Current Approaches to Free Flap Monitoring

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Postoperative monitoring of free flaps remains an essential component of care in patients undergoing microsurgical reconstructive surgery. Early recognition of vascular problems and prompt surgical intervention improve the chances for flap salvage. Physical examination remains the cornerstone of free flap monitoring, but more recently, additional technologies have been developed for this purpose. In this article, current approaches to free flap monitoring are reviewed.

INTRODUCTION

Free flap surgery involves the transfer of a patient's own tissue from a donor site to a recipient site, which is typically the site of a defect. The donor site usually has a distant location with respect to the recipient site, and therefore in order to physically transfer tissue while maintaining its viability, that tissue's vascular supply must be divided at the donor site, and then reconnected through the creation of anastomoses at the recipient site. Like other types of vascular anastomoses, such as in cardiac surgery, thrombosis can occur, which threatens free flap survivability. Without surgical intervention, vascular compromise will eventually progress to irreversible and total loss of the free flap. On the contrary, with early identification and prompt intervention, many failing free flaps can be salvaged, which underscores the importance of postoperative flap monitoring.

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There are several approaches to monitoring free flaps postoperatively, including physical examination, laboratory testing, and the use of medical devices. Oftentimes, more than 1 method is employed to enhance the ability to detect a vascular problem. Each method of monitoring has its own advantages and disadvantages (discussed later), which generally determines which methods are used in a given case. Irrespective of which monitoring methods are used, the duration and frequency of free flap monitoring remain generally the same and are based on what is known about how and when free flap vascular compromise occurs:

1. *Duration*. Free flap vascular problems typically occur during the first 3 postoperative days (Chao, Meyerson, Povoski, & Kocak, 2013). Accordingly, free flaps are generally monitored starting immediately postoperatively until at least day 3, and in some cases for additional days depending on the nature of the procedure (e.g., difficulty) and surgeon preference (Chen et al., 2007).

2. *Frequency*. The likelihood of salvaging a failing free flap improves if the delay between the onset of a vascular problem and surgical intervention to correct that problem is reduced (Kroll et al., 1996). Excessively long delays before intervention occurs, during which the flap is ischemic, can result in partial or total flap loss. For this reason, free flaps are typically monitored frequently (every 30–60 min), especially during the first few days postoperatively, to identify vascular compromise as soon as possible so that action can be taken.

Free flaps are performed in both academic centers and nonacademic centers. The setting where specific types of free flaps are performed relates largely to the perioperative and postoperative care required, as well as the nature of patients who undergo these procedures. Patients undergoing free flap breast reconstruction generally tend to be healthy and, aside from flap monitoring, require few, if any, additional specialty services. Therefore, these cases are frequently performed in academic and nonacademic hospitals alike. The other major group of cancer patients who often require free flap reconstruction are patients with head and neck tumors. In contrast, these patients tend to have more numerous and significant medical comorbidities, as well as additional considerations such as airway, nutrition, and speech. For these

reasons, microvascular head and neck reconstruction is generally performed in academic hospitals. Trauma patients who suffer injuries severe enough to necessitate free flap reconstruction frequently will have sustained other major injuries and thus require multidisciplinary care that in many cases is most appropriately provided in an academic hospital as well.

POSTOPERATIVE FREE FLAP CARE

When considering free flap monitoring, a thorough understanding of postoperative free flap care is essential, because it allows the health care practitioner to differentiate between a true vascular problem that requires surgical intervention and an issue with the patient that can be corrected medically or at the bedside. Although there is no consensus on postoperative free flap care, there are general themes practiced by most microsurgeons.

In general, the free flap patient should be systemically well perfused, because this is a prerequisite for good perfusion of the flap. Related to this, the patient should receive maintenance levels of intravenous fluids at a minimum, especially if their oral intake has not returned to normal. Correspondingly, good urine output should be demonstrated, which is reflective of adequate intravascular volume status; if marginal or low, then additional volume replacement may be necessary. Patients should also be normotensive, which can be partially determined by comparing their preoperative and postoperative blood pressures. If there is a history of hypertension, a blood pressure measurement should be taken prior to administration of antihypertensive agents, as patients may be relatively hypotensive postoperatively because of opioid use and other perioperative medications. Many free flap protocols include warming of the patient and room to promote peripheral vasodilation and perfusion.

Pressure on free flaps should always be minimized, as excessive pressure may impede arterial inflow and/ or venous outflow. Depending on the anatomic site of the free flap, attention should be paid to patient positioning to ensure that the patient does not lie or rest on it, which may particularly be an issue for posteriorly located free flaps. Surgical dressings should be examined and confirmed to be not excessively tight, especially circumferential bandages on extremities that may be holding a splint in place, as well as surgical bras in patients who have undergone breast reconstruction. For extremity free flaps, the involved limb should be elevated to help control edema, which might otherwise accumulate and cause pressure on the microvasculature of the flap. Finally, activity restrictions, including weight-bearing status and range of motion, should be carefully reviewed, as they may impact pressure or tension on a free flap.

PHYSICAL EXAMINATION

Traditionally, physical examination findings have been the foundation of postoperative free flap monitoring and are considered by most microsurgeons to be the gold standard technique. In general, it is advisable to perform an initial free flap assessment with a practitioner who has previously examined the flap to establish a baseline; otherwise, it may sometimes be unclear whether physical examination findings in a particular case represent something that is normal versus abnormal. In addition, it is important to examine a free flap in the context of a patient's overall condition, to determine whether findings are related to the free flap itself or to a systemic issue.

Capillary Refill

In a capillary refill assessment, cutaneous blood is expunged from a small area of the free flap, usually by temporarily applying digital pressure to the flap itself, and then pressure is released to observe the return of blood flow into that area. This assessment applies only to free flaps with a skin paddle and cannot be performed in muscle free flaps that have been skin grafted. Typically, capillary refill is described in terms of time (normal 2–3 seconds), or whether it is "brisk" versus "delayed." Delayed capillary refill indicates an arterial inflow problem. In contrast, excessively brisk capillary refill indicates a venous outflow problem, as flap tissues become engorged with blood due to continued arterial inflow.

Color

For free flaps that have a skin paddle, the color of the flap skin should exhibit a pink color similar to the site from which the tissue was transferred (Figure 1). This can sometimes be a challenging assessment in patients with darker pigmentation. If the flap skin appears relatively

FIGURE 1. A normal-appearing free flap demonstrating a pink color similar to adjacent nonflap tissue.

pale (Figure 2), this may signal a problem with the arterial anastomosis resulting in decreased blood flow into the flap. On the contrary, if the flap skin demonstrates a purplish discoloration (Figure 3), this may indicate a problem with the venous anastomosis, with accumulation of venous blood in the setting of continued arterial inflow.

For free flaps without a skin paddle, which generally are muscle free flaps that have been skin grafted, color assessment is performed differently. In these cases, it is the color of the muscle that is assessed, which should be red under normal circumstances. Muscle tissue that appears a pale purple color suggests an underlying vascular problem. Skin grafts placed on muscle free flaps generally cannot be used as a means of monitoring free flaps because they have not yet undergone revascularization during the period of time that monitoring is performed.

Temperature

A free flap that is perfusing normally should exhibit a temperature that is comparable to adjacent nonflap areas of the patient. Free flap temperature can be assessed using either an actual measurement or physical examination, although the latter is significantly limited by the subjectivity of what constitutes warm versus cool. A difference of greater than 1°C–3°C (1.8°F–5.4°F) in temperature between a flap and adjacent nonflap skin may be indicative of a vascular problem (Chen et al., 2007). Temperature assessments tend not to be routinely used in postoperative free flap monitoring because of the greater accuracy of other methods discussed in this article.

Turgor

The balance between vascular inflow and outflow determines tissue turgor. Normally, a free flap should exhibit

FIGURE 3. A free flap demonstrating a purplish color that may be indicative of a venous outflow problem.

turgor that is similar to a patient's other nonflap tissues. If a free flap exhibits diminished turgor, this may herald an arterial inflow problem. A related finding in this situation is increased prominence of rhytids (wrinkles) on the skin paddle of a free flap, which are ordinarily obliterated and not visible when a flap is distended by normal amounts of vascular inflow. On the contrary, a free flap that is excessively swollen and firm may be experiencing a venous outflow problem. As with temperature assessments, it is important to compare flap turgor to adjacent nonflap tissues, as systemic issues can also alter turgor (e.g., volume status).

LABORATORY TESTING

Techniques of free flap monitoring that involve laboratory testing including tissue pH, blood glucose levels, and microdialysis (Chen et al., 2007; Salgado, Moran, & Mardini, 2009). These methods typically require repetitive invasive investigations to compare the flap tissues to values measured earlier in time and/or to systemic tissues. For this reason, laboratory testing is infrequently used in routine free flap monitoring.

MEDICAL DEVICES

Multiple types of medical devices have been developed to aid in the monitoring of free flaps (Smit, Zeebregts, Acosta, & Werker, 2010). These devices can be broadly classified into those that monitor the microvascular anastomoses themselves (color duplex ultrasonography, flow coupler, implantable Doppler) and those that perform an assessment at a more downstream point, usually at the external surface of the free flap (acoustic Doppler ultrasonography, laser Doppler flowmetry, and near-infrared and visible light spectroscopy).

FIGURE 2. A free flap demonstrating a pale color that may be indicative of an arterial inflow problem.

Acoustic Doppler Sonography

Acoustic Doppler sonography is one of the most commonly used methods of free flap monitoring and is ordinarily combined with physical examination. It employs the Doppler effect, which refers to the phenomenon whereby the frequency of a wave changes when its source and an observer move relative to one another. With acoustic Doppler sonography, a stationary probe emits ultrasound waves, and the frequency of those waves changes as a result of blood flow within the flap. The device then generates sound that is proportionate to flap blood flow. Ordinarily, upon completion of a free flap procedure, sites for Doppler monitoring are identified and marked with sutures (which can be done for both free flaps with a skin paddle and free muscle flaps that have been skin grafted), so that the same sites can be evaluated over time. Usually, sites of arterial flow are marked and assessed and produce a characteristic pulsatile auditory output. In some cases, a venous signal can also be identified, which in contrast produces a constant and relatively quieter sound, since venous flow is nonpulsatile and slower. Weakening or loss of a previously normal Doppler signal is indicative of a vascular problem.

Color Duplex Ultrasonography

Color duplex ultrasonography is a method of free flap monitoring that uses ultrasound to directly visualize vessels that have undergone microvascular anastomosis, including their real-time flow. The device consists of an ultrasound probe and a viewing monitor, which can be used in a radiology suite or transported to a patient room. Its use requires a radiology technician to operate the device, a radiologist to interpret the images, and the microsurgeon to assist in anatomical orientation. For these reasons, color duplex ultrasonography is not routinely used for free flap monitoring.

Flow Coupler

The venous anastomosis in free flap surgery is commonly created using a device called a *coupler*. A coupler is a hollow plastic (polyethylene) apparatus onto which the ends of the two veins to be connected are mounted, and through which venous blood will eventually flow. The flow coupler (Synovis Micro Companies Alliance, Inc., Birmingham, Alabama) is a coupler that is additionally fitted with a Doppler probe, whose signal is transduced through a wire connected to the coupler. The wire traverses the surgical wound and exits the incision where it is ultimately connected to a sound and power source. The device then generates a venous Doppler signal that can be heard continuously, with loss of the signal indicative of a vascular problem. Prior to hospital discharge, gentle traction on the wire results in disconnection from the coupler, which remains in the patient.

Implantable Doppler

The implantable Doppler utilizes the Doppler principle applied directly to the site of microvascular anastomosis, but unlike the flow coupler, it can be used at both arterial and venous anastomoses. Typically, the device, which consists of a Doppler probe that is wrapped around the site of anastomosis, is applied at the conclusion of a free flap reconstruction. The implantable Doppler can be applied to the arterial anastomosis, venous anastomosis, or both if two devices are used, and it is, therefore, important to know to which site(s) it has been applied because this governs the quality of the signal that is produced. The probe is attached to a wire that transmits the Doppler signal, which is brought out of the surgical incision and connected to a sound and power source. The device then produces auditory output similar to that produced by acoustic Doppler sonography. Weakening or loss of the signal suggests a vascular problem. An important point regarding the use of the implantable Doppler is that patient movement can cause the Doppler probe to move within the patient, which in turn can alter the signal even in the setting of a normal anastomosis. Despite this, any change in the signal warrants thorough flap assessment and notification of the microsurgeon. After the postoperative monitoring period, the wire is pulled, which removes the entire apparatus from the patient.

Laser Doppler Flowmetry

Free flap monitoring devices that utilize laser Doppler flowmetry make use of the Doppler effect applied to laser light (rather than ultrasound waves as in acoustic Doppler sonography). A probe is affixed to the surface of the flap using a dressing or sutures, and the probe emits laser light that experiences a shift in frequency based on the velocity of blood flow within the flap. The device reports velocity measurements in units often abbreviated as LDF (laser Doppler flow meter) units, which vary depending on both the type of flap and the particular patient. There are currently no standardized criteria for diagnosing vascular compromise using laser Doppler flowmetry. Although many groups suggest that a value greater than 2.0 LDF is indicative of a normal free flap, the specific criteria for a given case will depend on the flap type, device model, and surgeon preference.

Near-Infrared and Visible Light Spectroscopy

In spectrometry, a source emits light of a specific wavelength toward an object (chromophore), and a detector measures changes in the reflected light, such as reduction in intensity. Based on the characteristics of the reflected light and the chromophore, concentrations of the chromophore can be determined. Free flap monitoring devices that utilize spectroscopy commonly utilize near-infrared light (650–900 nm), which can measure concentrations of

oxygenated and deoxygenated hemoglobin, which vary depending on the degree of blood flow within a flap.

One of the more commonly used free flap monitoring devices that utilize near-infrared light spectroscopy is the T.Ox Tissue Oximeter (ViOptix Inc., Fremont, California). With this device, a probe is affixed to the flap skin paddle with an occlusive dressing. Usually, two criteria are used to diagnose vascular compromise: a 20-point drop within a 1-hour period or an absolute reading less than 30. The device can be set to alarm when these criteria or other user-specified criteria are met. Because the measurement will vary depending on the specific location on the flap, this site is usually chosen at the conclusion of a free flap procedure, and that same site is used to assess the flap during the postoperative period so that both the current measurement and overall trends can be obtained. When assessing a free flap whose reading has changed, the probe dressing should be inspected, as moisture under the dressing or migration of the probe can also affect the reading. In addition, excessive ambient light can alter device function, and therefore the probe should be covered except when examining the flap.

A relatively newer device is T-Stat (Spectros, CA), which uses visible light (475–600 nm) spectroscopy. However, there are currently no established criteria for diagnosing vascular problems with T-Stat.

CONCLUSION

Physical examination combined with acoustic Doppler sonography remains the cornerstone of postoperative free flap monitoring. Several medical devices are now available for flap monitoring, many of which provide continuous data related to flap perfusion and therefore serve to supplement traditional flap monitoring approaches. An understanding of how these devices work can assist in their usage and interpretation in postoperative free flap monitoring.

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