3D CT ANGIOGRAPHY OF ABDOMINAL WALL VASCULAR PERFORATORS TO PLAN DIEAP FLAPS

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Purpose: Since the first report of TRAM flap reconstruction, there have been numerous studies to reduce complications of elective breast reconstruction. Current methods of preoperative perforator localization can be time-consuming, inaccurate, and imprecise. Thus, we sought to evaluate ultra-high resolution 3D CT angiography for the preoperative mapping of DIEAP flap perforating vessels. *Methods*: We reviewed all perforator-based breast reconstructions performed over a 5-month period. Candidates for DIEAP flap reconstruction were sent for a focused CT scan of the abdominal wall, using the 64 slice multi-detector CT scanner. *Results*: This article presents our first 23 flaps in 17 patients with preoperative ultra-high resolution 3D CT angiography. The reconstruction plan changed in three patients (18%). There was one take-back for venous congestion, but no partial or total flap loss. *Conclusions*: Preoperative perforator flap planning for breast reconstruction utilizing 3D CT angiogram is safe, easy to read, and can change the operative plan. © 2007 Wiley-Liss, Inc. Microsurgery 27:641–646, 2007.

Since the first report of the transverse rectus abdominis myocutaneous (TRAM) flap used for reconstruction of the breast after oncologic resection,[1] there have been numerous modifications to reduce the morbidity of breast reconstruction using abdominal autologous tissues.[2–6] Our institution has seen a dramatic increase in perforator flap breast reconstruction over the past 6 years. During the evolution of surgical techniques from the pedicled TRAM flap, to the free TRAM, to the muscle-sparing free TRAM, to the deep inferior epigastric artery perforator (DIEAP) flap and superficial inferior epigastric artery (SIEA) flap, there has been a constant battle between attempts to minimize morbidity to the patient by reducing the dissection of the anterior abdominal wall, while maximizing flap blood flow and viability. It had been shown that partial flap necrosis and fat necrosis rates in DIEAP flaps are higher than those in Free TRAM flaps for breast reconstruction.[7] However, other reports have found little difference.[8,9] Better preoperative patient selection and intraoperative conversion to a different reconstructive technique based on intraoperative findings are suggested ways to reduce flap necrosis because of inadequate blood supply.

Several methods have been espoused to identify the vascular supply to perforator flaps, including physical exam,[7] hand-held unidirectional Doppler,[10–13] two-dimensional color flow Doppler imaging,[14–20] scanning laser Doppler,[21] thermography,[22,23] magnetic resonance imaging,[24] and, recently, CT angiography.[25,26] Thus, we sought to evaluate the use of ultra-high resolution three-dimensional computed tomography (3D CT) angiography for the preoperative mapping of abdominal wall perforating vessels. The authors also correlate the preoperative findings with intraoperative findings in regards to vessel location, usefulness in planning which perforating vessel was dominant or more easily dissected, and which breast reconstruction technique (DIEAP or SIEA) flaps were better suited for a given patient. This article reviews our first 17 patients who received ultra-high resolution 3D CT angiography preoperatively for the evaluation of their abdominal wall perforating vessels on which the planned DIEAP flaps would be based.

METHODS AND MATERIALS

We conducted an IRB-approved review of all perforator-based autologous tissue breast reconstruction patients at The Johns Hopkins Hospital Avon Foundation Breast Center between October 19, 2005 and March 19, 2006. Each patient has had a minimum of 6-months follow-up.

Patient Selection

All female patients who presented to The Johns Hopkins Hospital Avon Foundation Breast Center for breast reconstruction following mastectomy for treatment or prevention of breast cancer were evaluated for suitability of immediate or delayed breast reconstruction with free autologous tissue transfer versus implant-based reconstruction. Those women who were candidates for DIEAP flap reconstruction were then sent for a preoperative CT

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Table 1. Previous Abdominal Surgeries

Patient number	Previous abdominal surgery	Number of prior abdominal surgeries
1	Laparoscopic fertility surgery	1
2	C-section	1
3	Hysterectomy	1
5	c-section × 2, hysterectomy, lap chole	4
8	Lap chole	1
9	Lap oophorectomy, hysterectomy	2
10	c-section	1
12	c-section, appendectomy	2
13	Open tubal ligation	1
15	c-section × 2, hysterectomy	3
16	Ooporectomy, appendectomy	2
17	Lap chole	1

Patients 4, 6, 7, 11, and 14 did not have prior abdominal surgery. (c-section, cesarean section; lap, laparoscopic cholecystectomy; chole, cholecysctectomy).

Table 2. Listing of Comorbidities

Patient number	Comorbidities
1	MVP, asthma, herpes, depression
2	HIV, hepatitis C, depression
3	None
4	Heart murmur
5	GERD, hypercholesterolemia
6	GERD, gastritis, MVP, asthma
7	None
8	GERD, osteoarthritis
9	None
10	HTN, iron deficiency anemia
11	HTN
12	Depression, anxiety, endometriosis
13	Heart murmur
14	Left bundle branch block, GERD, HTN
15	Depression
16	Diabetes, HTN, hypothyroidism, hypercholesterolemia
17	HTN

MVP, mitral valve prolapse; HIV, human immunodeficiency virus; GERD, gastro-esophageal reflux disease; HTN, hypertension.

angiogram at our institution for a focused exam of the abdominal wall perforating blood vessels from the deep inferior epigastric artery, using the 64 slice multi-detector CT scanner. Any woman who desires autologous reconstruction is considered a candidate for DIEAP flap reconstruction if the volume of her infra-umbilical adipocutaneous tissue seems consistent with her breast volume goals, whether bilateral or unilateral, and assuming she did not have previous abdominal surgery precluding the use of that tissue. Many women lived out of town and could not return preoperatively for the CT scan, thus only 27% (23 of 86) planned flaps had a preoperative CT scan at our institution. Three patients had CT scans performed at outside facilities, but the raw data could not be imported into our system, and the images sent to us did not have the fine detail necessary to visualize the perforators. All CT scans which were performed at our institution during this time period were evaluated. No other patients were excluded from this study.

The preoperative 3D CT angiogram was then used as a roadmap for operative planning and intraoperative dissection of DIEAP flaps and in some cases SIEA flaps for autologous tissue reconstruction of the breast. The number of perforating vessels on the CT scans were noted preoperatively and correlated with intraoperative findings. The safety, utility, and reproducibility of the technique were evaluated by two attending surgeons. The surgeons also noted whether or not the use of these noninvasive CT angiograms affected their operative plan for DIEAP flap reconstruction versus SIEA flap reconstruction.

3D CT Angiography Protocol

All patients recruited for the study were preoperatively imaged at The Johns Hopkins Hospital, Department of Radiology using a Siemens Sensation 64 CT scanner (Siemens Medical Solutions, Malvern, PA) using the following protocol: KV 120, Effective mAs 250, Rotation time 0.33 s, detector collimation of 0.6 mm, slice thickness 0.75 mm, pitch of 0.8, Kernel of B30f medium smooth abdomen, reconstruction interval of 0.5 mm, Image order (acquisition) Cranial to caudal. Intravenous contrast was used with a total volume of 100 ml of VISIPAQUE^{TM}320 (Iodixanol, GE Healthcare, Princeton, NJ), injected at a rate of 3.0–3.5 ml/s utilizing a scan delay of 40 s. The CT data were sent to free standing workstation (Leonardo, Siemens Medical Solutions) running InSpace software. 3D mapping was done interactively using volume rendering (VRT) and maximum intensity projection (MIP) techniques. Real time rendering was used to optimally visualize the 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. These 3D reconstructions can be made into mpeg video clips, and can be viewed on-line (http://www.interscience.wiley.com/jpages/0738-1085/suppmat).

During the 5-month period from October 19, 2005 through March 19, 2006, we performed preoperative 3D CT angiograms for 17 patients, with a total of 23 flaps. Eleven reconstructions were unilateral, while six were bilateral. Ten reconstructions were delayed, while 13 were immediate. Three of the delayed reconstruction patients had preoperative radiation therapy. Twelve patients had previous abdominal surgery (Table 1). Average age, weight and BMI were 51 ± 8.3 years, 155 ± 24 pounds, and 26 ± 3.9 kg/m^2 respectively. Most patients had other medical comorbidities besides breast cancer (Table 2). Average length of stay was 3.6 days (range 3–7 days). Two patients were smokers; one was a

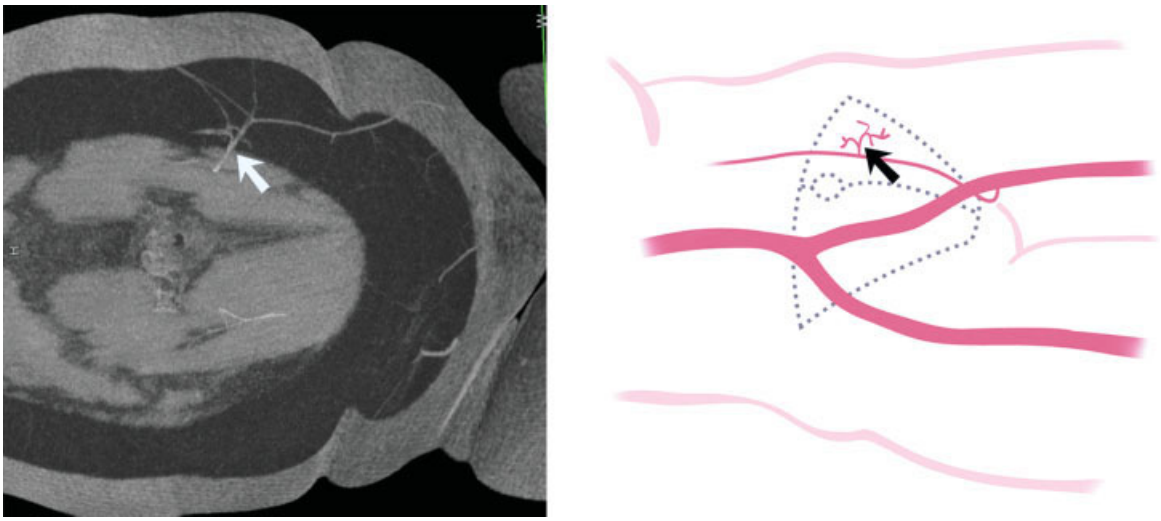

Figure 1. Oblique view of 3D CT angiogram of periumbilical perforators with schematic of patient orientation.

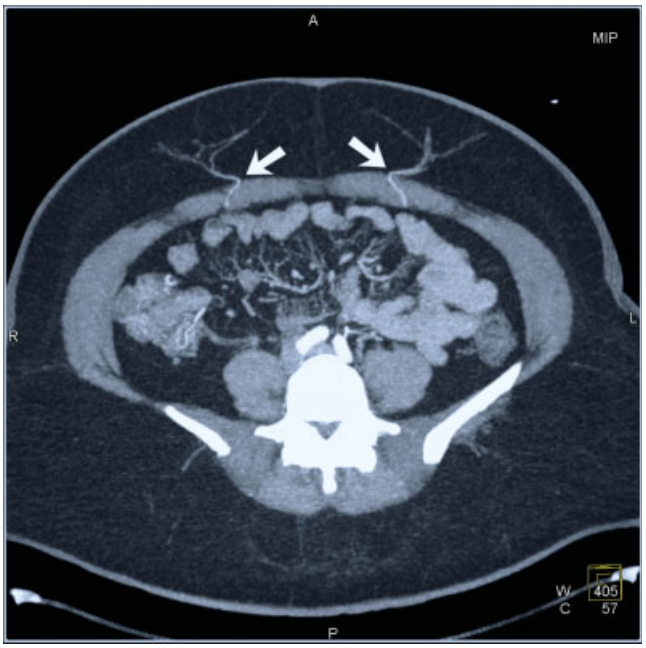

Figure 2. Axial view of 3D CT angiogram of periumbilical perforators.

diabetic. Breast specimen pathology of the immediate reconstruction patients found one patient had a T3 tumor and two patients had T2 tumors; all other patients had T1 tumors, ductal carcinoma in situ, or prophylactic mastectomies.

For these patients, we studied the number and location of abdominal perforators seen on CT scan and the intraoperative choice of pedicle. Breast specimen weights, flap weights, recipient vessels, operative time, preoperative and postoperative hematocrit and creatinine, and complications were recorded for all patients.

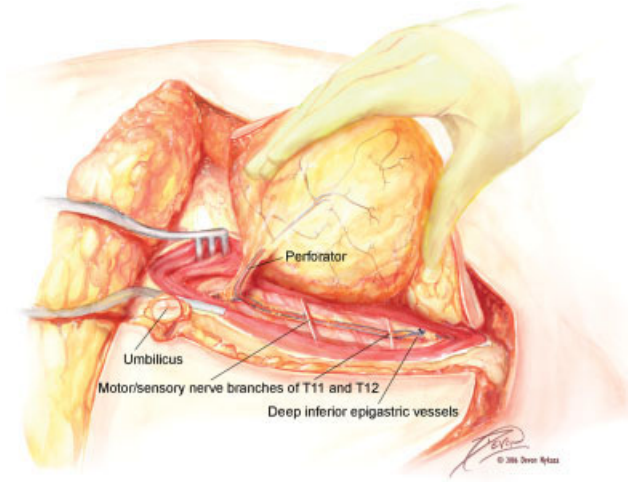

Figure 3. Illustration of intramuscular DIEAP flap dissection.

The patient's insurance companies did cover the costs of the abdominal CT scan.

RESULTS

During this 5-month period, 86 perforator flaps were planned, and 82 performed. Twenty three flaps in 17 patients underwent preoperative ultra-high resolution 3D CT angiography. (see Figs. 1–5) Of the 63 planned perforator flaps in patients without 3D CT scans, four flaps were intraoperatively aborted, while no flaps were intraoperatively aborted in the CT scan group. This difference was not statistically significant. Preoperative CT scan angiograms showed an average of 3.4 ± 1.4 right rectus abdominis perforators and 3.5 ± 1.3 left rectus abdominis perforators. Intraoperatively, all of these perforators were visually identified; all other perforators incidentally

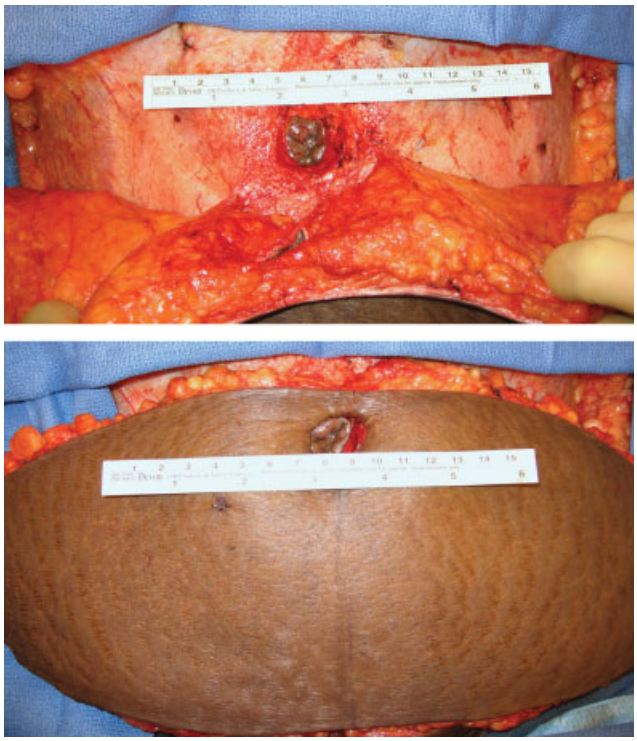

Figure 4. Intra-operative view of actual location of perforators, correlating precisely with CT findings.

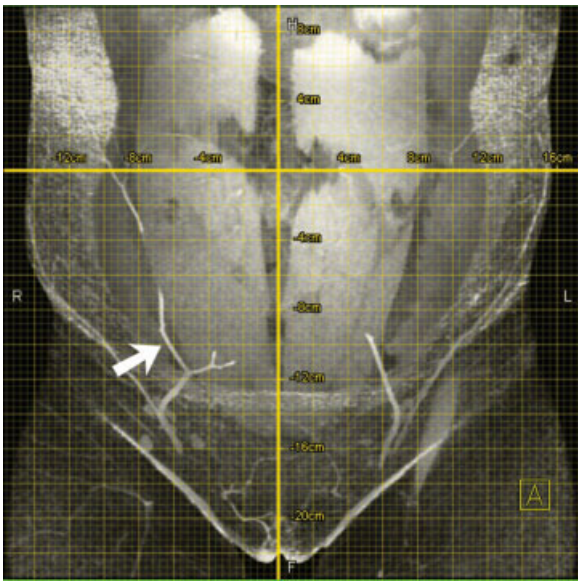

Figure 5. Coronal view of 3D CT angiogram demonstrating a large superficial inferior epigastric system in a patient with small deep inferior epigastric perforators. Overlying grid pattern is centered on the umbilicus.

located on intraoperative inspections measured less than 1 mm. Intraoperative deselection of perforators based on clinical exam resulted in the use of an average of 1.3 ± 0.7 perforators for right-sided DIEAP flaps, and 1.5 ± 0.7 perforators for left-sided DIEAP flaps. There were 23 DIEAP flap pedicles, and 2 SIEA flap pedicles (these total 25 since 2 flaps were bipedicled to gain extra volume for larger unilateral reconstruction). The pedicles were chosen based on the 3D CT angiograms and correlated with intraoperative findings. Recipient vessels were usually the internal mammary artery and vein, which were utilized for 21 flaps. The internal mammary vessel intercostal perforator was chosen for two anastomoses and the thoracodorsal vessels were also used twice.

For these patients, operative time averaged 7.7 ± 2.1 h (range 4–11). Hematocrit decreased appropriately based on blood loss and hemodilution from intravenous fluids; serum creatinine did not worsen because of to the dye load from the CT scan (Table 3).

The average breast specimen weighed 572 ± 326 g (range 222–1,429 g), while the average flap weighed 561 ± 219 g (range 243–1,080 g). Postoperative complications included minor marginal skin necrosis of the native skin-sparing mastectomy flap in two patients, delayed wound healing of the abdominal incision requiring local wound care in two patients, partial necrosis of the umbilicus in a patient with concomitant umbilical hernia repair,

Table 3. Preoperative and Postoperative Laboratory Values

	Preop HCT (%)	Postop HCT (%)	Preop Cr (mg/dl)	Postop Cr (mg/dl)
Average	39.6	29.5	0.7	0.6
Standard deviation	2.1	3.9	0.2	0.1
Minimum	35.9	23.8	0.5	0.5
Maximum	42.3	38.5	1.1	0.8

HCT, hematocrit; Cr, serum creatinine.

and one take-back for early venous congestion. In the take-back for venous congestion, the pedicle was kinked, and reinset of the flap resulted in total flap salvage. There was no partial or total flap loss, and minimal fat necrosis of less than 5% of the flap was palpable in the flap in a single patient.

The 3D CT scan changed the breast reconstruction plan in three patients and the overall operative plan in seven patients.

Two patients were changed from DIEAP flap to SIEA flap based on the CT scans. One patient had a significant change in operative plan based on the 3D CT scan when an incidental gallbladder polyp was identified. Her case was changed from planned bilateral mastectomy with DIEAP flaps, to bilateral mastectomy, tissue expanders, and laparoscopic cholecystectomy. Her final pathology was bilateral breast cancer and early stage cholangiocarcinoma. She subsequently went on to have bilateral DIEAP flaps in a staged fashion.

A ventral or umbilical hernia was identified in four patients preoperatively on the CT scan. Hernia repair was

thus added to the operative plan, although the breast reconstruction plan remained unchanged. The hernias were repaired following flap anastomosis and inset at the breast reconstruction site.

DISCUSSION

Plastic and reconstructive surgery hinges on the critical balance between donor site morbidity and blood supply of the reconstructive tissue. This holds true for breast reconstruction where a soft, supple, anatomical breast shape is the ultimate goal. There has been a natural progression from the TRAM flap to DIEAP or SIEA flaps for the reconstruction of oncologically created breast deformities in an effort to mimimize the morbidity of the harvesting of abdominal wall tissues. With increasingly complex surgical techniques comes a higher risk of losing critical flap viability to produce a stable, soft, supple breast form.

Various techniques have been proposed to help locate the delicate perforating blood vessels that supply the anterior abdominal adipo-cutaneous tissue used in many breast reconstructions. Doppler ultrasonography using a hand-held unidirectional Doppler probe is one of the most commonly used techniques, for perforator flaps in general and breast reconstruction in particular, because of its noninvasive nature, ease of use, and relative low expense.[10–13] However, it can be time-consuming, inaccurate, and imprecise. Two-dimensional color flow Doppler imaging provides significant preoperative information about the location of the abdominal wall perforators and the flow velocities within the blood vessels.[14–20] However, it too is time consuming and may require a specially trained ultrasonagrapher to perform the test. Scanning laser Doppler has also been proposed as a technique for preoperative localization of abdominal wall perforators.[21] However, in its current state of availability this technique does not seem practical for a busy clinical practice. MRI has also been used to detect abdominal perforators,[24] however, its high cost and lengthy scanning cycle make it less than ideal.

High resolution three-dimensional CT angiograms have proven to be a clinically effective tool for neurosurgeons[27] where the accurate diagnosis of cerebral aneurysms and complex surgical planning are paramount for improved clinical outcomes. Cardiologists and cardiac surgeons use gated 3D CT angiograms to evaluate coronary artery disease,[28] and transplant surgeons plan living related kidney transplants.[29] We have extended the use of high resolution three-dimensional CT angiography to aid preoperative planning of DIEAP flap reconstruction after mastectomy. Our series shows that all preoperatively detected perforators of 1 mm or greater were found intraoperatively, demonstrating a high level of clinical reproducibility. This information can be used to help design the flap dimensions to help center the flap over the dominant perforators, thus potentially improving survivability.

When the SIEA is large in relation to the DIEAP abdominal wall perforators, the surgeon may preoperatively plan to use the superficial system. In two patients, the surgeons noted that the SIEA system was dominant; therefore, the surgical plan to perform a DIEP flap was changed preoperatively to an even less invasive SIEA flap. Thus, the patient's rectus abdominis and anterior rectus fascia were spared any incision, as the SIEA was dissected suprafascially down into the groin. In a separate patient, the preoperative CT angiogram demonstrated an incidental gall bladder polyp. This postponed the DIEAP flap surgery in lieu of a cholecystectomy. Final pathology revealed a cholangiocarcinoma, a potentially lethal tumor, caught in a curable stage. This patient later went forward with a staged bilateral DIEAP flap breast reconstruction without complication.

The scanning time is relatively fast (less than 10 s), and the contrast dye load is acceptable. The 3D reconstruction can be done by the radiologist and the image can be manipulated by the plastic surgeon on a work-station or PC at their leisure in his/her office or in the operating room using appropriate software programs. It is simple to accurately measure distances of the perforators from a given landmark such as the umbilicus. This CT protocol can resolve vessels down to 1 mm. With practice, the surgeon can trace the perforator through the rectus to help pick which of the several possible perforators could be dissected with the least amount of trauma to the abdominal wall.

CONCLUSION

Ultra-high resolution 3D CT angiography is a fast, safe, and effective method for the preoperative mapping of anterior abdominal wall perforators which feed the adipocutaneous tissue used in autologous free tissue transfer for breast reconstruction. The images have a high degree of intraoperative anatomic correlation. The surgeon can then get a 3D image or data set which can visualize blood vessels down to 1 mm diameter. We believe this technique can be useful for both the novice and seasoned reconstructive surgeon alike, and deserves further prospective evaluation. Examples of full-color videos of the 3D CT angiograms are available at the following webpage: (http://www.interscience.wiley.com/jpages/0738-1085/suppmat).

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