A Novel Pilot Study Using Spatial Frequency Domain Imaging to Assess Oxygenation of Perforator Flaps During Reconstructive Breast Surgery

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Introduction: Although various methods exist for monitoring flaps during reconstructive surgery, surgeons primarily rely on assessment of clinical judgment. Early detection of vascular complications improves rate of flap salvage. Spatial frequency domain imaging (SFDI) is a promising new technology that provides oxygenation images over a large field of view. The goal of this clinical pilot study is to use SFDI in perforator flap breast reconstruction.

Methods: Three women undergoing unilateral breast reconstruction after mastectomy were enrolled for our study. The SFDI system was deployed in the operating room, and images acquired over the course of the operation. Time points included images of each hemiabdominal skin flap before elevation, the selected flap after perforator dissection, and after microsurgical transfer.

Results: Spatial frequency domain imaging was able to measure tissue oxyhemoglobin concentration (ctO_2Hb), tissue deoxyhemoglobin concentration, and tissue oxygen saturation (stO_2). Images were created for each metric to monitor flap status and the results quantified throughout the various time points of the procedure. For 2 of 3 patients, the chosen flap had a higher ctO_2Hb and stO_2. For 1 patient, the chosen flap had lower ctO_2Hb and stO_2. There were no perfusion deficits observed based on SFDI and clinical follow-up.

Conclusions: The results of our initial human pilot study suggest that SFDI has the potential to provide intraoperative oxygenation images in real-time during surgery. With the use of this technology, surgeons can obtain tissue oxygenation and hemoglobin concentration maps to assist in intraoperative planning; this can potentially prevent complications and improve clinical outcome.

Key Words: perforator flap, breast reconstruction, microsurgery, perfusion mapping, near-infrared imaging, spatial frequency domain imaging

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Abdominal-based, autologous flaps are well-established options for breast reconstruction after mastectomy.[1–5] Commonly used options include the pedicled transverse rectus abdominis myocutaneous, free transverse rectus abdominis myocutaneous, and deep inferior epigastric perforator (DIEP) flaps.[6–11] The dissection of these flaps requires adequate perfusion to ensure success; in addition, the advent of microsurgical reconstruction is further associated with potential risks and complications of microsurgery.

Technological advances are necessary to improve flap perfusion and minimize donor-site morbidity. In particular, vessel thrombosis, partial and total flap loss, and fat necrosis are associated with poor outcomes.[6,12] As early recognition has been shown to lead to improved flap salvage and success,[12] it is vital that vascular compromise is detected effectively to expedite surgical and therapeutic intervention for free flap salvage. Currently, the standard of care to monitor perfusion is the clinical observation of skin warmth, color, capillary refill, and dermal bleeding. This subjective approach leads to a wide degree of variability in reported rates of flap loss.[13]

Methods to identify early flap failure intraoperatively include thermal, flow, perfusion, and oxygen monitoring.[14] Each method has limitations precluding widespread use. We provide here a review of each method, purposely excluding computed tomographic angiography and magnetic resonance angiography because they are not widely used intraoperatively.

- Thermal monitoring using noncontact infrared imaging has been previously evaluated, particularly in the form of dynamic infrared thermography. However, this technique requires cooling the surface of the flap (cold challenge), which can prove challenging to implement routinely into clinical practice.[15,16]
- Flow monitoring by Doppler effect (performed either using ultrasound waves or optically)[17–20] and by laser speckle imaging[21,22] has been used to assess blood flow in microsurgically anastomosed arteries and veins. However, such methods are typically noisy, can require vessels to be exposed, can require contact, suffer from surrounding vessel interference, and provide limited information about presence or absence of flow.
- Perfusion assessment, or angiography, can be performed intraoperatively using optical fluorescence imaging.[23,24] This method attempts to monitor flaps by characterizing perfusion at the skin or superficial capillary level.[25,26] Although this method can reliably visualize perforator arteries in flaps, it remains by nature superficial and requires the injection of an exogenous contrast agent.
- Tissue oximetry probes have been introduced for flap monitoring, as they are easy to use and are relatively inexpensive.[27–30] The main advantage of this approach is direct measurement of tissue oxygenation, a surrogate for perfusion and indicator of tissue status. Such methods are intuitive to most clinicians as the technology is similar to pulse oximetry, which was introduced in the 1970s.[31–33] These methods rely on light absorption from tissue endogenous