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

Julie V. Vasile, M.D.,[1] Tiffany Newman, M.D.,[2] David G. Rusch, M.D.,[4] David T. Greenspun, M.D.,[5] Robert J. Allen, M.D.,[1] Martin Prince, M.D.,[3] and Joshua L. Levine, M.D.[1]

ABSTRACT

Preoperative imaging is essential for abdominal perforator flap breast reconstruction because it allows for preoperative perforator selection, resulting in improved operative efficiency and flap design. The benefits of visualizing the vasculature preoperatively also extend to gluteal artery perforator flaps. Initially, our practice used computed tomography angiography (CTA) to image the gluteal vessels. However, with advances in magnetic resonance imaging angiography (MRA), perforating vessels of 1-mm diameter can reliably be visualized without exposing patients to ionizing radiation or iodinated intravenous contrast. In our original MRA protocol to image abdominal flaps, we found the accuracy of MRA compared favorably with CTA. With our increased experience with MRA, we decided to use MRA to image gluteal flaps. Technical changes were made to the MRA protocol to improve image quality and extend the field of view. Using our new MRA protocol, we can image the vasculature of the buttock, abdomen, and upper thigh in one study. We have found that the spatial resolution of MRA is sufficient to accurately map gluteal perforating vessels, as well as provide information on vessel caliber and course. This article details our experience with preoperative imaging for gluteal perforator flap breast reconstruction.

KEYWORDS: Gluteal artery perforator flap, superior gluteal artery perforator flap, inferior gluteal artery perforator flap, magnetic resonance imaging angiography, preoperative imaging

The ability to dissect a perforating vessel of adequate caliber to provide blood flow to a flap of skin and subcutaneous fat without sacrificing the muscle has advanced breast reconstruction. Breasts with a natural appearance and feel can be created from a patient's own tissue while minimizing injury to the underlying muscle at the donor site. In contrast to implant breast reconstruction, sensation can develop in the reconstructed

[1]Center for Microsurgical Breast Reconstruction; [2]Weill Cornell Imaging at New York Presbyterian; [3]Columbia and Cornell Universities, New York, New York; [4]Drucker, Genuth, and Augenstein, P.C., Rockville, New York; [5]Greenwich Hospital, Greenwich, Connecticut.

Address for correspondence and reprint requests: Julie Vasile, M.D., Center for Microsurgical Breast Reconstruction, 1776 Broadway, Suite 1200, New York, NY 10019 (e-mail: jvasile1@msn.com).

Received: February 17, 2009. Accepted after revision: April 13, 2009.

DOI 10.1055/s-0029-1225535. ISSN 0743-684X.

breast as nerves grow into the autologous tissue and/or with direct coaptation of a sensory nerve in the perforator flap with a sensory nerve in the chest.[1,2] The abdomen is our first choice of donor tissue for breast reconstruction. However, gluteal flaps based on perforating vessels are an excellent alternative for patients with insufficient abdominal tissue, prior abdominoplasty, extensive abdominal liposuction, or failed abdominal flaps.

Gluteal artery perforator (GAP) flaps are nourished by arteries that perforate through the gluteal muscles and are harvested with preservation of the muscle and function.[3–5] The superior gluteal artery exits the pelvis superior to the piriformis muscle and its branches perforate through the gluteus medius and gluteus maximus muscles. The inferior gluteal artery exits the pelvis inferior to the piriformis muscle, and its branches perforate through the gluteus maximus muscle.[6] Superior gluteal artery perforator (SGAP) flaps harvest the superior buttock tissue. Inferior gluteal artery perforator (IGAP) flaps harvest the inferior buttock tissue. The in-the-crease IGAP flap is designed to remove the inferior buttock tissue "saddle bags" and hide most of the scar in the inferior gluteal crease.[3] The decision to choose an SGAP or IGAP flap is based on each individual patient's preference and anatomy.

A patient's preference toward an SGAP or IGAP flap is influenced by the trade-offs of each gluteal flap procedure. The scar from an SGAP flap can be covered by a bathing suit, but the scar is prominent on the buttock. In addition, harvesting an SGAP flap can disturb the superior fullness of the buttock, which is considered the aesthetic unit of the buttock. The scar from an IGAP flap is located in a less prominent area of the buttock in the inferior gluteal crease or where the shadow falls, but the lateral portion of the scar can be visible in a bathing suit. Harvesting an IGAP flap removes the "saddlebags," commonly an area of abundant fat deposition in women.

The highly variable anatomy of gluteal vessels can be challenging when designing an SGAP or IGAP flap. Cadaveric dissection studies show that the number and location of gluteal perforators from the superior gluteal artery and inferior gluteal artery vary greatly. The average number of relatively large perforators from the superior gluteal artery is reported to be between three to five (range, one to seven), and most of the perforators are located in a zone extending along the superior two-thirds of a line from the posterior superior iliac spine to the greater trochanter.[6,7] The average number of relatively large perforators from the inferior gluteal artery is eight (range, 4 to 12), and most of the perforators are located in a zone extending along the middle third of the lower buttock.[6]

The varying course of perforators adds another challenge to the difficulty of flap harvest. Perforators can traverse through the gluteus maximus and gluteus medius muscles at varying angles and for varying distances. They can even course between or around the gluteal muscles (septocutaneous vessel).[6] Superior gluteal artery perforators generally course through the gluteal muscle at a more vertical angle than inferior gluteal artery perforators, which can make dissection shorter, but produces a shorter SGAP flap pedicle length (6 to 8 cm). Inferior gluteal artery perforators traverse the gluteal muscle at a more oblique angle, producing a longer pedicle (8 to 10 cm), which can make the microsurgical anastomosis and insetting of the flap easier.[3,6] The vascular branching pattern of a perforator through subcutaneous fat (arborization) also varies.

The ability to preoperatively visualize gluteal perforating vessels is especially advantageous because of the high degree of vessel anatomic variability. Prior to the era of preoperative perforator imaging, a surgeon had little knowledge of an individual patient's anatomy until surgery was well underway. As a result, perforator selection could be a tedious decision process that occurred in the operating room at the expense of operating time and general anesthetic requirement. Our favored modality for GAP flap imaging has changed as technology has advanced. Initially, we only used a handheld Doppler ultrasound. A Doppler ultrasound is portable and simple to use but cannot differentiate perforating vessels from superficial and deep axial vessels, robust perforators from miniscule ones, or 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 vessels. 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 and is time-consuming.[9] The technique's most crucial drawback is an inability to produce anatomic images in a format that a surgeon can easily and independently view. As a result, we do not use this modality for imaging perforator flaps in our patients.

Increasingly, computed tomographic angiography (CTA) is used to image perforator flaps because this technique can demonstrate vessel anatomy, assess vessel caliber, accurately locate perforators, and produce anatomic images in a format that a surgeon can easily and independently view. Although CTA can be performed quickly,[8,9] 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.[10,11] 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.[12,13]

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 millisieverts [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.[14] In comparison, a computed tomography (CT) scan of the abdomen delivers 6 to 10 mSv of radiation, which is approximately equivalent to 3 years of environmental radiation.[8,10,14] 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.[15] However, we believe that alternative methods of vascular imaging should be employed whenever possible.

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.[12,16] Furthermore, unlike gadolinium contrast agents, iodinated CT contrast agents can induce renal insufficiency even in patients with normal renal function.[13,17] 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.[18,19] 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.

We have developed a protocol for preoperative gluteal artery perforator imaging that employs 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. MRI coils detect the released energy, and computer software processes the data into anatomic images. Exposure to a magnetic field or radiofrequency pulse with MRI has not been linked to the development of cancer.[20] Furthermore, the risks of anaphylaxis and nephrotoxicity in patients with normal renal function are extremely low with magnetic resonance angiography (MRA) contrast agents.[16,17] With recent advances in MRI 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 gluteal artery perforators used for breast reconstruction.

PATIENTS

Sixteen patients underwent preoperative MRA gluteal flap imaging from October 2008 to December 2008. Patients were excluded from receiving an MRA if they had a contraindication 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 were excluded. Patients who could not undergo MRA were imaged with CTA. Three patients imaged with MRA who underwent gluteal flap breast reconstruction are presented as case studies.

METHODS

A marker was placed at the superior point of the gluteal crease at the imaging center, and a photograph of the buttock was included in the radiologist's report. Figure 1

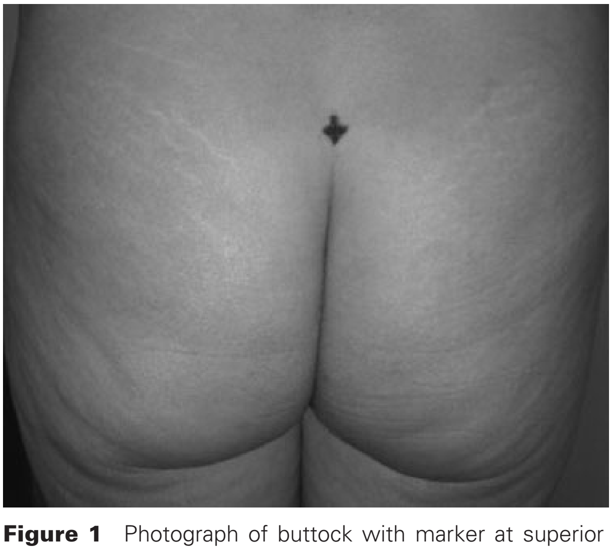


Figure 1 Photograph of buttock with marker at superior point of gluteal crease.

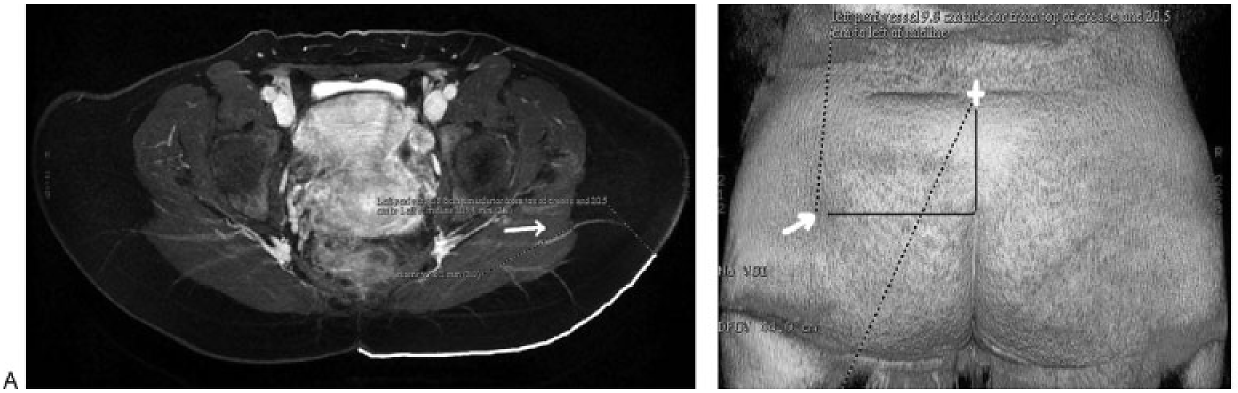


Figure 2 (A) Magnetic resonance imaging angiography (MRA; axial view). Arrow points to relatively large gluteal artery perforator. Curved red line demonstrates location of perforator calculated by measuring along curved skin surface from a point perpendicular to the point that perforator exits muscle fascia to the marker. (B) MRA three-dimensional reconstructed image demonstrating the location of the same perforator in relation to the marker along an x-, y-axis. The cross represents marker at superior point of gluteal crease. Arrow represents location of perforator at the skin surface.

is an example of a photograph taken at the imaging center. Preoperative MRA of the anterior abdominal wall, buttock, and upper thigh was performed on a long-bore, self-shielded General Electric 1.5-T MRI scanner with software version 14 (General Electric Signa HDx, Waukasha, WI). The position of each patient was prone, with additional high-resolution images taken in the supine position. The field of view extended vertically from 3 cm above the umbilicus to the upper thigh and transversely was set to match the width of the patient. Slice thickness was 3 mm with 1.5-mm overlap. The acquisition matrix was 512×192 to 256. The length of breath hold was $\sim$40 seconds for each acquisition. An axial LAVA sequence was acquired before and after the contrast injection with the following parameters: repetition time/echo time/flip $=$ 4.1/1.9/15 degrees. The injection consisted of 20 mL of gadobenate dimeglumine, followed by 20 mL of normal saline at a rate of 1.5 mL per second. Three successive images were acquisitioned, with the first acquisition starting 5 seconds after observing gadolinium arriving in the aorta on magnetic resonance fluoroscopy. Three-dimensional (3D) surface rendering was generated on an Advantage Windows Workstation.

The relatively large perforators (comparing size of one vessel to another) branching from the superior and inferior gluteal artery perforators were identified on each side of the buttock by a radiologist. The diameter in millimeters and location of each of the identified perforators were determined at the point at which the perforator exited the gluteus maximus or gluteus medius muscle fascia. The location of each of these perforators at the fascia level was measured at a perpendicular point on the skin surface in relation to a marker placed at the superior point of the gluteal crease on an x-, y-axis, where x denoted the distance in centimeters left or right from the marker and y denoted the distance in centimeters above or below the marker. The x, y measurements were taken along the curved surface of the buttock skin from the reconstructed MRA images when the patient was in the prone position. Figure 2 demonstrates an example of how measurements are determined from an identified gluteal artery perforator on an MRA. The course of each of the vessels through the gluteus muscle or around the gluteus muscle (septocutaneous vessel) was also noted and whether it joined the superior or inferior gluteal artery.

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

RESULTS

One hundred sixty relatively large gluteal vessels were identified by MRA in 32 buttocks. The characteristics of the gluteal vessels are organized in Table 1. Of the large-caliber vessels identified, 142 were intramuscular and 18 were septocutaneous. Ninety-two large vessels (57.5%) branched from the superior gluteal artery, 56 large vessels (35%) branched from the inferior gluteal artery, and 11 large vessels (7.5%) branched from the deep

Table 1 Characteristics of Large* Gluteal Vessels Identified on Magnetic Resonance Imaging Angiography

I. Number of buttocks	32
II. Total number large vessels identified	160
A. Number branching from superior gluteal artery	92 (57.5%)
a. Number of perforators	86
b. Number of septocutaneous vessels	6
B. Number branching from inferior gluteal artery	56 (35%)
a. Number of perforators	54
b. Number of septocutaneous vessels	2
C. Number branching from deep femoral artery	12 (7.5%)
a. Number of perforators	2
b. Number of septocutaneous vessels	10
III. Average number of large vessels per buttock	4.7 (range, 2–12)
A. Average number branching from superior gluteal artery	2.9 (range, 1–5)
B. Average number branching from inferior gluteal artery	1.8 (range, 0–7)
C. Average number branching from deep femoral artery	0.4 (range, 0–2)

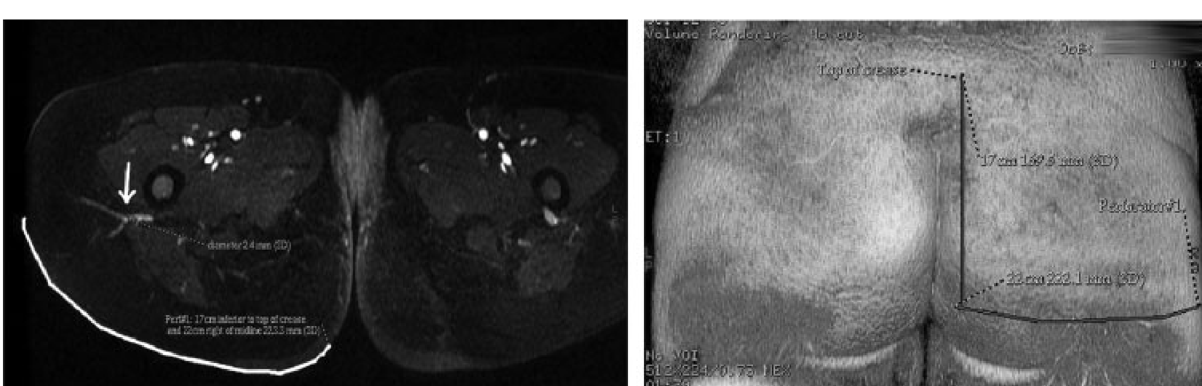
*Relatively large vessel in comparison to the size of other vessels in a patient.

femoral artery. An average of 2.9 (range, 1 to 5) relatively large vessels branched from the superior gluteal artery per buttock and an average of 1.8 (range, 0 to 7) relatively large vessels branched from the inferior gluteal artery per buttock. These numbers are lower than the cadaveric studies because only significantly sized vessels that could support a large flap were selected. The locations of all 160 gluteal vessels at the level of the superficial gluteal fascia were mapped and showed tremendous variability in location. The vessels branching from the superior gluteal artery correlated with the cadaveric studies and were located in a large general zone along the superior two-thirds of a line from the posterior superior iliac spine to the greater trochanter. The vessels branching from the inferior gluteal artery also correlated with the cadaveric studies and were located in a large general zone along the middle third of the buttock. The vessels branching from the deep femoral artery were located along the inferior lateral buttock in some patients.

Case 1

The first case was a 43-year-old woman with a history of 14 operations over 3 years for reconstruction of a right breast partial mastectomy with radiation and for a symmetrizing left breast augmentation. The operations included implant reconstruction, multiple infections, exchange of implants, extrusion of implant, placement of alloderm (LifeCell Corporation, Branchburg, NJ), removal of infected alloderm, pedicled latissimus dorsi muscle flap, and ultimately removal of implant on the right side. The patient had capsular contracture and malposition of the implant on the left side. The patient was not a candidate for an abdominal perforator flap reconstruction because she had a history of extensive

A



B

Figure 3 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating a branch of the right deep femoral artery traveling around the right gluteus maximus muscle (septocutaneous vessel). (B) MRA three-dimensional reconstructed image demonstrating the location of the septocutaneous vessel in relation to the skin surface anatomy of the buttock.

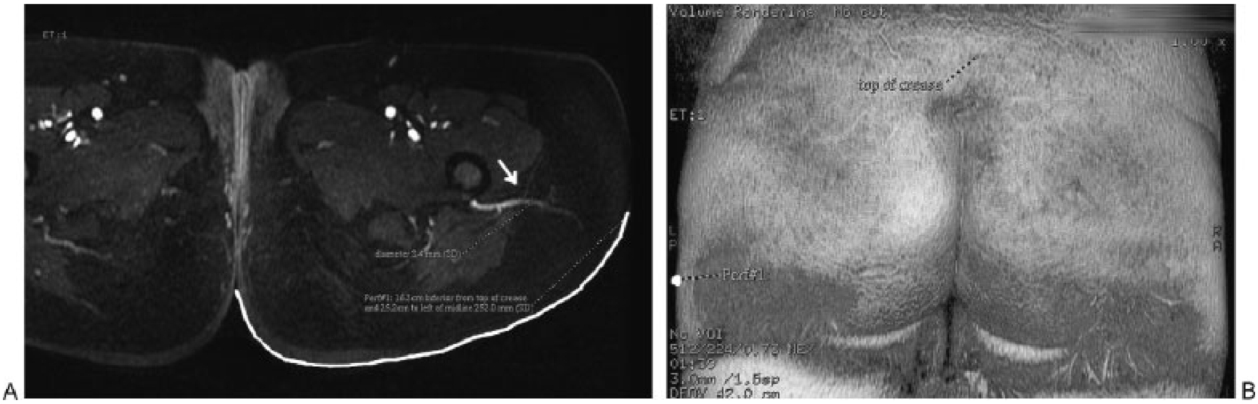


Figure 4 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating a septocutaneous vessel from a branch of the left deep femoral artery. (B) MRA three-dimensional reconstructed image demonstrating the location of the septocutaneous vessel in relation to the skin surface anatomy of the buttock (white dot on lateral left buttock).

abdominal liposuction. The patient desired bilateral in-the-crease inferior gluteal flaps to reconstruct the right breast and to augment the left breast after removal of the left implant.

An MRA was performed to identify a vessel that would be a suitable candidate for the in-the-crease gluteal flap (i.e., a relatively large vessel located inferiorly to enable most of the scar to be hidden in the inferior gluteal crease and located laterally to enable harvest of the posterior lateral subcutaneous fat). The MRA identified one vessel for the right flap and two vessels for the left flap that met the criteria. Figure 3A is an MRA demonstrating a branch of the right deep femoral artery traveling around the right gluteus maximus muscle (septocutaneous vessel). Figure 3B demonstrates the location of the septocutaneous vessel in relation to the skin surface anatomy on a 3D reconstructed image. Figure 4 is an MRA demonstrating a septocutaneous vessel from a branch of the left deep femoral artery and the location of the vessel in relation to the skin surface anatomy on a 3D reconstructed image. Figure 5 is an MRA demonstrating a left intramuscular inferior gluteal artery perforator and the location of the vessel in relation to the skin surface anatomy on a 3D reconstructed image. Figure 6 are photographs of posterior and lateral views of the donor site with the flaps and septocutaneous vessel locations marked. *O* marks the location of the septocutaneous vessel based on the coordinate measurements from the MRA. *X* marks the Doppler signal of the septocutaneous vessel. Each flap was designed to incorporate the septocutaneous vessel, harvest the posterior lateral subcutaneous fat, and result in a scar that is hidden in the inferior gluteal crease.

In the right flap, the septocutaneous vessel was identified intraoperatively in the location predicted by the preoperative MRA. The relatively large caliber and course of the septocutaneous vessel predicted by the MRA was confirmed intraoperatively. The right flap was successfully harvested and transferred based on the preoperatively selected septocutaneous vessel. In the left flap, both the septocutaneous vessel and intramuscular

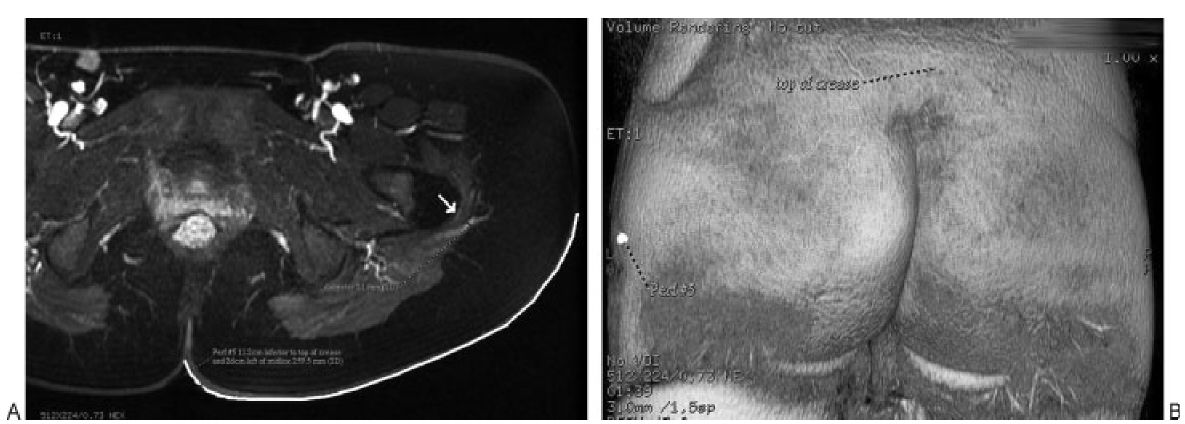


Figure 5 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating an inferior gluteal artery perforator coursing through the left gluteus maximus muscle. (B) MRA three-dimensional reconstructed image demonstrating the location of the intramuscular perforator in relation to the skin surface anatomy of the buttock (white dot on lateral left buttock).

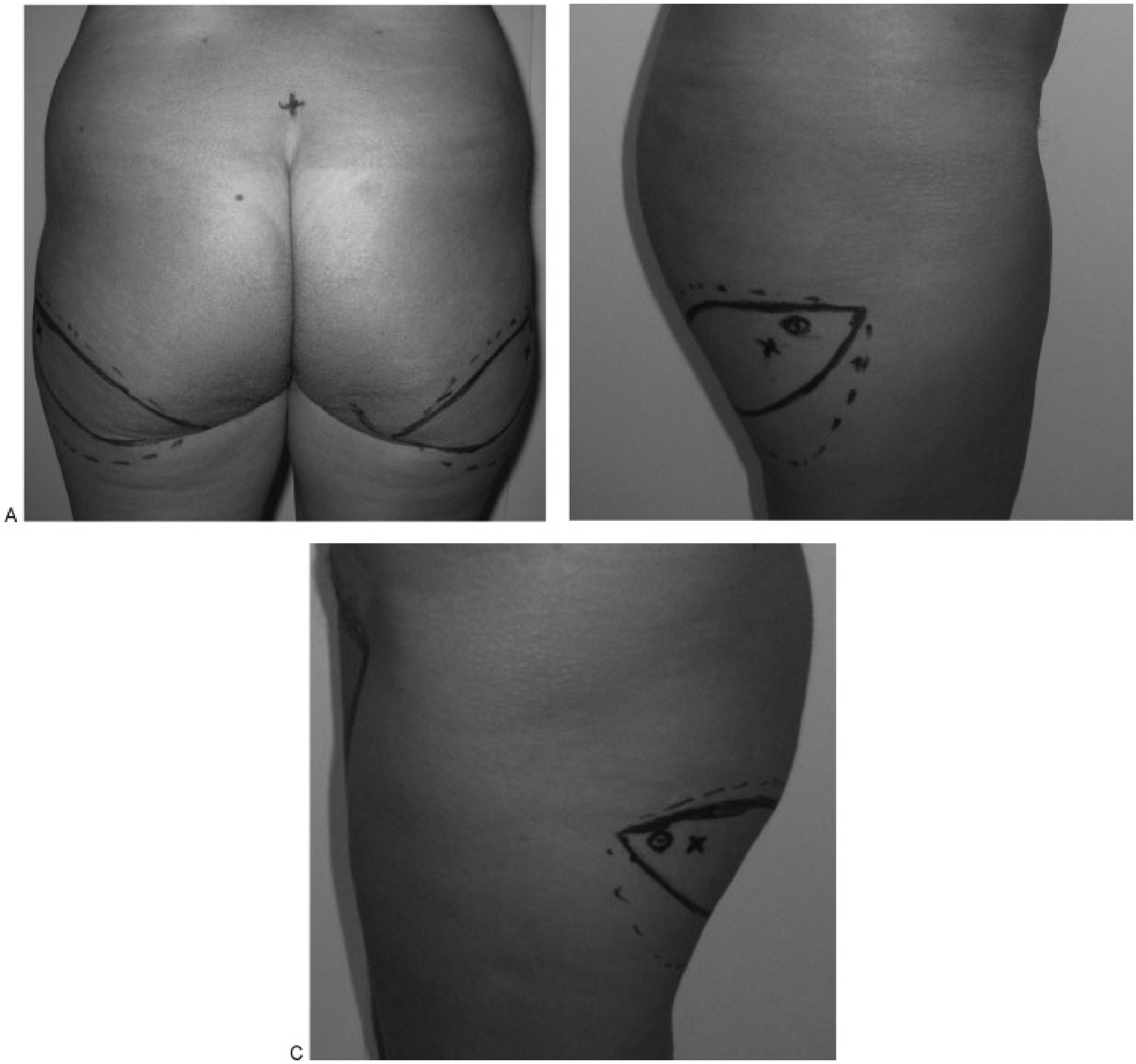


Figure 6 (A) Photograph of buttock (posterior view). Bilateral inferior in-the-crease gluteal flaps are outlined in black marker. Dotted line represents planned beveling of subcutaneous fat. (B,C) Photographs of buttock (lateral views). Circle denotes location of vessel using coordinate measurements calculated from the magnetic resonance imaging angiography. *X* denotes Doppler signal of the vessel.

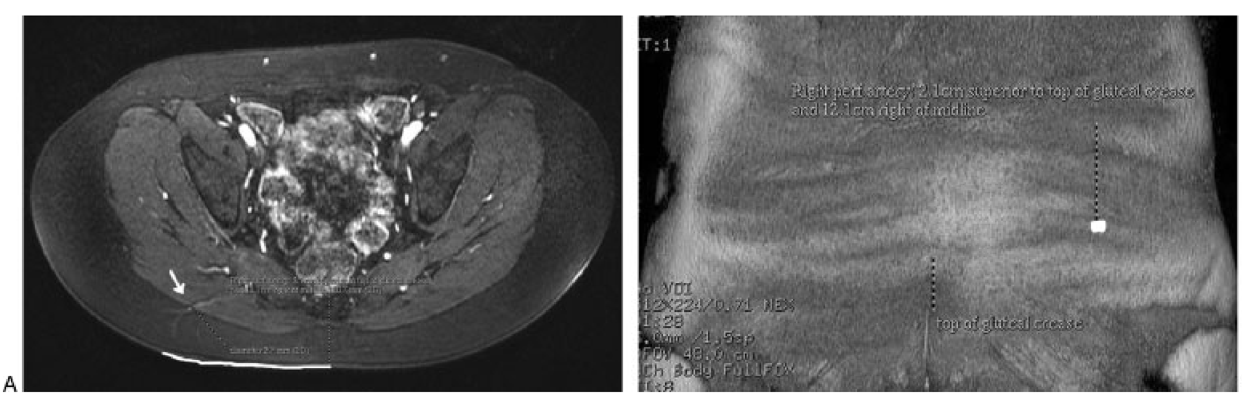
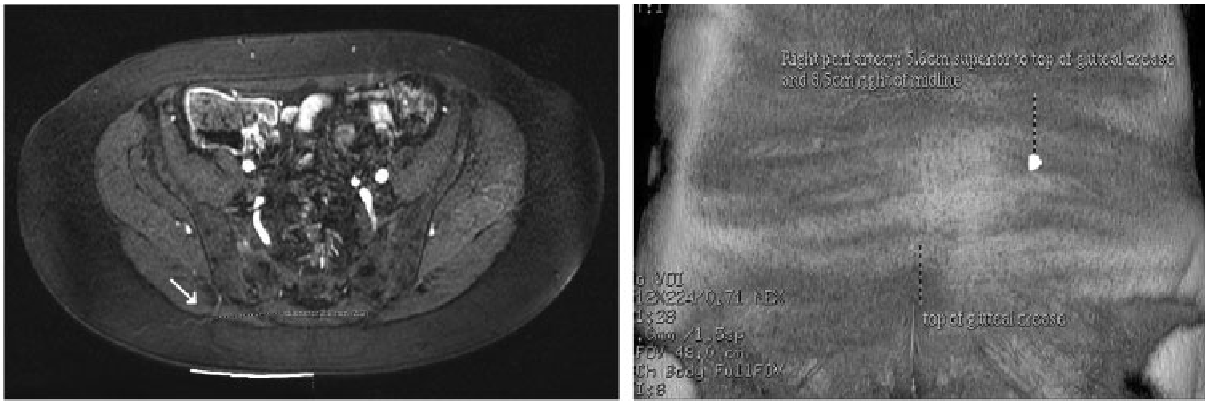


Figure 7 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating a superior gluteal artery perforator coursing through the right gluteus maximus muscle. (B) MRA three-dimensional reconstructed image demonstrating the location of the perforator in relation to the skin surface anatomy of the buttock (white dot on upper right buttock).



A B

Figure 8 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating a second superior gluteal artery perforator coursing through the right gluteus maximus muscle. (B) MRA three-dimensional reconstructed image demonstrating the location of the perforator in relation to the skin surface anatomy of the buttock (white dot on upper right buttock).

perforator were identified in the locations predicted by the preoperative MRA. The relatively large caliber and course of both vessels predicted by the MRA were confirmed intraoperatively. Although the vessel calibers of the intramuscular perforator and the septocutaneous vessel were similar, the intramuscular perforator was chosen to successfully carry the left flap due to an easier dissection. The dissection of the septocutaneous vessel was unexpectedly more difficult because the vessel was enveloped by thick fascia.

In both flaps, the MRA accurately determined vessel location, caliber, and course. There were no large vessels visualized on MRA that were not found in situ at surgery (false-positive). The surgeon did not encounter intraoperative vessels of significant size that were not identified on the preoperative MRA (false-negative).

Case 2

A 52-year-old woman had a history of failed right deep inferior epigastric perforator flap breast reconstruction. The patient desired autologous reconstruction with a superior gluteal flap. MRA was performed to identify a vessel that would be a suitable candidate for an SGAP flap (i.e., a relatively large vessel located in an area that would enable harvest of the superior gluteal subcutaneous tissue and the scar to be covered by underwear). The right buttock was selected as the donor site to maintain the patient in the left lateral decubitus position during flap harvest and dissection of the recipient vessels.

The MRA identified two suitable vessels in the right buttock. Figure 7 is an MRA demonstrating a superior gluteal artery perforator coursing through the right gluteus maximus muscle and the location of the vessel in relation to the skin surface anatomy on a 3D reconstructed image. Figure 8 is an MRA demonstrating a second intramuscular superior gluteal artery perforator and the location of the vessel in relation to the skin surface anatomy on a 3D reconstructed image. The locations of the Doppler signals of the two identified perforators were located within 0.5 cm of the locations of the perforators predicted by the MRA. An SGAP flap was designed to incorporate the identified perforators and enable the scar to be covered by underwear. Figure 9 is a photograph of the patient positioned in the left lateral decubitus position, with the flap and two perforators marked on the right buttock.

Both intramuscular superior gluteal artery perforators were identified intraoperatively in the location predicted by the preoperative MRA. The relatively large caliber and course of both vessels predicted by the MRA were confirmed intraoperatively. The right SGAP flap was successfully harvested and transferred based on the intramuscular perforator located most centrally in the flap. There were no large vessels visualized on MRA that were not found in situ at surgery (false-positive). The

Figure 9 Photograph of patient positioned in the left lateral decubitus position on a bean bag. Flap outlined in marker on the right buttock. Dots represent location of two perforators using coordinate measurements calculated from the magnetic resonance imaging angiography.

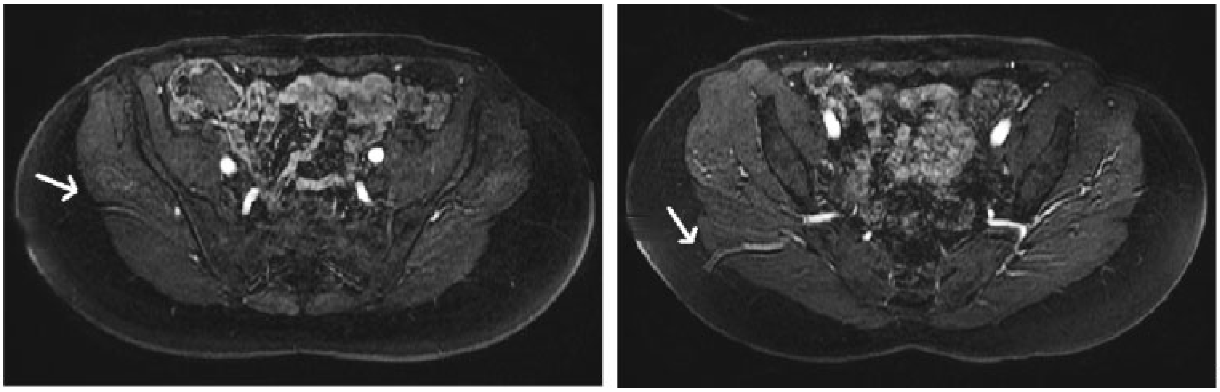


Figure 10 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating a right septocutaneous vessel branching from the superior gluteal artery and coursing between the gluteus maximus and medius muscles. (B) MRA (axial view) demonstrating a right superior gluteal artery perforator coursing through the right gluteus maximus muscle and splitting into two parallel branches.

surgeon did not encounter intraoperative vessels of significant size that were not visualized on the preoperative MRA (false-negative).

Case 3

A 56-year-old woman had a history of failed bilateral implant breast reconstruction with capsular contractures and discomfort. The patient desired autologous breast reconstruction with gluteal flaps because the abdomen could not be used as a donor site due to extensive abdominal liposuction. MRA was performed to image the gluteal vessels. On each side of the buttock, the MRA showed several suitable vessels on which to base a gluteal flap. Superolateral vessels were chosen to minimize a depressed contour deformity of the buttock. Both an intramuscular perforator and a septocutaneous vessel branching from the superior gluteal artery were identified in a superolateral location on each side of the buttock on MRA, as seen in Figs. 10 and 11. The width of the skin island of each flap was narrow, but designed to encompass both vessels on each side of the buttock and result in two symmetrical scars, as shown in Fig. 12. Planned beveling to harvest fat superiorly and maintain aesthetic fullness of the superior buttock can also be seen in Fig. 12. The locations of the Doppler signals of the vessels were located within 0.5 cm of the locations predicted by the MRA.

Both gluteal flaps were harvested simultaneously by two surgeons. The right flap was successfully harvested on the septocutaneous vessel, and the left flap was successfully harvested on the intramuscular perforator. The choice of vessel was solely based on the surgeon's personal preference for an intramuscular or septocutaneous vessel dissection. The dissection time for each flap was identical. There were no large vessels visualized on MRA that were not found in situ at surgery (false-positive). The surgeon did not encounter intraoperative vessels of significant size that were not visualized on the preoperative MRA (false-negative).

Our initial experience using MRA for preoperative imaging of the buttock demonstrated no

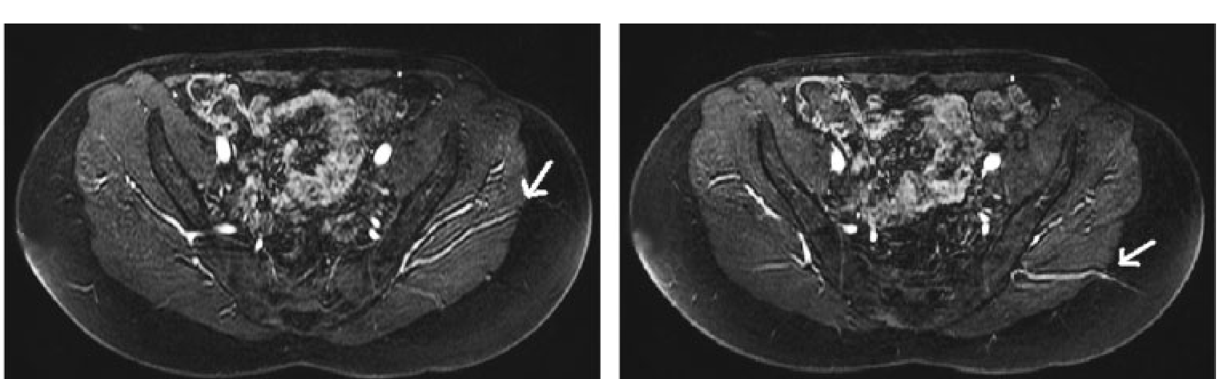


Figure 11 (A) Magnetic resonance imaging angiography (MRA; axial view) demonstrating a left septocutaneous vessel branching from the superior gluteal artery and coursing through the gluteus maximus and medius muscles. (B) MRA (axial view) demonstrating a left superior gluteal artery perforator coursing through the left gluteus maximus muscle.

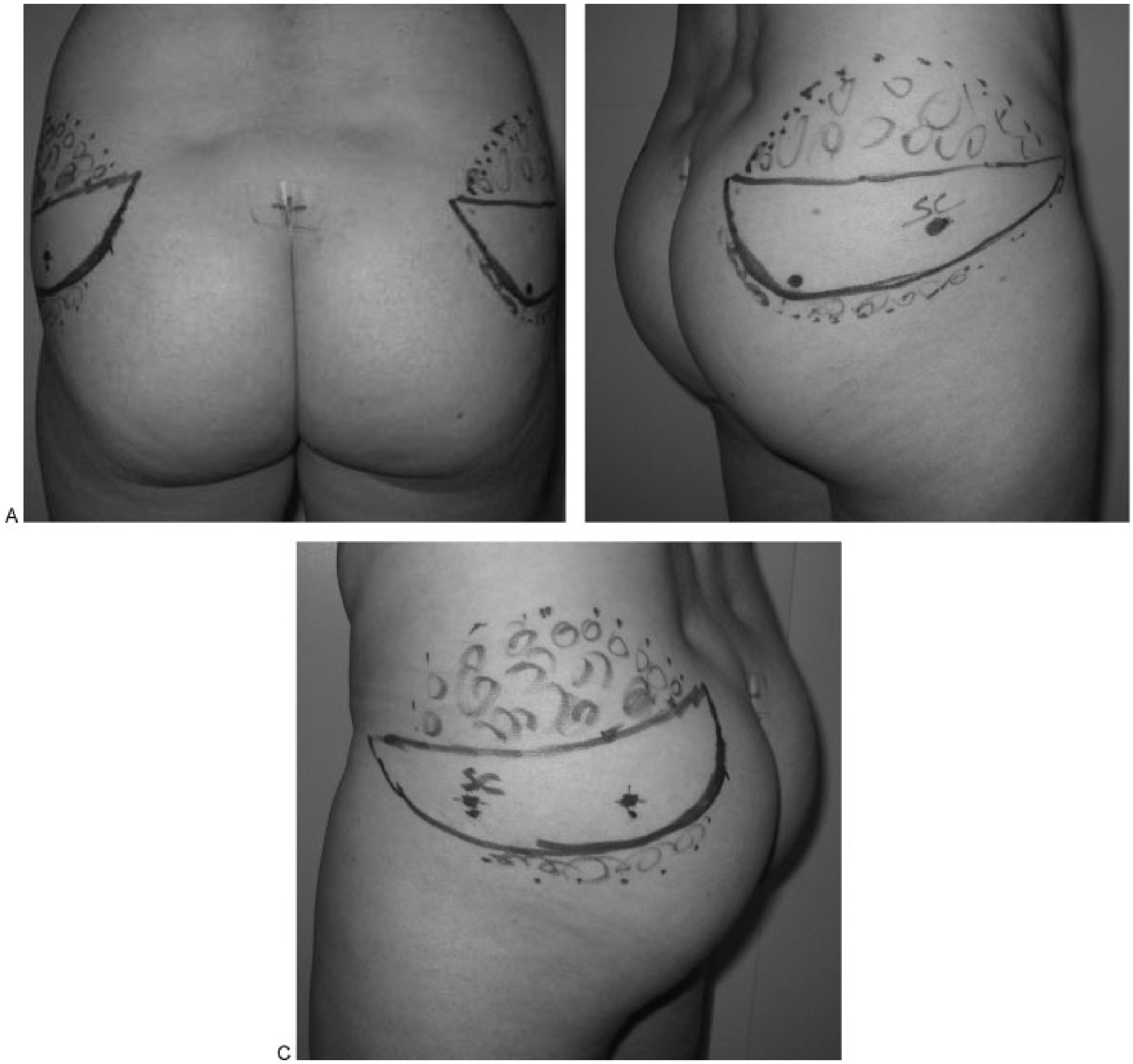


Figure 12 (A) Photograph of buttock (posterior view) with two superolateral flaps outlined in marker. The width of the skin island of each flap was narrow, but designed to encompass both a septocutaneous (marked SC) and an intramuscular perforating vessel from the superior gluteal artery on each side of the buttock and result in two symmetrical scars. Planned beveling to harvest fat superiorly is shown. (B,C) Photograph of buttock (lateral views).

false-positive or false-negative results and an excellent ability to "map" vessel locations. The locations of the identified vessels, as assessed by MRA, correlated with the intraoperative findings within 1 cm in all of the flaps. The relative size (i.e., comparing size of one vessel to another for the same patient) and course of the vessels visualized on MRA correlated with the intraoperative findings in all of the flaps. Because there is a high degree of user variability introduced when absolute measurements of such small structures are made on a viewing station by the radiologist and because intraoperative measurement of vessel diameter at the point at which perforators exit the fascia is impractical, we evaluated the relative size of perforator vessels for each patient.

DISCUSSION

Selection of perforating vessels with characteristics sufficient to supply circulation to transferred tissue is essential to the success of perforator flap breast reconstruction. Preoperative anatomic imaging enables identification of the optimal vessel to provide blood flow. We consider the foremost factors in determining the optimal perforator upon which to base a flap to be vessel diameter, length of pedicle, location at which a vessel enters the planned flap, and vessel arborization pattern within the subcutaneous fat. In this regard, a larger vessel diameter, pedicle of sufficient length for insetting, 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 muscle is selected. Provided there is adequate length for insetting, a perforator with a more direct intramuscular course is favored because the dissection is usually technically easier, proceeds more quickly, and reduces trauma to the gluteal muscle. In theory, a septocutaneous vessel is advantageous because of the reduction of trauma to the gluteal muscles during the flap harvest. However, in contrast with abdominal septocutaneous vessels, we discovered the dissection can sometimes be quite tedious with gluteal septocutaneous vessels (i.e., deep femoral artery branches) that are enveloped by thick fascia.

Preoperative imaging contributes to improved flap design and is a crucial advantage with the gluteal donor site because of the enormous variety of skin flap designs possible, based on the location of the optimal vessel. The design of a flap can also be adjusted to a patient's fat distribution if a suitable vessel can be identified on MRA preoperatively. As an interesting example, we present a unilateral breast reconstruction patient who was not a candidate for an abdominal flap and who desired the use of her upper buttock/lower back fat roll to reconstruct a breast because of an abundance of fat in this location and the desire to minimize a depressed contour of her buttock. Figure 13 is an MRA showing a left septocutaneous lumbar vessel. Of note, the subcutaneous fat measured on MRA was thicker at the level of the lumbar vessel than elsewhere in the buttock: 6.5 cm at the level of the lumbar vessel compared with 5.5 cm at the next thickest area of the buttock. Figure 14 is a photograph showing the design of the flap to incorporate the lumbar vessel and superior buttock/lower back fat roll. Beveling of the fat was performed superior to the skin paddle marking to harvest the lower back fat roll.

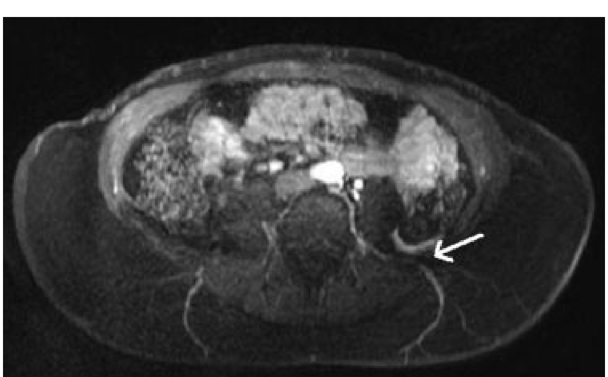


Figure 13 Magnetic resonance imaging angiography (axial view) demonstrating a left septocutaneous lumbar vessel.

Figure 14 Photograph of buttock. Flap is designed to incorporate a left septocutaneous lumbar vessel and thick fat on the superior left buttock. As a second option, a flap is designed to encompass superior gluteal artery perforators on the right buttock.

Preoperative knowledge of the location of the optimal vessels can enable the surgeon to design a smaller skin paddle directly over the vessels to decrease donor site wound-healing complications. An additional benefit is decreased anxiety for the surgeon with the knowledge that a suitable vessel exists for a patient's donor site. On occasion, we have changed the preoperative plan from a superior to an inferior GAP flap, and vice versa, based on vessel anatomy.

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. MRA has become our preferred modality for preoperative imaging of all perforator flaps because we have found the accuracy to be comparable to CTA, but with the advantage of lack of patient exposure to radiation and iodinated contrast. Our MRA experience with abdominal perforator flaps led us to make several modifications to optimize the protocol for gluteal imaging. We switched to a different gadolinium-based contrast agent, called gadobenate dimeglumine (Bracco, Princeton, NJ). This contrast agent binds to albumin and has a higher relaxivity and a longer half-life in the bloodstream to enable an increase in the craniocaudal field of view without sacrificing resolution. Using this agent, we can image a patient in the prone position from the level of the upper abdomen to the level of the midthigh. Thus, in one MRA study, we are able to visualize abdominal, gluteal, and thigh perforators. A patient imaged in this manner that unexpectedly is not a candidate for a particular perforator flap due to vessel anatomy or suddenly changes her preference does not require any additional studies.

We scan patients in the prone position because the curved shape of the buttock is compressed and distorted in the supine position. The supine position shifts the gluteal perforator location and makes it difficult to accurately locate the vessels intraoperatively when the patient is in the prone position. The abdominal wall is a flat plane, and the abdominal perforator location is comparatively unaffected in the prone position. 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. In addition, we found the quality of images obtained of abdominal wall perforators in the prone position is superior to those obtained in the supine position because respiratory motion is reduced in the prone position and motion artifact is minimized. We have found that imaging patients in the prone position allows us to accurately assess both the gluteal and abdominal perforators.

In addition, we refined our MRA protocol by switching from a 3-T to a 1.5-T scanner to improve image quality. With the 3-T scanner, artifact occasionally appeared due to signal interference from the lateral gluteal and thigh fat. The 1.5-T scanner suppresses signal from fat more homogeneously. Improved fat suppression is especially important for the gluteal donor site, which has an abundance of thick fat. Another advantage with the 1.5-T scanner is the signal from muscle is not as suppressed as with the 3-T scanner, so the relationship of perforators to muscle is more readily appreciated.

Advances in MRA computer software has enabled 3D reconstruction processing of MRA images after the images are acquired. 3D reconstruction software application allows reconstructed images to be rotated 360 degrees to visualize an identified vessel from different perspectives. This information is clinically important because it can affect pedicle selection. 3D surface rendering of MRA images aids in preoperative planning by locating an identified perforator on the skin surface. 3D surface rendering has been especially helpful in perforator selection and flap design with the gluteal donor site due to the curved anatomy.

CONCLUSION

The tremendous anatomic variability in the gluteal vasculature can make gluteal flap breast reconstruction challenging for surgeons at all experience levels with perforator flaps. MRA has sufficient resolution to visualize gluteal vessels, accurately map the location at which perforators penetrate the superficial gluteal muscle fascia, determine relative vessel size, view the course traversed by a vessel, and evaluate the arborization pattern of each vessel through the subcutaneous fat. 3D surface-rendering reconstructions to locate the vessel on the curved skin surface of the buttock have been extremely helpful with gluteal perforator selection and design of the flap. MRA is instrumental in our practice of perforator flap breast reconstruction. It has not only enhanced our ability to select the best perforators for each patient, but also 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, which can result in reduced 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. Tindholdt TT, Tonseth KA. Spontaneous regeneration of deep inferior epigastric artery perforator flaps after secondary breast reconstruction. Scand J Plast Reconstr Surg Hand Surg 2008;42:28–31
3. Allen RJ, Levine JL, Granzow JW. The in-the-crease inferior gluteal artery perforator flap for breast reconstruction. Plast Reconstr Surg 2006;118:333–339
4. Allen RJ, Tucker C Jr. Superior gluteal artery perforator free flap for breast reconstruction. Plast Reconstr Surg 1995;95: 1207–1212
5. Guerra AB, Metzinger SE, Bidros RS, Gill PS, Dupin CL, Allen RJ. Breast reconstruction with gluteal artery perforator (GAP) flaps: a critical analysis of 142 cases. Ann Plast Surg 2004;52:118–125
6. Ahmadzadeh R, Bergeron L, Tang M, Morris SF. The superior and inferior gluteal artery perforator flaps. Plast Reconstr Surg 2007;120:1551–1556
7. Nojima K, Brown SA, Acikel C, et al. Defining vascular supply and territory of thinned perforator flaps: Part II Superior gluteal artery perforator flap. Plast Reconstr Surg 2006;118: 1338–1348
8. Masia J, Clavero JA, Larrañaga JR, Alomar X, Pons G, Serret P. 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. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med 2007;357:2277–2284
11. Stein R. Too much of a good thing? The growing use of CT scans fuel medical concerns regarding radiation exposure. Washington PostJanuary 15, 2008:F1

12. 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
13. Parfrey P. The clinical epidemiology of contrast-induced nephropathy. Cardiovasc Intervent Radiol 2005;28(suppl 2): S3–S11
14. Safety in medical imaging. American College Radiology, Radiological Society of North America, Inc. Available at: www.radiologyinfo.org/en/safety/index.cfm?pg=sfty_xray &bhcp =1. Accessed September 1, 2008
15. Varnholt H. Computed tomography and radiation exposure. N Engl J Med 2008;358:852–853; author reply 852–853
16. 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
17. Niendorf HP, Alhassan A, Geens VR, Clauss W. Safety review of gadopentetate dimeglumine. Extended clinical experience after more than five million applications. Invest Radiol 1994;29(suppl 2):S179–S182
18. Cowper SE. Nephrogenic fibrosing dermopathy [NFD/NSF Website]. 2001–2007. Available at: http://www.icnfdr.org. Accessed August 7, 2008
19. Scheinfeld NS, Cowper SE. Nephrogenic fibrosing dermopathy. January 25, 2008. Available at: http://www.emedicine.com/derm/topic934.htm. Accessed August 7, 2008
20. Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. Radiology 2004;232:635–652