Near Infrared Spectroscopy for Monitoring Flap Viability Following Breast Reconstruction

Iain S. Whitaker, B.A. (Hons), M.A. (Cantab), M.B.B.Chir., F.R.C.S., Ph.D. [1, 2, 3]
George F. Pratt, M.B.B.S., P.G.DipSurgAnat. [2]
Warren Matthew Rozen, M.B.B.S., B.Med.Sc., P.G.DipSurgAnat., Ph.D. [2] Scott A. Cairns, B.M., M.R.C.S. [1, 4]
Matthew David Barrett, M.B.B.Ch., M.R.C.S. [1] Leong Yoon Hiew, M.B.Ch.B., F.R.C.S. [1]
Mark ACS Cooper, M.B.B.S., F.R.C.S. [1] David J. Leaper, M.D., Ch.M., F.R.C.S., F.A.C.S., F.L.S. [4]

[1] Department of Plastic, Reconstructive, and Burns Surgery, Welsh Centre for Burns and Plastic Surgery, Morriston Hospital, Swansea, United Kingdom;
[2] Department of Anatomy, Jack Brockhoff Reconstructive Plastic Surgery Research Unit, University of Melbourne, Victoria, Australia;
[3] Swansea University College of Medicine, Swansea;
[4] Department of Wound Healing, Cardiff University, Heath Park, Cardiff, United Kingdom.

Address for correspondence and reprint requests Iain S. Whitaker, B. A. (Hons), M.A. (Cantab), M.B.B.Chir., F.R.C.S., Ph.D., Swansea University College of Medicine, Singleton Park, Swansea, 5A2 8PP, UK (e-mail: iainwhitaker@fastmail.fm).

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Abstract

Free flap monitoring is essential to the early detection of compromise thereby increasing the chance of successful salvage surgery. Many alternatives to classical clinical monitoring have been proposed. This study seeks to investigate a relatively new monitoring technology: near infrared spectroscopy (NIRS). Patients were recruited prospectively to the study from a single center. During the research period, 10 patients underwent reconstruction with a free deep inferior epigastric perforator flap (DIEP). Measurements of flap perfusion were taken using NIRS in the preoperative and intraoperative phases and postoperatively for 72 hours. NIRS showed characteristic changes in all cases which returned to theater for pedicle compromise. In these cases, NIRS identified pedicle compromise prior to clinical identification. There were no false-positives. NIRS accurately identified all compromised flaps in our study. In most cases, there was an evidence of changes in oxygen saturation on NIRS prior to clinical observation. Further research, ideally double blind randomized control trials with large sample groups would be required to definitively establish NIRS as an ideal flap monitoring modality.

Keywords
- free flap
- perforator flap
- reconstructive surgery
- monitoring

Postmastectomy breast reconstruction using autologous free tissue transfer is a common procedure in the United Kingdom. In recent times, the trend has been toward technically challenging perforator-based reconstructions such as the deep inferior epigastric perforator flap (DIEP). These flaps provide the aesthetic advantage of autologous tissue while minimizing donor site morbidity. Increasing experience with these procedures and advances in preoperative planning have resulted in some specialized centers publishing flap loss rates of lower than 2%[1–3] however in some series, failure rates are as high as 5 to 20%.[4,5]

Flap failures are usually due to pedicle compromise and require urgent re-exploration and re-establishment of inflow and outflow for salvage to occur. It is well established that early detection of compromise leads to a higher salvage rate. To date, the gold standard for detection of a compromised flap remains clinical examination by an experienced practitioner[6] with the use of common bedside tests such as the handheld

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Doppler. However with this being subtle and subjective, especially in the case of muscle flaps, a reliable automated alternative has long been sought.

Near infrared spectroscopy (NIRS) employs a light source producing energy in the near infrared wavelengths, which is then collected by a detector, which measures the intensity at various wavelengths. Biological tissues are relatively transparent to light in these wavelengths and by measuring the amount of light absorbed by tissue chromophores (predominantly hemoglobin) it is able to infer the amount, and oxygen saturation of hemoglobin in tissues. Technological advances in recent years have resulted in miniaturization and reduction in cost making this technology increasingly feasible.

NIRS allows continuous, noninvasive monitoring of hemoglobin levels and oxygen saturations in a free flap. Typically, measurements of saturated and nonsaturated hemoglobin levels are taken at a depth of ~10 mm in the tissue. This data are fed back to a laptop computer, which displays graphic and numerical data. Based on the typical curves and values, abnormalities can be identified as arterial or venous in origin.[7]

Advantages of the NIRS system are that it is noninvasive and reliable. In addition, it can be used to monitor buried flaps provided the overlying skin is not more than 10 mm thick. Disadvantages include the cost of the unit and the fact that while current evidence suggests that it reliably detects circulatory failure prior to clinical signs, it may lag behind continuous monitoring devices such as the implantable Doppler as it measures indirect evidence of circulatory failure. While NIRS has been extensively investigated in animal models,[8–11] there is a relative paucity of reported uses in clinical practice.[7,12–18]

Methods

A prospective observational study was undertaken, recruiting all women who were undergoing autologous breast reconstruction following mastectomy, aged between 18 and 65 years old at a single institution (the Regional Plastic Surgical Centre at the Morriston Hospital in Swansea, Wales). Those with a history of healing complications, bleeding disorders, and systemic skin disease or infection, which may have influenced healing, were excluded. Also excluded were those who were currently participating in another trial or those having done so within 3 months of the current study and those undergoing evaluation for an unrelated disease, which may have interfered with trial participation. All patients gave written consent following study approval by the institutional ethics committee.

Following preoperative marking by the operating surgeon, preoperative measurements were taken from the donor sites, from each of the four zones marked on the DIEP flap. Measurements were made of tissue oxygen saturation (StO_2) and total hemoglobin index (THI) using the Inspectra (Model 650, Hutchinson Technology Inc. [Hutchinson, MN]) StO_2 monitor and its single-use measurement probe.

Using this monitor $StO_2$is the noninvasive, direct measurement of hemoglobin oxygen saturation in the microcirculation of a volume of tissue. StO_2 is a dynamic measurement that changes as oxygen supply and consumption change. THI is a relative index of the amount of hemoglobin in the volume of tissue illuminated by the sensor. Range is 1.0 to 99.0. It functions as a signal strength indicator. Preliminary data suggests that changes in THI may differentiate venous from arterial occlusions in breast reconstructions.[7] A graph may then be displayed showing consecutive StO_2 (gray line) and THI (red line), so that a trend may be discerned (►**Fig. 1**).

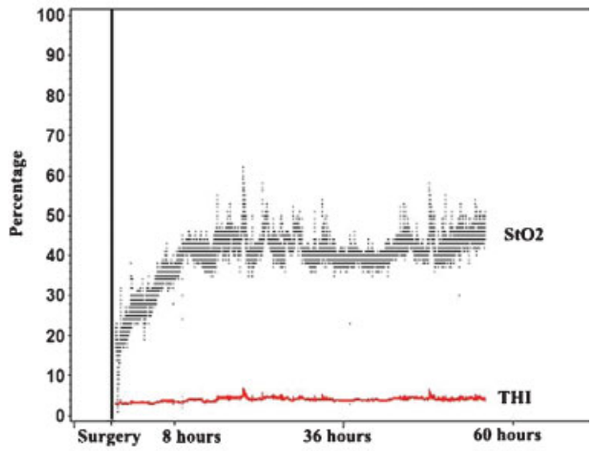

Figure 1 Typical outcome curves in an uncomplicated case. StO_2, tissue oxygen saturation; THI, total hemoglobin index.

Once the flap had been raised, and was dependent on one artery and vein, prior to being inset or the pedicle divided, intraoperative measurements were taken. At the end of the operation, the measurement probe was attached using adhesive to the visible skin paddle to provide 72 hours of continuous postoperative measurements in the monitoring recovery room area. In addition, clinical staff performed routine monitoring of the flap, using clinical markers of color, temperature, capillary refill time and flap texture. Traditional bedside tests such has handheld Doppler and capillary bleeding with a 25 gauge needle were also required. The monitors were set to alarm if the StO_2 or THI decreased to 50% or less of their starting values as in other studies.[7] After 72 hours, the monitoring probe was removed and the patient transferred to the general plastic surgery ward.

Flap complications included vascular compromise; either arterial or venous, thrombosis, occlusion or excessive edema, wound infection, and wound separation. These were defined as "early" if intervention was required within 72 hours of surgery or "late" if after this time. Flap complications requiring surgical intervention, leech therapy, or intravenous antibiotics were recorded. Following discharge patients were given a patient diary to complete and were followed in clinic at approximately 2, 6, and 12 weeks.

Results

Eleven patients aged between 28 and 61, with a median age of 46, were enrolled into the study but one patient requested withdrawal from the study on the day of surgery. The length of postoperative stay ranged from 6 to 13 days. All 10 patients

Table 1 Statistical Comparisons for Primary Objective

	Immediately Postsurgery		*p*-Value
	No Intervention (Group A) $N = 6$	Intervention (Group B) $N = 4$	Group A versus Group B Postsurgery[a]
Average StO_2	47.1 ± 20.4 (52.2) 0.0 – 78.2	26.9 ± 8.1 (28.2) 16.0 – 35.8	0.0169
Average THI	5.9 ± 2.8 (5.2) 2.2 – 10.3	6.7 ± 3.2 (7.3) 2.9 – 10.4	0.6734
Average HbO_2	315 ± 237 (262) 0 – 789	198 ± 127 (206) 50 – 353	0.3736
Average StO_2 per unit volume THI	8.5 ± 4.4 (8.1) 0.0 – 17.7	4.5 ± 1.4 (4.6) 2.8 – 6.6	0.0218

HbO2, hemoglobin and oxygen saturation; StO2, tissue oxygen saturation; THI, total hemoglobin index.
[a]Wilcoxon Rank Sum Test.

underwent reconstruction with a free DIEP flap ($n = 10$). Of these 10 patients, 4 required further intervention with evacuation of hematoma or revision of the anastomosis. One flap was lost despite re-exploration (free flap loss 10%, salvage rate 75%).

The four patients who required intervention went back to the theater within 24 hours of their index reconstructive surgery (13 to 23 hours). Three of these patients had revision of their anastomoses, and the fourth underwent evacuation of a hematoma. No patients had intervention for arterial problems. Patient number 5 had leeches placed on the flap following revision surgery, but ultimately lost her flap. Patients number 13 and 16 had some minor debridement performed between 3 and 5 days postindex surgery, and Patient number 17 required no further interventions.

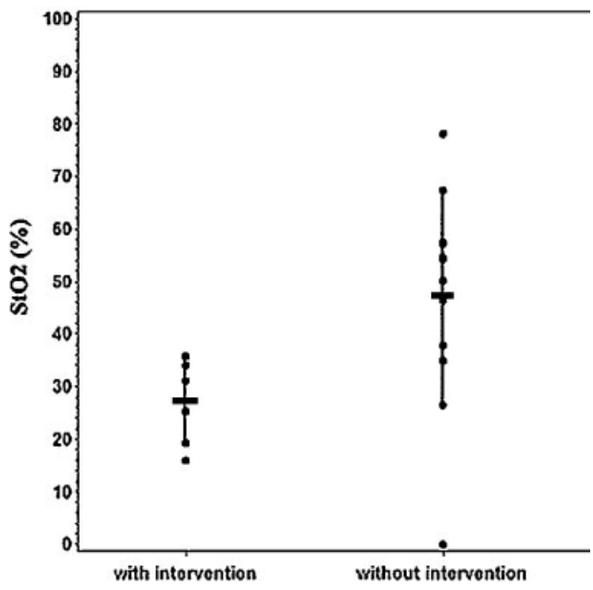

Figure 2 Tissue oxygen saturation (StO_2) measurements for all cases, comparing the intervention and no-intervention groups. Each data point is entered, with the horizontal marks signifying the mean values, and the vertical marks signifying all values within one standard deviation (SD) of the mean.

Comparing the StO_2 and THI in the intervention with the nonintervention groups immediately postoperatively, there is a significant difference in StO_2 ($p = 0.0169$) but not in THI (►**Table 1**, ►**Fig. 2**). In the cases of the venous congestion in the flaps, one flap (Patient number 5, ►**Fig. 3**) had virtually unrecordable readings in recovery before subsequently returning to theater when the flap deteriorated clinically. In patients number 16 (►**Fig. 4**) and 17, the changes in StO_2 and THI preceded the first recorded clinical observation. No false-positives were experienced specifically, the NIRS receiver did not alarm for any case which did not return to the operating theater.

Discussion

As yet no monitoring method, save perhaps the handheld Doppler has satisfied Creech and Miller's 1975 criteria for free flap monitoring.[19] Broadly, these state should be noninvasive, reliable, repeatable and recordable, rapid, cheap, objective, and simple to use by even the most junior member of staff.

A vast range of technologies have been proposed for postoperative monitoring and discussed in the literature, but there is no consensus on the topic. This is reflected in the wide variety of techniques currently in use to monitor flaps including the use of clinical monitoring alone, pulse oximetry,[20,21] perfusion photoplethysmography,[22,23] surface temperature measurement,[24,25] fluorometry,[25,26] microdialysis,[27,28] ultrasound,[29,30] implanted (Cook-Swartz) Doppler probes,[31,32] laser Doppler flowmetry,[33,34] impedance plethysmography,[35,36] confocal microscopy,[37] nuclear medicine,[38,39] subcutaneous pH measurement,[40,41] hydrogen clearance,[42,43] externalization of part of a buried flap,[44] and white light spectrometry.[45] Surveys of plastic surgical units and oral and maxillofacial units in the UK have shown that there is a vast range in the methods, organization, and implementation of postoperative monitoring used following free tissue transfer.[46,47]

Recent publications confirm that the survival of a compromised flap is dependent on ischemic time.[48–50] Of the flaps which require intervention approximately half have a successful outcome. These complications typically occurs

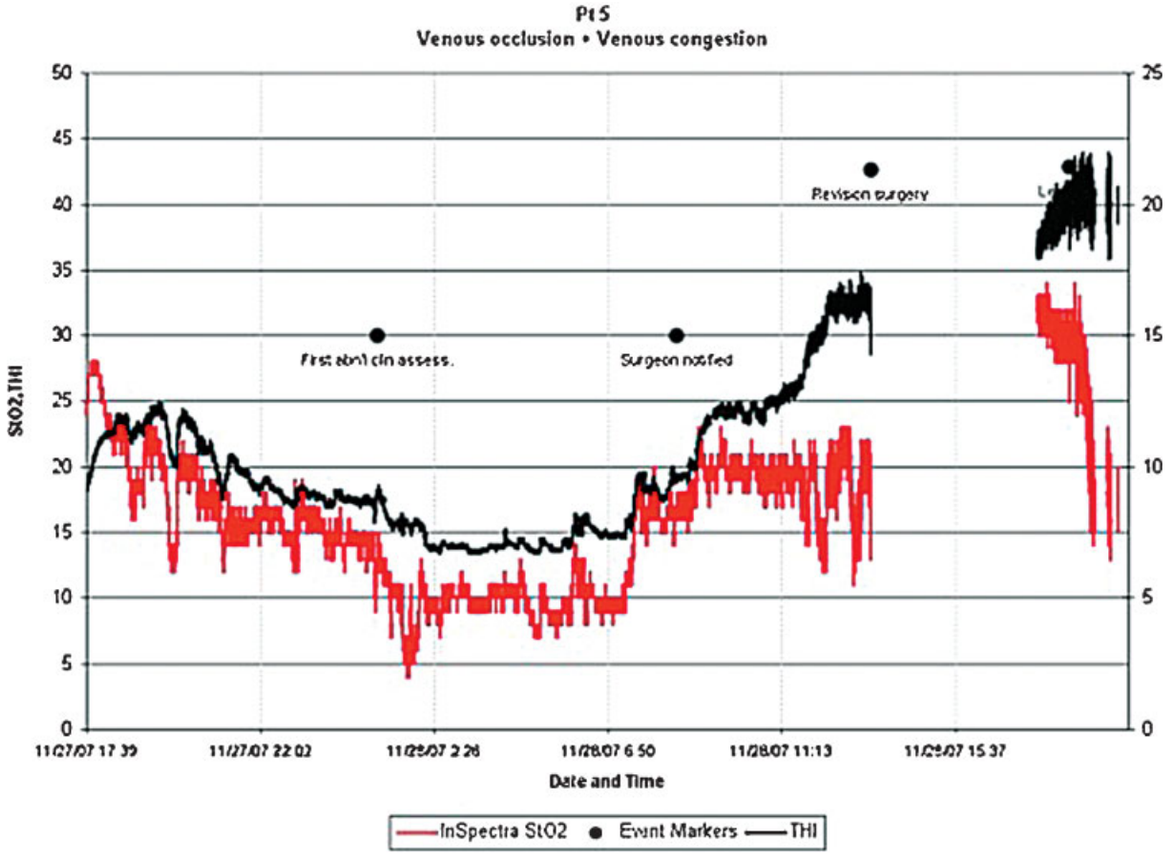

Figure 3 Abnormal NIRS, StO_2, and THI curves for patient number 5 with event points.

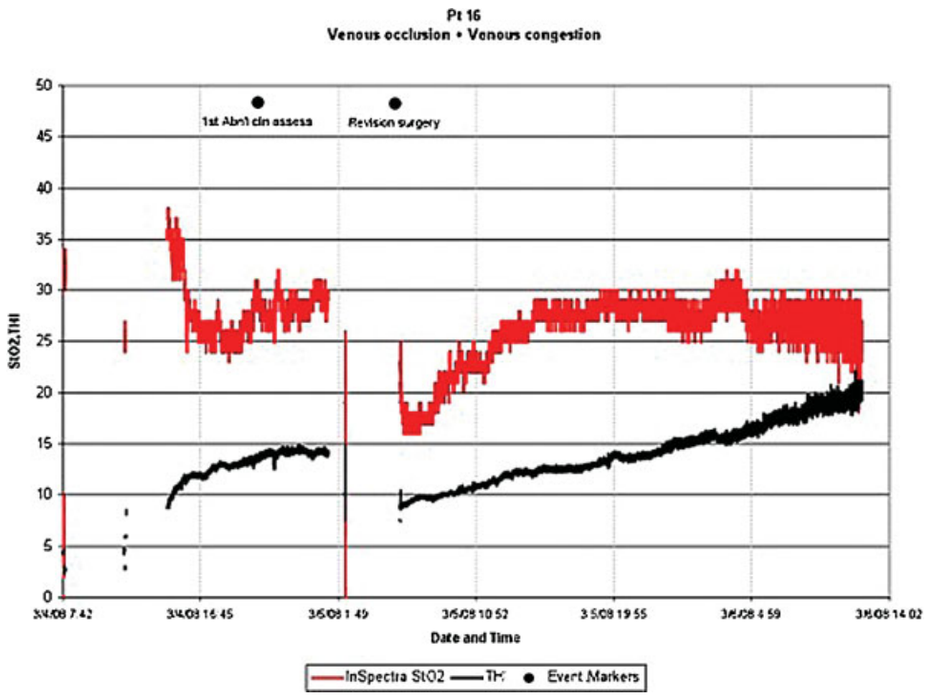

Figure 4 Abnormal NIRS, StO_2, and THI curves for patient number 15 with event points.

within the first 48 hours of the surgery and are irreversible if not corrected within 12 hours of onset.[4]

The use of a monitoring system to enable early identification and intervention in a failing flap would clearly have benefits in reducing patient morbidity. Additionally, a monitoring system which could differentiate between arterial or venous embarrassment would allow the surgical team to take a much more targeted approach to the salvage surgery. Many pre-existing monitoring techniques are able to identify arterial insufficiency but struggle in the identification of venous outflow problems, yet these are more injurious to the flaps, and having a greater effect on flap survival rates. NIRS is a noninvasive technique, which provides continuous perioperative and postoperative monitoring. It can be used with minimal training, and can also differentiate venous insufficiency.

There was a statistically significant difference in postoperative readings for the intervention group compared with the nonintervention group, and the monitor showed significant changes in StO_2 and THI which preceded clinical observations. This shows that the use of NIRS can be used to predict those flaps at an increased likelihood of failure and can pre-empt clinical findings.

In those flaps where NIRS accurately predicted impending flap problems, the patients were not returned to theater until the clinical signs became apparent. Early intervention in a struggling flap has been shown to improve flap survivability, and the use of NIRS to monitor patients, shown in this study, may result in a timely return to theater prior to the onset of clinical changes with a corresponding increase in flap survivability.

False-positive alerts have been raised as a potential concern for all monitoring modalities. In the case of NIRS, occasionally the sensor can become dislodged, particularly if there is a buildup of serosanguineous exudate in the context of muscle flaps. Appropriate application of the probe should be checked in the event of any alarm. This problem did not arise in our series.

Conclusion

NIRS appears to be a reliable and accurate monitoring method which is capable of consistently identifying pedicle compromise before clinical changes significant enough to trigger a return to theater. Other series have suggested that NIRS is also capable of differentiating between venous and arterial compromise in a flap. NIRS has also been investigated in buried flaps. Further research including large double blind randomized control trials would be required to definitively establish the reliability of this technology but in the event of the NIRS trace becoming a trusted trigger for return to theater there is a potential for increased flap salvage rates and better patient outcomes.

Notes

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References

1 Ahn CY, Shaw WW, Berns S, Markowitz BL. Clinical experience with the 3M microvascular coupling anastomotic device in 100 free-tissue transfers. Plast Reconstr Surg 1994;93(7):1481–1484
2 Spector JA, Draper LB, Levine JP, Ahn CY. Routine use of microvascular coupling device for arterial anastomosis in breast reconstruction. Ann Plast Surg 2006;56(4):365–368
3 Jandali S, Wu LC, Vega SJ, Kovach SJ, Serletti JM. 1000 consecutive venous anastomoses using the microvascular anastomotic coupler in breast reconstruction. Plast Reconstr Surg 2010;125(3):792–798
4 Bui DT, Cordeiro PG, Hu QY, Disa JJ, Pusic A, Mehrara BJ. Free flap reexploration: indications, treatment, and outcomes in 1193 free flaps. Plast Reconstr Surg 2007;119(7):2092–2100
5 Disa JJ, Cordeiro PG, Hidalgo DA. Efficacy of conventional monitoring techniques in free tissue transfer: an 11-year experience in 750 consecutive cases. Plast Reconstr Surg 1999;104(1):97–101
6 Pratt GF, Rozen WM, Chubb D, et al. Modern adjuncts and technologies in microsurgery: an historical and evidence-based review. Microsurgery 2010;30(8):657–666
7 Repez A, Oroszy D, Arnez ZM. Continuous postoperative monitoring of cutaneous free flaps using near infrared spectroscopy. J Plast Reconstr Aesthet Surg 2008;61(1):71–77
8 Stranc MF, Sowa MG, Abdulrauf B, Mantsch HH. Assessment of tissue viability using near-infrared spectroscopy. Br J Plast Surg 1998;51(3):210–217
9 Thorniley MS, Sinclair JS, Barnett NJ, Shurey CB, Green CJ. The use of near-infrared spectroscopy for assessing flap viability during reconstructive surgery. Br J Plast Surg 1998;51(3):218–226
10 Hayden RE, Tavill MA, Nioka S, Kitai T, Chance B. Oxygenation and blood volume changes in flaps according to near-infrared spectrophotometry. Arch Otolaryngol Head Neck Surg 1996;122(12):1347–1351
11 Irwin MS, Thorniley MS, Doré CJ, Green CJ. Near infra-red spectroscopy: a non-invasive monitor of perfusion and oxygenation within the microcirculation of limbs and flaps. Br J Plast Surg 1995;48(1):14–22
12 Cai ZG, Zhang J, Zhang JG, et al. Evaluation of near infrared spectroscopy in monitoring postoperative regional tissue oxygen saturation for fibular flaps. J Plast Reconstr Aesthet Surg 2008;61(3):289–296
13 Colwell AS, Wright L, Karanas Y. Near-infrared spectroscopy measures tissue oxygenation in free flaps for breast reconstruction. Plast Reconstr Surg 2008;121(5):344e–345e
14 Keller A. Noninvasive tissue oximetry for flap monitoring: an initial study. J Reconstr Microsurg 2007;23(4):189–197
15 Keller A. A new diagnostic algorithm for early prediction of vascular compromise in 208 microsurgical flaps using tissue oxygen saturation measurements. Ann Plast Surg 2009;62(5):538–543

16 Shan XF, Cai ZG, Yu GY, Li Y, Ding HS. [Application of near infrared spectroscopy in monitoring blood oxygen saturation of fibula flaps]. Zhonghua Kou Qiang Yi Xue Za Zhi 2008;43(7):398–401
17 Scheufler O, Andresen R. Tissue oxygenation and perfusion in inferior pedicle reduction mammaplasty by near-infrared reflection spectroscopy and color-coded duplex sonography. Plast Reconstr Surg 2003;111(3):1131–1146
18 Scheufler O, Exner K, Andresen R. Investigation of TRAM flap oxygenation and perfusion by near-infrared reflection spectroscopy and color-coded duplex sonography. Plast Reconstr Surg 2004;113(1):141–152, discussion 153–155
19 Creech B, Miller S. Evaluation of circulation in skin flaps. In: Grabb WC, Myers MB, eds. Skin Flaps. 1975:21–38
20 Lindsey LA, Watson JD, Quaba AA. Pulse oximetry in postoperative monitoring of free muscle flaps. Br J Plast Surg 1991;44(1):27–29
21 Achauer BM, Black KS, Beran AV, Huxtable RF. Transcutaneous PO2 monitoring of flap circulation following surgery. Birth Defects Orig Artic Ser 1979;15(4):517–522
22 Stack BC Jr, Futran ND, Shohet MJ, Scharf JE. Spectral analysis of photoplethysmograms from radial forearm free flaps. Laryngoscope 1998;108(9):1329–1333
23 Stack BC Jr, Futran ND, Zang B, Scharf JE. Initial experience with personal digital assistant-based reflectance photoplethysmograph for free tissue transfer monitoring. Ann Plast Surg 2003;51 (2):136–140
24 Chiu ES, Altman A, Allen RJ Jr, Allen RJ Sr. Free flap monitoring using skin temperature strip indicators: adjunct to clinical examination. Plast Reconstr Surg 2008;122(5):144e–145e
25 Issing WJ, Naumann C. Evaluation of pedicled skin flap viability by pH, temperature and fluorescein: an experimental study. J Craniomaxillofac Surg 1996;24(5):305–309
26 Denneny JC III, Weisman RA, Silverman DG. Monitoring free flap perfusion by serial fluorometry. Otolaryngol Head Neck Surg 1983;91(4):372–376
27 Udesen A, Løntoft E, Kristensen SR. Monitoring of free TRAM flaps with microdialysis. J Reconstr Microsurg 2000;16(2):101–106
28 Mourouzis C, Anand R, Bowden JR, Brennan PA. Microdialysis: use in the assessment of a buried bone-only fibular free flap. Plast Reconstr Surg 2007;120(5):1363–1366
29 Rosenberg JJ, Fornage BD, Chevray PM. Monitoring buried free flaps: limitations of the implantable Doppler and use of color duplex sonography as a confirmatory test. Plast Reconstr Surg 2006;118(1):109–113, discussion 114–115
30 Prantl L, Pfister K, Kubale R, et al. Value of high resolution ultrasound and contrast enhanced US pulse inversion imaging for the evaluation of the vascular integrity of free-flap grafts. Clin Hemorheol Microcirc 2007;36(3):203–216
31 Whitaker IS, Smit JM, Acosta R. A simple method of implantable Doppler cuff attachment: experience in 150 DIEP breast reconstructions. J Plast Reconstr Aesthet Surg 2008;61(10):1251–1252
32 Swartz WM, Izquierdo R, Miller MJ. Implantable venous Doppler microvascular monitoring: laboratory investigation and clinical results. Plast Reconstr Surg 1994;93(1):152–163
33 Yuen JC, Feng Z. Monitoring free flaps using the laser Doppler flowmeter: five-year experience. Plast Reconstr Surg 2000;105 (1):55–61
34 Svensson H, Pettersson H, Svedman P. Laser Doppler flowmetry and laser photometry for monitoring free flaps. Scand J Plast Reconstr Surg 1985;19(3):245–249
35 Concannon MJ, Stewart DH, Welsh CF, Puckett CL. Impedance plethysmography: a new method for continuous muscle perfusion monitoring. Plast Reconstr Surg 1991;88(2):292–298
36 Harrison DH, Mott G. Impedance monitoring for subcutaneous free flap transfers. Br J Plast Surg 1989;42(3):318–323
37 Altintas MA, Altintas AA, Guggenheim M, Knobloch K, Niederbichler AD, Vogt PM. Monitoring of microcirculation in free transferred musculocutaneous latissimus dorsi flaps by confocal laser scanning microscopy—a promising non-invasive methodical approach. J Plast Reconstr Aesthet Surg 2010;63(1):111–117
38 Top H, Sarikaya A, Aygit AC, Benlier E, Kiyak M. Review of monitoring free muscle flap transfers in reconstructive surgery: role of 99mTc sestamibi scintigraphy. Nucl Med Commun 2006;27(1):91–98
39 Aygit AC, Sarikaya A. Technetium 99m sestamibi scintigraphy for noninvasive assessment of muscle flap viability. Ann Plast Surg 1999;43(3):338–340
40 Raskin DJ, Erk Y, Spira M, Melissinos EG. Tissue pH monitoring in microsurgery: a preliminary evaluation of continuous tissue pH monitoring as an indicator of perfusion disturbances in microvascular free flaps. Ann Plast Surg 1983;11(4):331–339
41 Dickson MG, Sharpe DT. Continuous subcutaneous tissue pH measurement as a monitor of blood flow in skin flaps: an experimental study. Br J Plast Surg 1985;38(1):39–42
42 Machens HG, Mailaender P, Reimer R, Pallua N, Lei Y, Berger A. Postoperative blood flow monitoring after free-tissue transfer by means of the hydrogen clearance technique. Plast Reconstr Surg 1997;99(2):493–505
43 Thomson JG, Kerrigan CL. Hydrogen clearance: assessment of technique for measurement of skin-flap blood flow in pigs. Plast Reconstr Surg 1991;88(4):657–663
44 Hallock GG, Koch TJ. External monitoring of vascularized jejunum transfers using laser Doppler flowmetry. Ann Plast Surg 1990;24 (3):213–215
45 Hölzle F, Loeffelbein DJ, Nolte D, Wolff K-D. Free flap monitoring using simultaneous non-invasive laser Doppler flowmetry and tissue spectrophotometry. J Craniomaxillofac Surg 2006;34(1):25–33
46 Whitaker IS, Oliver DW, Ganchi PA. Postoperative monitoring of microvascular tissue transfers: current practice in the United kingdom and Ireland. Plast Reconstr Surg 2003;111(6):2118–2119
47 Whitaker IS, Gulati V, Ross GL, Menon A, Ong TK. Variations in the postoperative management of free tissue transfers to the head and neck in the United Kingdom. Br J Oral Maxillofac Surg 2007;45 (1):16–18
48 Smit JM, Acosta R, Zeebregts CJ, Liss AG, Anniko M, Hartman EHM. Early reintervention of compromised free flaps improves success rate. Microsurgery 2007;27(7):612–616
49 Smit JM, Zeebregts CJ, Acosta R. Timing of presentation of the first signs of vascular compromise dictates the salvage outcome of free flap transfers. Plast Reconstr Surg 2008;122(3):991–992
50 Hofer SO, Damen TH, Mureau MA, Rakhorst HA, Roche NA. A critical review of perioperative complications in 175 free deep inferior epigastric perforator flap breast reconstructions. Ann Plast Surg 2007;59(2):137–142