Toolbox for Autologous Breast Reconstruction

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Overview of Perforator Imaging and Flap Perfusion Technologies

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PERFORATOR IMAGING AND FLAP TECHNOLOGY

Breast reconstruction has become an important consideration for women after mastectomy. The current American Society of Plastic Surgeons' (ASPS) procedural statistics reveal that approximately 25% of reconstructions are performed using autologous tissue and 75% are performed using prosthetic devices.[1] Although autologous breast reconstruction is less commonly performed than prosthetic-based reconstruction, there are many circumstances in which its use is preferred and indicated. The discrepancies between autologous and prosthetic reconstruction based on ASPS statistics are because of a variety of reasons. Arguments for prosthetic reconstruction include its ease relative to autologous reconstruction, patient factors that include shorter hospitalizations and less recovery time, as well as good to excellent aesthetic outcomes. Although, autologous reconstruction is considered by many surgeons as superior to prosthetic-based reconstruction in terms of overall aesthetics, some view it as too complicated, technically challenging, and more time consuming. Thus, the challenge has been to make autologous reconstruction more efficient, predictable, and reproducible.

From a historical perspective, autologous reconstruction has been limited by several factors, including selecting ideal patients, optimizing flap selection, length of surgery, and donor site morbidities. Donor site morbidities such as weakness, bulge, and hernia were occasionally observed after the use of traditional musculocutaneous flaps such as the pedicled transverse rectus abdominis musculocutaneous (TRAM).[2] As free tissue transfer methods of breast reconstruction became popular, donor site issues became less frequent; however, other obstacles such as anastomotic patency, postoperative monitoring, and ensuring flap survival became relevant.

The evolution of free tissue transfer and perforator flaps can be chronicled to a period in which patients became increasingly concerned about the mentioned donor site morbidities that were related to complete harvest of the donor site muscles. Perforator flap surgery was the perfect solution to this issue because the muscles were completely preserved. However, performing perforator flap surgery has demanded an entirely new skill set that includes identification and selection of suitable perforator vessels, dissection of intramuscular perforators, assessment of flap perfusion based on one or several perforators, and reliable postoperative monitoring. As patient demand for perforator flaps increased, surgeons began searching for technologies and tools that would make these operations more predictable and reproducible as well as enable them to perform these flap surgeries more consistently.

Over the past decade, there have been a variety of technological advancements that have facilitated the ability to deliver reproducible and predictable outcomes with autologous breast reconstruction. Preoperative advancements have enabled surgeons to identify suitable perforators

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and to determine the patency of primary source vessels, namely the inferior epigastric and internal mammary vessels. Intraoperative advancements have enabled surgeons to assess anastomotic patency, vessel flow, and flap perfusion. Postoperative advancements have facilitated the ability of surgeons and nursing staff to monitor flaps based on tissue flow characteristics and discriminate between arterial and venous flow disturbances.

This article chronicles many of these advancements and reviews the current toolbox that surgeons now have at their disposal when performing autologous reconstruction. Some of the earlier tools include the acoustic Doppler ultrasonography and color duplex Doppler, whereas some of the newer tools include computed tomographic angiography (CTA), magnetic resonance angiography (MRA), dynamic infrared thermography (DIRT), fluorescent angiography and near-infrared spectroscopy (NIR). This article focuses on preoperative, intraoperative, and postoperative tools that have enabled the achievement of more reliable and predictable outcomes, especially in the setting of microvascular breast reconstruction.

HISTORICAL OVERVIEW

Over the past several centuries, surgeons and anatomists have been curious about soft tissue vascularity and cutaneous circulation.[3] A variety of methods have been described to better understand circulatory patterns. Early studies used vascular injection techniques that included India ink, colored wax, and latex. Other methods included tissue corrosion that used various metals, resins, or acids. With the introduction of radiography, the vascular anatomy could be better understood using radiopaque agents such as barium sulfate and lead oxide.

The importance of optimizing tissue perfusion increased when plastic surgeons began moving tissues from one part of the body to another. Flaps such as the latissimus dorsi and TRAM allowed for the reconstruction of many complex deformities. These flaps were based on an axial or source vessel that had many tributaries that traversed through the muscle and the adipocutaneous layer. Although the course of the axial artery and vein were generally constant and well known, the architecture of the microcirculation was variable and relatively unknown. Thus, the early era of flap transfer resulted in several morbidities that ranged from fat necrosis, partial flap necrosis, and in a few cases, total flap necrosis.[4] Many of these morbidities were the result of inadequate tissue perfusion at the distal aspects of the flap because of poor microcirculation. Intent on understanding these microcirculatory patterns and reducing morbidities, surgeons partnered with industry to develop specific tools that would allow a better understanding and appreciation of the anatomy and perfusion.

The need and evolution of technology in the setting of flap reconstruction can be traced to the evolution of perforator flaps. Historically, musculocutaneous flaps resulted in fat necrosis in 5% to 10% of cases; however, with perforator flaps, this percentage increased.[5] This increase is because with perforator flaps, the entire adipocutaneous component of the flap is based on 1 or 2 perforating vessels rather than several. Factors such as the number of perforators, location of the perforators, and caliber of the perforators became important. In an early study evaluating outcomes after deep inferior epigastric perforator (DIEP) flap breast reconstruction, Kroll[6] demonstrated fat necrosis in 62% of flaps. However, with experience and a better understanding of the perforator anatomy and circulatory patterns, this number was significantly reduced.

Anatomic studies classified the various types of perforators into 5 groups,[7] including the single direct perforator as used for the superficial inferior epigastric artery (SIEA) flap and the 4 indirect perforators that include the subcutaneous, muscle, perimysial, and septal flaps. Although this classification was useful, it still did not provide sufficient preoperative information regarding the location and perfusion capabilities.

PREOPERATIVE ASSESSMENT FOR FLAP SURGERY

There are many questions that arise when considering the role of preoperative imaging before flap surgery, the most important of which is whether or not it is necessary for all patients and whether or not it improves outcomes. The answers to these questions are arguable, but there is no question that imaging will provide useful information. Advocates of preoperative imaging cite that the accurate identification of perforators facilitates preoperative decision making. Both the sensitivity and positive predictive value are 99.6%.[8] Given that harvesting perforator flaps is a complex operation with very little room for error, a preoperative knowledge of the location of dominant perforators lessens and shortens the learning curve associated with predictably and successfully mastering this operation. Skeptics of preoperative imaging state that preoperative knowledge of the perforators does not guarantee success and that performance and mastery of the technical exercise is necessary.

At present, several modalities are available for the preoperative assessment of perforators.[9–18]

These include duplex and color duplex ultrasonographies, CTA, MRA, and DIRT. Although, these modalities provide useful information, other factors such as scheduling, cost, and convenience may be relevant factors. In some cases, preoperative imaging is associated with radiation, whereas in others, the imaging tests may yield erroneous information because accuracy depends on the patient position and respiratory phase. The remaining sections of this article focus on what has been learned from these modalities.

Duplex and Color Duplex Ultrasonographies

Perhaps the first tool that surgeons used for preoperative mapping was Doppler ultrasonography. Although there are many clinical applications for the Doppler, plastic surgeons were interested in the Doppler to map out perforating vessels throughout the cutaneous territory of a flap.[9–11,19–22] There were several early studies using color Doppler that provided useful information related to the location, caliber, and flow patterns of the perforators in the planning of the TRAM flap.[9–11,19,20] Cluster analyses demonstrated that perforators were located throughout the anterior abdominal wall with most dominant perforators being situated around the periumbilical area.[9] Perforators exceeding 2.2 mm were far fewer but were identifiable in all 4 quadrants of the anterior abdominal wall.

There were other benefits of using Doppler assessment. Information such as flow, direction, and velocity was easily determined. In a study evaluating flap perfusion in TRAM, DIEP, and superior gluteal artery perforator (SGAP), it was determined that the highest blood flow and velocity was achieved in the TRAM flap followed by the DIEP and SGAP flaps.[20] Specific flow measurements in various vessels were obtained and included the deep inferior epigastric artery (DIEA) (10.45 mL/min), the superior gluteal artery (9.95 mL/min), and the internal mammary artery (37.66 mL/min). The imaging could differentiate between venous and arterial signals.[20] The perforator detection was found to be 96% effective. The principle limitation of the color duplex ultrasonography was that it could not provide 3-dimensional or architectural detail of the perforator system. Giunta[22] reported a relatively high number of false-positive results (46%) using the hand-held Doppler for localization of perforators. In a comparative study evaluating Doppler ultrasonography and CTA, Rozen and colleagues[23] found that CTA was superior to Doppler based on visualization of the DIEA, its branching pattern, and the perforators.

CTA

Computerized tomography may in some ways represent the gold standard for preoperative imaging.[12–15,24] This was the first of the highly accurate methods of perforator assessment. The benefits of CTA include precise anatomic localization of the perforators and the course of the perforator through the muscle. The technique of CTA is straightforward and involves the intravenous injection of a contrast medium. No oral contrast is necessary. Using multislice computerized tomography, axial and coronal images demonstrating the vascular architecture are obtained (**Fig. 1**).

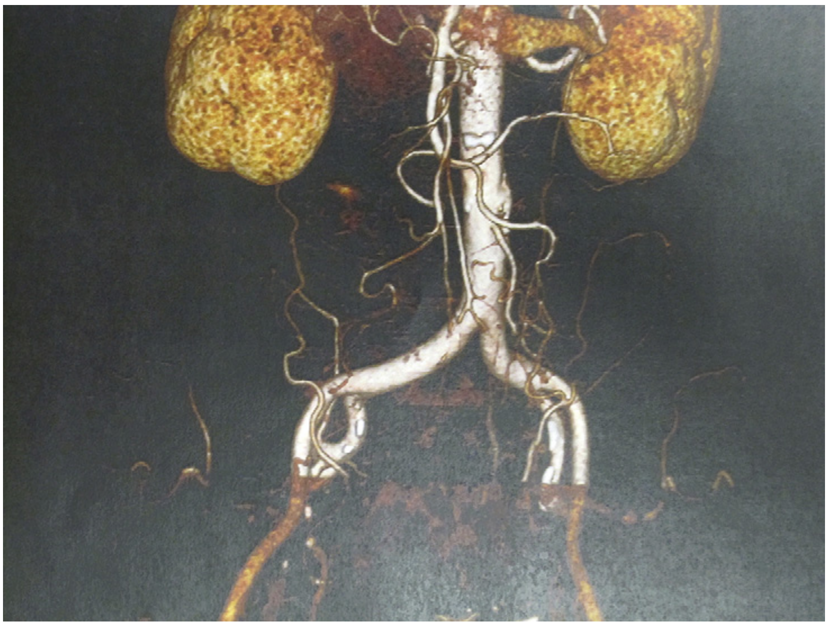

Fig. 1. CTA demonstrating patency of the deep inferior epigastric vessels.

This technique has proved reliable for preoperative assessment of the microcirculatory system and has provided valuable anatomic information as well.

The deep inferior epigastric vascular system has been well studied using the CTA. The traditional classification of the DIEA vessels included 3 types: type 1 occurred in 29% of patients and included a single vessel, type 2 occurred in 57% of patients and included a bifurcating vessel, and type 3 occurred in 14% of patients and included a trifurcating vessel.[25] This classification was modified based on the results obtained by using CTA in 498 abdominal walls. Rozen and colleagues[24] demonstrated that the DIEA branching pattern was different from that expected and developed a classification system based on 5 varieties. The groups included type 0 (<1%) in which the DIEA was absent, type 1 (43%) in which there was 1 DIEA trunk, type 2 (48%) in which there were 2 DIEA trunks, type 3 (9%) in which there were 3 DIEA trunks, and type 4 (<1%) in which there were 4 DIEA trunks. The relationship between the DIEA branching pattern and the perforators was also studied. Type 2 branching patterns were associated with a reduced transverse distance of the intramuscular portion of the perforator, whereas type 3 patterns exhibited an increased transverse distance.[24] The number of perforators was unrelated to the branching pattern.

There have been other clinical benefits related to the information generated using CTA. Casey[13] has demonstrated that preoperative CTA has had a beneficial effect on reducing the operative times and increasing the number of suitable perforators to be included in a flap and has reduced the incidence of a postoperative abdominal bulge. The latter is presumably related to selecting perforators in which the dissection would minimize injury to the innervation of the rectus abdominis muscle. Given that the intercostal innervation of the rectus abdominis muscle originates at the junction of the central and lateral thirds of the muscle, selection of medial rather than lateral perforators may reduce the incidence of nerve trauma. It was found that CTA had no beneficial effect on complications related to anastomosis, flap failure rates, occurrence of fat necrosis, and complications relayed to dehiscence or delayed healing.

CTA has been demonstrated to be a valuable tool in women who had prior abdominal surgery who are interested in DIEP flap reconstruction. Rozen and colleagues[26] studied 58 patients who had a total of 96 abdominal scars with CTA to determine if there was any disruption to the perforators or the primary source vessels. It was found that paramedian incisions invoked the most damage to the vascular supply, negatively affecting the perforators, SIEA, and DIEA vessels. On the contrary, laparoscopic incisions invoked the least damage. **Table 1** reviews the findings after CTA in the setting of different abdominal incisions.

The benefits of standard CTA are clearly evident. Advancements in computerized imaging have enabled the standard images to be reconstructed into a 3-dimmensional image.[15,27,28] The benefits of 3-dimensional imaging are that it permits accurate visualization of the right and left sides and may be useful when deciding between the right and left flap. It also provides information on whether to select medial or lateral row perforators. The correlation of 3-dimmensional imaging parallels the intraoperative anatomy and findings more accurately than standard CTA imaging. Finally, it may provide information that dissuades one from performing a perforator flap and choose instead to perform a muscle-sparing free TRAM.

MRA

MRA represents the next generation in vascular imaging.[16,17,29,30] This is in part because the imaging quality is maintained or enhanced without the aid of ionizing radiation. When compared with CTA, MRA has lower spatial resolution but greater contrast resolution.[29] This feature enables MRA to

Table 1
Effect of various abdominal incisions on the patency of the DIEA, SIEA, and perforating vessels

Scar	n	SIEA Disruption	DIEA Disruption	Perforator Disruption
Laparoscopy	20	None	None	None
Open Appendectomy	20	All (ipsilateral)	None (ipsilateral)	Medial row of DIEA
Pfannenstiel	35	Medial branch (30/35)	None	NR
Paramedian	3	All (ipsilateral)	All (ipsilateral)	All (ipsilateral)
Open Cholecystectomy	1	None	None	None
Midline	17	None	None	Crossover

Abbreviation: NR, not reported.

detect very small perforators that might otherwise not be visualized on CTA. Basically, MRA-produced images require magnetic fields, radio waves, and computers. High-quality images can be obtained with or without contrast agents. The benefit of MRA is that the quality of the vascular conduits or perforators as well as the flow patterns can be seen. This visualization is especially useful for perforator flaps virtually anywhere in the body. The main limitation of MRA is that motion can affect visualization. Patients must hold their breath during the imaging phase.

MRA enables the surgeon to become aware of the perforator location, size, and distance from the umbilicus. Chernyak and colleagues[29] described the utility of MRA in 21 patients undergoing DIEP flap reconstruction. Of these patients, 11 had bilateral DIEP flaps; therefore, 30 flaps were harvested. Axial, 3-dimensional, gadolinium-enhanced, T1-weighted, fat-suppressed, gradient-echo magnetic resonance images were obtained in all patients. Within the group of 21 patients, a total of 118 perforators were visualized with a mean diameter of 1.1 mm (range, 0.8–1.6 mm). Of these perforators, 30 were considered ideal. The mean diameter in this subgroup was 1.4 mm (range, 1–1.6 mm). These imaged perforators were then compared with operative findings. Intraoperatively, a total of 122 perforators were identified. All the 118 perforators seen on MRA were visualized. The 30 flaps were raised on 33 perforators that included a single-perforator flap in 27 and a double-perforator flap in 3. Of the 33 perforators that were harvested, 28 were considered ideal based on the preoperative MRA. Thus, there is good to excellent correlation (97%) between MRA and operative findings.

Other studies demonstrating the benefits of MRA for perforator flaps have been reported. Greenspun and colleagues[17] reviewed the outcomes in 31 women (50 flaps) scheduled for DIEP flaps. All perforators visualized on MRA using a gadolinium-based contrast agent were found intraoperatively. The specific intraoperative location of the perforators was within 1 cm of that predicted using MRA in 100% of patients. In 3 flaps, the DIEA perforators were small and the SIEA system was relatively large. MRA successfully predicted the preferred use of an SIEA flap instead of the DIEP flap in 3 of 3 women (100%). In the same study, the surgeons used a surface Doppler and found signals that corresponded to MRA findings in 44 of the 50 flaps. In 6 flaps, no Doppler signal was found preoperatively; however, intraoperatively, the perforator was clearly visualized in all 6 flaps.

Vasile and colleagues[30] demonstrated that a similar technology could be applied to the gluteal and upper thigh regions to determine the location of perforating vessels. They used a 1.5-T scanner rather than the 3.0-T scanner to improve image quality. MRA was used in 32 buttocks and imaged 142 perforators. The superior gluteal artery was the source for 92 (57.5%) perforators, the inferior gluteal artery for 56 perforators (35%), and the deep femoral artery for 11 (7.5%) perforators. The investigators concluded that MRA contributes to improved flap design based on the location and course of the perforating vessels. This information may determine whether an inferior or a superior gluteal perforator flap should be used.

Masia and colleagues[16] have used MRA without contrast agents and have obtained remarkably clear images of abdominal perforators. In 56 women having DIEP flap breast reconstruction, a dominant perforator was identified using MRA and correlated with intraoperative findings in all (100%). Using a refined imaging system, the investigators were able to accurately determine the location of the dominant perforator, define its intramuscular course, and reliably evaluate the SIEA and determine its dominance or lack thereof. The dominant perforator was paraseptal in 14% of flaps and intramuscular in 86% of flaps. Of the intramuscular perforators, the origin was from the lateral row in 55% and from the medial row in 31%.

DIRT

The concept of thermal imaging to assess cutaneous circulation is not novel. It has been used since the 1980s.[31,32] However, the application of thermal imaging to map out perforating vessels for the preoperative planning of DIEP flaps is novel. DIRT has been described and used for musculocutaneous and fasciocutaneous flaps but has only recently been used for the planning and mapping of perforator flaps.[18,33–35]

The technique of DIRT is straightforward. The principle is based on surface cooling (cold challenge) followed by a period of rewarming. This cold challenge causes relative hypoperfusion of the cutaneous surface. After termination of the cold challenge, the tissues naturally rewarm. As the tissues rewarm, an infrared camera analyzes the changes in cutaneous perfusion and localizes hot spots that correlate with the location of the perforating vessels. These hot spots are validated based on Doppler ultrasonography to ensure accuracy.

In the only clinical study to date evaluating the role of DIRT for preoperative planning, de Weerd and colleagues[18] evaluated 23 patients before having DIEP flap breast reconstruction. They found that it was the rate of rewarming that was critical to perforator selection. Perforators associated with rapid rewarming were more reliable than those associated with slow rewarming. They also concluded that the pattern of rewarming was important. Rapid rewarming associated with a progressive enlargement in the area was associated with the more dominant perforators. Other findings included a large number of perforators located at the tendinous inscriptions as well as in the lateral row. Of the 23 flaps, all were based on lateral row perforators, 14 were at the tendinous inscription, 9 were based on a single perforator, and 14 were based on 2 perforators. **Table 2** provides a comparison of the various preoperative imaging modalities.

INTRAOPERATIVE ASSESSMENT

Preoperative mapping of the perforators represents the first step in the performance of perforator flaps. The next logical step is to assess the perfusion of these flaps based on the primary blood supply. Traditionally, flap perfusion has been assessed by observing the color of the flap and determining the rate of capillary refill in the center and at the periphery of the flap. Other methods have included assessment of bleeding along the cut edges of the flap, which typically includes arterial and venous bleeding in equal proportions. Excessively dark venous blood with minimal or no arterial bleeding is a sign of poor perfusion. The main limitation with these methods of analysis is that there has not been a way to quantitate relative perfusion along the entire surface of the flap.

Fluorescent Angiography

Fluorescent angiography is a relatively new technology that allows for direct visualization of perfusion within a cutaneous territory.[36–43] This technique can be used on tissue that is elevated as a flap or on a cutaneous territory that has not been elevated. The images are captured after the intravenous injection of indocyanine green (ICG). An image-capturing device is then positioned a few inches above the cutaneous territory to be imaged. This device is linked to a computer that analyzes the data and generates the real-time image. Images are obtained about 15 seconds after the ICG injection. In the setting of flap reconstruction, the images can be captured before flap elevation, during flap elevation, after flap elevation, and postoperatively. Fluorescent angiography has also been useful to assess the perfusion and viability of the mastectomy skin flaps as a means of minimizing skin necrosis.

One of the first applications of fluorescent angiography in the setting of autologous reconstruction was to confirm and validate the early studies that described the 4 zones of the TRAM flap. The original zones of the TRAM flap were reported by Scheflan and colleagues[44,45] and Hartrampf and colleagues[46] who described the 4 zones of an abdominal flap based on the presumed vascular perfusion. Zone 1 was based directly over the muscle or source vessel, zone 3 was adjacent and lateral to zone 1, zone 2 was just across the midline, and zone 4 was lateral to zone 3. Holm and colleagues[43] have revisited this traditional paradigm using video angiography and ICG. They demonstrated that abdominal flap zone based on this technique was different than previously thought. Zone 2 was actually lateral to zone 1 and zone 4 was lateral to zone 3.

Other clinical applications have included assessing the perfusion in various free tissue transfer operations. Pestana and colleagues[42] used fluorescent angiography in 23 patients with defects of the head and neck, breast, and extremities. Flaps included the TRAM, DIEP, SIEA, SGAP, lateral arm, anterolateral thigh, and latissimus dorsi. The safety and efficacy of the technique was demonstrated. The ability to assess perfusion at the distalmost aspects of muscle and musculocutaneous flaps was confirmed. Areas of the flap with relative hypoperfusion went on to develop small areas of necrosis or eschar formation. The

Table 2
Comparison of the various tools for assessing the characteristics of the source and perforating vessels

Test	Radiation Exposure	Contrast	Caliber	Location	Flow	Course	Accuracy
Doppler	No	No	No	Yes	No	No	Low
Color Duplex	No	No	No	Yes	Yes	No	Moderate
MDCTA	Yes	Yes	Yes	Yes	No	Yes	High
MRA	No	Yes	Yes	Yes	No	Yes	High
DIRT	No	No	No	Yes	Yes	No	Moderate

Abbreviation: MDCTA, multidetector computed tomographic angiography.

patency of the microvascular anastomosis was confirmed based on arterial inflow and venous outflow.

An almost equally important application of successful breast reconstruction using autologous reconstruction is predicting the viability of the mastectomy skin flaps. Predicting the viability of these skin flaps has always been challenging and when compromised could result in dramatic complications related to skin necrosis. In a recent article, the incidence of minor or major necrosis of the mastectomy skin flaps was 18.3%.[47] Komorowska-Timek and Gurtner[36] have evaluated the mastectomy skin flaps using fluorescent angiography. They found the technique to be beneficial, especially in cases of mastectomy with nipple-areolar preservation. Alterations in perfusion were noted in some women despite what appeared to be a normal nipple-areolar complex. All cases of poor perfusion based on fluorescent angiography, which were not debrided initially, went on to develop mastectomy skin flap necrosis in the corresponding areas. Jones and colleagues[38,40] have demonstrated that patients with a history of tobacco use or connective tissue disorders are more likely to have perfusion alterations of the skin flaps after mastectomy. These alterations can be predicted using fluorescent angiography.

POSTOPERATIVE ASSESSMENT

Postoperative assessment of flap circulation has traditionally required subjective interpretation of objective data. Traditional methods of flap monitoring have included hand-held Doppler probes, surface temperature assessment, flap turgor, capillary refill, and flap color.[48] Although these methods can be effective, they are usually not continuous, subject to interpretation, and depend on clinical personnel. It is also important to differentiate between arterial inflow and venous outflow problems. With inflow problems, the flap becomes pale, cool, and soft with delayed or absent capillary refill. With venous outflow problems, the flap becomes tense, congested, and purple, with brisk capillary refill. The reality of flap monitoring is that there is a short window of opportunity in which the flap can be salvaged in the event of altered flow. With a musculocutaneous or muscle flap, this window is typically about 2 hours. After 2 hours, there may be irreversible ischemic damage to muscle fibers, resulting is flap necrosis. With a perforator flap, this window of opportunity is increased and ranges from 3 to 6 hours because there is no muscle. The metabolic activity of skin and fat is less than that of muscle; therefore, these tissues are better able to tolerate ischemia.

NIR

NIR for monitoring free flaps has received considerable attention over the past several years.[49–51] This technology permits continuous monitoring of oxygen saturation within the cutaneous layer of the flap. A flat surface probe is placed on the skin, which emits near-infrared light (**Fig. 2**). This probe is able to detect the hemoglobin content in the surface vessels. This light has a maximum penetration depth of 2 cm. The probe is linked to a computer that translates the data into a linear measurement (**Fig. 3**). This measurement is constant for a given flap. Alteration in flow, including arterial or venous, is detected immediately, even before there are any clinical signs of altered flap perfusion.

Clinical application of this technology has been encouraging. Keller[50] has used NIR in 145 patients and 208 flaps. All patients were monitored intraoperatively and for 36 hours postoperatively.[50] Of the 208 flaps, 5 demonstrated abnormalities in the spectroscopy measurements. All these flaps were salvaged, in part because of the early diagnosis of altered perfusion. Colwell and colleages[49] applied NIR in 7 patients having free flap breast reconstruction using abdominal flaps. The baseline oxygen tension measurements ranged from 70% to 99% with a mean of 83%. Zone 1 readings remained unchanged after flap elevation; however, zone 4 readings were reduced by 15% to 20% (the mean oxygen tension being 64%). With clamping of the vessels to occlude flow, the measurements dropped by 25% to 38%. Saint-Cyr[52] has used NIR on mastectomy skin flaps. It was demonstrated that factors predisposing to skin necrosis included aggressive medial and inferior parenchymal resections as well as the length of the mastectomy flaps.

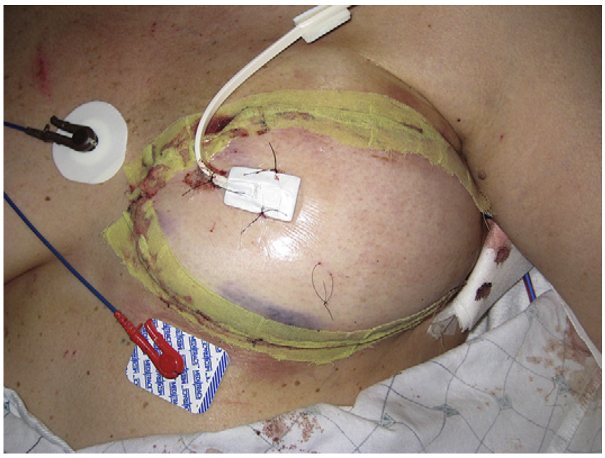

Fig. 2. Monitoring probe on the surface of a flap to detect changes in tissue oxygenation.

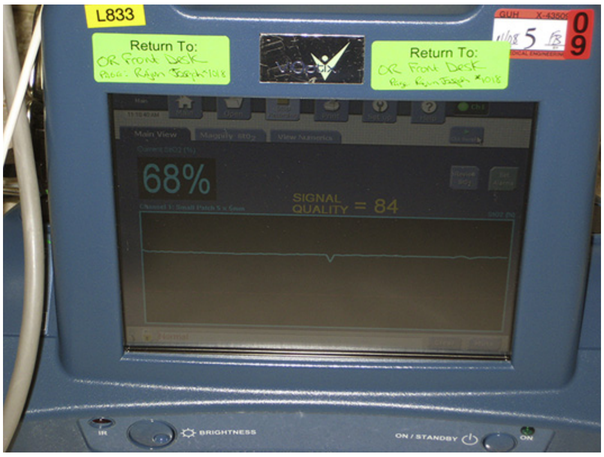

Fig. 3. The visual tracing of tissue oxygenation as achieved using NIR.

SUMMARY

The influx of technology has facilitated the ability to perform reconstructive procedures using autologous tissue. These technologies can be applied preoperatively, intraoperatively, and postoperatively. The reproducibility of these techniques has proved to be reliable and should increase the numbers of autologous reconstructions performed. The degree of accuracy in predicting the location and course of these perforators is unmatched based on conventional modalities. The quality of the images and the ability to easily translate this preoperative knowledge to the operating room is invaluable. Surgeons can now determine how much of a flap will survive based on intraoperative perfusion studies, which should reduce the incidence of fat necrosis. Using advancements in postoperative flap monitoring, surgeons and nurses can detect changes in tissue oxygenation and flow patterns earlier than they can using conventional methods. All these advancements have furthered the ability to perform reconstruction using microvascular techniques and are hoped to translate into improved outcomes.

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