CLASSIFICATION SCHEMA FOR ANATOMIC VARIATIONS OF THE INFERIOR EPIGASTRIC VASCULATURE EVALUATED BY ABDOMINAL CT ANGIOGRAMS FOR BREAST RECONSTRUCTION

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Background. Many studies demonstrate direct patient benefits from use of preoperative computed tomography angiograms (CTA) for abdominal tissue-based breast reconstruction. We present a novel classification schema to translate imaging results into further clinical relevance. *Methods.* Each hemiabdomen CTA was classified into a schema that addressed findings of expected anatomy, anatomy that necessitates a change in operative technique and anatomy that suggests less morbid procedures may be considered. *Results.* Eighty-six patients (172 hemiabdomens) were available for study. Of the reconstructions performed in this time period, 40 (47%) were bilateral and 46 (53%) unilateral. Based on perforator size and location, relative perimuscular anatomy, and continuity of vessels, five categories were defined: type I "Traditional" anatomy ($n = 150$, 87%), type II "Highly Favorable" anatomy ($n = 11$, 6.4%), type III "Altered-Superiorly Translocated" anatomy ($n = 9$, 5.2%), type IV "Superficial Dominant" anatomy ($n = 26$, 15%), and type V "Hostile" anatomy ($n = 4$, 2.3%). The additive total is greater than 100%, because vessels may fall into more than one category. *Discussion.* In providing the microsurgeon with a preoperative vascular map that has the potential to influence the preoperative, operative, and postoperative course, abdominal CTAs should be considered a worthy adjunct to the diagnostic armamentarium of the reconstructive surgeon. These classifications and their clinical impacts become even more important in centers performing increasing numbers of bilateral reconstructions. We believe that our simple schema can facilitate effective use of this powerful tool, aiding in overall care of the breast reconstruction patient. © 2010 Wiley-Liss, Inc. Microsurgery 00:000–000, 2010.

For women desiring free autologous tissue transfer breast reconstruction, abdominal-based perforator flaps are frequently considered as a primary option. The ability to perform this procedure depends on uninterrupted delivery of arterial inflow and venous outflow from either the deep inferior or superficial inferior epigastric vessels. This situation does not always exist, and, when it does, the anatomy can be variable.[1,2] Surgical successes may depend on correct perforator choice.

Previous authors have demonstrated that use of preoperative computed tomographic angiograms (CTA) translates to significant operative time and money savings and a reduction of postoperative complications.[2–5] The use of this technique therefore has the potential ability to significantly improve outcomes. The mechanisms for these noted benefits are presumed to be the ability to target perforators of choice, which leads to decreasing the need for intraoperative inspection and temporary preservation of candidate perforators, decreasing frequency of time consuming and morbid intramuscular dissection, increasing the ability to identify potential flap failures prior to creating donor site incisions, and increasing the accuracy of choice of perforators that are capable of maximum perfusion.[2,6]

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This study was designed to classify the clinically relevant anatomic scenarios identifiable from preoperative vascular maps obtained through CTA of the abdomen in women, undergoing perforator-based breast reconstruction. We further designed this project to determine the relative frequencies of findings that could potentially prevent intraoperative procedure failures as well as the relative frequencies of findings that could potentially convert procedures to those with minimal abdominal wall donor site disruption.

METHODS

We performed a single institution retrospective analysis of all patients undergoing free autologous tissue transfer breast reconstruction from abdominal donor sites over a 12-month period (mid-April 2008 to mid-April 2009). Preoperatively, most patients received either a 64-slice multidetector computed tomography or Dual Source Scanner CTA as previously described.[7] The Johns Hopkins Medicine Institutional Review Board approved this study.

All scans were done on either a 64 MDCT or Dual Source Scanner using 120 kVp, 150 maAs, 0.75-mm slice thickness, and 0.5-mm interscan spacing. The scan protocol consisted of injection of 100 cc of Omnipaque-350 (GE Healthcare, Princeton, NJ) at 4 cc/second and scanning beginning a ~30 seconds after initiation of injection. The CT data were sent to free standing workstation (Leonardo, Siemens Medical Solutions) running InSpace software. 3D mapping was done interactively using volume rendering and maximum intensity projection techniques. Real-time rendering was used to optimally visualize the

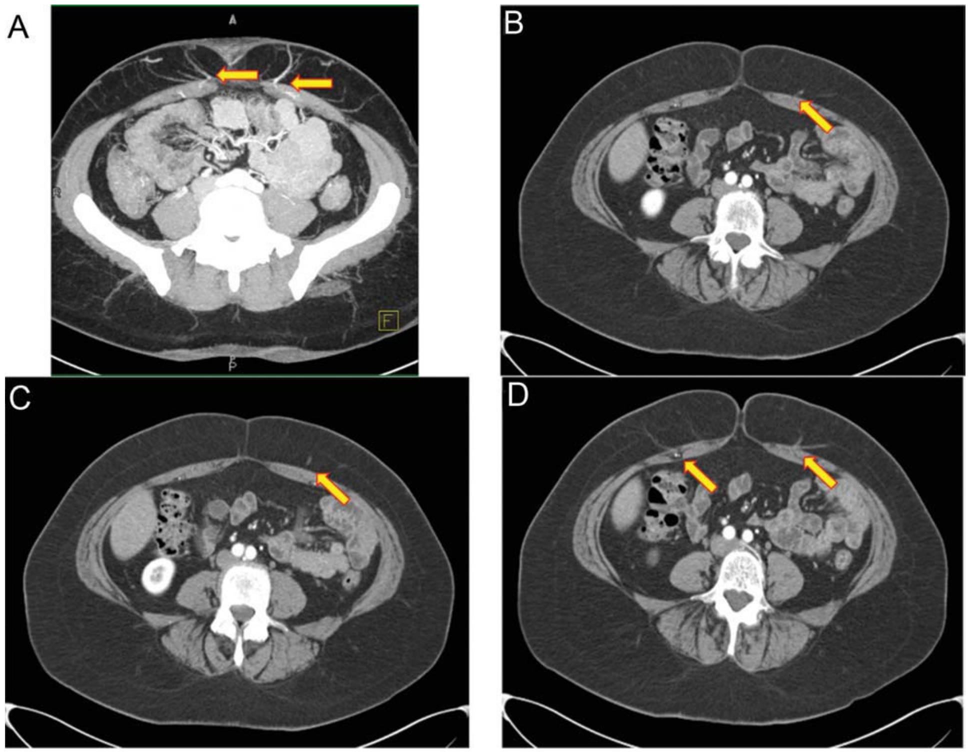

Figure 1. Type I—Traditional anatomy. This series of CTAs identifies typical periumbilical perforators available for use with the deep inferior epigastric system. ***A:*** *3D axial view.* ***B–D:*** *2D axial views. The arrows point out some typical perforators. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

abdominal perforators, and grid mapping was superimposed to map the vessels to the umbilicus. A range of rendering parameters was used to optimize display of muscle, soft tissue, and the vasculature.

The CT angiograms were reviewed by two independent surgeons evaluating each hemiabdomen for classification into a schema that addressed findings of expected anatomy, anatomy that necessitates a change in operative technique to increase the probability of flap success, and anatomy that suggests less morbid procedures may be considered. Both the standard 2D axial images and also the 3D images were evaluated. The frequency and significance of the classifications were then evaluated for potential clinical impact. Because of the nature of a retrospective chart review, much of the analysis is descriptive. Whenever comparative data are obtained, we applied the following analysis: all testing were two-sided at the 0.05 α level. A chi-square statistic was used when the characteristic or outcome was categorical, and a Student's t test was used when the variable of interest was continuous. Ninety-five percent confidence intervals (95% CI) were calculated using the modified Wald method.

RESULTS

Eighty-six patients (172 hemiabdomens) were available for study. Of the reconstructions performed in this time period, 40 (47%) were bilateral and 46 (53%) unilateral. For unilateral reconstructions, the donor flap was more often harvested from the left side (28% vs. 15%), but this was not statistically different. Sixty-five percent of patients had previously had at least one abdominal surgical procedure.

Based on perforator size and location, relative perimuscular anatomy, and continuity of vessels, five types of clinically relevant anatomies were found.

Type I vasculature was defined as ''Traditional.'' This included patients with deep inferior epigastric vessels in continuity with source vessels and perforators. Additionally, the vessels demonstrated variable intramuscular courses and branching but ultimately divided into one or a few perforators of adequate size in peri and infraumbilical locations that displayed dominance over the remainder of the perforators. This occurred in 150 hemiabdomens (87%; 95% CI: 81%–91%) (Fig. 1).

Type II vasculature was defined as ''Highly Favorable.'' This group included patients with a dominant perforator in continuity with source vessels that followed a course along the medial edge of the rectus to the retromuscular surface, requiring minimal to no muscular dissection. This scenario has previously been identified as increasing the ease of the operating and decreasing the manipulation of the abdominal wall donor site with potential for decreased abdominal wall morbidity.[8] The ''medial wrap-around'' perforator or ''circummuscular variant"[8] occurred in 11 hemiabdomens (6.4%; 95% CI: 3.5%–11%)—interestingly, nine times on the right and two times on the left (Fig. 2).

Type III vasculature was defined as ''Altered-Superiorly Translocated.'' This group of vessels demonstrated superior translocation of the dominant perforator significantly above what would normally be included in the cranial incision of donor site dissection, which we make with the goal of keeping the final scar at the bikini line for optimal cosmesis (we defined this point as greater than or equal to one centimeter above the umbilicus). Nine hemiabdomens (5.2%; 95% CI: 2.6%–9.8%) displayed this anatomy (Fig. 3).

Type IV vasculature was defined as ''Superficial Dominant.'' These patients demonstrated a superficial inferior epigastric system seemingly adequate to support transferred abdominal tissue. Other authors have defined this to be a diameter of 1.5 mm.[3,9] When the superficial inferior epigastric vein (SIEV) is large, it is typically identified, dissected, and evaluated to see if it will be required for ''extra venous drainage'' even if the flap is primarily based on the deep inferior epigastric artery perforator (DIEP) vessels. Twenty-six of the hemiabdomens (15%; 95% CI: 10–21%) in our series demonstrated this anatomical variation (Fig. 4).

Type V vasculature was defined as ''Hostile.'' These hemiabdomens demonstrated anatomy thought to be inadequate for perforator flap-free tissue transfer. This group included vessels that were not in continuity due to previous injury or ligation at previous abdominal procedures, $n = 4$ (2.3%; 95% CI: 0.7%–6.0%). These four hemiabdomens were in two patients (both of the patients had bilateral ligation of the DIE vessels during prior gynecologic surgeries); one patient went on to have successful bilateral superior gluteal artery perforator reconstructions. In the other patient, a DIEP flap with a short pedicle and saphenous vein graft was attempted, but had ''no reflow'' phenomenon. Although not specifically noted in our series, this group is also to include those patients with multiple small perforators without evidence of dominance, reported by other authors.[2] (Fig. 5).

The additive total is greater than 100%, because vessels may fall into more than one category (e.g., a high perforator that is also a ''medial wraparound''). Clinically, the surgical plan was altered preoperatively in 11 patients (13%) based on CT scans demonstrating types III and IV together; not all patients with a hemiabdomen of types III or IV required an altered surgical plan if they were having a unilateral reconstruction and the contralateral hemiabdomen had a better perforator. These five anatomic types with their various clinical considerations are summarized in Figure 6.

Although not formally part of our study aim, we did collect data on flaps that were intraoperatively aborted and/or postoperatively re-explored due to factors such as hematoma or thrombosis. Overall, four flaps in three patients were intraoperatively aborted due to a technical error on one side of a planned bilateral breast reconstruction. Of these three patients, two had unilateral chest wall radiation fibrosis and therefore underwent unilateral DIEP flap reconstruction on the radiated side with implant-based reconstruction on the contralateral side, whereas the third patient did not have any radiation and proceeded to have bilateral implant-based reconstruction (this accounts for the fourth aborted flap—the contralateral ''good'' flap was also discarded, so that the patient could have symmetrical implants). There were nine takebacks; seven were salvaged and two failed. One flap had late compromise (postoperative day 10) resulting in significant (greater than 50%) fat necrosis.

DISCUSSION

High-resolution CT angiograms are a clinically useful modality for neurosurgeons[10] where the accurate diagnosis of cerebral aneurysms and intricate surgical planning is critical. Cardiologists and cardiac surgeons use gated 3D CT coronary angiograms to assess coronary artery disease,[11] and living-related kidney transplants can be optimized by the transplant surgeons.[12] At our institution, we have extended the use of high-resolution CT angiography to aid preoperative planning of DIEP flap harvest. Our previously published series shows that all preoperatively detected perforators of 1 mm or greater were found intraoperatively, demonstrating a high level of clinical accuracy.[7] We have also implemented preoperative CTA for our superior gluteal artery perforator (SGAP) flap patients.[13]

In addition to CTA, multiple methods exist for making clinical decisions about flap vasculature including clinical examination,[14–16] handheld unidirectional Doppler assessment,[15,17–20] two-dimensional color flow Doppler imaging,[21–25] scanning laser Doppler,[26] thermography,[27,28] laser-assisted indocyanine green fluorescent dye angiography,[29] and magnetic resonance angiography.[30–32] Preoperative knowledge of the anatomical characteristics of these vessels is invaluable information in determining operative feasibility, increasing operative efficiency, and minimizing risks of complications.[4,5] The use of preoperative CTA for imaging the abdominal donor site before breast reconstruction is well described in the literature,[4,7,33,34] and we have been using it as our preferred preoperative imaging modality since October 2005 at the Johns Hopkins Breast Center.[7] The drawbacks of CTA include radiation exposure, exposure to contrast (with its inherent anaphylaxis and nephrotoxic risks), the possibility of extravasation injury, and increased cost.[34,35] However, the

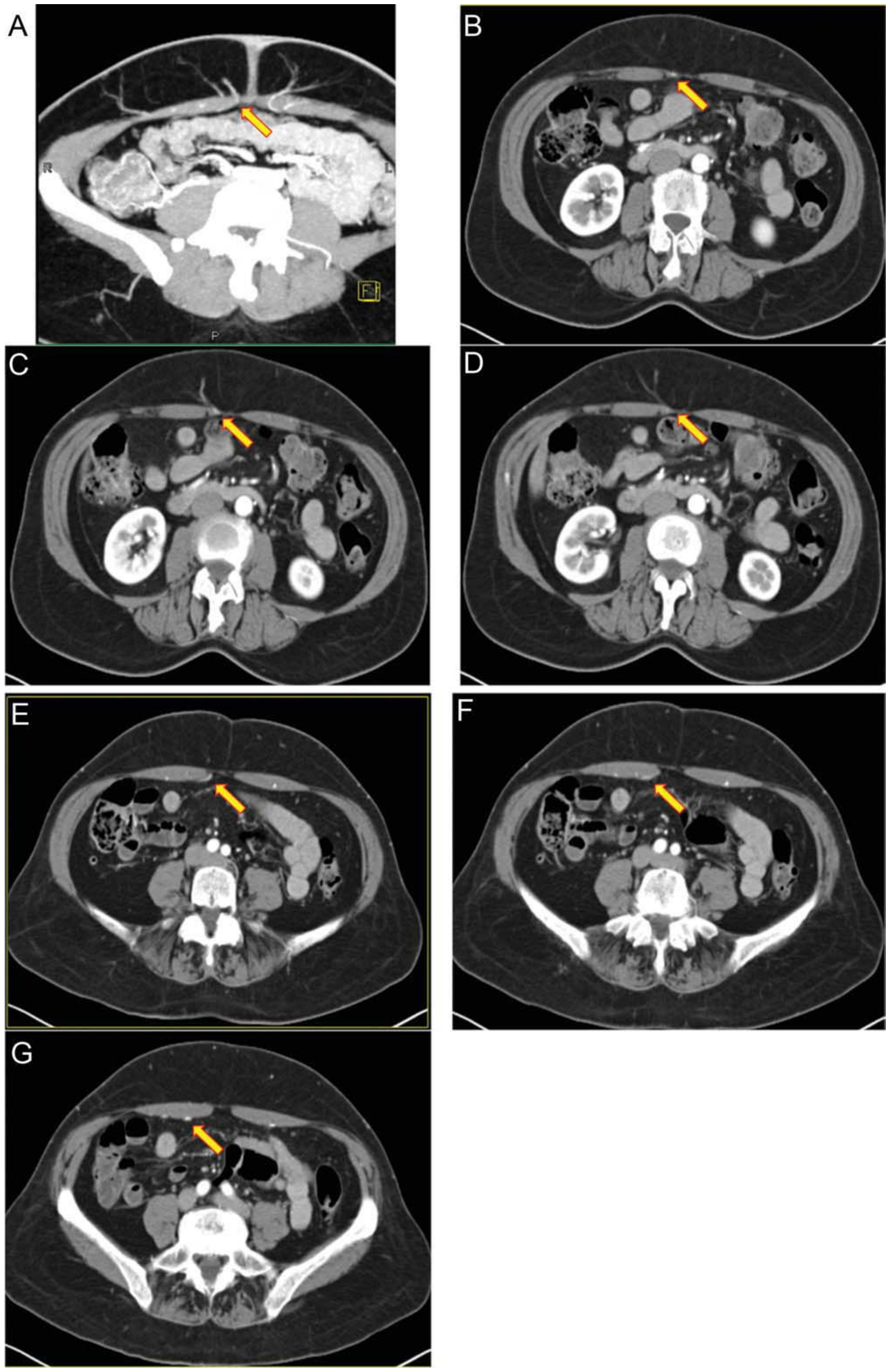

Figure 2. Type II—Highly favorable anatomy. This series of CTAs demonstrates a perimbilical perforator that wraps around the medial border of the right rectus abdominal muscle and travels below it towards its origin. This perforator has no intramuscular path and thus has an anatomy highly favorable to surgical dissection with minimal morbidity. We call this a "medial wraparound" vascular pedicle. ***A:*** *3D axial view.* ***B–G:*** *2D axial views. The arrow points to the medial wraparound perforator; all other perforators follow a traditional intramuscular course. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

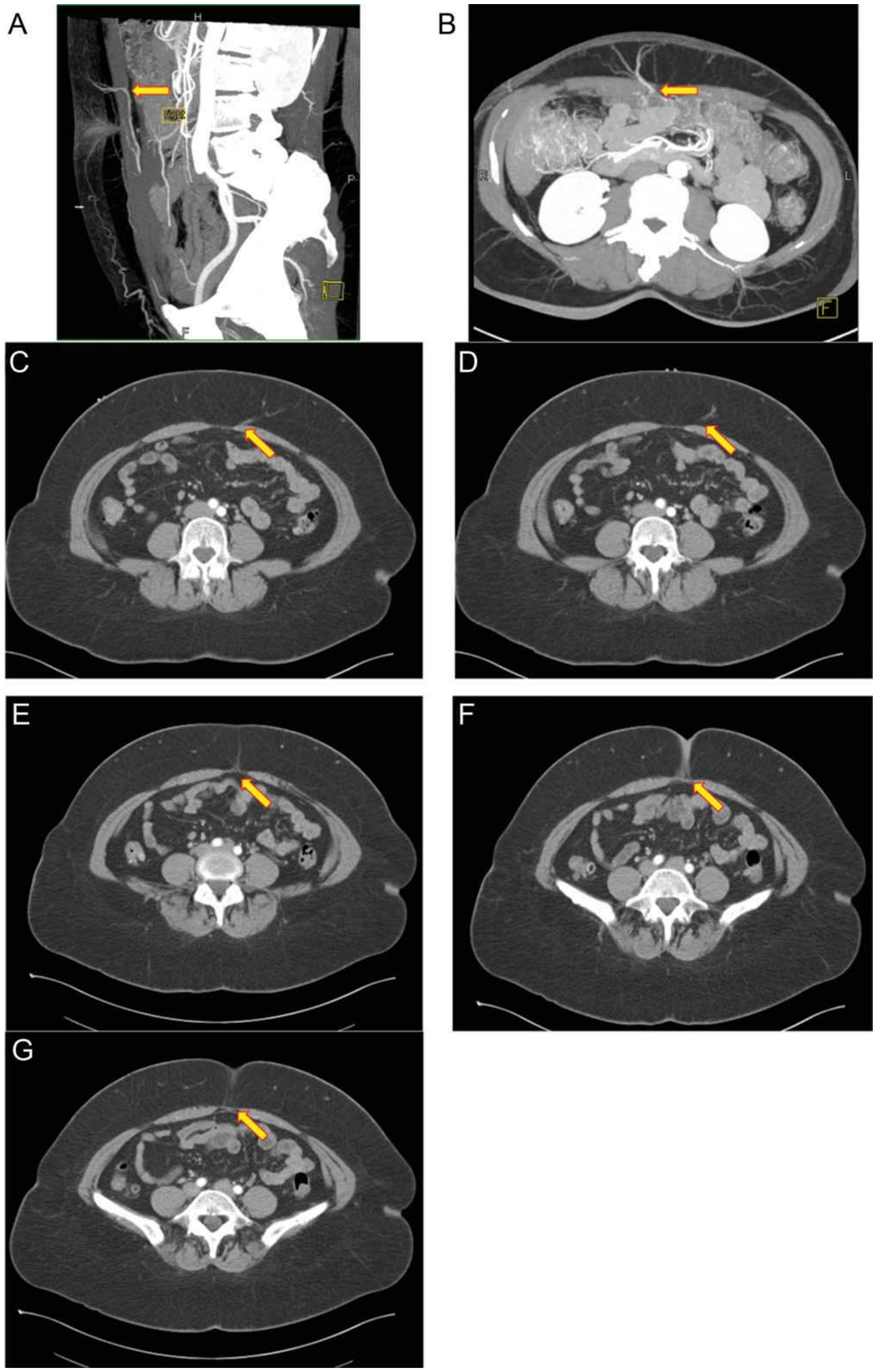

Figure 3. Type III—Altered anatomy—superiorly translocated. This series of CTAs identifies a high perforator located greater than one centimeter above the umbilicus that would have been excluded with most standard abdominal incisions. ***A:*** *3D sagittal view.* ***B:*** *3D axial view.* ***C,D:*** *2D axial views; the arrow points to the perforator, which is superior to the umbilicus.* ***E–G:*** *2D axial views; the arrow points to the umbilicus, which is inferior to the perforator of choice. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

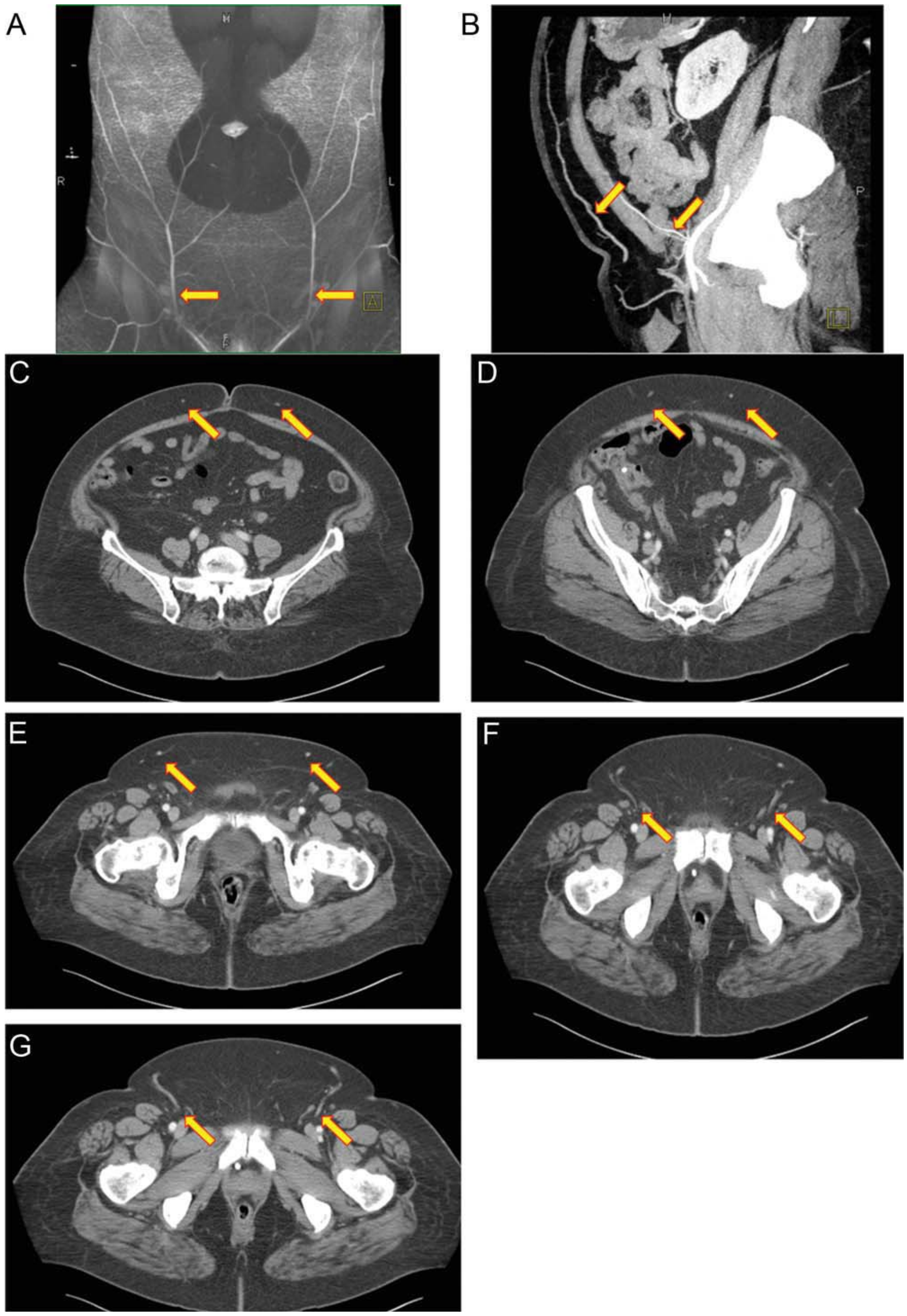

Figure 4. Type IV—Superficial dominant anatomy. This series of CTAs demonstrates large caliber superficial inferior epigastric (SIE) vessels coursing through the subcutaneous tissue of the abdomen. These vessels can be traced to their origin where their caliber and length appear quite suitable for use in the reconstruction. ***A:*** *3D AP view.* ***B:*** *3D sagittal view.* ***C–G:*** *2D axial views. Note that the superficial vessels appear to be larger in caliber than the submuscular deep inferior epigastric vessels. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

benefits of CTA are many and include precise localization and size determination of all perforator choices, delineation of the relative perimuscular anatomy, and confirmation of continuity with source vessels.

The majority of our patients in this series demonstrated type I ''traditional'' anatomy. It is in these situations that the reduced operating times and reduced partial or total failure rates noted by other authors[2,3,5,7,36] is

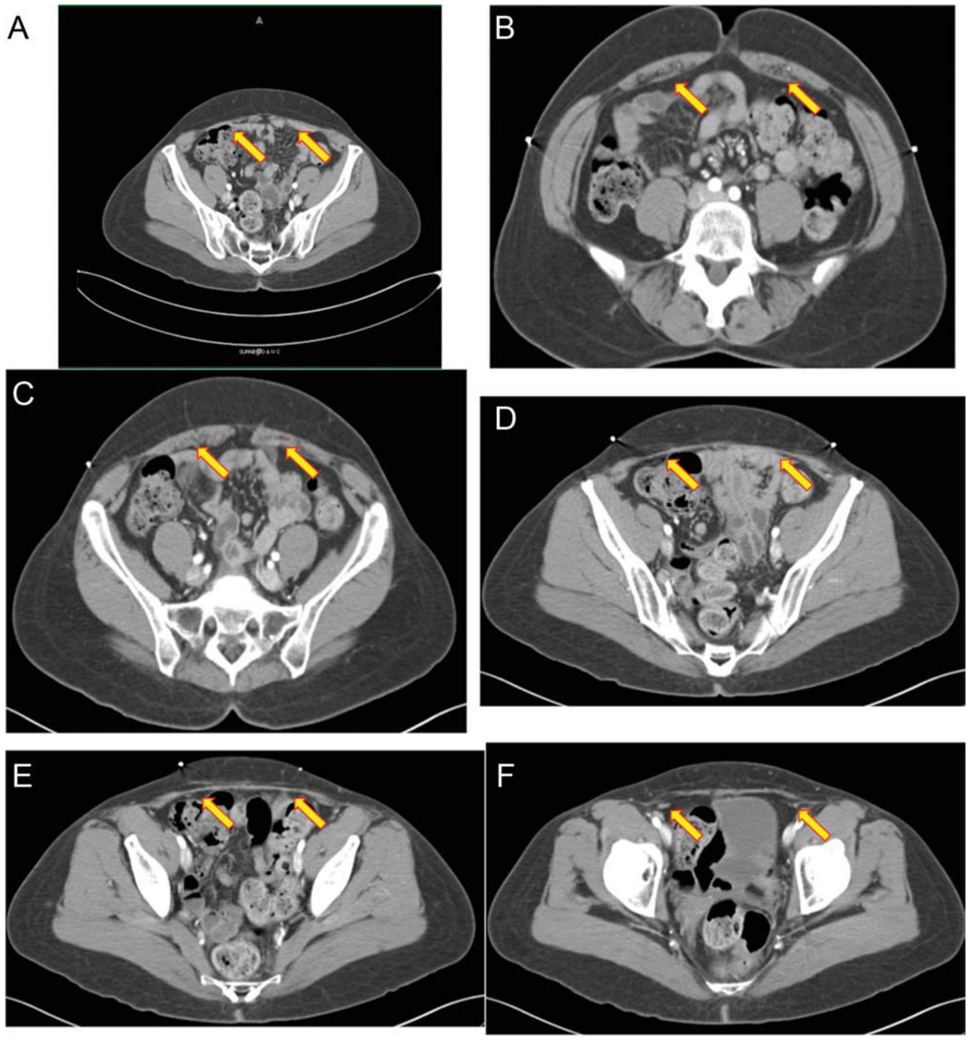

Figure 5. Type V—Hostile anatomy. This series of CTAs demonstrates caudal denervation of the rectus abdominus and surgical disruption of the deep inferior epigastric system (from a previous Pfannenstiel incision). Note that periumbilical perforators still exist but are not fed by the inferior system. This anatomy is not amenable to traditional DIEP flap breast reconstruction, but may require a pedicled TRAM. ***A–E:*** *2D axial views; arrows point to the muscle without DIE vessels—note that some occasional perforators still exist.* ***F:*** *2D axial view; arrows point to the DIE vessels near the iliac vessels. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

facilitated by the ability to pick the largest perforator with the shortest intramuscular course while minimizing time spent examining for pulsations, Doppler signals, diameter, and location. Furthermore, there is potentially significant time savings from less need to temporarily preserve multiple possible candidate perforators. Specifically, Casey et al.[3] demonstrated statistically significantly decreased operative times and statistically significantly decreased number of perforators used.

Type II ‘‘highly favorable’’ anatomy may allow the expansion of the pool of patients eligible for perforator flap procedures. If a reliably quick and easy dissection could be expected, patients with risk factors and comorbid diseases that make prolonged operating times dangerous, or increased BMI, that make abdominal work more complicated, could be offered the procedures. Type IV, ‘‘superficial dominant’’ vasculature may also allow extension of the procedure to patients previously considered poor candidates. This type has the benefit of needing no fascial incision, and thus the flap harvest is very similar to an abdominoplasty procedure, with just some additional dissection toward the superficial femoral ring while following the superficial inferior epigastric artery vessels.

Type III ‘‘altered’’ and V ‘‘hostile’’ findings may have the greatest impact of all. In our study, 6.9% of the hemiabdomens, if relied upon for reconstruction with standard skin design, would have likely led to intraopea-

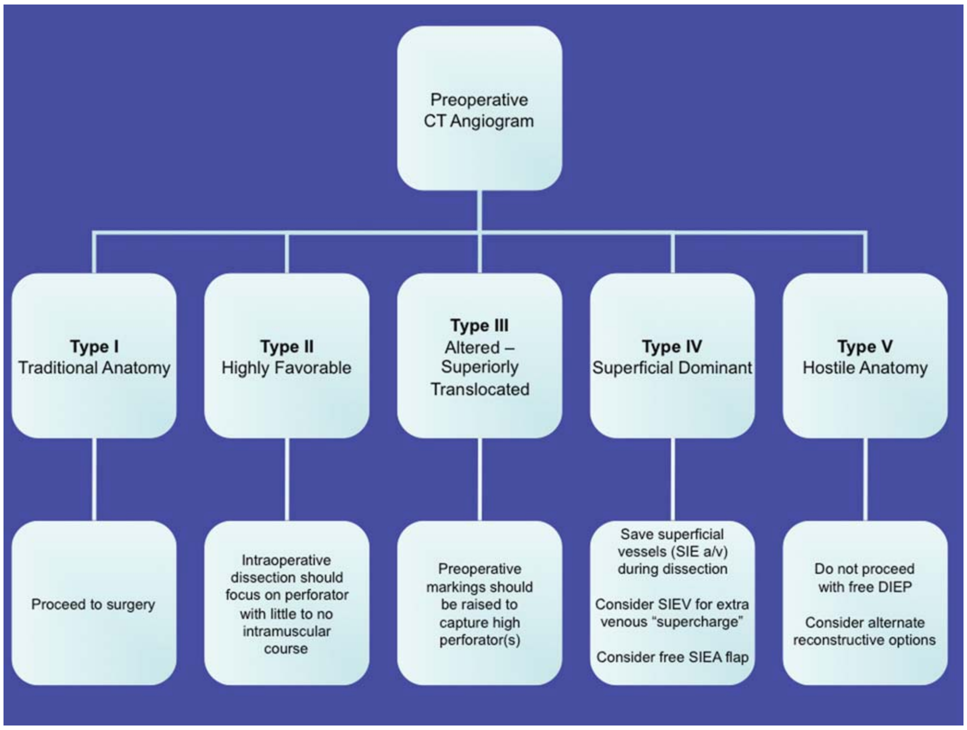

Figure 6. Schema of our classification system of the anterior abdominal wall vasculature used for perforator-based breast reconstruction. These five most common anatomic types are depicted in Figures 1–5. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

tive failure of the DIEP flap. With the preoperative knowledge provided by the CTAs, six patients in 1 year were saved from experiencing a reconstruction with a high risk of failure.

Additionally, any changes in operative plans were made preoperatively allowing for preoperative discussion with the patient regarding translation of scar locations into possibly less ideal locations, use of different donor sites and tissues and concomitant morbidities. This avoided both the need for intraoperative surprises and results unexpected by the patients. High-risk patients with previous surgeries are also able to learn early in the decision-making process, in which reconstructive techniques are available to them.

The question must be asked as to whether the preoperative plan that is developed using the CTA information is then later changed intraoperatively due to an incorrect reading of the CTA. Because of the nature of a retrospective review, we could not always discern whether the surgeons actually deviated from their preoperative plans. In our clinical experience, intraoperatively changing plans are highly unusual after the plan has been formulated with the CTA information. That is, if a type II medial wraparound vessel is identified, it would be dissected; if a type IV large SIEV is identified, it would be dissected and saved. This would have to be addressed in a prospective study to get a precise answer.

Our distribution of bilateral cases is statistically different ($P = 0.0012$) from a previously published series[37] from our institution, in which 46 were bilateral and 131 were unilateral, and represents a changing trend.

In our series, nearly half of the reconstructions were bilateral, an increase from previous years and a trend that is expected to continue as more women opt for prophylactic treatments. In a bilateral abdominal-based perforator flap reconstruction, no lifeboat (such as the opposite hemiabdomen in a unilateral flap) exists. Situations requiring use of more than a hemiabdomen to reconstruct one breast also do not allow for ready-made backup plans. In these situations, preoperative knowledge of patterns of vascular anatomy is even more essential to prevent catastrophes.

Other authors have also found that preoperative knowledge of anatomy can lead to alterations in surgical plans. Rozen et al.[2] demonstrated a change in plan in 20% of their patients preoperatively imaged with 3D CTAs and have been able to plan more limited muscular work based on data from the scans.[6] Casey et al.[3] reported a need to change plans in 7% of their cases.

Although CTA can help guide surgeon and patient along the reconstructive decision tree, both should be well aware of the risks of the study, which, though small, include radiation exposure, exposure to contrast, the risk of anaphylaxis, nephrotoxicity, the possibility of extravasation injury, and increased cost.[34,35] Further analysis of the risk/benefit rations with additional prospective, randomized, controlled trials may help to elucidate these issues. We believe that the CT angiograms help the reconstructive breast surgeon avoid potential complications (i.e., dissecting a perforator toward an inferior epigastric pedicle that has been injured or ligated during a previous abdominal surgery) or save them time (i.e., guiding the surgeon towards a perforator with little to no intramuscular course).[3]

In providing the microsurgeon with preoperative vascular maps that have the potential to determine operative feasibility, alter the operative course, increase operative efficiency, and decrease complications, abdominal CTA should be considered a worthy weapon in the diagnostic armamentarium of the reconstructive surgeon. The ability to readily classify results into a simple schema can facilitate effective use of this powerful tool, aiding in overall care of the breast reconstruction patient.

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