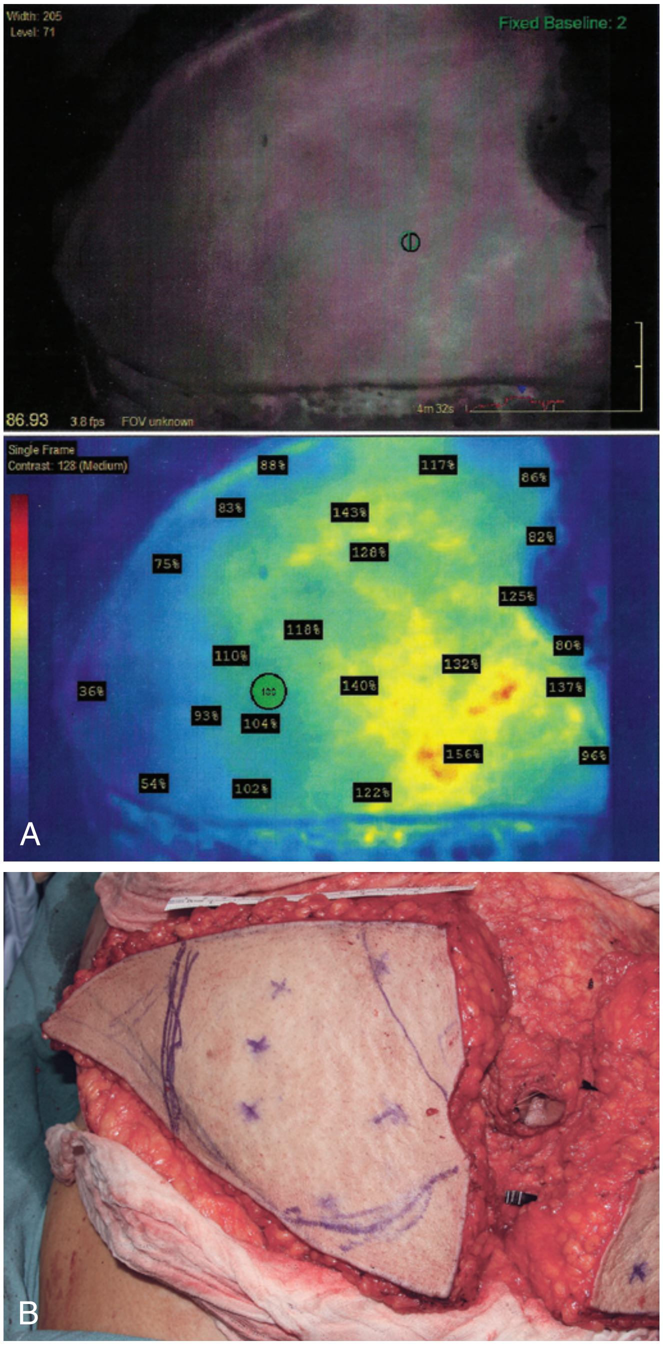

Figure 4.8 (A, upper) Image captured using ICG angiography of a right abdomen muscle-sparing transverse rectus abdominis free flap following dissection. (A, lower) The user assigns a value of "100%" to an area that appears to have optimal perfusion, and the software included with the system analyzes the intensity of signal of the rest of the image, assigning relative perfusion values. (B) Photographic appearance of the same flap. Perforator locations were marked with an "x" using a skin marker.

flap looked non-viable by ICG angiography but did survive) rate. Although they concluded that ICG angiography was not superior to clinical judgment in assessing flap perfusion for most patients, they hypothesized that a good indication for ICG angiography was in assessing flap vascularity in dark skinned individuals, since clinical assessment is more difficult in these patients. A caveat of utilizing ICG to assess flap viability includes the fact that superficial perfusion at the time of dye injection can be affected by many variables including blood pressure, volume status, patient temperature, use of vasopressors, and other factors that influence resistance in the microcirculation. Also, it has not been definitively determined at what timepoint following flap dissection a stable state of perfusion has been achieved in which ICG angiography results will be most accurate. They also pointed out that computer algorithms for quantitative assessment of flap perfusion continue to be refined.

Venous congestion is also difficult to define using ICG angiography. Delayed clearing of fluorescent dye is expected when venous compromise to a flap exists, but there are no set timepoints as to what should be considered delayed as of yet. Again, venous outflow is a dynamic process and may change with time such that the information obtained at the time of ICG angiography may not be an accurate reflection of the ultimate fate of the flap. Expert opinion has suggested re-imaging 5–20 min after administration of ICG to look for dye clearance if venous congestion is a concern following flap dissection, transfer, or inset.[14]

Further experience with ICG angiography will no doubt better define its accuracy and utility. At the present time, the author utilizes ICG angiography when clinical findings are equivocal as a confirmatory study. In addition to utilizing it to determine whether the entire skin paddle is perfused in perforator flap reconstruction, it also seems useful following microvascular anastomosis and flap inset in some cases, such as in head and neck reconstruction following flap folding and placement into spaces where the flap and its vasculature may be compressed or under modest tension. Additionally, it may be useful in cases involving anastomotic revision following a thrombotic event, both to visualize the patency of the pedicle as well as to confirm the viability of the flap, which may be difficult following ischemia and reperfusion or resolution of venous congestion, when the flap may be hyperemic or ecchymotic, respectively.

FREE FLAP DESIGN

A diagnostic test that identifies the correct position of a cutaneous perforating blood vessel prior to skin incision is desirable because it permits the surgeon to design the skin paddle of a flap such that the blood supply is reliable by centering the perforator in the middle of the skin paddle. Such a test can eliminate the occasionally unnecessary skin incision when no viable perforator exists, allowing a different donor site to be chosen, and is requisite in the design of free-style perforator flaps, by definition. An accurate method of pre-incision perforator localization may also help to minimize the size of the incision needed by eliminating the need for a large exploratory incision to look for the perforator.

The accuracy of ICG in assessing perforator is higher in thin flaps, since the depth of visualization is only about 1 cm. In thicker flaps, the ICG "blush" becomes very diffuse as it travels farther away from the perforator, where it is carried by smaller and smaller branching blood vessels to the skin. Thus, ICG angiography has been utilized by some to help design thin cutaneous perforator flaps, such as the anterolateral thigh flap in non-obese patients. As the amount of subcutaneous fat increases, the accuracy of ICG angiography in locating the position of deep perforators decreases.

Onoda et al.[15] compared ICG angiography with the Photodynamic Eye to CTA. They found ICG angiography had an 84% positive predictive value and CTA 100% positive predictive value in a series of 50 patients undergoing a variety of free and pedicled flaps with a skin paddle component. Perforators were difficult to detect by ICG angiography when the flap thickness was >20 mm, with perforators being correctly identified in only 12 of 50 flaps (24% sensitivity). In contrast, CTA was not very useful in detecting perforators when the flap thickness was <8 mm, showing only 30% sensitivity in these patients. Perforators with a long course through subcutaneous fat are most easily visualized by CTA. They recommended utilizing ICG angiography in combination with handheld Doppler ultrasound when the flap thickness was ≤8 mm, and CTA in combination with handheld Doppler ultrasound to localize perforators when the flap thickness was ≥20 mm, in order to minimize time and expense while still maintaining reasonable accuracy. For flaps with intermediate thickness, they recommended using a combination of all three modalities.

MASTECTOMY SKIN FLAP NECROSIS

In breast reconstruction, whether with autologous tissues or implants, ICG angiography is employed to predict mastectomy skin flap necrosis. An estimated 20% of implant-based breast reconstructions experience necrosis of the native breast skin.[16] An even higher rate of necrosis is reported in patients undergoing skin-sparing and nipple-sparing mastectomies. Necrosis can lead to infection, delayed tissue expander expansion, implant exposure, and implant loss. Several investigators have examined ICG angiography as a tool to help decrease necrosis rates by indicating to the surgeon what parts, if any, of the mastectomy skin flaps will go on to full-thickness loss and should be excised prior to breast reconstruction.

Using the SPY 2001 Imaging System (Novadaq, Bonita Springs, FL), an earlier version ICG imaging system, Phillips et al.[17] prospectively compared ICG angiography with clinical assessment and fluorescein dye angiography as methods for assessing mastectomy skin viability in 51 patients undergoing implant-based reconstruction. Fluorescein was administered in a dose of 10 mg/kg intravenously, then the breast skin was inspected after waiting 15 min. Under a Wood's lamp, they observed yellow fluorescence indicating adequate perfusion and blue fluorescence indicating inadequate perfusion. Yellow-blue mottling was also observed and indicated intermediate or indeterminate perfusion, and these areas were counted as predictive of necrosis. ICG and fluorescein angiography both predicted the occurrence of partial or full thickness skin necrosis in 19 of 21 cases where clinical judgment had failed (sensitivity, 90%). ICG correctly predicted no necrosis in 15 of 30 cases (specificity, 50%) and fluorescein correctly predicted no necrosis in 9 of 30 cases (specificity, 30%), thus leading the authors to conclude that ICG angiography is a better predictor of mastectomy skin flap necrosis than fluorescein dye angiography and clinical judgment.

Munabi et al.[18] found that the Spy Elite System predicted mastectomy flap necrosis in 62 breasts with 88% sensitivity and 83% specificity when the value was ≤7 absolute perfusion units calculated by the included SPY-Q quantitative software, based on a fixed grayscale. False-positive cases were more likely in patients with a smoking history and/or in which epinephrine-containing tumescent solution was used during mastectomy. By excluding these patients, the specificity increased to 97%. They concluded that ICG angiography was a useful as an adjunctive way of assessing skin flap viability but did not replace clinical judgment. Duggal et al.[19] found that patients who underwent ICG angiography had a lower skin flap necrosis rate compared with historical controls, prior to the introduction of ICG angiography in their practice (13% vs 23.4%, p=0.01).

LYMPHATIC SURGERY

Lymphedema is a chronic, progressive, and, ultimately, debilitating condition. Until recently, treatment was mostly centered on decongestive physiotherapy, including manual drainage techniques and compression garment usage. Microsurgical techniques, such as lymphovenous bypass, in which subcutaneous lymphatics are anastomosed to adjacent small veins, have ushered in new hope for patients with lymphedema. Such techniques owe their success not only in increased microsurgical skill, finer instrumentation, and high quality optical magnification, but also to ICG-based imaging that allows visualization of subcutaneous lymphatics, both for diagnostic purposes and surgical intervention.

Lymphoscintigraphy was previously considered the main imaging modality for the evaluation of lymphatic function. Lymphoscintigraphy can detect abnormalities of lymphatic flow and provides quantitative assessment of lymphatic function. However, the technique is expensive, time-consuming, requires the use of radioactive pharmaceuticals, and is not of high enough resolution to localize individual lymphatic channels for microsurgical treatment. In contrast, ICG can be injected subcutaneously and used to follow lymphatics in real-time during surgery. The appearance of lymphatics as visualized by ICG lymphography appear to correlate with the stage of lymphedema.[20–23] Linear visualized lymphatics are associated with normal lymphatic flow. Dermal backflow patterns represent pathologic blockage of the lymphatic channel.

Intraoperatively, approximately 0.2 mL of ICG is injected subcutaneously into the first and fourth web spaces of the hand or foot of the affected limb as well as into the lateral border of the Achilles tendon or at the wrist flexion crease.[22] After injection, circumferential fluorescent images of lymphatic drainage channels are visualized using the near-infrared camera system. The near-infrared spectral range includes the fluorescence maximum of ICG (about 800 nm) and human tissue is relatively transparent to near-infrared light. The lymphatic channels are simultaneously traced with a skin-marking pen. ICG lymphography can be used diagnostically or in planning treatment with microsurgical lymphovenous bypass. Linear patterns represent targets for lymphovenous bypass (Fig. 4.9). Backflow patterns do not lend themselves to localization of a lymphatic vessel that can be used for microsurgical anastomosis. Skin incisions are then made and the lymphatic channels are dissected in the subcutaneous tissues using high-power magnification. Visualization of the lymphatics within the subcutaneous fat can