

Comparative analysis of fluorescent angiography, computed tomographic angiography and magnetic resonance angiography for planning autologous breast reconstruction

Michael P. Chae^{1,2}, David J. Hunter-Smith^{1,2}, Warren Matthew Rozen^{1,2}

¹Department of Surgery, Monash University, Monash Medical Centre, Clayton, Victoria 3168, Australia; ²Monash University Plastic and Reconstructive Surgery Group (Peninsula Clinical School), Peninsula Health, Frankston, Victoria 3199, Australia

Correspondence to: Dr. Warren Matthew Rozen, MBBS, BMedSc, MD, PhD, FRACS. Department of Plastic and Reconstructive Surgery, Frankston Hospital, Peninsula Health, 2 Hastings Road, Frankston, Victoria 3199, Australia. Email: warrenrozen@hotmail.com.

Background: The high incidence of breast cancer and growing number of breast cancer patients undergoing mastectomy has led to breast reconstruction becoming an important part of holistic treatment for these patients. In planning autologous reconstructions, preoperative assessment of donor site microvascular anatomy with advanced imaging modalities has assisted in the appropriate selection of flap donor site, individual perforators, and lead to an overall improvement in flap outcomes. In this review, we compare the accuracy of fluorescent angiography, computed tomographic angiography (CTA), and magnetic resonance angiography (MRA) and their impact on clinical outcomes.

Methods: A review of the published English literature dating from 1950 to 2015 using databases, such as PubMed, Medline, Web of Science, and EMBASE was undertaken.

Results: Fluorescent angiography is technically limited by its inability to evaluate deep-lying perforators and hence, it has a minimal role in the preoperative setting. However, it may be useful intraoperatively in evaluating microvascular anastomotic patency and the mastectomy skin perfusion. CTA is currently widely considered the standard, due to its high accuracy and reliability. Multiple studies have demonstrated its ability to improve clinical outcomes, such as operative length and flap complications. However, concerns surrounding exposure to radiation and nephrotoxic contrast agents exist. MRA has been explored, however despite recent advances, the image quality of MRA is considered inferior to CTA.

Conclusions: Preoperative imaging is an essential component in planning autologous breast reconstruction. Fluorescent angiography presents minimal role as a preoperative imaging modality, but may be a useful intraoperative adjunct to assess the anastomosis and the mastectomy skin perfusion. Currently, CTA is the gold standard preoperatively. MRA has a role, particularly for women of younger age, iodine allergy, and renal impairment.

Keywords: Breast reconstruction; indocyanine green fluorescence angiography (ICGFA); computed tomographic angiography (CTA); magnetic resonance angiography (MRA)

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Introduction

Given the high prevalence and incidence of breast cancer in society (1,2) and a growing number of women with breast cancer opting for mastectomy over breast-conserving operations (3), breast reconstruction has become an

important part of breast cancer management. It can improve patients' psychosexual well-being and their overall psyche in response to breast cancer management (4-8). Autologous breast reconstruction (and in particular those with perforator-based free flaps) has demonstrated a natural-appearing,

aesthetically-pleasing, long-lasting restorative option, with low donor site morbidity (9,10). Recent advancements in operative techniques and imaging modalities have facilitated complex microvascular breast reconstructions to become safer, more reliable procedures (11-13).

Various autologous tissues have been utilized for breast reconstruction, such as omentum (14), latissimus dorsi (15-18), deep circumflex iliac artery (groin) flap (19,20), lateral thigh (tensor fascia latae) flap (21), gluteal musculocutaneous flap (22-25), gracilis flap (26), and triceps flap (27). In recent times, the anterior abdominal wall has become the most frequently used donor site due to the added aesthetic benefit at the donor site, akin to a concomitant abdominoplasty. Initially, transverse rectus abdominis muscle (TRAM) flaps were successful in providing adequate volume replacement for breast reconstructions (28,29). However, a high rate of donor site morbidity, such as rectus abdominis muscle weakness and ventral hernia, resulted in the development of muscle-sparing techniques, mainly the deep inferior epigastric artery perforator (DIEP) flaps (10,30). DIEP flaps are fasciocutaneous flaps based on musculocutaneous perforators derived from the deep inferior epigastric artery (DIEA) (31,32). They were able to provide sufficient tissue volume and a superior functional and aesthetic outcome at the donor site than the TRAM flaps (12,33). However, early studies reported a steep learning curve of the microsurgical technique leading to a longer dissection time, and an increased flap complications, such as fat necrosis and flap loss (34). To this effect, the use of preoperative imaging has been instrumental.

Preoperative assessment of the donor site microvasculature anatomy with advanced imaging modalities has assisted surgeons in the appropriate selection of the donor site, perforator, and flap leading to an overall improvement in the flap outcomes (35,36). According to the consensus reached at the Navarra meeting, a perforator should be selected on the basis of its caliber, central location within the flap, direct venous connection with the main superficial venous system, and it preferably demonstrates a broach subcutaneous branching pattern and has a shorter intramuscular (IM) course for ease of dissection (37). Hence, an ideal preoperative imaging technique should accurately demonstrate the individual variations in the location and caliber of the perforators, their IM course, and the branching pattern of the DIEA (38). Early investigators have relied on handheld Doppler probes and color duplex ultrasonography to detect perforators, characterize them in flow velocity and resistivity, and create a perforator map on the abdominal wall (39-41). Both ultrasound techniques are inexpensive, do not expose

patients to radiation or potentially nephrotoxic intravenous contrast agents, can detect perforators with diameter greater than 0.5 mm, identify any underlying vessel damage secondary to atherosclerosis or previous surgery (42-45). However, they are subject to significant inter-observer variability, and are associated with poor consistency with intraoperative findings, high false positive and negative rates (39,41,46,47). Hence, they are now superseded by modern imaging technologies with objective findings, such as fluorescent angiography, computed tomographic angiography (CTA), and magnetic resonance angiography (MRA).

In this review, we evaluate the accuracy of fluorescent angiography, CTA, and MRA, and compare their impact on the clinical outcomes of patients undergoing autologous breast reconstruction, mainly TRAM and DIEP flaps, since they have attracted the most number of clinical studies and have provided the highest level of evidence (48).

Methods

We reviewed the published English literature from 1950 to 2015 from well-known databases, such as PubMed, Medline, Web of Science, and EMBASE, using search terms, such as “autologous breast reconstruction”, “DIEP flap”, “fluorescent angiography”, “computed tomographic angiography”, and “magnetic resonance angiography”.

Results

Fluorescent angiography (FA)

FA utilizes intravenous dyes that fluoresce and emit infrared energy upon excitation by a light source, which produces real-time videos that facilitate evaluation of the anastomotic patency and the extent of soft tissue perfusion (49,50). Originally, the investigators employed fluorescein dye, which accumulates extracellularly in the soft tissue, fluoresces upon excitation by the ultraviolet (UV) light, and is renally excreted (51,52). However, the long time it takes to reach the maximum intensity (15 minutes), relatively frequent adverse effects, reports of allergic reaction, and the steep learning curve associated with using a Woods lamp for interpretation have resulted in the fluorescein dye being replaced by the indocyanine green (ICG) dye. ICG is an FDA-approved, biliary excreted, water-soluble dye that enables image capture within 2-3 minutes of intravenous administration (53). ICG is excited by laser and transmits infrared energy that is recorded by devices equipped with inbuilt software

Table 1 Comparison of basic characteristics of the perforator imaging technologies

Characteristics	ICGA	CTA	MRA
Availability	+	+++	+
Cost (USD)	795 (59)	400 (60)	600 (61,62)
Image acquisition	2-3 min (53)	<10 sec	20 min
Breath holding during scanning	NA	5 sec (63)	20 sec (64)
Reproducibility	+	+++	++
Operator dependence	Yes	No	No
Patient size dependence	Yes	No	No
Panoramic view	Yes	Yes	Yes
3D view	No	Yes	Yes

ICGA, indocyanine green angiography; CTA, computed tomographic angiography; MRA, magnetic resonance angiography; NA, not applicable; 3D, three-dimensional.

algorithms that generate quantitative data, such as LifeCell SPY system (LifeCell Corp, Branchburg, New Jersey, USA), IC-View (Pulsion Medical Systems AG, Munich, Germany), and FLARE imaging system (Beth Israel Deaconess Medical Center, Boston, MA, USA) (54-56). Furthermore, ICG has a short half-life (3-4 minutes) (57), which enables multiple consecutive measurements, in contrast to fluorescein, which is retained in the tissues (58). It strongly binds to the plasma proteins leading to rapid washout from the circulation and has a superior side effect profile with a low rate of anaphylaxis (1 in 42,000) (Table 1) (65,66).

Laser-assisted ICGFA (LA-ICGFA) has demonstrated utility by characterizing vascular flow dynamics and tissue perfusion in various disciplines (67-75). In reconstructive surgery, investigators have utilized LA-ICGFA intraoperatively to assess the patency of microvascular anastomosis in free flaps (76,77) and calculate the intrinsic transit time through the anastomosis (78) that correlate with postoperative flap compromise and accurately predict early re-exploration. One of the significant limitations of LA-ICGFA is that it can only provide information a few millimeters deep from the skin (55). This is adequate for evaluating thin areas, such as the extremities, head and neck, and the trunk (79). However, since majority of autologous breast reconstructions are based on the abdomen and a thick pannus is preferred for a DIEP flap, LA-ICGFA has a minimal role in the preoperative planning (55). In breast reconstruction, LA-ICGFA may be useful intraoperatively during flap harvest to assess the flap perfusion, confirm blood flow within the microvascular anastomosis, and detect acute changes in the flap circulation, such as arterial occlusion,

venous thrombosis, and pedicle torsion (80). Moreover, it can be used to evaluate the perfusion of mastectomy skin flaps and facilitate the reconstructive surgeon to debride areas that are likely to develop necrosis (59).

A number of studies in the literature have examined the accuracy of LA-ICGFA in estimating postoperative complications, such as mastectomy skin flap necrosis (81-83), partial flap necrosis (53) and microvascular thrombosis (Table 2) (84). Using fluorescein dye, Losken *et al.* reported a sensitivity and specificity of 75% and 71% respectively to detect mastectomy skin flap necrosis (81). Using ICG dye, Newman *et al.* retrospectively reviewed and derived that LA-ICGFA can detect postoperative skin necrosis with a sensitivity and specificity of 100% and 91% respectively (82). In a prospective study of 51 implant breast reconstructions in 32 patients, Phillips *et al.* compared the efficacy of fluorescein to the ICG dye and reported that both dyes have the same sensitivity of 90% in detecting skin necrosis but ICG had a slightly superior specificity (83). In a retrospective study of ten patients undergoing TRAM flaps, Yamaguchi *et al.* report that intraoperative LA-ICGFA can detect partial flap necrosis with a sensitivity of 75% (53). Moreover, Holm *et al.* have demonstrated that LA-ICGFA accurately detects microvascular thrombosis as the cause of free flap re-exploration with a sensitivity of 100% and specificity of 86% (84).

In the literature, there are only two studies where using LA-ICGFA is correlated with clinical outcomes (Table 3) (59,97). Komorowska-Timek *et al.* applied LA-ICGFA intraoperatively in 24 consecutive patients undergoing breast reconstruction and the areas of inadequate dye penetration

Table 2 Comparison of accuracy of the perforator imaging technologies

Perforator imaging technology	Author	Year	P/R	Patients	Technical parameters (dye/rows/Tesla)	Sensitivity (%)	Specificity (%)
FA	Yamaguchi (53)	2004	R	10	ICGD	75	
	Losken (81)	2008	P	42	FD	75	71
	Newman (82)	2010	R	12	ICGD	100	91
	Holm (84)	2010	P	20	ICGD	100	86
	Phillips (83)	2012	P	32	FD	90	30
	Phillips (83)	2012	P	32	ICGD	90	50
CTA	Alonso-Burgos (85)	2006	P	6	4	100	
	Rosson (86)	2007	P	17	64	100	
	Rozen (47)	2008	P	8	64	100	
	Rozen (61)	2009	P	6	64	100	
	Gacto-Sánchez (87)	2010	P	12	16	100	
	Scott (46)	2010	P	22	64	94.30	
	Masia (88)	2010	P	36	64	100	
	Pauchot (63)	2012	P	10	64	84.30	100
	Tong (89)	2012	R	69	128	79	92
	Cina (62)	2013	P	23	64	95.60	
	Pellegrin (90)	2013	R	41	64	97.60	
MRA	Rozen (61)	2009	P	6	1.5 & 3.0	50	100
	Chernyak (91)	2009	P	19	3	97	
	Greenspun (92)	2010	P	31	3	96	
	Newman (93)	2010	P	25	1.5	99	
	Alonso-Burgos (94)	2010	P	8	3	100	
	Masia (95)	2010	P	56	1.5	100	
	Pauchot (63)	2012	P	10	64	95.70	100
	Cina (62)	2103	P	23	64	91.30	
	Versluis (96)	2013	P	23	1.5 EP	100	

FA, fluorescent angiography; CTA, computed tomographic angiography; MRA, magnetic resonance angiography; P, prospective study; R, retrospective study; ICGD, indocyanine green dye; FD, fluorescein dye; EP, equilibrium phase.

suggesting poor tissue perfusion were resected (97). The authors reported that a resultant total complication rate of 4%, which was lower than 15.1% recorded from their previous 148 patients and 206 breast reconstructions ($P < 0.01$) (97). Duggal *et al.* retrospectively reviewed the clinical outcomes in 184 patients undergoing breast reconstructions receiving intraoperative LA-ICGFA (59). The authors report that LA-ICGFA was associated with a significant reduction in mastectomy skin flap necrosis ($P = 0.01$) and re-operation rate ($P = 0.009$). There was also a trend demonstrated in the reduction of partial and complete flap loss rate ($P = 0.237$ and $P = 1.00$, respectively).

Computed tomographic angiography (CTA)

First reported by Masia *et al.* in 2006 (98), CTA is widely used for preoperative imaging and planning free tissue transfers by numerous institutions around the world and is currently considered the best of the three options due to its high accuracy and reliability (Table 1) (35,60,86,107-111). Ongoing advances in CTA, such as an increasing number of detector rows, ensure that the modality remains fast and produces high detail (48). For interpretation, the scan data can be three-dimensionally (3D) reconstructed digitally on either a free software, such as Osirix (Pixmeo, Geneva,

Table 3 Comparison of clinical outcomes from the perforator imaging technologies

Perforator imaging technology	Author	Year	Patients	Reduction in operative time (min)		Mastectomy skin necrosis (%)	Flap complications		Donor site morbidity		Incidental findings (%)
				Control	Total		Flap harvest	Total (%)	Fat necrosis (%)	Partial flap loss (%)	
ICGA	Komorowska-Timek (97)	2010	20	148		4 vs. 15.1 (P<0.01)					
	Duggal (59)	2014	71	59		13 vs. 23.4 (P=0.01)	14 vs. 22 (P=0.237)	1.4 vs. 3.4 (P=1)			
CTA	Masia (98)	2006	30	30	100						
	Rozen (47)	2008	8	NA							
	Rozen (35)	2008	40	48			0	0	0	0 vs. 14.6 (P=0.006)	
	Uppal (99)	2009	26	NA			7.5 vs. 16.7 (P=0.19)	0 vs. 10.4 (P=0.024)			
	Casey (100)	2009	68	145			10.9 vs. 13.4 (P>0.05)	2 vs. 3.8 (P>0.05)	1 vs. 9.1 (P<0.05)		
	Smit (101)	2009	70	68				0 vs. 4	0 vs. 1		
	Ghattaura (102)	2010	50	50				4 vs. 0	0 vs. 6		
	Masia (88)	2010	357	100	100 (P<0.05)			2 vs. 12	1 vs. 4		
	Minqiang (103)	2010	22	22	96 (P<0.05)			5 vs. 9	0 vs. 5		
	Gacto-Sanchez (87)	2010	35	35	98 (P<0.001)	127 (P<0.001)		Total complications: 0 vs. 14 (P<0.001)		2 vs. 15 (P=0.001)	
	Fansa (104)	2011	20	20	26 (P<0.028)			5 vs. 4 (P=1)	1 vs. 0 (P=1)		36
	Tong (89)	2012	51	18				No difference			29.30
MRA	Malhotra (105)	2013	100	100							
	Pellegrin (90)	2013	41	NA							
	Rozen (61)	2009	6	NA			No difference between MRA and CTA				
	Schaverin (106)	2011	126	NA	25 (unilateral) (P>0.05), 40 (bilateral) (P>0.05)		Reduction (P<0.05)				

ICGA, indocyanine green angiography; CTA, computed tomographic angiography; MRA, magnetic resonance angiography; vs., versus; NA, not available.

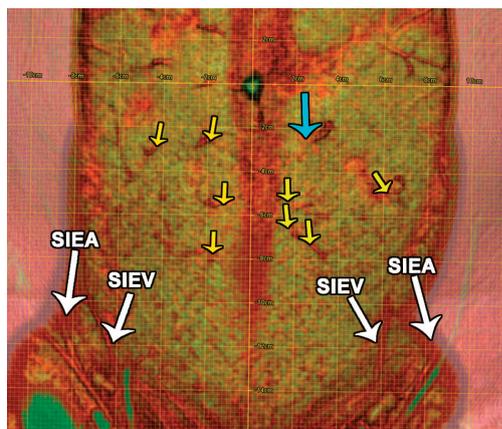


Figure 1 CTA with VRT reformat, demonstrating a large 1.5 mm perforator (blue arrow) and multiple smaller perforators (yellow arrows) at the point at which they pierce the anterior rectus sheath. A numbered grid is centered at the umbilicus for localization. The SIEA and SIEV on each side were demonstrated. Reproduced with permission from reference (112). CTA, computed tomographic angiogram; VRT, volume rendered technique; SIEA, superficial inferior epigastric artery; SIEV, superficial inferior epigastric vein.

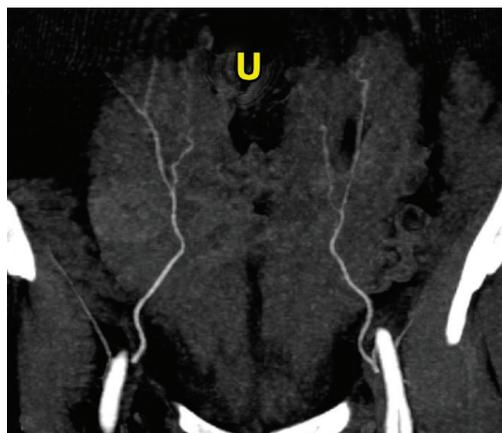


Figure 2 CTA with VRT reformat, demonstrating the branching pattern of the DIEAs. The left side is a type 2 (bifurcating) pattern and the right is a type 3 (trifurcating) pattern. U, umbilicus; CTA, computed tomographic angiogram; VRT, volume rendered technique; DIEAs, deep inferior epigastric arteries. Reproduced with permission from reference (112).

Switzerland), or a commercially available software, such as Siemens Inspace (Siemens, Berlin, Germany). Using 3D volume rendering technique in the software facilitates the creation of a perforator location map and illustrates the



Figure 3 Computed tomographic angiogram (CTA) with axial maximum intensity projection (MIP) reformat, demonstrating the subcutaneous course of perforators. Based on the subcutaneous distribution and branching pattern of the perforator selected (arrow), a preoperative estimate of well-vascularized flap volume can be achieved. CTA, computed tomographic angiogram; MIP, maximum intensity projection. Reproduced with permission from reference (112).

subcutaneous course of the perforators (see *Figure 1*); and secondly, the maximum intensity projection technique can help visualize the vascular pedicle in the coronal plane (see *Figure 2*) and in the axial plane, which can further depict its IM course (see *Figure 3*) (85,113).

The major advantages of CTA are its wide availability, affordability, non-invasive nature, high reproducibility and operator-independence. Furthermore, it has a fast scanning time of less than 5 minutes (36) and produces images in high spatial resolution and in multiplanar or 3D panoramic views that facilitates ease of interpretation. As a result, the location, caliber, and course of musculocutaneous perforators as small as 0.3 mm in diameter can be readily displayed (47). In contrast to ultrasonography, the image quality is less affected by the body habitus (47) and it can clearly demonstrate both DIEA and superficial inferior epigastric artery (SIEA), and their branching patterns. In addition, the CTA can be used to screen for comorbidities, such as metastatic diseases, and detect any underlying abdominal wall defects (48) or other incidentally discovered lesions, such as angiomyolipoma and adrenal mass, that may alter the surgical management (89,90).

A plethora of studies have been reported in the literature demonstrating high accuracy of CTA in detecting perforators suitable for perforator-based free flap reconstructions (*Table 2*). Most investigators report sensitivity and specificity close to 100% (46,47,61-63,85-90). Furthermore, CTA can also characterize the DIEA branches, IM course, and both superficial and deep venous systems supporting a flap with high sensitivity (100%, 97.1%, 91.3%, 94.4%, respectively) (62). In comparison to Doppler ultrasound, Rozen *et al.* demonstrated that CTA

produces superior visualization of the DIEA, its branching pattern, its perforators ($P=0.0078$), and additionally, the SIEA (47). Similarly, Scott *et al.* exhibit that CTA is significantly more sensitive than color Duplex ultrasound in detecting the top two perforators (94.3% *vs.* 66.3%, respectively) (46). Compared to the MRA, CTA has a superior fat-to-vessel contrast ($P=0.007$), but a poorer muscle-to-vessel contrast ($P=0.001$) (63). The former indicates that CTA is able to produce higher quality images of the subcutaneous course of a perforator; however, the latter signifies that MRA is technically superior at delineating the IM course of a perforator.

Enhanced understanding of the microvascular anatomy facilitated by CTA has assisted reconstructive surgeons in selecting an appropriate donor site, perforator, and flap, and numerous studies demonstrate that this has directly translated into an improvement in the clinical outcomes (*Table 3*). The studies have reported a significant reduction in the flap harvest time and the total operative time (35,87-89,98-106). This leads to reduced exposure to general anesthesia, reduced risk of infection, and reduced intraoperative bleeding (35). Furthermore, the use of CTA for preoperative planning is associated with a reduction in postoperative flap complications, such as fat necrosis, partial, and total flap loss, and donor site morbidity, such as abdominal bulge and herniation (35,47,87-89,100-103). Interestingly, one study by Malhotra *et al.* demonstrated no improvement in flap complications from preoperative CTA, even though there was a significant reduction in the operative time ($P<0.05$), intraoperative blood loss ($P<0.05$), and inpatient hospital stay ($P<0.05$) (105).

The main limitations associated with CTA stem from potential sensitivity to the iodinated intravenous contrast, contrast-induced nephrotoxicity in patients with renal impairment, and exposure to ionizing radiation. The latest CTA scanning protocols that assess a targeted area for identifying abdominal wall perforators (114) and the development of radiation dose reduction software and algorithms in the latest scanners (60,115) have decreased the average radiation exposure to 5 mSv per scan (62,98,107,111). This dose is equivalent of two abdominal X-rays, is significantly lower than a routine abdominal CT scan (63), and is theoretically associated with a 1-in-4,270 risk of fatal radiation-induced cancer (116). Moreover, perforators at the recipient site are not simultaneously imaged in order to minimize radiation. Most often, the patients have had a contrast-CT scan of the chest wall for their original breast cancer staging. Nonetheless, the

recipient vessels, most commonly the internal mammary perforators, can be adequately visualized using a handheld Doppler probe (114). Furthermore, thoracic imaging poses risk to the radiation-sensitive contralateral breast and thyroid.

Magnetic resonance angiography (MRA)

Recently, MRA with Gadolinium-based contrast has become popular in order to bypass the risk of radiation associated with CTA (*Table 1*) (61). Recent advances in the image acquisition technique, introduction of novel contrast agents, and increasing availability of MRI scanners with stronger field strength have significantly improved the accuracy and the quality of MRA images (117). Delayed equilibrium phase (EP) technique acquires images when both the artery and the vein are enhancing, compared to the conventional first-pass, or arterial-phase, technique (96). As a result, EP facilitates a longer image acquisition time leading to higher spatial and contrast resolution, produces diagnostic quality data despite minor motion artifacts, and has 100% sensitivity in detecting abdominal perforators (96). In addition, investigators have reported prone position to minimize respiratory-related motion artifacts (92,118,119). However, this method remains controversial since it alters the natural curved anatomy of the abdomen compromising the image quality of the perforators and since patients are indeed operated in supine position (62).

In contrast to the conventional gadolinium contrast agents, extracellular contrast agents, such as gadobenate dimeglumine, offer slightly higher relaxivity (120). However, it only has a short half-life of 100 seconds (120). Newer blood pool contrast agents, mainly gadofosveset trisodium (121), has demonstrated superior quality images secondary to a longer imaging window and a relatively large R1 (122). Gadofosveset trisodium has a long half-life of 28 minutes and reversibly binds to serum albumin with high fraction (90%) (123) leading to stronger contrast enhancement of the vessels (124,125). Stronger field strength 3.0 T scanners are increasingly becoming commonplace. They demonstrate superior spatial resolution and augment gadolinium-based contrast enhancements with reduced acquisition time and a decreased susceptibility to motion artifacts (126-129).

One of the significant benefits of MRA is that it eliminates exposure to ionizing radiation. Furthermore, gadolinium-based contrast agents have a safer risk profile, such as the rate of acute allergic reaction (0.07% *vs.* 3%), in comparison to radioactive contrasts (130,131). Thus, MRA

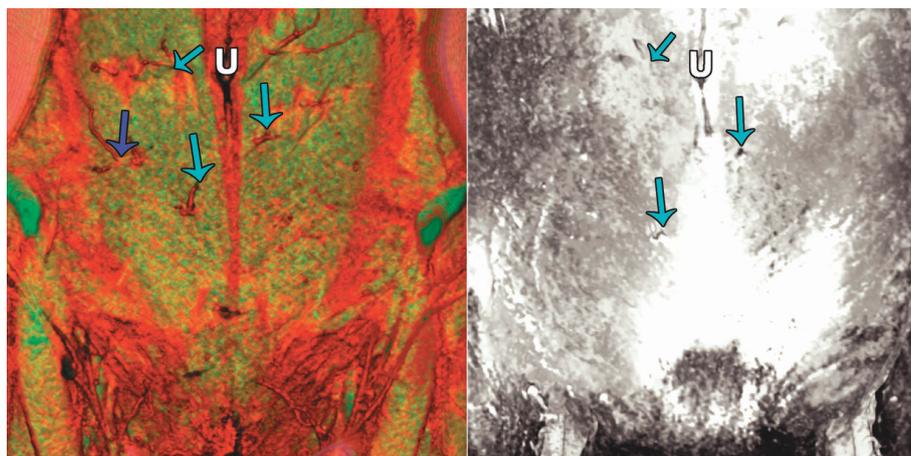


Figure 4 Volume-rendered, three dimensional reconstructions of the cutaneous perforators of the DIEA using CTA on the left, and MRA on the right. Three large (>1 mm) perforators were demonstrated with both modalities (light blue arrows), while one large perforator was demonstrated on CTA alone (dark blue arrow). DIEA, deep inferior epigastric artery; CTA, computed tomography angiography; MRA, magnetic resonance angiography. Reproduced with permission from reference (84).

may be advantageous in patients with younger age, iodine allergy, and impaired renal function. Moreover, muscle-to-vessel contrast ratio is superior in MRA, compared to CTA, leading to a clearer depiction of the perforator IM course (63). In autologous breast reconstructions, there are a growing number of reports demonstrating its accuracy in delineating perforators and its potential role in improving clinical outcomes.

Despite high specificity (100%), Rozen *et al.* reported in an earlier study that MRA has low sensitivity (50%) in detecting abdominal wall perforators for breast reconstruction, suggesting it as an inferior option to CTA for perforator mapping purposes (see *Figure 4*) (61). Advances in the imaging technique, contrast agents, and the application of higher field strength scanners have improved its accuracy in the last decade (*Table 3*) (36). As a result, more recent studies report a high sensitivity (91.3% to 100%) with MRA (62,63,91-96). Of note, the accuracy of IM course depiction is high with MRA (62,93-95). In contrast to CTA, there is a relative paucity in the literature describing MRA for a large clinical series describing its impact on clinical outcomes. Schaverien *et al.* report that in 126 patients, MRA reduced the rate of partial flap loss ($P<0.05$) and the total operative time in both unilateral and bilateral cases by 25 and 40 minutes, respectively (106). However, the latter did not reach statistical significance. In an early study, Rozen *et al.* demonstrated that using MRA reduced the incidence of flap complications to 0% in six

patients (61).

One of the major drawbacks of MRA is related to its relatively high cost and low availability since an average MRA scan costs USD 600, compared to USD 400 for a CTA (61). Furthermore, due to its poor spatial resolution, MRA is limited at detecting perforators smaller than 0.8 mm in diameter (61). However, the recent introduction of novel contrast agents (132) and higher field strength scanners (133) are expected to improve on this limitation. Moreover, due to an expanded examination window, MRA is more susceptible to motion artifacts and requires the patients to breath-hold for a long period of time (64). Despite its safer profile compared to ionizing contrast agents, gadolinium-based agents still presents with adverse effects, such as nephrogenic systemic fibrosis (134-137). Only 200 cases have been reported worldwide and this appears to be predisposed in patients with underlying impaired renal function. In addition, MRA is absolutely contraindicated in patients with severe obesity, implanted defibrillator or a pacemaker, implanted ferromagnetic device, and a cochlear implant. It is relatively contraindicated in patients with artificial heart valves and other types of implants. It is difficult to perform in patients with claustrophobia, severe anxiety, and confusion who are unable to lie still.

Discussion

Breast cancer is the most common cancer worldwide

and is associated with the most common cancer-related deaths in women worldwide (2,138). Since an increasingly number of women opt for mastectomy (3), postmastectomy breast reconstruction has become an essential component of the holistic treatment in patients with breast cancer to ensure their psychosexual wellbeing. To this end, breast reconstruction with autologous tissue has been demonstrated to provide the most functional and aesthetically pleasing outcome. Abdominal wall-based, rectus muscle-sparing DIEP flaps are considered the gold standard since they provide ample volume without causing significant donor site morbidity (10,30). However, DIEP flaps are associated with longer microsurgical dissection leading to longer operative times and an increase in the postoperative microvascular complications.

To this effect, preoperative planning with modern imaging technology has become a crucial component of fashioning a DIEP flap for breast reconstruction. Handheld Doppler probes and color Duplex ultrasound are the first modality to be adapted for use in the preoperative setting (45). Although widely available and affordable, Doppler ultrasound is not sensitive or specific enough to be reliable and used routinely (108). Furthermore, it is susceptible to inter-observer variability and is unable to illustrate SIEA anatomy (46). Fluorescent angiography has been studied to preoperatively delineate the caliber and the location of the perforators (139). However, since this technology is only able to provide information up to a few millimeters deep from the skin and thick abdominal pannus is preferred in DIEP flaps, it has become less frequently used preoperatively (55). Instead, investigators are now using LA-ICGFA to assess microvascular anastomotic patency intraoperatively and evaluate perfusion in mastectomy skin flap (55,77).

Since CTA was first reported for breast reconstruction by Masia *et al.* (98), it has become the preferred preoperative imaging modality due to its high accuracy and reliability (38,88,108). With a free software, 3D images of the perforator anatomy can be created, from which its caliber, location, subcutaneous branching pattern, the DIEA and the SIEA anatomy can be easily visualized (113,140). However due to concerns surrounding radiation exposure, high-risk contrast agents, and contrast-related nephrotoxicity, MRA has been investigated recently as an alternative (61,95). Despite early findings suggesting low sensitivity in detecting perforators (61), recent advances in the image acquisition technique, the introduction of higher quality contrast agents, and availability of stronger 3.0 T scanners have enhanced the quality of perforator imaging from MRA

(36,92,132). However, the image quality of CTA remains superior to the latest MRA technology. As a result, the latter has currently only preferred for a subset of patients in the younger age group, with iodine allergy and impaired renal function.

Conclusions

Preoperative imaging is an essential component of planning postmastectomy autologous breast reconstructions with DIEP flaps. Fluorescent angiography technology has been investigated as a preoperative imaging tool in the past. However, the investigators have demonstrated that it may instead be a useful intraoperative adjunct to evaluate the patency of microvascular anastomosis and the mastectomy skin perfusion. Currently, CTA is and remains the gold standard preoperative imaging modality due to its high accuracy, sensitivity, and specificity. In order to eliminate the radiation risk from CTA and the toxicity from radiosensitive contrast agents, MRA has been investigated in its role. Despite recent advancements, the image quality of MRA is still inferior to CTA and its widespread use is limited by high cost and lack of availability. Hence, MRA is best reserved for a subset of patients who are at a high risk from CTA, such as women with younger age, iodine allergy, and renal impairment.

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