeons use a heparinized saline solution at concentrations of 100 unit/mL as a local irrigation solution during microvascular anastomosis[48]. The heparinized saline solution as an irrigation solution during microvascular anastomosis has shown lower rates of thrombus formation compared to saline and lactated ringers. It provides high concentrations of heparin locally to the site of microvascular anastomosis to prevent thrombus formation without systemic anticoagulation effect. It can be used liberally during the primary anastomosis, during any anastomotic revision, or at the time of take back since the systemic absorption is minimal.

Numerous intraoperative and postoperative protocols with the use of pharmacologic anticoagulants exist in the literature, but there is no consensus on an ideal protocol. Systemic heparin given as a bolus at the time of microvascular anastomosis was routine in early microsurgery history. The studies report a range of doses from a flat 5,000 units up to 160 units/kg[46,49]. Although systemic heparin did not significantly increase flap survival or decrease thrombus formation, it did increase the risk of flap hematoma[48]. More recently, systemic heparin has not been given routinely but is reserved for patients with a history of thromboembolic events or in patients with extensive thrombosis at the time of flap salvage. Operative intervention for thrombectomy is the standard and systemic anticoagulation can be used to supplement flap salvage but does not replace operative exploration.

Dextran is a polysaccharide that is a product of fermentation with a molecular weight of 40 or 70. Dextran 40, a low molecular weight dextran, is a non-protein colloid given intravenously to expand plasma volume, cause hemodilution, and impair platelet function[50]. Dextran 40 was used for venous thrombosis prophylaxis and was typically given as 50-100 g the day of surgery and then a fixed dose of 500 mL daily for 2-5 days postoperatively in autologous free flap breast reconstructions infancy[50-52]. Later studies demonstrated free flap survival and thrombotic complication did not improve with routine use of dextran 40 and had an increased risk of other systemic complications[50,52,53]. Dextran 40 is no longer routinely used during standard autologous free flap breast reconstruction. However, for patients with a known hypercoagulable state, Dextran 40 has been described for thrombosis prevention[52].

Antiplatelet medication:

Antiplatelet therapy such as aspirin has been used as prophylaxis against thrombus in microvascular free flap surgery. Aspirin or acetylsalicylic acid inhibits cyclooxygenase, decreasing the production of arachidonic acid metabolism, including TxA2, a potent platelet aggregator and vasoconstrictor, thus inhibiting thrombus formation. Aspirin has been effective in the prevention of thrombus formation associated with cerebrovascular events and myocardial infarction[16]. Most recent studies demonstrated no significant reduction of thrombosis or flap failure with the use of aspirin but did increase the risk of hematoma[54,55]. These more recent studies have shifted the routine use of antiplatelet therapy to more restricted use for high-risk patients.

Patients with a history of unprovoked thromboembolic events, multiple miscarriages, or a known hypercoagulable state can successfully undergo autologous free flap breast reconstruction. However, the patients should be counseled on the risk of flap failure, reoperation, prolonged hospitalization, need for systemic anticoagulation, use of antiplatelet therapy, increased risk of bleeding complications, and significant risks of other thromboembolic events such as DVT, PE or stroke[56]. Consideration of hematology consultation and coagulopathy work-up before surgery can aid in the formulation of a proper anticoagulation plan to maximize success in this patient population. Hypercoagulability is a relative contraindication for autologous free flap breast reconstruction but not an absolute contraindication.

MANAGEMENT

Up to about 5%-6% of autologous breast free flap reconstructions require operative exploration for vascular compromise[26,57]. Venous thrombosis is the most common cause of flap compromise, followed by arterial compromise, then hematoma or infection[48,57]. Timely recognition of vascular compromise is critical to flap survival, and early intervention is associated with higher flap salvage rates[16,57-59]. Intraoperative recognition and revision have significantly better prognoses and lower flap loss rates[48]. However, flap salvage rate has been shown to be highest within the first 24 h of the initial surgery with close to 94% salvage rates[26] and drops considerably further during the postoperative period, down to 12.1% salvage rate by postoperative day 3[12,26]. Improved salvage rates are associated with early intervention, the use of alternative recipient vessels, and fewer microsurgical revisions[60]. Close flap monitoring is most crucial in the first 24 h postoperatively to detect flap compromise [Figure 4], and if vascular thrombosis is suspected, then immediate return to the operating room is indicated.

Troubleshooting a failing free flap starts with distinguishing between arterial and venous compromise. The next step is to identify the cause of the problem and the mechanisms to correct the problem. The anastomosis can have technical issues such as intimal injury, a back walled suture in the anastomosis or inadequate recipient vessel. Mechanical problems such as hematoma, seroma, tight inset, pedicle kink or twist can all impair vascular flow. Problems within the flap include damaged perforators or pedicle, superficial dominant venous system with engorged SIEV and venous congestion with dark dermal bleeding.

The first step is to evaluate the arterial and venous anastomosis for adequate flow. This can be assessed with a strip test, intraoperative Doppler, or angiography with the use of indocyanine green[61]. If arterial or venous thrombosis is identified, maneuvers to remove the thrombus, correct the problem and reestablish perfusion are performed.

Direct thrombectomy:

When a thrombus within the vessel is suspected, the first step is to open or cut out the anastomosis. The vessels should be inspected for intimal injury or technical errors, such as a suture catching the vessel backwall that may be the source of thrombus. Direct thrombectomy can be performed at the anastomosis. Jewler's forceps can be used to gently milk the clot out of the vessel in an atraumatic fashion. The vessel is then copiously irrigated with heparinized saline irrigation. The vessel lumen is inspected again for any intimal injury and cut back to healthy tissue. Adequate flow of the recipient artery is evaluated to ensure complete removal of a possible proximal thrombus. The anastomosis is then revised, and the flap reassessed for perfusion.

Fogarty:

If the thrombus cannot be directly removed from the vessel using Jewler's forceps, then a Fogarty catheter can be used to perform the thrombectomy in free flap salvage[62]. The Fogarty catheter is passed distal to the thrombus, gently inflated the balloon to fill the lumen of the vessel without overexpansion, then slowly and gently pulled back to remove the clot. Fogarty catheters can damage the vessel lumen; therefore, it is imperative to limit the number of passes and not overexpand the balloon. Improper technique can denude the endothelium and cause intimal dissection, vessel rupture, or balloon rupture inside the vessel, leaving foreign material within the vessel lumen[63,64]. Once the thrombus has been removed, it is critically important to carefully inspect for any intimal injury before proceeding with anastomotic revision.

Thrombolysis:

If thrombectomy cannot be accomplished or distal thrombosis in the microvascular circulation is suspected, then targeted thrombolytic therapy is a crucial next step. Tissue plasminogen activator (TPA) is an enzyme that catalyzes the conversion of plasminogen to plasmin and breaks down fibrin in thrombus. TPA is a thrombolytic that can be used in flap salvage. Thrombolytics are often given when there is extensive clot burden, incomplete thrombectomy and evidence of microvascular thrombosis in the capillary system seen with no-reflow phenomenon. No reflow phenomenon occurs when arterial inflow has been reestablished and adequate venous thrombectomy has been performed, but there is inadequate venous flow from the flap vein.

Thrombosis at the level of anastomosis is adequately treated with thrombectomy and does not require thrombolytic intervention. However, distal arteriolar and capillary thrombus cannot be manually or mechanically evacuated but instead require chemical thrombolysis[65,66]. TPA is typically injected into the flap arterial system and allowed to marinate within the flap, then drain out the flap venous system. The goal is to target thrombolytic therapy within the flap without introduction into the systemic circulation. This allows higher doses of TPA to be administered without systemic complications. The typical dilution dose of TPA given during flap salvage is 1 mg/mL. A slow injection of 2-10 mg of dilute TPA is performed over a one-to-two-minute period[46,48,66,67], followed by a 10-15 min rest in the flap microcirculation. TPA administration can be repeated immediately thereafter until adequate venous flow has been accomplished[16,66,68]. TPA is directly administered to the flap during flap salvage and has not demonstrated an increased risk of hematoma to either the flap or abdomen[28,48]. Flap salvage rate with the use of thrombolytics is lower, likely due to the increased thrombus burden that necessitated thrombolytic therapy[48]. When salvaging a failing flap with significant clot burden, this is typically the last maneuver that can be done to void the flap of thrombus and reestablish perfusion.

CONCLUSION

Reconstructive autologous free flap breast reconstruction is a growing field with innovation, technological advancements, broader application, and increased availability to patients. Core principles of microsurgery such as meticulous dissection, atraumatic vessel handling, adequate magnification, appropriate recipient vessel selection, and tension-free anastomosis with direct intima to intima contact are key maneuvers for a successful microsurgical reconstruction. Identification and correction of inflow or outflow problems intraoperatively can prevent thrombus formation and flap compromise. If vascular compromise is suspected postoperatively, immediate return to the operating room for exploration is a must. Every microsurgeon must develop an algorithm to first diagnose the problem, then implement a stepwise plan to execute the maneuvers needed to reestablish perfusion to the flap in order to successfully salvage a failing flap.

DECLARATIONS

Authors' contributions

The author contributed solely to the article.

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Conflicts of interest

The author declared that there are no conflicts of interest.

Ethical approval and consent to participate

The University of Washington Medical Center stated that the study does not need to complete an IRB since the figures are examples of surgical techniques similar to a case report. The author states that there is no ethical concern since the photos do not include any PHI or patient identifiers such as a face or unique tattoos.

Consent for publication

All patients gave consent for participation and publication.

Copyright

© The Author(s) 2023.

REFERENCES

1. McLean DH, Buncke HJ Jr. Autotransplant of omentum to a large scalp defect, with microsurgical revascularization. *Plast Reconstr Surg* 1972;49:268-74. DOI PubMed
2. Holmström H. The free abdominoplasty flap and its use in breast reconstruction. An experimental study and clinical case report. *Scand J Plast Reconstr Surg* 1979;13:423-27. DOI PubMed
3. Surgery. National plastic surgery statistics. Available from: https://www.plasticsurgery.org/documents/News/Statistics/2020/plastic-surgery-statistics-full-report-2020.pdf. [Last accessed on 8 Jun 2023].

4. Sultan SM, Greenspun DT. Lumbar artery perforator flaps in autologous breast reconstruction. *Clin Plast Surg* 2023;50:301-12. DOI PubMed
5. Nguyen DH, Ma IT, Choi YK, Zak Y, Dua MM, Wapnir IL. Creating a biological breast implant with an omental fat-augmented free flap. *Plast Reconstr Surg* 2022;149:832-5. DOI PubMed
6. Broyles JM, Balk EM, Adam GP, et al. Implant-based versus autologous reconstruction after mastectomy for breast cancer: a systematic review and meta-analysis. *Plast Reconstr Surg Glob Open* 2022;10:e4180. DOI PubMed PMC
7. Saldanha IJ, Broyles JM, Adam GP, et al. Implant-based breast reconstruction after mastectomy for breast cancer: a systematic review and meta-analysis. *Plast Reconstr Surg Glob Open* 2022;10:e4179. DOI PubMed PMC
8. Gill PS, Hunt JP, Guerra AB, et al. A 10-year retrospective review of 758 DIEP flaps for breast reconstruction. *Plast Reconstr Surg* 2004;113:1153-60. DOI
9. Jandali S, Wu LC, Vega SJ, Kovach SJ, Serletti JM. 1000 consecutive venous anastomoses using the microvascular anastomotic coupler in breast reconstruction. *Plast Reconstr Surg* 2010;125:792-8. DOI PubMed
10. Pannucci CJ, Basta MN, Kovach SJ, et al. Loupes-only microsurgery is a safe alternative to the operating microscope: an analysis of 1,649 consecutive free flap breast reconstructions. *J Reconstr Microsurg* 2015;31:636-42. DOI
11. Allen R, Guarda H, Wall F, Dupin C, Glass C. Free flap breast reconstruction: the LSU experience (1984-1996). Available from: https://www.x-mol.com/paper/1212929277945520135?adv [Last accessed on 8 Jun 2023].
12. Chang EI, Chang EI, Soto-Miranda MA, et al. Comprehensive evaluation of risk factors and management of impending flap loss in 2138 breast free flaps. *Ann Plast Surg* 2016;77:67-71. DOI
13. Kalmar CL, Drolet BC, Kassis S, et al. Breast Reconstruction free flap failure: does platelet count matter? *Ann Plast Surg* 2022;89:523-8. DOI PubMed
14. Kadle R, Cohen J, Hambley W, et al. A 35-year evolution of free flap-based breast reconstruction at a large urban academic center. *J Reconstr Microsurg* 2016;32:147-52. DOI
15. Krüger-Genge A, Blocki A, Franke RP, Jung F. Vascular endothelial cell biology: an update. *Int J Mol Sci* 2019;20:4411. DOI PubMed PMC
16. Hanasono MM, Butler CE. Prevention and treatment of thrombosis in microvascular surgery. *J Reconstr Microsurg* 2008;24:305-14. DOI PubMed
17. Clemens MW, Kronowitz SJ. Current perspectives on radiation therapy in autologous and prosthetic breast reconstruction. *Gland Surg* 2015;4:222-31. DOI PubMed PMC
18. Ugurlu AM, Basat SO, Ceran F, Ozalp B, Berkoz O. The effects of limited adventitiectomy on vascular anastomosis: An experimental study in rats. *J Plast Surg Hand Surg* 2017;51:129-35. DOI PubMed
19. Stranix JT, Azoury SC, Lee ZH, et al. Matched comparison of microsurgical anastomoses performed with loupe magnification versus operating microscope in traumatic lower extremity reconstruction. *Plast Reconstr Surg* 2020;145:235-40. DOI
20. Serletti JM, Deuber MA, Guidera PM, et al. Comparison of the operating microscope and loupes for free microvascular tissue transfer. *Plast Reconstr Surg* 1995;95:270-6. DOI
21. Alghoul MS, Gordon CR, Yetman R, et al. From simple interrupted to complex spiral: a systematic review of various suture techniques for microvascular anastomoses. *Microsurgery* 2011;31:72-80. DOI
22. Arora R, Mishra KS, Bhoye HT, et al. Mechanical anastomotic coupling device versus hand-sewn venous anastomosis in head and neck reconstruction-an analysis of 1694 venous anastomoses. *Indian J Plast Surg* 2021;54:118-23. DOI PubMed PMC
23. Grewal AS, Erovic B, Strumas N, Enepekides DJ, Higgins KM. The utility of the microvascular anastomotic coupler in free tissue transfer. *J Plastic Surgery* 2012:20. DOI
24. Head LK, McKay DR. Economic comparison of hand-sutured and coupler-assisted microvascular anastomoses. *J Reconstr Microsurg* 2018;34:71-6. DOI PubMed
25. Spector JA, Draper LB, Levine JP, Ahn CY. Routine use of microvascular coupling device for arterial anastomosis in breast reconstruction. *Ann Plast Surg* 2006;56:365-8. DOI PubMed
26. Shen AY, Lonie S, Lim K, et al. Free flap monitoring, salvage, and failure timing: a systematic review. *J Reconstr Microsurg* 2021;37:300-8. DOI PubMed
27. Heidekrueger PI, Ninkovic M, Heine-Geldern A, Herter F, Broer PN. End-to-end versus end-to-side anastomoses in free flap reconstruction: single centre experiences. *J Plast Surg Hand Surg* 2017;51:362-5. DOI PubMed
28. Ahmadi I, Herle P, Miller G, et al. End-to-end versus end-to-side microvascular anastomosis: a meta-analysis of free flap outcomes. *J Reconstr Microsurg* 2017;33:402-11. DOI PubMed
29. Zhang X, Mu D, Yang Y, et al. The value of BMI for breast reconstructions with the SIEA flaps: predicting the ideal intercostal plane for the end-to-end microvascular anastomosis and the possibility of utilizing the TDA as a salvage recipient choice. *Aesthetic Plast Surg* 2022;46:2742-52. DOI
30. Saint-Cyr M, Chang DW, Robb GL, Chevray PM. Internal mammary perforator recipient vessels for breast reconstruction using free TRAM, DIEP, and SIEA flaps. *Plast Reconstr Surg* 2007;120:1769-73. DOI PubMed
31. Apostolides JG, Magarakis M, Rosson GD. Preserving the internal mammary artery: end-to-side microvascular arterial anastomosis for DIEP and SIEA flap breast reconstruction. *Plast Reconstr Surg* 2011;128:225e-32e. DOI PubMed
32. Hamdi M, Blondeel P, Van Landuyt K, Monstrey S. Algorithm in choosing recipient vessels for perforator free flap in breast reconstruction: the role of the internal mammary perforators. *Br J Plast Surg* 2004;57:258-65. DOI PubMed

33. Hemphill AF, de Jesus RA, McElhaney N, Ferrari JP. End-to-side anastomosis to the internal mammary artery in free flap breast reconstruction: preserving the internal mammary artery for coronary artery bypass grafting. *Plast Reconstr Surg* 2008;122:149e-50e. DOI
34. Robb GL. Thoracodorsal vessels as a recipient site. Available from:https://www.x-mol.com/paper/1212930923127709699?adv [Last accessed on 8 Jun 2023].
35. Saint-Cyr M, Youssef A, Bae HW, Robb GL, Chang DW. Changing trends in recipient vessel selection for microvascular autologous breast reconstruction: an analysis of 1483 consecutive cases. *Plast Reconstr Surg* 2007;119:1993-2000. DOI PubMed
36. Moran SL, Nava G, Behnam AB, Serletti JM. An outcome analysis comparing the thoracodorsal and internal mammary vessels as recipient sites for microvascular breast reconstruction: a prospective study of 100 patients. *Plast Reconstr Surg* 2003;111:1876-82. DOI PubMed
37. Hefel L, Schwabegger A, Ninković M, et al. Internal mammary vessels: anatomical and clinical considerations. *Br J Plast Surg* 1995;48:527-32. DOI
38. Ninković M, Anderl H, Hefel L, Schwabegger A, Wechselberger G. Internal mammary vessels: a reliable recipient system for free flaps in breast reconstruction. *Br J Plast Surg* 1995;48:533-9. DOI PubMed
39. Chang EI, Chang EI, Soto-Miranda MA, et al. Demystifying the use of internal mammary vessels as recipient vessels in free flap breast reconstruction. *Plast Reconstr Surg* 2013;132:763-8. DOI PubMed
40. Chang EI, Fearmonti RM, Chang DW, Butler CE. Cephalic vein transposition versus vein grafts for venous outflow in free-flap breast reconstruction. *Plast Reconstr Surg Glob Open* 2014;2:e141. DOI PubMed PMC
41. Sbitany H, Mirzabeigi MN, Kovach SJ, Wu LC, Serletti JM. Strategies for recognizing and managing intraoperative venous congestion in abdominally based autologous breast reconstruction. *Plast Reconstr Surg* 2012;129:809-15. DOI PubMed
42. Eom JS, Sun SH, Lee TJ. Selection of the recipient veins for additional anastomosis of the superficial inferior epigastric vein in breast reconstruction with free transverse rectus abdominis musculocutaneous or deep inferior epigastric artery perforator flaps. *Ann Plast Surg* 2011;67:505-9. DOI
43. Casey WJ 3rd, Rebecca AM, Smith AA, Craft RO, Buchel EW. The cephalic and external jugular veins: important alternative recipient vessels in left-sided microvascular breast reconstruction. *Microsurgery* 2007;27:465-9. DOI PubMed
44. Nelson JA, Fischer JP, Grover R, et al. Vein grafting your way out of trouble: Examining the utility and efficacy of vein grafts in microsurgery. *J Plast Reconstr Aesthet Surg* 2015;68:830-6. DOI
45. Langdell HC, Shammas RL, Atia A, et al. Vein grafts in free flap reconstruction: review of indications and institutional pearls. *Plast Reconstr Surg* 2022;149:742-9. DOI PubMed PMC
46. Vijan SS, Tran VN. Microvascular breast reconstruction pedicle thrombosis: how long can we wait? *Microsurgery* 2007;27:544-7. DOI
47. Oduah EI, Linhardt RJ, Sharfstein ST. Heparin: past, present, and future. *Pharmaceuticals* 2016;9:38. DOI PubMed PMC
48. 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;33:505-13. DOI
49. Conrad MH, Adams WP Jr. Pharmacologic optimization of microsurgery in the new millennium. *Plast Reconstr Surg* 2001;108:2088-96. DOI PubMed
50. Disa JJ, Polvora VP, Pusic AL, Singh B, Cordeiro PG. Dextran-related complications in head and neck microsurgery: do the benefits outweigh the risks? a prospective randomized analysis. *Plast Reconstr Surg* 2003;112:1534-9. DOI PubMed
51. Kaciulyte J, Losco L, Maruccia M, et al. Postsurgical antithrombotic therapy in microsurgery: our protocol and literature review. *Eur Rev Med Pharmacol Sci* 2019;23:4448-57. DOI
52. Herrera FA, Lee CK, Kryger G, et al. Microsurgery in the hypercoagulable patient: review of the literature. *J Reconstr Microsurg* 2012;28:305-12. DOI
53. Riva FM, Chen YC, Tan NC, et al. The outcome of prostaglandin-E1 and dextran-40 compared to no antithrombotic therapy in head and neck free tissue transfer: analysis of 1,351 cases in a single center. *Microsurgery* 2012;32:339-43. DOI
54. Lee KT, Mun GH. The efficacy of postoperative antithrombotics in free flap surgery: a systematic review and meta-analysis. *Plast Reconstr Surg* 2015;135:1124-39. DOI PubMed
55. Ashjian P, Chen CM, Pusic A, Disa JJ, Cordeiro PG, Mehrara BJ. The effect of postoperative anticoagulation on microvascular thrombosis. *Ann Plast Surg* 2007;59:36-40. DOI PubMed
56. Wang TY, Serletti JM, Cuker A, et al. Free tissue transfer in the hypercoagulable patient: a review of 58 flaps. *Plast Reconstr Surg* 2012;129:443-53. DOI
57. 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;119:2092-100. DOI PubMed
58. Hidalgo DA and Jones CS. The role of emergent exploration in free-tissue transfer: a review of 150 consecutive cases. Available from: https://www.x-mol.com/paper/1212950716287361028?adv [Last accessed on 8 Jun 2023].
59. 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;120:187-95. DOI
60. Chang EI, Carlsen BT, Festekjian JH, Da Lio AL, Crisera CA. Salvage rates of compromised free flap breast reconstruction after recurrent thrombosis. *Ann Plast Surg* 2013;71:68-71. DOI PubMed
61. Liu DZ, Mathes DW, Zenn MR, Neligan PC. The application of indocyanine green fluorescence angiography in plastic surgery. *J*

Reconstr Microsurg 2011;27:355-64. DOI PubMed

62. Wheatley MJ, Meltzer TR. The role of vascular pedicle thrombectomy in the management of compromised free tissue transfers. *Ann Plast Surg* 1996;36:360-4. DOI PubMed
63. Schweitzer DL, Aguam AS, Wilder JR. Complications encountered during arterial embolectomy with the fogarty balloon catheter: report of a case and review of the literature. *Vasc Surg* 1976;10:144-56. DOI PubMed
64. Davies MG, Dalen H, Svendsen E, Hagen PO. The functional and morphological consequences of balloon catheter injury in veins. *J Surg Res* 1994;57:122-32. DOI PubMed
65. Egozi D, Fodor L, Ullmann Y. Salvage of compromised free flaps in trauma cases with combined modalities. *Microsurgery* 2011;31:109-15. DOI PubMed
66. Chang EI, Mehrara BJ, Festekjian JH, Da Lio AL, Crisera CA. Vascular complications and microvascular free flap salvage: the role of thrombolytic agents. *Microsurgery* 2011;31:505-9. DOI PubMed
67. Casey WJ 3rd, Craft RO, Rebecca AM, Smith AA, Yoon S. Intra-arterial tissue plasminogen activator: an effective adjunct following microsurgical venous thrombosis. *Ann Plast Surg* 2007;59:520-5. DOI PubMed
68. Panchapakesan V, Addison P, Beausang E, et al. Role of thrombolysis in free-flap salvage. *J Reconstr Microsurg* 2003;19:523-30. DOI