Anatomic Imaging of Abdominal Perforator Flaps without Ionizing Radiation: Seeing Is Believing with Magnetic Resonance Imaging Angiography

David Greenspun, M.D.,[1,2] Julie Vasile, M.D.,[2] Joshua L. Levine, M.D.,[2] Heather Erhard, M.D.,[4] Rebecca Studinger, M.D.,[6] Victoria Chernyak, M.D.,[5] Tiffany Newman, M.D.,[3] Martin Prince, M.D.,[3] and Robert J. Allen, M.D.[2]

ABSTRACT

The tremendous variability of the inferior epigastric arterial system makes accurate imaging of the vasculature of the anterior abdominal wall an essential component of optimal perforator selection. Preoperative imaging of the abdominal vasculature allows for preoperative perforator selection, resulting in improved operative efficiency and flap design. Abdominal wall perforators of 1-mm diameter can be reliably visualized without exposing patients to ionizing radiation or iodinated intravenous contrast through advances in magnetic resonance imaging angiography (MRA). In this study, MRA imaging was performed on 31 patients who underwent 50 abdominal flaps. For each flap, the location, relative to the umbilicus, of the three largest perforators on both the left and right sides of the abdomen was determined with MRA. Vessel diameter and anatomic course were also evaluated. Postoperatively, a survey was completed by the surgeon to assess the accuracy of the MRA with respect to the intraoperative findings. All perforators visualized on MRA were found at surgery (0% false-positive). In 2 of 50 flaps, the surgeon transferred a flap based upon a vessel not visualized on the MRA (4% false-negative). This article details our experience with MRA as a reliable preoperative imaging technique for abdominal perforator flap breast reconstruction.

KEYWORDS: Deep inferior epigastric artery perforator, superficial inferior epigastric artery, abdominal perforator flap, magnetic resonance imaging angiography, preoperative imaging

Breasts with a natural appearance and feel can be created from a patient's own tissue without sacrificing the underlying muscle at a flap's donor site. In contrast to implant breast reconstruction, breasts reconstructed with autogenous tissue can develop sensation as nerves grow into a flap, even when nerve coaptation is not possible.[1] The abdomen remains an ideal donor site for breast reconstruction in women due

[1]Greenwich Hospital, Greenwich, Connecticut; [2]Center for the Advancement of Breast Reconstructive Surgery at New York Eye and Ear Infirmary; [3]Weill Cornell Imaging at New York Presbyterian, New York, New York; [4]Einstein-Weiler Hospital; [5]Montefiore Medical Center, Bronx, New York; [6]Providence Hospital, Southfield, Michigan.

Address for correspondence and reprint requests: Julie Vasile, M.D., Center for the Advancement of Breast Reconstructive Surgery at New York Eye and Ear Infirmary, 310 E. 14th St. New York, NY 10003 (e-mail: jvasile1@msn.com).

Received: November 20, 2008. Accepted: January 22, 2009.
DOI 10.1055/s-0029-1220862. ISSN 0743-684X.

to stretching of the abdominal skin that occurs with movement and weight changes, the soft consistency of the subcutaneous fat, and the color match of the abdominal skin with the chest skin.

To successfully perform an abdominal perforator flap breast reconstruction, a flap must be designed with a vascular supply that can provide adequate blood flow. Many factors determine the best perforator(s) that will support a given flap. Important considerations are vessel diameter, vessel location, vascular arborization pattern within the subcutaneous fat, vessel course within or around the rectus abdominis muscle, a patient's desired breast size, and a history of previous surgery. The anatomy of the deep inferior epigastric system is extremely variable and affects the technical difficulty of harvesting a perforator flap pedicle; vascular anatomy thus can affect dissection time. Cadaveric dissection studies show the deep inferior epigastric artery can remain a single trunk (29%), bifurcate (57%), or trifurcate (14%).[2,3] The number and caliber of perforating vessels have a high degree of variability, with the largest perforators usually located in a zone extending from 2 cm superior to the umbilicus to several centimeters inferior and lateral to it.[4] The variable course of perforators adds another challenge to the difficulty of flap harvest. Perforators can intersect with a tendinous insertion, travel just under the anterior rectus fascia for variable distances, and traverse the rectus abdominis muscle at variable angles and for variable distances. Perforators can also course around the medial edge of the rectus abdominis muscle without even penetrating the muscle (septocutaneous vessel).[5,6]

Prior to the era of preoperative imaging of the abdominal wall vasculature, a surgeon had little knowledge of a given patient's perforator anatomy until surgery was well underway. As a result, perforator vessel selection was a tedious process that occurred in the operating room at the expense of operating time and general anesthetic requirement. The options available for perforator imaging have changed as technology has advanced. Unidirectional Doppler ultrasound was the sole method of perforator imaging in the early days of perforator flap surgery.[7] A unidirectional Doppler ultrasound is portable and simple to use but cannot differentiate perforating vessels from superficial and deep axial vessels or robust perforators from miniscule ones and cannot accurately locate perforators that do not exit perpendicular from the fascia.[8,9] Furthermore, Doppler ultrasound does not provide any information about the anatomic course of a vessel.

In comparison, color Duplex sonography provides more detailed information about the anatomy of the inferior epigastric system. In addition, Duplex sonography can assess vessel caliber and hemodynamic flow. Unfortunately, color Duplex has some significant shortcomings. This method of preoperative vascular evaluation requires highly trained technicians with knowledge of perforator anatomy, is time consuming, and requires a patient to maintain the same position for nearly a hour.[8] Moreover, the technique's most crucial drawback is an inability to produce anatomic images in a format that a surgeon can easily and independently view.

Increasingly, computed tomographic angiography (CTA) is being used to image abdominal wall perforators because this technique can demonstrate the deep and superficial inferior epigastric vascular anatomy, assess vessel caliber and course, accurately locate perforators, and produce anatomic images in a format that a surgeon can easily and independently view. Although CTA can be quickly performed in as few as 15 minutes,[8–10] patients must be exposed to ionizing radiation. Recent articles in the medical literature and lay press warn that physicians may be exposing patients to excessive and potentially unnecessary radiation and question the long-term effects of such exposure.[11,12] Patients with breast cancer often have a heightened concern for any factor that can potentially increase the risk of developing a second cancer and may perceive the risks of radiation exposure even more negatively. A subset of our patients with breast cancer gene (*BRCA*) mutations, which confer an increased risk of developing both breast and ovarian cancer, are especially concerned about receiving radiation to the abdomen. Furthermore, iodinated contrast for CTA has been associated with small, but real risks of anaphylaxis and nephrotoxicity.[13,14]

Ionizing radiation overcomes the binding energy of electrons, knocking them out of orbit and creating ions, which can damage DNA and potentially cause point mutations and translocations. Such mutations have been linked to the development of cancer.[11] The dose of radiation from one chest X-ray (0.1 mSv) is relatively low and is approximately equivalent to the dose of environmental radiation one receives by virtue of living on earth for 10 days.[15] In comparison, a computed tomography (CT) scan of the abdomen delivers 6 to 10 mSv of radiation, which is approximately equivalent to 3 years worth of environmental radiation.[8,15] Controversy lies in the amount of radiation needed for cancer induction, but experts agree that unnecessary exposure to ionizing radiation should be avoided. Frequently, the diagnostic utility of CT outweighs the uncertain, low risk of cancer induction.[16] However, we believe that alternative methods of vascular imaging should be employed whenever possible in the planning of perforator flaps.

We have developed a protocol for preoperative abdominal wall vascular imaging that employs magnetic resonance imaging angiography (MRA) and spares a patient exposure to ionizing radiation and iodinated contrast. Magnetic resonance imaging (MRI) works by using a magnetic field to uniformly align the spin of hydrogen atoms in tissue. The subsequent application of a radiofrequency pulse results in release of energy as hydrogen atoms return to their relaxed state. An MRI coil detects the released energy, and computer software processes the collected data into anatomic images. Exposure to a magnetic field or radiofrequency pulse with MRI has not been linked to the development of cancer.[17] Furthermore, the risks of anaphylaxis and nephrotoxicity in patients with normal renal function are extremely low with MRA contrast agents.[18,19] With recent advances in magnetic resonance imaging technology, the spatial resolution of small-caliber vessels has dramatically improved, and 1-mm perforating vessels can be detected with this technique. This article details our initial experience with MRA for preoperative imaging of abdominal perforator vessels used for breast reconstruction.

PATIENTS AND METHODS

Patients

Thirty-one patients were imaged with MRA from September 2006 to August 2007. Patient demographics are presented in Table 1. Patients were excluded from the study if an MRA was contraindicated due to a metal foreign body or inability to receive intravenous gadolinium contrast (for which no patient was disqualified). The surgeons in this study are based in multiple states and operate on patients from a broad geographic region. Patients unable to travel to the one radiological center that used our MRA protocol also were excluded. Patients who could not undergo MRA were imaged with CTA.

Methods

Preoperative imaging of the anterior abdominal wall was performed on patients in the supine position with a Phillips 3-T MRI scanner with software version 10.6 (Philips Medical Systems, Bothell, WA). The vertical field of view extended from 3 cm above the patient's umbilicus to the public symphysis; transversely, the field of view was equal to the width of the patient. Slice thickness was 4 mm with 2-mm overlap. The acquisition matrix was 512×384. The length of breath hold was 29 seconds for each acquisition. An axial THRIVE sequence was acquired before and after administration of intravenous gadolinium with the following parameter: repetition time (TR)/echo time (TE)/flip = 4.8/2.4/10 degrees. The injection consisted of 20 mL of gadolinium, followed by 20 mL of normal saline at the rate of 2 mL per second. Multiple acquisitions were performed to obtain the most optimal timing for opacification of the arterial perforator. Three successive images were acquisitioned, with the first acquisition starting 20 seconds after the injection was initiated. Three-dimensional surface-rendering of the images was generated on an Aquarius Net Workstation Version 1.7.2.19 (TeraRecon, Inc. San Mateo, CA).

The three largest deep inferior epigastric perforating arteries were identified on each side of the abdomen by a radiologist. The diameter in millimeters and location at which each of the identified perforators exited the anterior rectus fascia was determined. The location of each of these perforators was determined in relation to the umbilicus on an x-, y-axis; *x* denoted the distance in centimeters left or right from the umbilicus, and *y* denoted the distance in centimeters above or below the umbilicus. An example is shown in Fig. 1. The course of

Table 1 Patient Demographics

Patients/flaps	31/50
Average age (y)	51 (range, 30–65)
Bilateral breast reconstruction (No. of patients)	18
Unilateral breast reconstruction (No. of patients)	13
Immediate reconstruction (No. of flaps)	30
Delayed reconstruction (No. of flaps)	20
DIEP flaps	47
SIEA flaps	3

DIEP, deep inferior epigastric perforator; SIEA, superficial inferior epigastric artery.

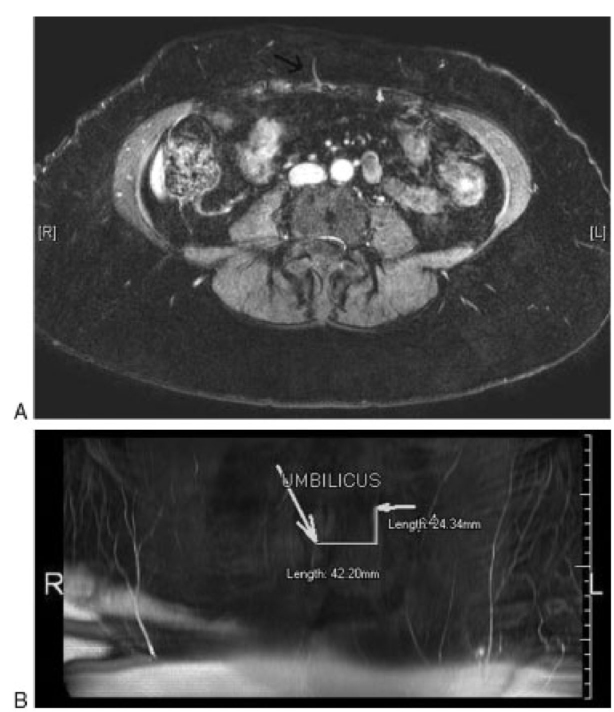


Figure 1 (A) Abdominal magnetic resonance imaging angiography (MRA) (axial view). Arrow points to a large perforator. (B) Abdominal MRA showing coordinate measurements of the perforator in relation to the umbilicus.

each of the vessels through the rectus abdominis or around the rectus abdominis muscle (septocutaneous vessel) was also noted. The diameter of the superficial inferior epigastric artery was also determined if it appeared to be of sufficient diameter to possibly support flap transfer.

Before surgery, the operating surgeon reviewed the MRA images and the radiologist's report and selected the perforating vessels that he or she felt were optimal for each patient undergoing reconstruction. In the office, on the day prior to the surgery, the locations of the most suitable perforators were marked with indelible ink on the abdomen using the x- and y-coordinates from the MRA as a "map"; a handheld Doppler was used to assess the abdomen as well. Flaps were designed to incorporate perforators that the surgeon selected based upon MRA. A photograph was taken of the patient's abdomen with the markings to bring to the operating room. An example is shown in Fig. 2. The patients were instructed to cleanse with Hibiclens (Mölnlycke Health Care, LLC, Norcross, GA) but not to scrub the markings off the skin.

Immediately after the surgery, a survey was completed by the surgeon. The following parameters were examined: whether or not the three largest perforators visualized on MRA were found in situ at surgery; correlation of the vessel location and relative size as determined by MRA with the intraoperative findings; whether or not the surgeon transferred a flap based upon the vessel(s) anticipated after reviewing the MRA; whether or not the surgeon encountered intraoperative perforators of significant size not visualized on MRA (false-positive and false-negative); and correlation of vessel location identified by Doppler with the MRA and intraoperative findings.

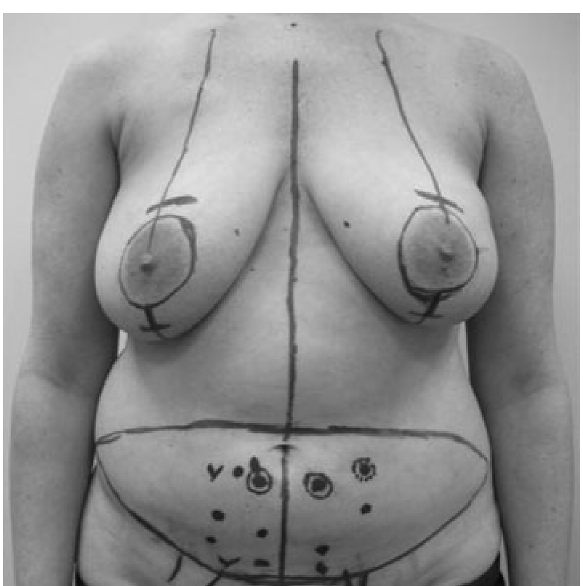


Figure 2 Photograph demonstrating preoperative markings. Dot surrounded by circle represents optimal perforator detected by magnetic resonance imaging angiography (MRA), Dot surrounded by broken circle represents a second-choice perforator detected by MRA. Dot represents arterial signal detected by Doppler ultrasound. *V* represents venous signal detected by Doppler ultrasound.

RESULTS

Fifty abdominal flaps were successfully transferred in 31 patients. All perforators visualized on MRA were found at surgery (0% false-positive). In two flaps, preoperative MRA failed to demonstrate significantly sized lateral row perforators vessels that were used for tissue transfer (4% false-negative rate). In both of these flaps, the signal from the patient's buttock fat was inadequately suppressed and obscured the signal from the lateral portion of the abdomen.

The locations at which the identified perforators pierced the anterior rectus fascia, as assessed by MRA, correlated with the intraoperative findings within 1 cm in 100% of the patients. The relative size (i.e., comparing size of one vessel to another for the same patient) of the perforators visualized on MRA correlated with the intraoperative findings in 100% of the patients. Because there was a high degree of user variability introduced when absolute measurements of such small structures were made on a viewing station by the radiologist and because intraoperative measurement of vessel diameter at the point at which perforators exit the fascia was impractical, we evaluated the relative size of perforator vessels for each patient.

In 45 of 50 flaps (90%), the surgeon used the preoperatively selected vessel for tissue transfer (42 deep inferior epigastric perforator [DIEP] and three superficial inferior epigastric artery [SIEA] flaps). The surgeon selected an SIEA flap in three cases where the deep inferior epigastric artery perforators were very small and the superficial inferior epigastric artery was relatively large. The MRA successfully predicted the need to use an SIEA flap due to inadequate deep inferior epigastric perforators in three of three flaps (100%).

In 44 of 50 flaps (88%), a distinct Doppler signal was detected on the surface of the abdominal wall preoperatively in locations that correlated with the "coordinate map" of the perforators produced using MRA. In the six flaps in which a correlating Doppler signal could not be detected, the surgeon found perforators intraoperatively in the location anticipated by the preoperative MRA; flaps were transferred based on these perforators. Although this article does not quantify a false-positive rate for vessel detection with Doppler sonography, in most flaps the Doppler detected extraneous signals that did not correlate with significantly sized perforators at surgery.

DISCUSSION

Preoperative anatomic imaging markedly enhances the ability of a surgeon to devise a surgical strategy before going to the operating room and is employed routinely for all patients in our practice. We consider the foremost factors in determining the optimal perforator upon which to base a flap to be vessel diameter, location at which a vessel enters the planned flap, and vessel arborization pattern within the subcutaneous fat. In this regard, a larger-vessel diameter, central location of the vessel on the flap, and a pattern of arborization that suggests perfusion of the tissue to be transferred are all considered favorable.

The course of a vessel is a secondary factor that influences perforator selection. If two vessels appear to be of similar size and both have equivalent vascular arborization patterns within the subcutaneous fat, then the vessel that can be dissected more easily or with the least trauma to the rectus abdominis muscle is selected. A perforator with a shorter intramuscular course or a septocutaneous vessel are favored because the dissection is technically easier, proceeds more quickly, and reduces trauma to the rectus abdominis muscle. Figure 3 shows an abdominal MRA that demonstrates a perforator coursing through the left rectus abdominis muscle. Figure 4 shows an abdominal MRA demonstrating a large septocutaneous vessel that courses medial to the rectus abdominis muscle and arborizes toward the center of the flap.

Preoperative knowledge of vessel anatomy contributes to improved flap design. Although flap design itself was not a specific parameter evaluated in this study, in nine patients, the surgeon shifted the abdominal perforator flap either more cephalad or caudal than usual based upon the vascular anatomy demonstrated on MRA. Flap design was altered in a cephalad direction to capture perforators above the umbilicus when adequate perforators were not present in the lower abdomen. Flap design was shifted caudally when the superficial inferior epigastric system appeared dominant or the best perforators were located toward the pubis. Without anatomic preoperative imaging, such modifications could never be made.

Figure 3 Abdominal magnetic resonance imaging angiography (axial view). Arrow points to a perforator with an intramuscular course through the left rectus abdominis muscle.

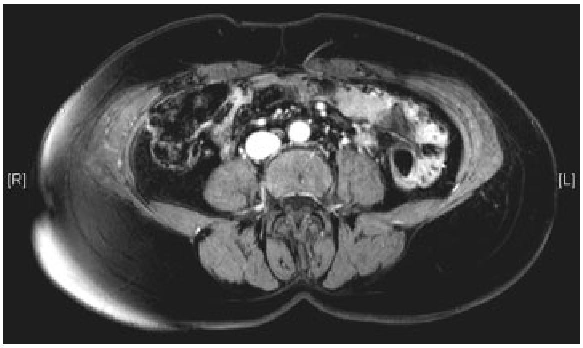


Figure 4 Abdominal magnetic resonance imaging angiography (axial view) demonstrating a large septocutaneous vessel, coursing medial to the left rectus abdominis muscle and arborizing toward the center of the flap.

In select cases, the assurance of the presence of suitable perforator vessels may allow a patient with a history of abdominal surgery, which would have previously been considered a contraindication, to undergo an abdominal perforator flap procedure.[20] As a dramatic example, we present a patient imaged preoperatively with CTA. The patient had a history of central abdominal liposuction and a miniabdominoplasty 18 years ago, but desired the abdomen as the donor site for breast reconstruction. Figure 5 demonstrates a single perforator identified at 4.6 cm inferior and 5.2 cm lateral to the umbilicus. A DIEP flap was planned and successfully transferred based upon this vessel. Traditionally, without preoperative imaging, this patient would never have been a candidate for DIEP flap breast reconstruction.

Increased surgical efficiency and decreased operating time are additional benefits of preoperative imaging. We compared the average operating time for 15 DIEP flaps in 10 patients imaged preoperatively with MRA to the same senior surgeon's average operating time in a published 10-year review in which no patient underwent preoperative imaging.[21] The average operating time for a

Figure 5 Abdominal computed tomographic angiography (axial view). Arrow points to a large right lateral row perforator in a patient with a history of a miniabdominoplasty and central abdominal liposuction 18 years ago.

unilateral DIEP flap reconstruction decreased from 4.6 to 3.5 hours. The average operating time for a bilateral DIEP flap reconstruction decreased from 7.3 to 6 hours.

Gadolinium-containing contrast agents used for MRA have several distinct advantages over iodinated contrast agents used for CTA. The incidence of an acute allergic reaction to iodinated contrast is 3%, which is orders of magnitude higher than the 0.07% incidence of allergic reaction to gadolinium contrast.[13,18] Furthermore, unlike gadolinium contrast agents, iodinated CT contrast agents can induce renal insufficiency even in patients with normal renal function.[14,19] Gadolinium contrast agents can potentially induce nephrogenic systemic fibrosis (NSF), also called nephrogenic fibrosing dermopathy. Reports of NSF, however, have been limited to patients with impaired renal function. NSF is a very rare disease with just over 200 cases reported worldwide.[22,23] Although our patients are generally healthy and thus are not at significant risk for developing NSF, a creatinine level is drawn preoperatively in patients with a history of renal disease, hypertension, diabetes, or any other indication that renal function may be impaired.

Our initial experience with MRA demonstrated zero false-positive results, only two false-negative results in 50 flaps, and an excellent ability to "map" perforator locations. We thus believe the accuracy of MRA for determining perforator location should be considered on par with CTA. In Masia et al's similarly designed study mapping the three largest perforators on each hemiabdomen using CTA,[8] there were no false-positive and no false-negative results. Rozen et al's study, mapping perforators greater than 1 mm using CTA,[24] showed one false-positive and one false-negative result.

A careful review of our data demonstrated that in the two flaps in which the surgeon transferred tissue on a vessel that was not visualized on the preoperative MRA, the vessel used was a lateral row perforator. We suspect that this reflects the fact that the MRA imaging protocol we employed did not always effectively detect lateral row vessel signals because fat suppression was sometimes imperfect. We have since refined our MRA protocol to eliminate the problem of inadequate visualization of lateral row perforators caused by signal interference from the thigh and buttock fat. To achieve better fat suppression laterally, we now use a 1.5-T scanner to eliminate the inhomogenous fat suppression associated with a 3-T magnet. We have also made several other modifications, described below, that enhance image quality and expand the field of view.

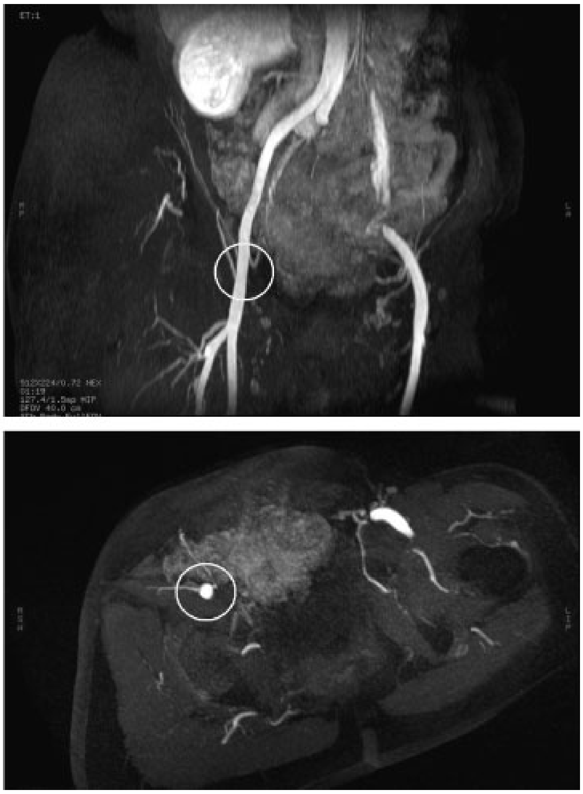
Gadobenate dimeglumine (Bracco, Princeton, NJ) is a gadolinium-based contrast agent that binds to albumin and has a longer half-life in the bloodstream. This allows an increase in the imaged craniocaudal field of view. Using this agent, we can now image a patient in the prone position from the level of the upper abdomen to the level of the mid thigh. Thus, in one MRA study, we are able to visualize abdominal, gluteal, and thigh perforators. A patient imaged in this manner who unexpectedly is not a candidate for an abdominal perforator flap or suddenly changes her preference to undergo a gluteal or transverse upper gracilis perforator flap does not require any additional studies.

We scan patients in the prone position because the quality of images obtained of the abdominal wall perforators in this position is superior to those obtained in the supine position. Respiratory motion is reduced in the prone position and motion artifact is minimized. The location at which the perforators exit the anterior rectus fascia in relation to the umbilical stalk's attachment at the level of the anterior rectus fascia is unaffected by the prone position because fascia is a stable structure. Furthermore, the curved shape of the buttock is greatly distorted in the supine position, whereas the anatomy of the abdominal wall is comparatively unaffected in the prone position. Scanning in the supine position distorts the gluteal perforator location and makes it difficult to accurately locate the vessels intraoperatively when the patient is then in the prone position. We have found that imaging patients in the prone position allows us to accurately assess both the gluteal and abdominal perforators.

Three-dimensional reconstructions facilitate the visualization of vessels from different perspectives, which can aid in preoperative planning. Figure 6 shows two images from an abdominal MRA of the SIEA and superficial circumflex iliac artery branching from the femoral artery. The 3-D reconstruction software application allows reconstructed images to be rotated 360 degrees. Such images allow us to more easily identify situations in which the SIEA and superficial circumflex iliac artery originate from a common trunk. This information is clinically important because it can affect pedicle selection. A common trunk generally has a larger diameter and potentially makes an SIEA flap a more attractive option than in situations where the SIEA vessel has an independent origin.

In comparison with our initial protocol, our current imaging protocol appears to render images with improved resolution and with sufficient fat suppression to reliably visualize lateral row abdominal perforators. We anticipate that the new protocol will reduce the incidence of false-negative results.

For surgeons interested in using MRA, our current MRA protocol in detail is as follows. Preoperative imaging of the anterior abdominal wall, buttock, and upper thigh is performed on a long bore, self-shielded General Electric (GE) 1.5-T MRI scanner with software version 14 (GE Signa HDx, Waukasha, WI). The field of view extends vertically from 3 cm above the umbilicus to the upper thigh and transversely is set to match the width of the patient. Slice thickness



A

B

Figure 6 (A,B) Software application allows 360-degree rotation of 3-D reconstruction magnetic resonance imaging angiography images, which allows clear identification that the superficial inferior epigastric artery (SIEA) and superficial circumflex iliac artery do not originate from a common trunk off the femoral artery. Circle is surrounding the origin of the SIEA and superficial circumflex iliac artery off of the femoral artery.

is 3 mm with 1.5-mm overlap. The acquisition matrix is 512×192 to 256. The length of breath hold is $\sim$40 seconds for each acquisition. An axial LAVA sequence is acquired before and after the contrast injection with the following parameters: TR/TE/flip = 4.1/1.9/15 degrees. The injection consists of 20 mL of gadobenate dimeglumine, followed by 20 mL normal saline at a rate of 1.5 mL per second. Three successive images are acquisitioned, with the first acquisition starting 5 seconds after observing gadolinium arriving in the aorta on magnetic resonance fluoroscopy. Three-dimensional surface rendering is generated on an Advantage Windows Workstation.

CONCLUSION

MRA allows a surgeon to visualize the superficial and deep inferior epigastric vasculature in a reproducible format, accurately map the location at which perforators penetrate the anterior rectus fascia, determine relative vessel size, view the course traversed by a given perforator, and evaluate the arborization pattern of each perforator through the subcutaneous fat. Improved flap design to capture the best available perforator for each patient is, in our opinion, the net result of preoperative imaging. Additionally, patients who were traditionally not candidates for abdominal perforator flap breast reconstruction may, in select cases, become candidates. MRA is instrumental in our practice of perforator flap breast reconstruction. Not only has it enhanced our ability to select the best perforators for each patient, but it has allowed us to do so in the preoperative period in the comfort of a relaxed environment. Shifting the brunt of the perforator selection process to the preoperative period improves efficiency in the operating room and reduces operating time. We consider MRA to be the preoperative imaging method of choice because unlike CTA, this modality does not require exposure of patients to the harmful effects of ionizing radiation or to iodinated contrast agents. We believe that preoperative imaging is an invaluable tool in the perforator flap surgeon's armamentarium.

REFERENCES

1. Blondeel PN, Demuynck M, Mete D, et al. Sensory nerve repair in perforator flaps for autologous breast reconstruction: Sensational or senseless? Br J Plast Surg 1999;52:37–44
2. Moon HK, Taylor GI. The vascular anatomy of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. Plast Reconstr Surg 1988;82:815–832
3. Rozen WM, Palmer KP, Suami H, et al. The DIEA branching pattern and its relationship to perforators: the importance of preoperative computed tomographic angiography for DIEA perforator flaps. Plast Reconstr Surg 2008;121:367–373
4. Kikuchi N, Murakami G, Kashiwa H, et al. Morphometrical study of the arterial perforators of the deep inferior epigastric perforator flap. Surg Radiol Anat 2001;23:375–381
5. Heitmann C, Felmerer G, Durmus C, et al. Anatomical features of perforator blood vessels in the deep inferior epigastric perforator flap. Br J Plast Surg 2000;53:205–208
6. Vandevoort M, Vranckx JJ, Fabre B, et al. Perforator topography of the deep inferior epigastric perforator flap in 100 cases of breast reconstruction. Plast Reconstr Surg 2002;109:1912–1918
7. Allen RJ, Treece P. Deep inferior epigastric perforator flap for breast reconstruction. Ann Plast Surg 1994;32:32–38
8. Masia J, Clavero JA, Larranaga JR, et al. Multidetector-row computed tomography in the planning of abdominal perforator flaps. J Plast Reconstr Aesthet Surg 2006;59:594–599
9. Rozen WM, Phillips TJ, Ashton MW, Stella DL, Gibson RN, Taylor GI. Preoperative imaging for DIEA perforator flaps: a comparative study of computed tomographic angiography and Doppler ultrasound. Plast Reconstr Surg 2008;121:9–16
10. Rozen WM, Ashton MW, Stella DL, et al. The accuracy of computed tomographic angiography for mapping the perforators of the DIEA: a cadaveric study. Plast Reconstr Surg 2008;122:363–369

11. Brenner DJ, Hall EJ. Computed tomography-an increasing source of radiation exposure. N Engl J Med 2007;357:2277–2284
12. Stein R. Too much of a good thing? The growing use of CT scans fuel medical concerns regarding radiation exposure. Washington Post 2008 Jan 15; F1
13. Katayama H, Yamaguchi K, Kozuka T, et al. Adverse reactions to ionic and nonionic contrast media. A report from the Japanese Committee on the Safety of Contrast Media. Radiology 1990;175:621–628
14. Parfrey P. The clinical epidemiology of contrast-induced nephropathy. Cardiovasc Intervent Radiol 2005;(28 suppl 2): S3–S11
15. Safety in medical imaging. American College Radiology Radiological Society North America, Inc. Available at www.radiologyinfo.org/en/safety/index.cfm?pg=sfty_xray&bhcp=1. Accessed September 1, 2008
16. Varnholt H. Computed tomography and radiation exposure. N Engl J Med 2008;358:852–853
17. Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. Radiology 2004;232:635–652
18. Dillman JR, Ellis JH, Cohan RH, Strouse PJ, Jan SC. Frequency and severity of acute allergic-like reactions to gadolinium-containing IV contrast media in children and adults. AJR Am J Roentgenol 2007;189:1533–1538
19. Niendorf HP, Alhassan A, Geens VR, Claub W. Safety review of gadopentetate dimeglumine extended clinical experience after more than five million applications. Invest Radiol 1994; 29(suppl 2):S179–S182
20. De Frene B, Van Landuyt K, Hamdi M, et al. Free DIEAP and SGAP flap breast reconstruction after abdominal/gluteal liposuction. J Plast Reconstr Aesthet Surg 2006;59:1031–1036
21. Gill PS, Hunt JP, Guerra AB, et al. A 10-year retrospective review of 758 DIEP flaps for breast reconstruction. Plast Reconstr Surg 2004;113:1153–1160
22. Cowper SE. Nephrogenic fibrosing dermopathy [NFD/NSF Website]. 2001–2007. Available at http://www.icnfdr.org. Accessed August 7, 2008
23. Scheinfeld NS, Cowper SE. Nephrogenic fibrosing dermopathy. 2008 Jan 25. Available at http://www.emedicine.com/derm/topic934.htm. Accessed August 7, 2008
24. Rozen WM, Ashton MW, Stella DL, Phillips TJ, Grinsell D, Taylor GI. The accuracy of computed tomographic angiography for mapping the perforators of the deep inferior epigastric artery: a blinded, prospective cohort study. Plast Reconstr Surg 2008;122:1003–1009