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Review

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Strategies for prevention and management of partial flap loss or fat necrosis in microvascular autologous breast reconstruction

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Abstract

Partial flap loss (skin involved) or fat necrosis following autologous breast reconstruction remains a dreaded postoperative complication despite significant advances in microsurgical techniques. Several strategies have been proposed in the preoperative and intraoperative period to prevent this complication ranging from preoperative imaging, intra-operative tissue perfusion assessment, appropriate perforator selection (location and number), maximizing inflow and outflow with additional anastomoses and/or pedicles, and minimizing ischemia time. Postoperative management of partial flap loss (when there is skin involvement) and fat necrosis remains a challenge, with very little published data focusing on classification, timing, and techniques. Early intervention versus close observation may depend on multiple patient factors and the degree or volume of necrosis. Secondary intervention options include hyperbaric oxygen therapy, fat aeration with a needle, liposuction, fat grafting, addition of another flap or implant, depending on the nature of the defect. This review summarizes the current evidence for each of these strategies to help the current surgeon understand their options in preventing and managing patients suffering from partial flap loss.

Keywords: Partial flap loss, fat necrosis, prevention of fat necrosis

INTRODUCTION

Autologous free tissue transfer is considered a safe, common, and highly successful technique for breast reconstruction. The historical evolution from the pedicled transverse rectus abdominis muscle (pTRAM) to free TRAM (fTRAM), then muscle-sparing TRAM (msTRAM), and finally deep inferior epigastric artery perforator (DIEP) or superficial inferior epigastric artery (SIEA) flaps has been remarkable but also introduced new challenges. Important advancements in preoperative flap planning, harvest, and postoperative monitoring have significantly decreased the rate of major complications such as total flap loss. Furthermore, working in multidisciplinary teams when planning for immediate autologous reconstruction allows for better planning and therefore better outcomes. However, several minor complications are still routinely encountered, including donor site morbidity (e.g., bulge/hernia and wound dehiscence) and partial flap loss or fat necrosis. While the reported incidence of fat necrosis ranges widely due to inconsistent postoperative assessment and lack of standardization, a systematic review of 70 articles conducted by Khansa *et al.* found a reported incidence of 3.0%-37.9% and the mean rate of fat necrosis to be 11.3%[1]. Widely accepted risk factors include smoking, obesity [BMI (kg/m^2) > 30], postoperative radiation therapy, and ischemia[2]. While some factors are clearly beyond our control at the time of surgery, there are certain techniques we can employ to minimize the risks of complications. In this article, we aim to provide a summary of the current literature on strategies for the prevention and management of partial flap loss (skin involved) and fat necrosis to best guide today's surgeon.

PREVENTION

Preoperative imaging

Numerous studies on the value of preoperative imaging for DIEP and other autologous flaps have been published[3,4]. Preoperative imaging to map perforator location and intramuscular course has been reported to decrease operative time, total flap loss, and fat necrosis[5]. This is based on the knowledge that a better understanding of perforator course will help delineate vascular territories and therefore minimize fat necrosis in under-perfused areas. The most common imaging modality utilized is CT Angiography (CTA), but similar benefits have been reported using MR Angiography (MRA) and even ultrasound[6]. There is always a concern for the cost of imaging, additional radiation exposure, and possible incidental findings leading to delays in care and additional workup[7]. MRA is a strong competitor against CTA, as it does not have any radiation exposure (although the radiation dose of a CTA can now be reduced to as low as 5 millisieverts, which is the equivalent of two abdominal X-Rays) and has a safer contrast allergy profile. MRA has been described as having a clearer definition of the intramuscular perforators, whereas CTA is superior in evaluating subcutaneous course. Davis *et al.* even describe using preoperative imaging to identify atypical venous connections and predict venous congestion[8].

Intraoperative perfusion assessment

The introduction of indocyanine green laser angiography (ICG or SPY angiography) has also proven to be beneficial for more than mastectomy flap evaluation. This technology allows the surgeon to assess perforator location and intraoperative tissue perfusion during flap harvest, aiding in perforator selection. The surgeon can also evaluate tissue perfusion after anastomosis to detect early signs of ischemia or venous congestion, which could lead to partial or complete flap loss. SPY angiography technology can be employed intraoperatively to assess the perforasome territory based on the selected perforator for a DIEP flap. The authors routinely clamp the other perforators temporarily to gauge the perfusion of the skin paddle and/or adipose tissue. Additional perforators can be harvested if the perforasome territory is deemed inadequate. Once the flap is transferred and anastomosed, repeat SPY angiography objectively confirms that the flap is well perfused. This technology is also useful in identifying early or partial venous congestion which may lead to complete or partial flap necrosis and has been demonstrated to decrease postoperative complications[9]. Routinely, we repeat the SPY assessment after 15-20 min to assess for fluorescein clearance.

We strongly recommend trimming any portion of the skin paddle and/or sub-Scarpal fat that is clearly hypoperfused during arterial phase as well as poorly draining on the venous phase evaluation. A flap with superficially dominant venous drainage can also become apparent during this stage and should prompt the surgeon to perform a second venous outflow anastomosis. This is supported by Hembd *et al.*, who reported on 506 DIEP flaps with decreased odds of fat necrosis with the use of indocyanine green angiography, without a reduction in flap failure rates. Overall incidence was 13% and the use of ICG was independently associated with a decrease in the odds ratio[10]. Similarly, Momeni also reported a series of 80 patients, 137 flaps, and an overall incidence of 14.6% of fat necrosis. ICG angiography was used to guide debridement in one cohort, reducing the incidence of fat necrosis from 18/79 to 2/58[11]. Another group similarly demonstrated a decreased rate of fat necrosis from 59.5% to 29% with ICG as well as a reduced rate of second surgery from 45.9% to 20.8%[12]. Parmeshwar *et al.* performed a systematic review of the use of ICG angiography. Based on the analysis of 9 articles and a comprehensive review involving a total of 355 patients and 824 free flaps, the researchers concluded that there was a significant disparity in flap fat necrosis, but no difference in total or partial flap loss. They suggest that ICG angiography is a more effective and efficient technique to reduce fat necrosis and is more sensitive than clinical assessment[13]. However, most recently, Yoo *et al.* reported their experience with 353 DIEP flaps, revealing a 10.9% incidence of fat necrosis and no difference with the use of ICG angiography[14]. Other less common intraoperative imaging techniques include Doppler, dynamic infrared thermography, and hyperspectral imaging.

Perforator selection (Medial *vs.* lateral)

Saint-Cyr has published numerous studies on the perforasome theory, which help us understand and maximize flap perfusion. He reports the majority of perforators are located in the periumbilical region[15]. However, this eccentric location has led other authors to question whether the medial row perforators were indeed the optimal choice. Kamali *et al.* reported a nearly 3-fold higher incidence of fat necrosis in flaps, based solely on the medial row *vs.* lateral row (24.5% *vs.* 8.2%) and no difference with flaps based on lateral only *vs.* both medial and lateral. They suggested increasing the number of perforators harvested along the same row to minimize fat necrosis[16]. However, Garvey *et al.* reviewed 228 patients with 120 medial and 108 lateral perforator flaps with similar rates of fat necrosis and partial flap necrosis[17]. In another study by Saint-Cyr, he offered further insights into the zones of perfusion based on medial *vs.* lateral row and effects on flap harvest and design. The authors reported that lateral row perforators rarely crossed midline so unilateral DIEP flap which require more than hemi-abdominal volume should be harvested based on medial row perforators[18]. Lastly, Hembd *et al.* reviewed 409 DIEP flaps and noted an incidence of 14.4% fat necrosis with a decrease in the odds ratio for this endpoint when using lateral row, or both medial and lateral row perforators. They recommend using larger caliber perforators and lateral row perforators alone, or in addition to medial row perforators, rather than just harvesting more perforators due to the increased risk of abdominal bulge[19].

Number of perforators

To minimize donor site morbidity, the surgeon often strives to minimize the number of perforators harvested while maintaining adequate flap perfusion. Khansa *et al.* reported the most important predictor of fat necrosis was flap type, with the lowest degree of fat necrosis in the Free TRAM flaps (6.9%), then the SIEA flaps (8.1%), followed by the pedicled TRAM (12.3%), and finally the DIEP flap at 14.4%[1]. A 2010 study by Baumann *et al.* found less fat necrosis in msTRAMs or multiple perforator DIEPs than single perforator DIEPs. The lowest incidence of fat necrosis was actually reported in flaps with 3-5 perforators (predominantly msTRAMs)[20]. Their findings were validated by Garvey *et al.*[21]. Bhullar *et al.* also concluded that medial row perforators had a wider perfusion zone and suggested harvesting at least 2-3 perforators of substantial caliber[22]. Both Wu and Saint-Cyr reported increased rates of fat necrosis in single-perforator DIEP flaps by 3-fold and 2-fold, respectively[23,24]. However, it is well known that increasing the number of harvested perforators potentially risks higher donor site morbidity. Taking all the aforementioned into consideration, surgeons must carefully balance these factors in the decision making of flap harvest and perforator selection to maximize flap perfusion and minimize donor site morbidity[25].

Maximize perfusion (APEX/supercharging)

A novel option to maximize perfusion by incorporating both medial and lateral row perforators yet minimizing the donor site morbidity was described by Dr. Allen *et al.* The abdominal perforator exchange (APEX) flap allows harvest of two perforators while sparing the intervening rectus fibers by adding an additional anastomosis to reconnect the medial and lateral division prior to division of the primary pedicle. DellaCroce *et al.* reported his 6-year experience with 364 flaps and nearly eliminated abdominal bulge/hernia. The operative time was 34 min longer on average. Only one patient presented with diffuse fat necrosis[26]. Other surgeons have also advocated supercharging by harvesting a second or third pedicle (SIEA, SCIA, and/or DCIA) to improve the perfusion of the flap. Both these options require increased technical difficulty and complexity, but in experienced hands, they can optimize flap perfusion without an increase in donor site morbidity. Further studies are needed to better understand appropriate patient selection and long-term evidence on these refinements.

Additional venous outflow

Some incidences of fat necrosis may not be due entirely to ischemia but are rather a result of progressive venous congestion. For example, superficially dominant venous drainage may not be apparent during the index operation. We strongly recommend dissecting the superficial inferior epigastric vein (SIEV) routinely during DIEP flap harvest to serve as an indicator of risks of venous congestion and a secondary outflow as needed. Engorgement of the SIEV during DIEP harvest is an early indicator of possible superficial dominance. ICG angiography can often confirm this anatomical variant with delayed drainage of the dye until the SIEV is vented. Ming-Huei Cheng often routinely augments his venous outflow using the SIEV through a variety of configurations to connect to the DIEV or a secondary recipient vein. He elects to routinely dissect a length of at least 7-10 cm of SIEV. He reported 32 episodes of venous congestion in 162 patients undergoing unilateral DIEP flap reconstruction. Salvage consisted of either venous augmentation or SIEV substitution with no statistical difference in flap salvage. This was mostly done by anastomosis of the SIEV to either the 2nd vena comitantes or the internal mammary vein with the use of a vein graft or DIEV[27].

Minimize ischemia time

The easiest and quickest way to prevent partial flap necrosis is to minimize flap ischemia time. High-volume surgical centers with dedicated surgical teams and experienced surgeons have demonstrated remarkable efficiency with DIEP flaps, and there are anecdotal reports of DIEP flaps being routinely performed now in under 2 h. Lee *et al.* reported 86 patients with a mean ischemia time of 89 min and an incidence of fat necrosis at 17.4%. Ischemia time was found to be significant in both univariate and multivariate analyses. The authors report the threshold of 99.5 min as a cutoff for higher rates of fat necrosis[28]. Ideally, a microsurgical operative team would include dedicated and experienced nurses, surgical technicians, anesthesiologists, and surgeons. In other surgical subspecialties (i.e., transplant, bariatrics, hepatobiliary), designated centers of excellence have lower complication rates and patients are occasionally funneled by their insurance to these facilities to receive their care. There are already several large private groups in the USA dedicated solely to breast reconstruction with good outcomes. Whether this model or designation of excellence is applicable to microsurgical breast reconstruction remains to be seen.

Flap inset

Blondeel *et al.* have already published excellent guides on aesthetic breast reconstruction based on the footprint, conus, and skin envelope. Often, for patients with extremes in body mass index, maximizing the volume harvested results in flap design where the distal portions of the flap may have questionable perfusion. Wade *et al.* reported a statistically significant relationship between the incidence of fat necrosis and BMI (kg/m^2) as a continuum as well as BMI (kg/m^2) > 35 as an independent variable[6]. For these situations, we strongly recommend careful consideration of flap orientation during inset to bury any questionable portion of the flap. An oblique or vertical inset permits the area of maximal perfusion on a medial row perforator to be utilized as the visible skin paddle inset along the inframammary fold. Careful attention should be given to insetting the healthiest portion of the flap along the "social breast" or cleavage area, ensuring that any fat necrosis that may develop will form along the lateral and inferior regions of the breast. Patients tolerate fat necrosis in these areas much better, because it is less likely to cause visible deformity when wearing a brassiere or clothing. If a buried partial flap loss occurs, it typically evolves into fat necrosis, which can be more easily managed than a necrotic skin paddle with underlying tissue ischemia.

MANAGEMENT

Indications for intervention/classification

There is currently only one proposed classification system for fat necrosis. Similar to the well-known Baker grading scale for capsular contracture, the authors based this classification on whether the fat necrosis is palpable, visible, and/or painful. Not surprisingly, the most severe Type IV (painful) always requires surgical intervention. Type II (palpable but not visible) was mostly observed (48%), with 17% undergoing biopsy and 35% debridement. For Type III (visible and palpable), 11% underwent biopsy and 89% underwent debridement[29].

Classification systems may be useful in many conditions but should not be considered a definitive guide for management. Breast cancer patients may be hypersensitive and anxious about any palpable masses or lumps in their reconstructive breasts due to concern for cancer recurrence. Additionally, our breast surgeons and non-surgical colleagues (hematology/oncology or radiation oncology) may be less familiar with the diagnosis and management of fat necrosis, which can lead to concern when a palpable firm nodule or mass is noted during examination in the postoperative period. Open communication between all providers is crucial to avoid unnecessary interventions and to provide appropriate reassurances and workup. It is of utmost importance to educate all multidisciplinary team members in recognizing fat necrosis from other differential diagnoses, in order to provide timely onset of therapy and avoid unnecessary tests or interventions. In the study by Haddock *et al.*, the authors reported per single incidence of fat necrosis, 0.69 revisions, 1.22 imaging studies, 0.77 biopsies, and 1.7 additional oncologic office visits[3]. The cost and psychological toll on the patient for additional imaging, biopsy and surgery is not trivial and often overlooked. The majority of management for this issue is conservative and symptom-oriented. If fat necrosis is only diagnosed via imaging and is asymptomatic, no intervention is indicated. Some of these patients may need a lower threshold for treatment of areas of fat necrosis to avoid further unnecessary worry and/or evaluation.

Timing of intervention

Ellis *et al.* performed a systematic literature review to develop an algorithm for the management of fat necrosis based on six articles with level 3 evidence. Again, the incidence varied from 12.7%-40.4% in clinical diagnosis. The authors noted clinical examination to be the most homogenous diagnostic approach for fat necrosis, identifying it as a palpable lump or mass of any size. Ultrasound should demonstrate a solid mass with increased echogenicity of the subcutaneous tissues or a simple cyst not consistent with tumor recurrence, and further investigation should be conducted 12 months post-mastectomy, once flap swelling has resolved and flap softening has occurred[30].

Many astute clinicians and patients often notice mild discoloration or firm areas of a flap postoperatively, especially along the periphery. These areas are likely mild ischemia and/or congestion, which may evolve into partial flap loss or fat necrosis. Routine imaging is not recommended, as these smaller areas of fat necrosis are likely to resolve spontaneously and do not require any intervention. For any patients where there is a palpable mass with significant concern, ultrasound is a cost-effective and simple tool to confirm the benign post-surgical change and calm their fears. Our general recommendation is expectant observation, massage, and providing reassurance that any persistent areas of concern can be addressed in the future. Tenderness is expected, and some patients with mild or moderate discomfort can be offered non-steroidal analgesics and careful observation. Narcotics may be necessary for patients suffering from severe flap necrosis and severe pain until surgical intervention can be scheduled.

Hyperbaric oxygen (HBO) has been studied in animal models extensively, but there is more limited data on human clinical use due to a lack of standardization and availability. Baynosa and Francis summarized the recent studies which demonstrated utility in salvage of compromised grafts/flaps and improved flap survival. The mechanism of action is likely related to improved tissue oxygenation, fibroblast function, neovascularization and minimizing ischemic-reperfusion injury, which theoretically would also minimize fat necrosis or partial flap loss[31]. HBO may be relatively contraindicated in select patients due to the risk of pneumothorax if there was any concern for iatrogenic injury during recipient vessel exposure. Further research is needed to better understand the role of HBO for our autologous breast reconstruction patients.

Anecdotal reports have described a successful technique of aeration of fat necrosis under local anesthesia after breast reduction. The authors recommend early intervention using an 18-gauge hypodermic needle to puncture the area of fat necrosis multiple times. This technique is similar to lawn aeration done to minimize soil compaction and maximize penetration of air, water, and nutrients to grass roots. Theoretically, this technique introduces new channels into the threatened area of ischemia tissue to either deliver blood, oxygen and/or nutrients, as well as creating channels for macrophages to access and break down the necrotic fibrosis. The exact mechanism requires further study but is an interesting option to consider for the management of areas of early fat necrosis. Obviously, this should be judiciously used near the pedicle to avoid inadvertent damage to the entire flap perfusion.

In our experience, even moderately large areas of firmness and fat necrosis often fully or partially resolve enough to become acceptable to patients after 3-6 months. For these smaller zones of fat necrosis that are truly bothersome to the patient (visible, painful, and/or palpable), elective removal can easily be performed during second stage revision, usually after 3 months.

For the management of more significant partial flap loss, the clinical evaluation must distinguish between fat necrosis occurring within a fully buried portion of a flap or "partial flap necrosis" where a visible superficial skin flap is necrotic. For an exposed area, earlier intervention with surgical debridement may be necessary if there is a large volume of flap loss (> 25%) and concern for infection. However, these situations can often be successfully managed conservatively with wound care and reassurance to minimize deformity. In our experience, these rarely require a return to the operating room unless a majority of the flap is necrotic and poses a significant risk of gangrenous necrosis. Aggressive debridement should be avoided as this may actually expose tenuous tissue that would otherwise recover, and instead convert these tenuous areas into additional volume loss, thereby creating a secondary deformity that is extremely difficult to correct without further surgery or additional flap(s). Topical antimicrobials such as silver sulfadiazine can be applied to minimize the risk of infection until the tissue fully demarcates. Patients should be advised to expect wound dehiscence and development of an eschar and home health care may be useful to arrange. Once the tissue is fully demarcated, debridement of the eschar and underlying dead fat is easy to perform in the clinic as this area is usually insensate. Wet-to-dry dressings and/or negative pressure therapy can also be applied to facilitate wound closure via secondary intention. It is often not necessary to fully debride all the fat necrosis as the healthy portion of the flap will granulate and cover deeper fat necrosis. Deep areas of fat necrosis are often not palpable or noticeable to the patient and do not require any further intervention. Secondary correction of the smaller resulting deformity can be performed with scar revision, flap repositioning or advancement, and/or fat grafting once the wound is fully healed.

Small *vs.* moderate *vs.* large size deformity

The size of the defect must be considered when discussing treatment options to correct the deformity. Small areas adjacent to the scars can be directly excised. Deeper areas or more remote areas from the scar (i.e., the upper medial breast) can be removed with liposuction rather than reopening the entire incision for exposure and risk creating a large dead space. Autologous fat transfer is the most minimally invasive treatment which can readily correct minor deformities. A more aggressive cutting tip cannula may be necessary for very dense areas of fibrosis. Ultrasound-assisted liposuction (UAL) can facilitate the removal of moderately large areas. A larger area may require multiple sessions to slowly scrape out the fat necrosis and replace it with autologous fat transfer. Hassa *et al.* successfully treated 54 breast reconstructions with fat necrosis with UAL. The average size was 2.72 cm and half the patients only required one session. Thirty-seven percent (20 patients) required two sessions, and the remaining 13% (7 patients) required three sessions. Complete resolution was confirmed in 44 patients (81.5%) and only one thermal burn complication was noted[32]. We personally believe it is not necessary to fully remove the fat necrosis with direct liposuction, as simply breaking up a larger fibrotic mass facilitates the body's natural lytic process. During liposuction for moderately large zones of fat necrosis, our group's primary goal is to soften the area of concern and minimize visible deformity prior to transfer of autologous fat. Patients must be warned to expect multiple sessions to fully address moderately large zones of fat necrosis.

Larger volume loss can also be corrected with the addition of an implant if the soft tissue envelope is adequate and the patient is amenable. Care must be taken to avoid damaging the pedicle during pocket dissection for the implant. We would strongly encourage waiting at least 3 months to maximize the revascularization from the surrounding soft tissue before risking injury to the primary pedicle. In larger defects where both skin and volume are deficient, a secondary flap and/or expander-implant may be necessary. The thoracodorsal artery perforator flap (Tdap), latissimus flap and epigastric perforator flaps are great local flap options that can be advanced, rotated, or transferred as propeller flaps into the defect. In the most severe scenarios, it may be beneficial to consider another free flap. Common alternative secondary free flaps include the transverse upper gracilis, profunda artery perforator, lumbar artery perforator, lateral thigh perforator, and gluteal free flaps. Careful evaluation of the remaining donor sites and discussion with the patient is needed to address the defect with the most appropriate flap.

DISCUSSION

Despite significant advances in preoperative and intraoperative surgical technology and a better understanding of flap perfusion, partial flap necrosis and fat necrosis remain persistent nemesis for surgeons performing autologous breast reconstruction. The majority of studies are retrospective and limited in size. Current evidence supports the use of both preoperative imaging and intraoperative ICG Angiography to maximize flap perfusion and debride poorly perfused tissue. The choice of which perforators to harvest remains a challenge to maximize perfusion and minimize donor site morbidity. Both the introduction of the APEX flap or a secondary venous outflow have shown promise in improving flap physiology to improve outcomes, but require slightly more technical effort with additional anastomoses and an unclear benefit. Minimizing ischemia time is an easy goal for all surgeons and often can be achieved by creating dedicated microsurgical care teams.

The current evidence is often inconclusive and poor in quality (level 3 or lower evidence). This calls for the need to standardize the diagnosis of fat necrosis, evaluate the timing of intervention and techniques, and establish a classification grading system to allow for prospective large-volume studies to better understand the true incidence of fat necrosis and the most appropriate management strategies. Consideration during flap inset to bury any areas of questionable perfusion can avoid partial flap necrosis and convert this into fat necrosis which is easier to manage. HBO and fat aeration have been suggested to improve fat necrosis in the postoperative period with limited evidence. Mild to moderate partial flap necrosis or fat necrosis can often be conservatively managed successfully to minimize deformity. Ultimately, most patients with symptomatic fat necrosis due to pain or deformity require secondary correction with a combination of techniques, including fat transfer, liposuction, flap advancement, addition of local or secondary free flaps for soft tissue, and addition of an expander or implant for volume.

CONCLUSIONS

As Benjamin Franklin wisely stated, "An ounce of prevention is worth a pound of cure", and that certainly still holds true in dealing with partial flap failure and fat necrosis following autologous breast reconstruction. As such, the majority of the suggested strategies are focused on pre-surgical planning and intraoperative decision-making to successfully harvest a maximally perfused flap. Navigating this complication remains a complex challenge for even the most skilled of microsurgeons, and often requires multiple additional procedures to remove the necrotic tissue and restore the deficiency using fat transfer, additional flaps, and/or placement of an expander or implant.

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