A Prospective Analysis of Free Flap Monitoring Techniques: Physical Examination, External Doppler, Implantable Doppler, and Tissue Oximetry

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Abstract

No universally accepted method of flap monitoring exists, and several techniques are in use. Repeated physical examination is most popular and is often supplemented with a handheld, external Doppler, and/or implantable Doppler probes; near-infrared spectroscopy is less commonly used. We investigated the nursing and resident house staff's experience and confidence with physical exam for flap monitoring. Also, a consecutive series of 38 patients with free flaps were monitored using physical examination, external Doppler, implantable arterial and venous Doppler probes, and near-infrared spectroscopy. Five patients developed signs of microvascular complications within 3 days of surgery; all were explored and salvaged. Neither the residents nor the nursing staff were universally trained or experienced in flap monitoring by physical exam. In all patients, changes in the appearance of the flap suggestive of a microvascular complication lagged 30 to 60 minutes after the adjunctive monitoring methods indicated that a problem had occurred. Near-infrared spectroscopy was the first warning sign in four of the five patients. Two patients were explored before thrombosis of the anastomoses occurred. Near-infrared spectroscopy may identify early microvascular complications more reliably than physical examination, external Doppler, or implantable Doppler.

Keywords

- monitoring techniques
- microsurgery
- near infrared spectroscopy
- external Doppler
- implantable Doppler

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The goal of postoperative free flap monitoring is to detect microvascular complications before permanent injury to the flap occurs and thus maximize the potential for salvage.[1,2] Vascular compromise usually occurs within 48 hours of surgery.[1,3] Typical causes include anastomotic thrombosis, kinking or external compression of the pedicle, and hematoma. Many authorities consider physical examination to be the gold standard for flap monitoring, but this technique employs mostly subjective findings.[4–7] Common parameters evaluated include capillary refill time, skin color, tissue turgor, and temperature, as well as maneuvers such as needle pricks to evaluate the color and character of bleeding from the flap. Frequent examinations are labor intensive, and interpretation of the findings requires experience. However, the personnel likely to be called about a potentially failing flap have many other clinical responsibilities and may have little training or

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experience evaluating flaps. Furthermore, different observers may disagree about the significance of their findings. For all of these reasons, physical examination alone is not always reliable, and more objective methods are desirable.

A variety of adjunctive monitoring methods are used to supplement physical exam, and none is clearly superior to the others.[8–15] About 75% of surgeons use a handheld Doppler and ~16% use an implantable Doppler.[4–6,16–20] Implanted probes can be used to monitor both arteries and veins, and provide continuous, real-time, qualitative information about blood flow. They are attractive for monitoring buried flaps that cannot be evaluated by physical exam or the external Doppler. Near-infrared spectroscopy (NIRS) is used by less than 5% of microsurgeons but is increasingly recognized as a sensitive way to measure tissue oxygen saturation (StO_2), which reflects net perfusion and oxygen consumption and can reliably detect vascular compromise.[4,14,21–29] NIRS provides continuous real-time data that is both quantitative and objective.

At the time of this study, our hospital was developing practice protocols to support an evolving microsurgical service. The number of operations was growing, but there was no specialized unit for monitoring. Patients typically stayed overnight in the postanesthesia care unit (PACU) and were then transferred to different floors. The nurses and residents who cared for these patients were not necessarily experienced with flap monitoring. The aims of our study were (1) to assess the level of experience and attitudes toward flap monitoring among the nurses and house staff and (2) to determine the most useful method of free flap monitoring under these circumstances.

Methods

The study protocol was approved by our institutional review board and included two components. A questionnaire about the level of training and experience in flap monitoring by physical exam was distributed to the nurses working in the PACU, the surgical intensive care unit, and regular surgery floors. The first- and second-year residents who take in-house call for the plastic surgery service were also asked to complete the survey. Each respondent completed only one survey. Then, a prospective series of consecutive patients with free flaps—including external skin paddles—performed between January 2006 and February 2007 was monitored using repeated physical examination supplemented with the external Doppler, arterial and venous implantable Doppler probes, and NIRS.

Separate implantable Doppler probes (Cook Medical Inc., Bloomington, IN, USA) were used to monitor the arterial and venous anastomoses. The plastic cuff holding the transducer was secured around each vessel with a hemoclip. The transducers were placed immediately distal to the anastomoses, and the connecting wires were stapled to the skin. Five days after surgery the wires were removed, leaving the transducer in situ.

After the skin paddle was inset, a handheld Doppler (Datascope IABP-Doppler, Huntliegh Healthcare, Inc., Eatontown, NJ, USA) with an 8-MHz probe was used to identify the most prominent cutaneous signal, which was marked with a small suture. Finally, a StO_2 sensor (Vioptix, Fremont, CA, USA) was applied to the skin paddle. The sensor emits a near-infrared light signal (600 to 900 nm). It measures scattered and absorbed light, which reflects the oxygen content of hemoglobin and makes use of proprietary software to calculate StO_2. The sensor was applied to the area of the skin paddle with the maximum tissue oxygenation.

Time 0 ($T = 0$) was defined as the end of the operation, when the flap was initially assessed using all of the monitoring techniques, and just before transfer to the PACU. In the PACU, pertinent physical findings regarding the location and character of the cutaneous skin paddle, implantable Doppler signals, and the StO_2 readings were all reviewed with the nursing staff. Thereafter, patients were examined hourly, and the flaps were interrogated at the same times using the adjunctive monitoring tools. All patients stayed overnight in the PACU. The next morning they were transferred to regular nursing floors or one of the surgical intensive care units, if needed. The monitoring protocol was continued for 72 hours.

The nurses immediately reported any changes in the appearance of the flap suggestive of vascular compromise to the resident on call. They were specifically asked to report prolonged (more that 3 seconds) or rapid (less than 2 seconds) capillary refill time, swelling, loss of skin turgor, or if the flap became pale, cool, mottled, or dark and congested. They were asked to report any changes in the handheld or implantable Doppler signals, as well as a reduction in StO_2 of 30% or more. If any of these events occurred, the time was documented and the resident on call was contacted to assess the patient.

Clinical Results

Thirty-eight patients (11 men, 27 women) with a mean age of 38.5 years (range: 21 to 84) had free flaps with exposed skin paddles. There were 18 deep inferior epigastric perforator (DIEP) flaps, 15 anterior lateral thigh perforator (ALT) flaps, and 5 muscle-sparing transverse rectus abdominis flaps. All anastomoses were end-to-end, using interrupted 9–0 nylon for the arteries and a coupler (Synovis Micro Companies Alliance, Birmingham, AL, USA) for the veins. Local heparin irrigation was used, but systemic anticoagulation was not employed.

If any of the monitoring methods suggested that a flap was threatened, it was promptly explored. Five patients (13%) developed signs of microvascular complications including two ALT and three DIEP flaps. Problems with the ALT flaps developed more than 60 hours after surgery, whereas problems with the DIEP flaps were noted between 12 and 24 hours after surgery. Venous complications alone occurred in three patients, simultaneous arterial and venous complications occurred in one patient, and one patient was explored before either anastomosis had clotted. All flaps were successfully salvaged, and details are described below. ►**Table 1** summarizes the results.

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Table 1 Summary of the Events and Time Course for Patients Who Required Reoperation for Microvascular Complications

Patient	First Event	Second Event	Third Event Pat
1	Reduction in StO_2	Obvious physical findings	Re-operation
	T = 64	Venous Doppler lost	T = 66
		T = 65	
2	Reduction in StO_2	Subtle physical findings	Obvious physical findings
	Venous Doppler lost	Arterial Doppler lost	Reoperation
	T = 60.5	External Doppler lost	T = 63.3
		T = 62.8	
3	Reduction in StO_2	Subtle physical findings	Reoperation
	T = 23	T = 24	T = 26
4	Reduction in StO_2	Subtle physical findings	
	T = 7.5	Reoperation	
		T = 8.0	
5	Reduction in StO_2	Subtle physical findings	
	T = 12	Venous Doppler diminished	
		Arterial Doppler diminished	
		External Doppler diminished	
		Reoperation	
		T = 12.75	

Patient 1 was a 38-year-old male who underwent scalp and cranial reconstruction with an ALT flap for complications related to hydrocephalus. Saphenous vein grafts were used between the facial vessels and the donor vessels. At T = 64 hours, there was an abrupt reduction in StO_2 from 74% ± 2% to 40%. There was no immediate change in the flap's appearance, or any of the Doppler signals. The patient had put on his eyeglasses for the first time after surgery and it appeared that the earpieces compressed the vein grafts. Despite removal of the glasses, the StO_2 declined to 19% at T = 65. By then, the flap appeared "darker and somewhat congested" with "brisk" capillary refill. The signal from the venous implantable Doppler was diminished, but signals from the external Doppler and the implantable arterial Doppler were unchanged. At T = 66 the flap was explored; the venous graft was found to be thrombosed and had to be replaced, although the graft on the arterial side remained patent. After surgery, the StO_2 was 73% ± 3%; the implantable Doppler signals, external Doppler signals, and physical appearance of the flap returned to baseline.

Patient 2 was an 84-year-old female who underwent excision of an advanced basal cell cancer, cranioplasty, and scalp reconstruction with an ALT flap. Saphenous vein grafts were used to bridge between the donor vessels and the external jugular vein and superior thyroidal artery. After surgery, the StO_2 was 96% ± 2% with "strong" signals from both the implantable and external Dopplers. There was "good" capillary refill, and the flap was "warm and soft." At T = 60.25, the patient tripped on the Doppler cables while getting out of bed, causing an abrupt traction injury to the vascular anastomoses. Between T = 60.25 and T = 60.5, the StO_2 fell to 25% ± 1%, and the signal from the implantable venous Doppler ceased. Signals from the handheld Doppler, the implantable arterial Doppler, and the physical appearance were all unchanged at this time. By T = 62.8, StO_2 was 20% ± 2%, and there were no detectable Doppler signals. At this time, the flap had "slight venous congestion," but upon arrival in the operating room at T = 63.3, the flap was found to be clearly more "congested." Both anastomoses were kinked and clotted at the plastic cuffs of the implantable Doppler probes. They were revised using vein grafts and then the StO_2 rebounded to 82% ± 2%. The flap was "well-perfused with normal capillary refill," with a "strong" external Doppler signal. The implantable Doppler probes were not replaced.

Patient 3 was a 45-year-old female who underwent immediate left breast reconstruction with a DIEP flap. Between T = 0 and T = 20 the StO_2 was 50% ± 2% and the physical findings included "good capillary refill" and "no congestion." All Doppler signals were "strong." Between T = 20 and T = 23, the StO_2 slowly fell to 35% ± 1%, but there were no changes in the appearance of the flap or in the Doppler signals. At T = 24, StO_2 was 25% ± 5% and the examiner documented "possibly some congestion." The implantable Doppler signals were "unchanged" and the external Doppler signal was still "strong." The patient returned to the operating room at T = 26. The deep inferior epigastric vein was bleeding from a branch point and the resulting hematoma had started to compress the vascular pedicle. A hemoclip was used to stop the bleeding, but neither anastomosis was revised. Two hours later, the $StO_2$was 60% ± 1%, the capillary refill

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time was "3 seconds" with "no congestion," and "strong" implantable and external Doppler signals were documented.

Patient 4 was a 49-year-old female who underwent immediate right breast reconstruction with a DIEP flap. For 7 hours after surgery, the StO_2 was 75% ± 5%. Examiners reported that the skin paddle was "warm and pink" with "good capillary refill" and "no congestion." All the Doppler signals were "strong." From T = 7 to T = 7.5, the StO_2 fell to 40% ± 3%, but there were no changes in the appearance of the flap or in any of the Doppler signals. The patient returned to the operating room at T = 8. By this time, the physical findings included "early signs of congestion" and "rapid capillary refill." There was also "questionable swelling" of the flap. There were still "good" signals from the implantable probes and a "positive" external Doppler signal. A "small amount of blood" was found around the vascular pedicle, but no active source of bleeding was identified. The venous anastomosis was explored and found to be patent, but clot was obstructing the deep inferior epigastric vein, which appeared to have been injured. The area was repaired with a vein graft. After surgery, the StO_2 was 86% ± 5% and the flap had some peripheral blood staining with "good" signals from both the implantable and external Dopplers.

Patient 5 was a 48-year-old female who underwent delayed right breast reconstruction with a DIEP flap. At T = 11, the StO_2 was 82% ± 3% and the flap appeared healthy. At T = 12, the StO_2 had fallen to 50% ± 5% but the flap still appeared "healthy" and all the Doppler signals were "good" or "strong." When the patient returned to the operating room at T = 12.75 the StO_2 was still 50% ± 2% and the flap was "cool and pale" with "questionable ischemia." Signals from the implantable and external Doppler probes were diminished. A hematoma was found around the anastomoses. The pedicle was "kinked and compressed" by the flap. No site of active bleeding was identified. The pedicle was repositioned and the StO_2 rebounded to 70% ± 6%. It was not necessary to revise either anastomosis. The flap was again "warm and pink" and the implantable and handheld Doppler signals were "strong."

Survey Results

Sixty-one nurses and 51 residents (response rates of 86% and 93%, respectively) provided data. Seventy-four percent of nurses and 57% of residents reported some training in flap monitoring; 90% of nurses and 67% of residents reported they had at least some experience evaluating flaps in the first few days after surgery; 68% of nurses and 47% of residents reported some experience evaluating flaps with vascular compromise. Eighty-seven percent of nurses and 61% of residents said that they felt confident in their ability to diagnose a flap with vascular compromise based upon physical findings.

Discussion

Physical examination is an essential medical skill. However, changes in the physical exam, as recognized by the personnel who evaluated free flaps after surgery, were never the initial evidence of pending flap failure. Eventually, all five patients who were explored for microvascular complications developed changes in the appearance of the flap, but these changes lagged behind the adjunctive methods of flap monitoring (range 30 to 60 minutes). Even at the time of reoperation, the examiners described definitive physical findings in only two patients (patients 1 and 2). Findings in the others patients were less clear, and descriptions were qualified with terms like "some," "possible," "questionable," and "early." Forty minutes after examiners first described "slight venous congestion" for patient 2's flap, they described the flap as simply "congested." However, definitive changes in the physical findings were never reported for the other patients.

Early changes in the appearance of a compromised flap are subtle. Although there are no specific physical findings associated with pending flap failure, most experienced microsurgeons have a general mental picture of what a failing flap looks like. These findings become quite clear as time passes, but when obvious physical evidence of vascular insufficiency is present, the flap may have already sustained irreversible injury. It is instructive to note that the appearance of patient 2's flap, which was the most acutely threatened, was initially thought to be normal. Physical findings suggestive of vascular compromise were present 2.5 hours after the injury to the pedicle, but they were not obvious until 2.8 hours after the injury.

Given that the initial findings associated with microvascular complications are both nonspecific and subtle, it is not surprising that they are difficult to recognize. Furthermore, the residents and nurses who typically are responsible for monitoring free flaps have variable degrees of training, experience, and confidence in their ability to evaluate these flaps. Less-experienced personnel may only be familiar with late physical findings associated with a clearly compromised flap. The nurses reported a greater degree of training, experience, and confidence in their skills than did the house staff. Residents are usually assigned to the plastic surgery service for 1-month rotations, which may not be enough time to develop the skills to accurately evaluate flaps after surgery. The level of experience among the residents may be further diluted on nights and weekends, when personnel from other services take call on the plastic surgery floors.

Although commonly used, the handheld Doppler is not specific for the vessel of interest, and the examiner may inadvertently interrogate a vessel adjacent the flap. There are also times when it impossible to find a cutaneous signal from a flap that is well perfused. Either of these situations can lead to erroneous conclusions about the health of the flap. In this study, subjective changes in the quality of the handheld Doppler signal were never the initial sign of pending microvascular complications. For example, in patient 2, the external Doppler signal ceased 2.3 hours after there was a traction injury to the anastomoses. No qualitative change in the signal was reported prior to this time. For Patient 5, the external Doppler signal was diminished 45 minutes after a reduction in StO_2. For Patients 1, 3, and 4, no changes in the signal from the handheld Doppler were documented prior to reoperation.

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The handheld Doppler is most commonly used to assess flow in an arterial perforator, although changes in venous flow may be a more sensitive predictor of flap failure. In this series, three out of the five episodes of flap compromise were caused by venous insufficiency alone. In these cases, signal changes were not detected using the handheld Doppler, probably because arterial flow continued for some time after thrombosis of the veins. It is very likely that the Doppler signals from the arterial perforators would have eventually been diminished, but the potential for flap salvage may also have been diminished by that time. For patients with simultaneous arterial and venous compromise, subjective changes in the external Doppler signals did occur, but they were not the initial finding. We did not have any instances of arterial thrombosis antecedent to venous thrombosis, but it is likely that the handheld Doppler would be useful to identify this problem.

Both handheld and implantable Doppler share an important problem: it is difficult to define exactly what constitutes a change in the signal quality that should trigger reoperation. We explored any flap when there was a change in the Doppler signals. Because all patients with changes in Doppler signals eventually developed complications, this approach is probably justified. However, some patients developed vascular complications without changes in the Doppler signals. It is possible that changes in Doppler signals for these patients occurred, but they were too subtle to be noticed by the examiners. In two cases, the venous limb of the flap pedicle clotted while the arterial limb remained patent, and the implantable Doppler probes accurately identified this situation. Monitoring the vein with an implantable Doppler is probably sufficient and preferable to monitoring the artery; other authors have made similar recommendations.[30]

False-positive signals have been reported with implantable Dopplers and may occur if the transducer detects a signal from an adjacent vessel.[31] In the setting of breast reconstruction, some authors have postulated that changes in the volume of the thoracic cavity during ventilation cause a back-and-forth motion of blood in the internal mammary vein, which can generate a false-positive Doppler signal despite absence of blood flow across the anastomosis.[32] Although the implantable Doppler is considered especially useful for buried flaps, Ferguson et al noted false-positive signals from 31% of thrombosed veins in this situation.[33]

Changes in implantable Doppler signals were never the first or only sign pointing to flap failure. On the other hand, falling StO_2 was one of the first signs of pending flap failure in all of the patients, and preceded others by at least 30 minutes. The only exception to this occurred in Patient 2, when there was a simultaneous reduction in StO_2 and loss of the venous implantable Doppler signal. This was likely related to traction on the implantable Doppler cable. In the other four cases, the decision to return to the operating room was based solely on a reduction in flap StO_2 data. The StO_2 of healthy tissue is ~83% and is affected by many parameters including pO_2, temperature, cardiac output, etc.[25] Consequently, instantaneous values are not as useful as trends in multiple values over time. A reduction in tissue oxygen levels of 30% compared with baseline suggests that the flap is compromised.[26] When external events interrupted blood flow to the flap (Patients 1 and 2), there was an abrupt fall in StO_2. In other situations, StO_2 reduction was gradual, occurring over 30 minutes to 3 hours.

Unless veteran personnel are available, physical exam alone is probably insufficient for flap monitoring. Our experience suggests that even in larger hospitals, these personnel are not always available, and adjunctive monitoring methods can be useful. Adjunctive monitors should be easy to use, inexpensive, and sensitive enough to identify failing flaps before irreversible tissue injury occurs, but without generating excessive false-positive alarms. Monitors should also provide continuous data and be suitable for all types of flaps.[7,34] Quantitative outputs are preferable to qualitative outputs and would facilitate research about the indications and methods of flap monitoring. Quantitative data would potentially refine the decisions about when reoperation is necessary; this situation is often ambiguous with current techniques.

Flap failure is a rare event. There were too few observations in this study to allow for meaningful statistical analysis of the events and outcomes. Any study of flap failure, especially a single-institution prospective study, is likely to be plagued by this problem. Our reexploration rate was higher than some, but the rate of flap failure was not.[2,3,35–41] Despite these limitations, it may be possible to draw generalizations from our data. With NIRS, the tipping point leading to flap failure is easy to identify. Furthermore, StO_2 was the earliest, or one of the earliest, signs of pending flap failure in each patient. Two of the five patients returned to the operating room before their anastomoses clotted. It is possible that these flaps would have remained viable without intervention, but given the clinical findings (active bleeding in one patient and a kinked pedicle in the other) this seems unlikely.

There are drawbacks to NIRS monitoring. An exposed skin paddle is required and the sensor may need frequent repositioning. The system is also costly. The retail price of a NIRS sensor is about $1275, and there are usually no charges for the other hardware. The retail price of an implantable Doppler probe is $435.00 and the reusable monitor costs $3500.00. Even with these costs, there may be an opportunity for overall savings if patients can be safely monitored on regular nursing floors instead of specialized intensive care units, and this is now our practice. Furthermore, if the monitor improves success rates for free flaps, the price might seem easier to bear. Teams with already high success rates may not realize a benefit from NIRS as readily as ones that have room to reduce their rate of complications.

Conclusion

Although we may never have good evidence about monitoring techniques, efforts to improve them will probably continue. NIRS appears to be particularly effective at early identification of microvascular complications, in some cases even before thrombosis occurs.

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