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ORIGINAL ARTICLE

The anatomy and variations of the internal thoracic (internal mammary) artery and implications in autologous breast reconstruction: clinical anatomical study and literature review

Alice C. A. Murray · Warren M. Rozen · Alberto Alonso-Burgos · Mark W. Ashton · Emilio Garcia-Tutor · Iain S. Whitaker

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Abstract
Background The internal thoracic (IT) vessels (otherwise known as the thoracica interna or internal mammary vessels) are widely used as recipient vessels in autologous breast reconstruction. Despite this, normal and pathological variations in IT artery architecture have been described, and these have the potential to complicate dissection and the selection of suitable vessels.
Methods A clinical anatomical study of 240 IT arteries (120 patients) and review of the literature was undertaken. Participants comprised 120 female patients undergoing preoperative imaging of the IT artery prior to autologous breast reconstruction, 42 with computed tomographic angiography (CTA) and 78 with ultrasound.
Results There was complete concordance between surgical and radiological findings. An IT artery was present in 100% of cases, with a duplicate IT artery in two cases (1% overall). The position of the IT artery was between two IT veins most frequently (71.5% of cases), and was lateral to the vein(s) least frequently (6%). There were large IT perforators from the first and second intercostal spaces in 87 and 91% of cases, respectively, with the incidence of such perforators reducing in the lower spaces. The literature highlighted a range of cadaveric and clinical cases in which there was absence of a patent IT artery, variant course or size, and variant relationship to the IT vein.
Conclusion A range of congenital, pathological and iatrogenic variants in IT artery anatomy have the potential to limit the use of the IT artery in autologous breast reconstruction. Preoperative imaging with ultrasound or CTA may provide a clear and accurate method of identifying these anatomical variations pre-operatively.

Keywords Free flap · Perforator flap · Reconstructive surgery · Anatomy · Variation

A. C. A. Murray · W. M. Rozen (✉) · A. Alonso-Burgos · M. W. Ashton · E. Garcia-Tutor · I. S. Whitaker
Department of Anatomy and Cell Biology, Jack Brockhoff Reconstructive Plastic Surgery Research Unit, The University of Melbourne, Grattan St, Parkville, VIC 3050, Australia
e-mail: warrenrozen@hotmail.com

Background

The internal thoracic (IT) vessels (otherwise known as the thoracica interna or internal mammary vessels) are widely used as recipient vessels in autologous breast reconstruction. In fact, they are often preferred to the thoracodorsal (TD) vessels due to their accessibility, ease of manipulation and freedom of flap placement [11, 28]. They are relatively spared following irradiation and axillary surgery compared with the TD vessels [26] and are usually preserved despite wide resections during mastectomies [17]. Numerous groups have reported success using IT recipient vessels for autologous breast reconstruction, and in particular for abdominal wall deep inferior epigastric artery perforator (DIEP) and transverse rectus abdominis myocutaneous (TRAM) flaps and for gluteal artery flaps [3, 11, 28]. This correlates with studies of the IT vessels over the past 20 years showing greater relative anatomical consistency than was previously thought, with vessels of adequate calibre reliably found at the level of the third intercostal space [1, 3, 13].

Despite this, a range of normal and pathological variations in vessel architecture have been described, in particular for the IT artery, and these have the potential to complicate dissection and the selection of suitable vessels [1, 8]. Even if relatively uncommon, the unexpected finding of an unsuitable IT artery can have profound implications for a particular patient. As such, consideration of preoperative imaging of the IT vessels has been suggested [9]. Imaging of the recipient site in autologous breast reconstruction can facilitate detailed preoperative planning which may ultimately improve operative success, and as such imaging of the IT arteries preoperatively has been an increasingly sought technique. Both ultrasound (conventional Doppler ultrasound and modern colour duplex ultrasound) and computed tomographic angiography (CTA) have each been widely used as non-invasive imaging techniques, with CTA more recently shown to provide accurate information about arterial architecture, including vessel origin, calibre, course, length and branching patterns [4]. We sought to undertake a clinical anatomical study of the IT artery and perform a review of the literature, as a means to assessing the incidence and types of variation in anatomy that exist for the IT artery and offer some insight into the role for pre-operative imaging.

Methods

A clinical anatomical study of the IT artery was undertaken through the use of preoperative imaging with either CTA or colour duplex ultrasound (see Fig. 1). Participants comprised 120 patients undergoing imaging of the IT vessels for the preoperative imaging of recipient site vasculature prior to breast reconstruction. Patients were all female, spanned the range of ages between 30 and 75, and were of mixed body habitus. All patients consented to the imaging, with institutional ethical approval prospectively obtained. For CTA, arterial phase scans were undertaken, in which a bolus tracking technique was used to identify filling of the IT artery with contrast as a means to initiate scanning. These technique provides pure 'arterial phase' scans, with no or minimal venous opacification and therefore confer a presumed improved accuracy for identifying arterial branches (by minimizing the risk of confounders due to confusion between arteries and veins). Intravenous contrast was used in all cases, with no oral contrast used, and comprised non-ionic iodinated contrast media: Ultravist 370 (Schering, Berlin, Germany) or Omnipaque 350 (Amersham Health, Princeton, USA) Intravenous access was accessed through a cubital fossa vein, with an 18-gauge cannula and injection performed with a biphasic power injection pump at a flow rate of 4–6 mL/s. Image reformatting software was achieved with either Siemens Syngo InSpace (Siemens, InSpace2004A_PRE_19), or Osirix (OsiriX Medical Imaging Software, GPL Licensing Open Source Initiative). Multi-planar three dimensional reconstructions were achieved with maximum intensity projection (MIP) and volume rendered technique (VRT) reconstructions. For duplex ultrasound, a flow value was assigned to the pulsatile arterial flow in order to accurately identify the IT artery.

A retrospective analysis of prospectively recorded data was undertaken, with surgical and radiological correlation performed in each of the 120 cases. Imaging findings comprised the presence or absence of an ipsilateral IT artery, its source vessel of origin, its position as the most medial or lateral structure in the intercostal space (the third intercostal space was used as the reference for these measurements, being a common site for dissection of the vessels in this clinical setting), and the presence of more than one arterial trunk. Internal mammary perforating arterial branches were also assessed, and the presence of a perforator over 1 mm from any of the first five intercostal spaces was recorded. Vessel size was measured as the internal diameter of each vessel, representing lumen diameter.

Results

In each of the 240 sides (120 patients) in which imaging of the IT artery and veins was performed, the IT artery was present and visible on imaging, both for ultrasound (78 cases; see Fig. 2) and for CTA (42 cases; see Figs. 3, 4, 5). Furthermore, in all cases there was complete concordance between surgical and radiological findings.

The primary outcome measures and their results are shown in Table 1. In all cases an IT artery was present, with no cases demonstrating an absence of the IT artery. In

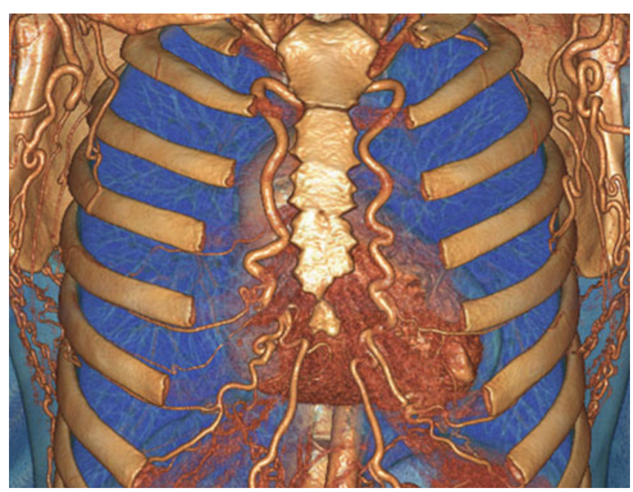

Fig. 1 Computed tomographic angiogram (CTA) of the thoracic vasculature in a patient with coarctation of the aorta, with volume rendered technique (VRT) reconstruction, demonstrating a dilated internal mammary system and clear representation of its communication with the intercostal arteries and its terminal musculophrenic and superior epigastric arteries

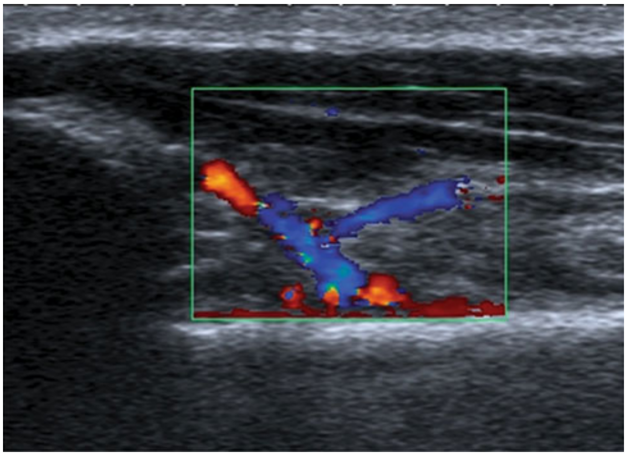

Fig. 2 Colour duplex ultrasound of the internal mammary vessels, demonstrating their course through the intercostal and pectoralis major musculature. Reproduced with permission from Rozen et al. [29]

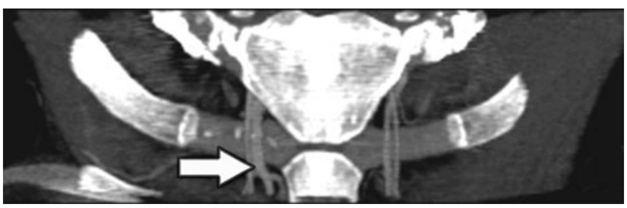

Fig. 3 Computed tomographic angiogram (CTA) of the thoracic vasculature, with volume rendered technique (VRT) reconstruction, demonstrating a duplicate internal mammary artery on the right and single internal mammary artery on the left

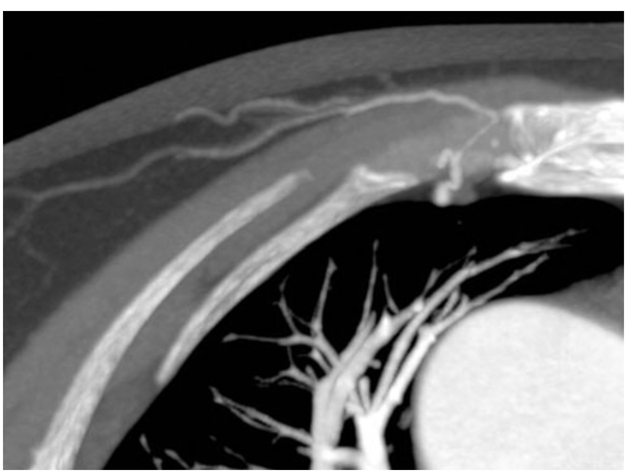

Fig. 4 Computed tomographic angiogram (CTA) of the thoracic vasculature, with maximum intensity projection (MIP) axial reconstruction, demonstrating the internal mammary artery and course of a second intercostal space perforator through the pectoralis major and subcutaneous tissues

two cases, however, there was a duplicate IT artery (1% of overall cases). In all cases the IT artery arose from the subclavian artery. In terms of the position of the IT artery

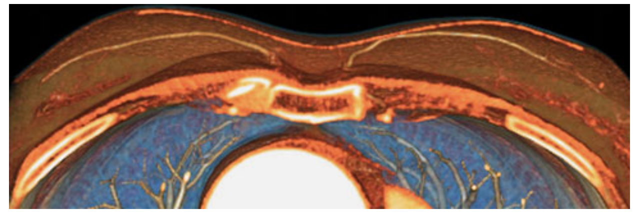

Fig. 5 Computed tomographic angiogram (CTA) of the thoracic vasculature, with maximum intensity projection (MIP) axial reconstruction, demonstrating the internal mammary artery and course of a third intercostal space perforator through the breast parenchyma

at the lateral sternal border, as the most medial structure, most lateral structure or location between two IT veins within the intercostal space, the central position between the two veins was the most frequent position (71.5% of cases), while the lateral position was the least frequent (6% of cases). The presence of major arterial perforators (>1 mm diameter) from each of the first five intercostal spaces was assessed on imaging, and it was found that there were usually dominant IT perforators from the first and second intercostal spaces (occurring in 87 and 91% of cases, respectively), with the incidence of such perforators reducing the more caudal the intercostal space from the second space down, with only 6 and 5% of cases showing such branches in each of the lower two spaces, respectively (see Table 1).

Discussion

The internal mammary vessels as recipient vessels were initially described by Longmire in his paper on microvascular oesophageal reconstruction in 1947 [23] and it was only in 1980 that Harashina successfully performed anastomosis of the free groin flap to the internal mammary vessels for breast reconstruction [16]. Shaw et al. presented a series of ten cases in which he variably used the IT artery and/or veins as recipient vessels, with seven cases utilizing the IT artery and four in which the IT vein were used. The lack of usability was largely due to the fact that the internal mammary vein was small at the level of the fifth rib and was a poor match for the larger donor superior gluteal vein [32]. Feller et al. [10] described suitable IT arteries for anastomosis, but again described inconsistent venous diameter; reporting: “the artery might be adequate as a recipient vessel…(but) the vein is most often found to be inadequate as a recipient vein so that the external jugular or the cephalic vein… is pulled through subcutaneously into the dissected chest pocket”.

These previous authors highlighted a perceived lack of anatomical consistency, however, much of their anatomical data was based on a small number of limited cadaveric

Table 1 Summary of anatomical features of the internal mammary artery as demonstrated on preoperative imaging

Number of trunks of the IMA (*n*/%)	
Zero trunks (absent IMA)	0/240 = 0%
One trunk	238/240 = 99%
Two trunks	2/240 = 1%
Location of the IMA at 3rd intercostal space	
Medial postion—medial to vein(s)	54/240 = 22.5%
Lateral position—lateral to vein(s)	14/240 = 6%
Central position—between veins	172/240 = 71.5%
Presence of perforating branch of the IMA >1 mm in diameter	
First intercostal space	209/240 = 87%
Second intercostal space	219/240 = 91%
Third intercostal space	155/240 = 65%
Fourth intercostal space	15/240 = 6%
Fifth intercostal space	13/240 = 5%

studies. Since then, a number of seminal papers have gone on to accurately describe the IT vessel anatomy at each intercostal level. These studies have proved highly important, as they have potentiated the utilization of a recipient site which is seldom scarred from previous surgery and provides great freedom in flap positioning. The current study contributes data forming the largest anatomical series on this artery in the literature, and highlights the substantial variability in its course.

IT artery origin and course

The IT artery runs caudally from its origin of the undersurface of the first part of the subclavian artery, about 2 cm above the clavicle. Occasionally the IT artery can have a common origin with the thyrocervical trunk, scapular artery, dorsal scapular artery, thyroid artery or costocervical trunk [18]. From there, it passes inferiorly, posterior to the respective brachiocephalic vein and medial to the scalenus anterior muscle. It continues, at a depth ranging from 17 to 22 mm [6], dorsal to the sternoclavicular joint and costal cartilage and ventral to the parietal pleura along the internal surface of the rib cage. The artery remains lateral to the sternal margins. From the third intercostal space, the artery runs between transversus thoracis and the outer intercostal muscle layers which separates the vessels from the parietal pleura and increases the safety of mammary harvest [27]. Between the sixth and seventh costal cartilage the IT artery divides into superior epigastric and musculophrenic arteries. The mean length of the IT artery on each side between origin and termination are: right IT artery = 18.05 cm and left IT artery = 18.09 cm [22]. The IT artery is always accompanied by at least one vein [18]. These findings were matched in the current study.

IT artery position at the lateral sternal border

Various distances between the IT artery and lateral sternal border have been reported, anywhere from 6 to 24 mm [1, 18, 32, 34]. There have been different methods of measurement and different points of reference. Glassberg [12] showed with computed tomography that the mean distance between the IT vessels on the right was 15.7 and 14.7 mm on the left. Ninkovic et al., using ultrasound demonstrated consistency in the location and large calibre of IT artery at the third and fourth intercostals space. The mean distance to the sternum was 15.35 mm [28]. Hefel et al. [18] in female cadaveric studies measured a mean distance of 14.97 mm on the right and 14.53 mm on the left. Arnez et al. [1] reported an average distance of 14 mm with a range of 6–24 mm. The position of the artery relative to the IT veins has been scarcely and variably reported. The current study was able to contribute this data to the literature, demonstrating that the artery can variably lie between, lateral or medial to the IT veins.

IT artery diameter

The diameter of the IT artery varies at each intercostal level, with a range of 0.99–2.55 mm at the fourth rib where the IT vessels are commonly used [18, 22]. The IT artery tends to be larger on the right than the left [11, 18]. Arnez et al. [1] measured the IT artery at the third, fourth and fifth intercostal spaces and found that the average diameter was 2.8, 2.6 and 2.6 mm, respectively. Feng [11] reported a diameter of 2.36 ± 0.50 mm at third intercostal space. Hefel et al. in their cadaveric study found the IT vessels suitable for anastomosis in all cases as the smallest diameter was 0.99 mm and this was substantiated by Doppler ultrasound measurements. The mean diameter on the right was 1.88 mm and the left 1.76 mm [18]. Ninkovic et al. [28] demonstrated a mean diameter 1.87 mm.

The perforating branches of the IT artery

Direct perforators arise from the IT artery to the breast and skin at each intercostal space, 1–2 cm lateral to the sternum, found either superficial or deep to the pectoralis major muscle [13]. IT perforators as recipient sites, first described in 1999, have recently been seen as a preferable option to the regional IT vessels [3]. Previous studies have suggested that IT perforators appear largest in diameter at the second, followed by the third intercostal space where the diameter is on average 1 mm (range 0.5–1.5 mm) for the artery and 1.7 mm (range 0.5–3 mm) for the vein, highlighting that anatomical variants are common [13, 17, 31]. The current studies differed from previous studies, in that first or second intercostals space perforators were by far the largest, and were usually substantially larger than 1 mm in diameter. IT perforators have been used successfully for DIEA, TRAM and SIEA flaps. Unlike with the IT vessels there is no need to dissect out costal cartilage or pectoralis major and the IT artery is preserved as an arterial conduit for future coronary revascularisation [30]. However, dissection of the perforators can be difficult and vessels may be unsuitable due to their calibre.

The IT vein

The IT vein is also an important consideration in using the IT vessels as a recipient site, as the absence or unsuitability of the IT vein for venous anastomoses necessitated the search for a separate recipient vein. Although an analysis of the venous anatomy was outside the scope of the current study, variations in the IT vein have been frequently reported as the limiting factor in use of the IT vessels as recipients [34]. Such variations include the course, relationship to the IT artery, bifurcation pattern and diameter [1, 8].

Anatomical variations in the IT Artery

Variations in IT artery properties between different racial groups and gender have been described. The mean diameter of the internal mammary artery is larger in American females (2.9 mm) as compared with European females [18]. Compared to Caucasians, Han et al. [14] have shown that in Asians there are differences in the bifurcation pattern of the IT vein. Additionally there are some less common anatomical variations that may preclude IT vessel use, with these including congenital arteriovenous fistulae between the IT vessels and pulmonary artery [33], and collateralisation from the IT artery to the iliac artery in aorto-iliac vascular disease [2].

Pathological changes in the IT artery

Pathological vascular changes affecting the IT artery have the potential to adversely affect flap survival. IT patency can be altered in vasculitides of medium and large-sized vessels. Segmental occlusions of the IT artery and collateralisation around these areas have been reported in Buerger's disease, and aneurysmal changes and total obstruction as sequelae of Kawasaki disease [19, 20]. Subclavian stenosis can threaten the adequacy of the IT artery as a conduit and potentially alter vessel dimensions. Causes of subclavian stenosis include: thoracic outlet syndrome, chronic extra-arterial compression, radiation effects, anti-thrombin III deficiency, and/or thrombus of cardiac origin (such as in atrial fibrillation). Moussa et al. [25] have shown that CTA was successfully used preoperatively to assess calibre, luminal diameter and calcification of the left IT artery in a patient with bilateral subclavian stenosis. Arterial complications of thoracic outlet obstruction are common, these include chronic thrombosis of the subclavian artery, distal arterial micro emboli and subclavian aneurysm and subclavian artery thrombosis can extend into the origin of the IT artery and compromise its blood flow [36].

Iatrogenic changes in the IT artery

Adjunctive radiation treatment is an integral component of breast cancer management, with radiation effects within the thoracic vasculature of particular importance in cases of delayed breast reconstruction. Possible operative findings in the IT vessels after radiotherapy include periarterial fibrosis, direct damage to arterial walls and IT vein wall thickening [34]. Radiotherapy-related scarring and fibrosis of the IT vessels can result in the unusability of IT vessels [11] with reports of complete IT artery occlusion post-mastectomy and radiotherapy [15], and radiation-induced occlusion of the subclavian artery [7]. Previous radiotherapy is a documented reason for non-usage of the IT artery in coronary artery bypass graft (CABG) surgery [21] and IT artery graft patency is lower after mediastinal irradiation due to fibrosis and scarring [5].

In addition to radiotherapy, previous surgery at the donor and recipient site in breast cancer patients has the potential to significantly alter vascular anatomy. Local vascular morphology and larger source vessels have been shown to be markedly altered after surgery, with both division of major arterial or venous channels, as well as changes in local vessel calibres shown to occur in response to surgical delay. These changes are not always predictable, highlights the role for preoperative imaging in selected cases.

A detailed awareness of individual anatomy preoperatively can facilitate selection of suitable IT vessels where appropriate and guide surgical approach, which may in turn reduce intra-operative dissection time and surgical error, as shown in other body regions [35]. Additionally, the ability to accurately measure vessel calibre enables matching of both donor and recipient sites, which may reduce conversion rates to alternative vasculature [24], or subsequent flap complications [11], as a result of diameter discrepancy.

Conclusion

The IT vessels provide a valuable and reliable recipient site for autologous breast reconstruction. Detailed anatomical studies have improved our knowledge and understanding of the origin, course, related structures and dimensions of the internal mammary artery and veins. However, congenital anatomical variations, as well as pathologic and iatrogenic processes, have the potential to significantly alter vascular anatomy such that IT artery may become unusable for use in the setting of autologous breast reconstruction. Preoperative imaging with either ultrasound or CTA may provide a clear and accurate method of identifying these anatomical variations preoperatively.

Ethical Approval Institutional Ethical Approval was obtained prospectively, and conforms to the provisions of the Declaration of Helsinki in 1995. The subject gave informed consent and patient anonymity has been preserved.

Conflict of interest None.

References

1. Arnez ZM, Valdatta L, Tyler MP et al (1995) Anatomy of the IM veins and their use in free TRAM flap breast reconstruction. Br J Plast Surg 48:540
2. Ben-Dor I, Waksman R, Satler LF et al (2010) A further word of caution before using the internal mammary artery for coronary revascularization in patients with severe peripheral vascular disease. Catheter Cardiovasc Interv 75(2):195–201
3. Blondeel PN (1999) One hundred free DIEP flap breast reconstructions: a personal experience. Br J Plast Surg 52:104–111
4. Bluemke DA, Chambers TP (1995) Spiral CT angiography: an alternative to conventional angiography. Radiology 195(2):317–319
5. Brown ML, Schaff HV, Sundt TM (2008) Conduit choice for coronary artery bypass grafting after mediastinal radiation. J Thorac Cardiovasc Surg 136(5):1167–1171
6. Bruneton JN, Dalfin FY, Caramella E et al (1986) Value of ultrasound in localizing the internal mammary vessels. Eur J Radiol 6(2):142–144
7. Budin J, Casarella WJ, Hardiadis L (1976) Subclavian artery occlusion following radiotherapy for carcinoma of the breast. Radiology 118:169–173
8. Clark CP, Rohrich RJ, Copit S et al (1997) An anatomical study of the internal mammary veins: clinical implications for free-tissue transfer breast reconstruction. Plast Reconstr Surg 99(2):400–404
9. Demirtas Y, Cifci M, Kelahmetoglu O, Demir A, Danaci M (2009) Three-dimensional multislice spiral computed tomographic angiography: a potentially useful tool for safer free tissue transfer to complicated regions. Microsurgery 29(7):536–540
10. Feller AM (1994) Free TRAM: results and abdominal wall function. Clin Plast Surg 21(2):223–232
11. Feng LJ (1997) Recipient vessels in free-flap breast reconstruction: a study of the IM and thoracodorsal vessels. Plast Reconstr Surg 99:405
12. Glassberg RM, Sussman SK, Glickstein MF (1990) The internal mammary vessels: importance in planning percutaneous transthoracic procedures. Am J Roentgenol 155:397–400
13. Hamdi M, Blondeel PN, Van Landuyt K et al (2004) Algorithm in choosing recipient vessels for perforator free flap in breast reconstruction: the role of the internal mammary perforators. Br J Plast Surg 57:258–265
14. Han S, Yoon SY, Park JM (2003) The anatomical evaluation of internal mammary vessels using sonography and 2-dimensional computed tomography in Asians. Br J Plast Surg 56(7):684–688
15. Hanet C, Marchand E, Keyeux A (1990) Left internal mammary artery occlusion after mastectomy and radiotherapy. Am J Cardiol 65(15):1044–1045
16. Harashina T, Imai T, Nakajima H, Fugino T (1980) Breast reconstruction with microsurgical free composite tissue transplantation. Br J Plast Surg 33(1):30–37
17. Haywood RM, Raurell A, Perks AG et al (2003) Autologous free tissue breast reconstruction using the internal mammary perforators as recipient vessels. Br Plast Surg 56(7):689–691
18. Hefel L, Schwabegger A, Ninkovic M et al (1995) IM vessels: anatomical and clinical considerations. Br J Plast Surg 48(8):527–532
19. Hoppe B, Lu JT, Thistlewaite P et al (2002) Beyond peripheral arteries in Buerger's disease: angiographic considerations in thromboangiitis obliterans. Catheter Cardiovasc Interv 57(3):363–366
20. Ishiwata S, Nishiyama S, Nakanishi S et al (1990) Coronary artery disease and internal mammary artery aneurysms in a young woman: possible sequelae of Kawasaki disease. Am Heart J 120(1):213–217
21. Karthik S, Srinivasan AK, Grayson AD et al (2004) Left internal mammary artery to the left anterior descending artery: effect on morbidity and mortality and reasons for nonusage. Ann Thorac Surg 78(1):142–148
22. Lachman N, Satyapal KS et al (1998) Morphometry of the internal thoracic arteries. Surg Radiol Anat 20:243–247
23. Longmire WP (1947) A modification of the Roux technique for antethoracic esophageal reconstruction: anastomosis of the mesenteric and internal mammary blood vessels. Surgery 22:94–100
24. Moran SL, Nava G, Behnam AB et al (2003) An outcome analysis comparing the thoracodorsal and internal mammary vessels as recipient sites for microvascular breast reconstruction: a prospective study of 100 patients. Plast Reconstr Surg 111(6):1876–1882
25. Moussa F, Kumar P, Pen V (2009) Cardiac CT scan for preoperative planning in a patient with bilateral subclavian stenosis needing coronary artery bypass. J Card Surg 24(2):196–197
26. Munhoz AM, Ishida LH, Montag E et al (2004) Perforator flap breast reconstruction using internal mammary perforator branches as a recipient site: an anatomical and clinical analysis. Plast Reconstr Surg 114(1):62–68
27. Netter F H (1989) Body wall plates. In: Colacina S (ed) Atlas of human anatomy. Ciba-Geigy Corporation, Summit, p 176
28. Ninkovic MM, Schwabegger AH, Anderl H (1998) IM vessels as a recipient site. Clin Plast Surg 25:213
29. Rozen WM, Alonso-Burgos A, Murray ACA, Whitaker IS (2011) Is there a need for preoperative imaging of the internal mammary recipient site for autologous breast reconstruction. Ann Plas Surg [Epub ahead of print]
30. Saint-Cyr M, Chang DW, Robb GL et al (2007) Internal mammary perforator recipient vessels for breast reconstruction using free TRAM, DIEP, and SIEA flaps. Plast Reconstr Surg 120(7):1769–1773
31. Schmidt M, Aszmann OC, Beck H et al (2010) The anatomic basis of the internal mammary perforator flap: a cadaver study. J Plast Reconstr Aesthet Surg 63(2):191–196
32. Shaw WW (1983) Breast reconstruction by superior gluteal microvascular free flaps without silicone implants. Plast Reconstr Surg 72(4):490–501
33. Sotozono K, Takatori M, Miyake F et al (1989) A patient with an arteriovenous fistula between the internal mammary artery and the pulmonary artery. Jpn Circ J 53(4):341–344

34. Temple CL, Strom EA, Youssef A (2005) Choice of recipient vessels in delayed TRAM flap breast reconstruction after radiotherapy. Plast Reconstr Surg 115(1):105–113
35. Uppal RS, Casaer B, Van Landuyt K (2009) The efficacy of preoperative mapping of perforators in reducing operative times and complications in perforator flap breast reconstruction. J Plast Reconstr Aesthet Surg 62:859–864
36. Wu CH, Sung SH, Chang JC (2009) Subclavian artery thrombosis associated with acute ST-segment elevation myocardial infarction. Ann Thorac Surg 88(6):2036–2038