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Optimising Computed Tomography Angiogram Assessment in Breast Reconstruction

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Introduction

Background: Computed Tomography Angiography (CTA) is established as a pre-operative tool for abdominal perforator flap surgery in breast reconstruction. We present a detailed CTA algorithm guiding the surgeon to safe flap raising.

Methods: An algorithm for logical assessment of the CTA has been developed over the senior author's 9.5-year experience, which guides hemi-abdomen and perforator choice, number of perforators required and whether a muscle sparing TRAM or even a TRAM flap is the optimal choice for each individual.

Results: This algorithm has been used successfully and taught locally. Total flap loss rate in 350 flaps was 0.57%, partial flap loss rate 0.28% and fat necrosis rate 2.57%.

Conclusions: This simple, methodical and reliable CTA algorithm represents a way to limit the learning curve for less experienced surgeons.

Keywords: Algorithm; Breast Reconstruction; Computed Tomography Angiogram; Deep Inferior Epigastric Perforator; CTA; DIEP

Introduction

The pre-operative planning of breast reconstruction with abdominal based flaps is increasingly common and multi detector Computed Tomography Angiography (CTA) is regarded by many as the gold standard [1-3]. It has translated into reduced perforator dissection times and postoperative complications [4-7].

The senior author introduced CTA into routine pre-operative evaluation 8 years ago and developed a logical algorithm to optimise safe flap raising. In a literature full of the utility of CTA, there is little on how to practically use the information they contain. This paper describes the algorithm which has been used successfully and taught locally.

Methods

Clinical Series

Data from the senior author's case series of abdominal based breast reconstructions were collected prospectively over a 9.5-year period. This included flap loss (total and partial) and fat necrosis, defined clinically as persistent lumpiness six months post-operatively.

CTA Technique

This has been described in detail elsewhere [8]. The CTA scanner used was a 64 slice multidetector-row computed tomography scanner (Siemens Medical Solutions, Erlangen, Germany), with 100ml of intravenous contrast (Omnipaque 350, Amersham Health, Princeton, NJ). The images were reformatted using commercially available software into maximum intensity projection and three dimensional volume rendered technique

(Siemens InSpace, Version: InSpace2004A_PRE_19, Malvern, PA, and recently Osirix (Osirix Medical Imaging Software, GPL Licensing Open Source Initiative)).

Algorithm

Patient assessment

Percentage of abdomen required

100% of the abdomen is defined as the total surface area of skin that could be harvested, according to standard incisions, from the top of the mons to the umbilicus and to the midaxillary line laterally on each side. 50% would generally be from the midline to the midaxillary line and would be half of the abdomen as defined above. On occasion, depending on the perforasome, the lateral 50% may refer to extending the flap 10% beyond the midline and discarding the lateral 10%. If bilateral breasts are being reconstructed, the total percentage of abdomen available cannot exceed 50%. In unilateral reconstruction, a requirement of more than 70% in our experience usually requires a bipedicled, or 'stacked' Deep Inferior Epigastric Perforator (DIEP) flap. Body habitus and a decision regarding contralateral breast volume alteration must be factored in. In general, 10% larger than estimated is raised to allow for breast tissue being denser than the abdomen or later superior pole liposuction to create ptosis. Note also that the medial portion of the abdomen is thicker than the peripheries.

Abdominal scars

Our group has previously published on CT imaging of the scarred abdomen [9]. Open appendicectomy scars are associated with disruption of the Superficial Inferior Epigastric Artery (SIEA) and veins (SIEVs) on the right hemi-abdomen. Midline scars obliterate crossover of branches of both deep and superficial systems. Pfannenstiel scars may disrupt medial superficial systems, and open cholecystectomy scars the superior system. Indeed, abdomens with pfannenstiel scars have on average larger diameter DIE perforators than those without, evidence perhaps of the delay phenomenon [10]. Although some of these configurations are predictable, due to variability in scar position and vascular remodelling, pre-operative CTA helps individual flap planning.

CTA assessment

The 3D reformat allows visualisation of the largest DIE perforators and the SIEAs. The co-ordinates for each perforator relative to the umbilicus is recorded. The direction of the vessels after they enter the flap can also be appreciated, giving an indication of the intraflap perforasome (figure 1). The axial views allow measurement of perforator diameter, demonstrate intra-muscular course and branching pattern within the adipose of the flap (figure 2). The following are then reviewed:

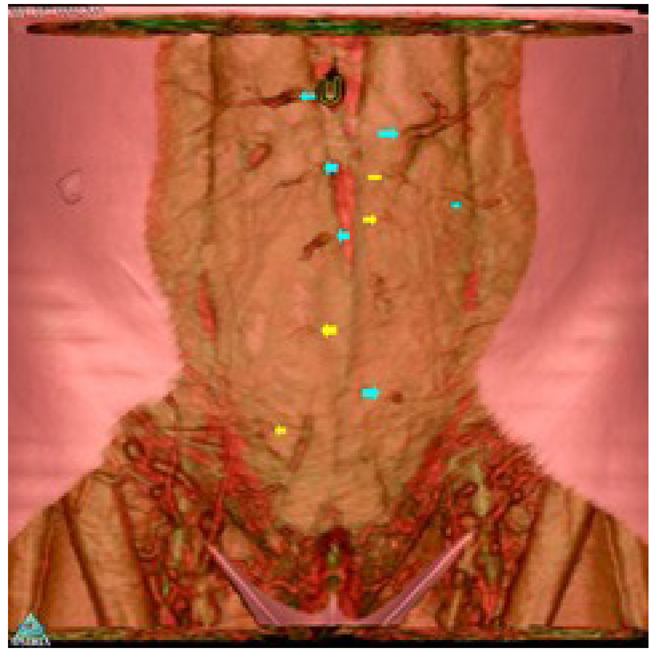

Figure 1: 3D reconstruction view showing direction perforators are taking and therefore their perforasome. Note most are inferolateral, but large perforator on left has a predominantly superolateral direction.

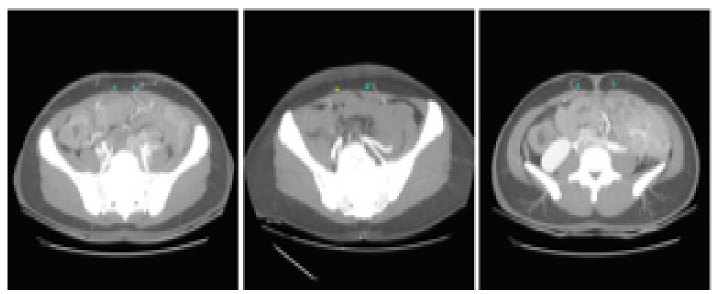

Figure 2: 2a (left)- Axial view showing paramuscular perforator and branching of perforators within adipose of flap; 2b (middle)- Axial view showing perforator with short intramuscular course; 2c (right)- Axial view showing perforator with long intramuscular course.

Perforator size

This represents the internal diameter of the perforating vessel and has been published and validated by our group, using the above software A single skilled surgeon, who has reported over 2000 CTAs, measures this [11,12]. The flap should be designed around the biggest perforator available.

From experience, a single perforator with a diameter of 1.5mm will generally supply 50% of the abdomen reliably. Two perforators of half the diameter are not equivalent to a single large one as illustrated by the exemple below:

Is a single 2.5mm perforator better than two 1.5mm perforators?

Consider Pouseille's law:

$Q=(P_1-P_2)\pi r^4/(8\eta l)$

where Q=flow, P_1=pressure at beginning of tube, P_2=pressure at end of tube, r=radius, η=viscosity, l=length.

It may be tempting to think that if two 1.5mm perforators are added they are equivalent to a single 3mm perforator. However, consider the single 2.5mm perforator. It's radius is 1.25mm and therefore the flow is proportional to 1.25^4, which is 2.44. Compare this to two 1.5mm perforators, where the flow is proportional to $2x(0.75^4)$, which is 0.63. The flow in the single 2.5mm perforator is nearly four times that of the two 1.5mm perforators.

A single perforator of 2.5mm or more, regardless of position in the flap, will supply almost all of the abdomen, which can be regarded as equivalent to the vascularity of a TRAM flap (Figure 3). When the perforator sizes are more modest, a single perforator DIEP can still be raised if the diameter of the perforator is 1.5mm or more and only 50-60% of the abdomen is required. When the perforators are all small, decisions need to be made regarding multiple perforator DIEPs versus muscle sparing- or even full TRAMs. In general if all of the perforators are less than 1.5 mm, then a 2 or 3 perforator DIEP should be raised. If the perforators are 1mm or less, then a muscle sparing TRAM or even TRAM is a safer option (Figure 4).

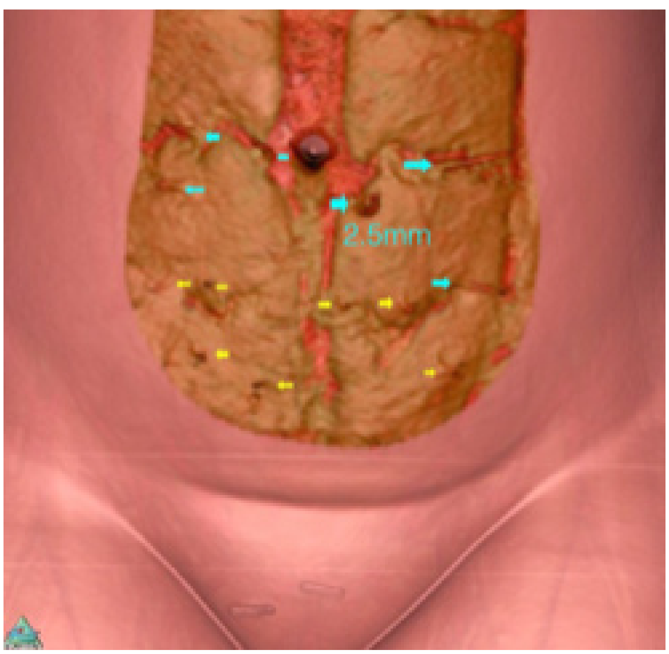

Figure 3: 3D reformats showing large left sided perforator, 2.5mm in diameter

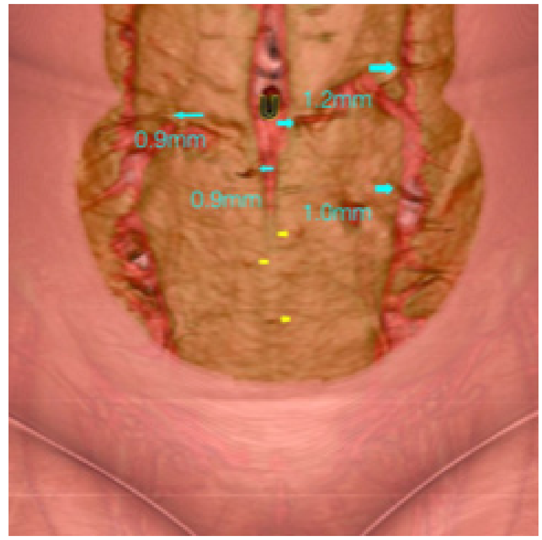

Figure 4: 3D reformats showing small perforators; 2 perforators over 1mm on left hemiabdomen and sub 1mm perforators on right. A two perforator DIEP could be raised based on the left side. Alternatively, on the right hemi-abdomen all the perforators are sub 1mm; therefore muscle needs to be incorporated to add vascularity. As the perforators are at the peripheries of the muscle, our preference would be be harvest a TRAM flap on this side.

Perforator location in flap

When there is a choice of perforator, it is best to aim for one with a central location in the flap and the appropriate perforasome. In general, if it is a unilateral reconstruction, a medial perforator is preferable whereas for a bilateral reconstruction, lateral perforators will be more central for each flap. If the best perforator is high, then the whole flap may need to be designed higher up to best incorporate its perforasome (Figure 5). If there is a choice between perforators it may be best to choose one with a shorter or even a paramuscular course, as seen on the axial views (Figure 2).

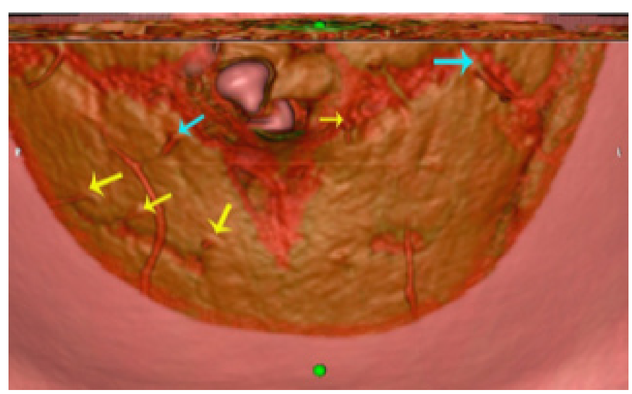

Figure 5: 3D reformats showing largest perforator located above umbilicus on left hemiabdomen (marked with large blue arrow).

Perforasome (intra-flap course)

It is essential to note that zones of vascularity as described for the TRAM flap do not apply to perforator flaps. In order to capture the best vascularised tissue in the flap based on the chosen perforator it is critical to look at the direction of the intraflap perforator course within the flap. Most tend to travel inferolaterally, as shown in the right hemi-abdomen in figure 1. In our experience, there is approximately three times greater vascularity in this direction than in any other. This means that a paraumbilical perforator with an inferolateral perforasome will adequately perfuse the hemi-abdomen. However, if a perforator of the same size and position has a superolateral perforasome, as in the left hemi-abdomen in figure 1, the inferomedial aspect of the hemi-abdomen will be poorly vascularised. If this inferomedial tissue is required a further perforator will be needed that encompasses this area in it's perforasome. The axials are also useful to look at perforator direction within the flap and their branching patterns (Figure 2).

Pedicle choice (DIEP or SIEA)

If the SIEAs are much larger than any of the DIE perforators, they may be the better choice. An accurate size can often be best appreciated on the axial view close to the origin of the vessels (Figure 6). The SIEA however must be central in the flap, or have an appreciable medial branch which is, and not have been transected by previous surgery. Often, they are very lateral, and therefore not suitable unless the whole flap is redesigned low and extending into the flanks. The SIEAs therefore should be entering the flap along the linea semilunaris or have an appreciable medial branch in order to be useful. This can be viewed on the SIEA 3D reformat (Figure 7). Overall, the SIEAs are only suitable in 5-10% cases. Transverse abdominal scars may limit the size of the flap or have damaged the superficial vessels so caution is advised with appendicectomy and hernia scars. Pfannenstiel scars are usually not an issue; the integrity of the pedicle can be visualised on the CTA.

Despite sometimes being the optimal choice of abdominal pedicle, the SIEA flap does have several disadvantages. The literature reveals a higher failure rate compared to the DIEP [13], possible higher rates of fat necrosis and seroma. The angiosome does not normally cross the midline [14], meaning the total volume available is usually only 50% of the abdomen. The pedicle is shorter, which may limit inset; typically a contralateral flap is used to allow the midline of the abdomen to be placed inferiorly and the vessels medially towards the internal mammary vessels. To account for short pedicle length and size mismatch, the internal mammary perforators may be the more optimal recipient vessels. The SIEA donor site however is the key advantage as the abdominal fascia is not breached. For bilateral reconstructions it can be ideal.

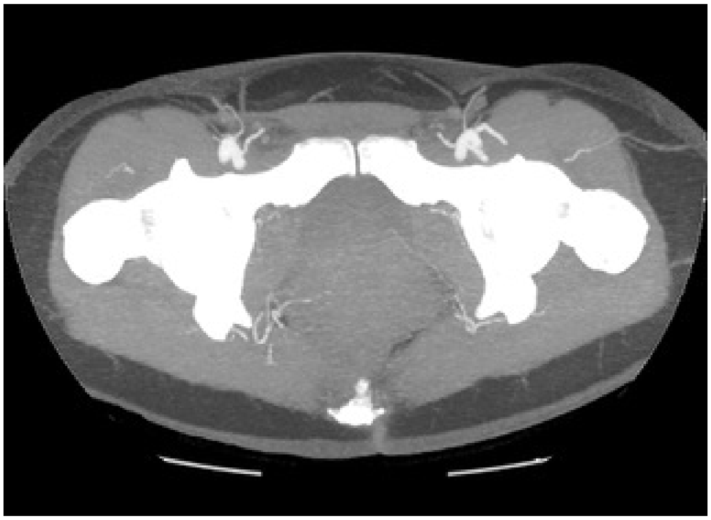

Figure 6: Axial view centred on SIEAs.

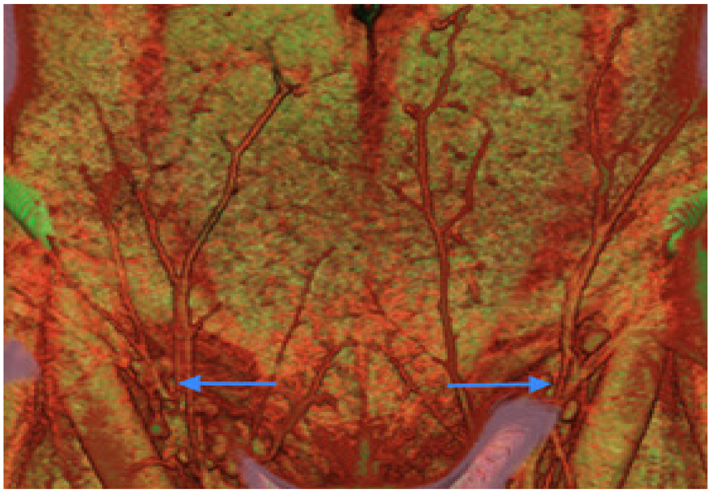

Figure 7: 3D reformats demonstrating SIEA vessels (blue arrows) which are central in flaps and have medial branches; note also the visible multiple SIEVs.

Several perforator DIEP flap, muscle sparing TRAM flap or TRAM

A full TRAM may be best vascularised, but this negates the donor advantages of a perforator flap. If there are several perforators over 1mm we would raise a two or rarely a three perforator DIEP.

If the perforators are all less than 1mm, we would choose a muscle sparing TRAM if the best perforators are medial. This means taking a strip of medial muscle and preserving the lateral muscle and thus the nerves that lie within it's substance. To be safe, a partial perforator dissection should in our opinion be performed to ensure that the larger perforators identified join the main pedicle.

It does not make sense to us to preserve the medial muscle whilst harvesting the lateral muscle through which the nerves run, as this means preserving a strip of denervated and therefore arguably useless muscle. If therefore the perforators are less than 1mm and are in the lateral row, we would elect to perform a TRAM. Every attempt is made to minimise the harvest of the anterior rectus fascia with the flap whilst encompassing the main perforators; this fascial sparing TRAM approach is guided by the CTA reformat. The overall algorithm is depicted in figure 8.

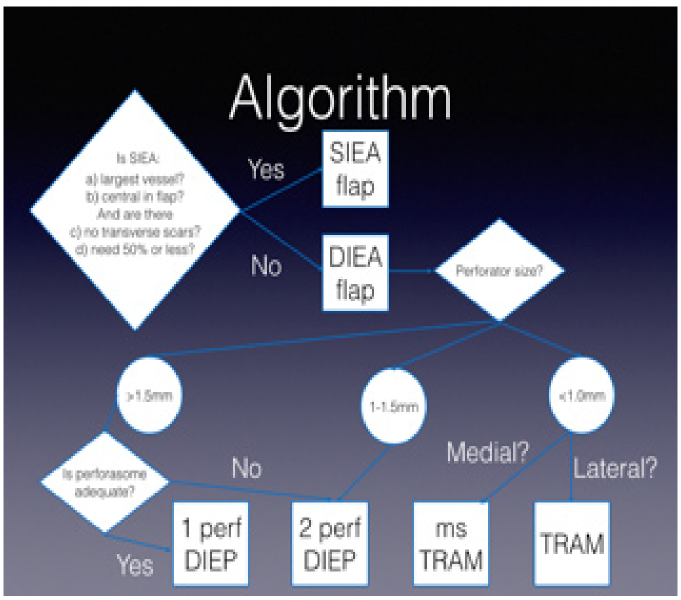

Figure 8: Planning algorithm.

Clinical examples

Worked examples are given below:

Case 1: a bilateral reconstruction is planned with 50% of the abdomen needed for each side. The 3D reformat shows a 1.5mm perforator on the left, but it is high in the flap and has a superolateral perforasome (Figure 9). There is a further 1mm perforator on this side. On the right, all the perforators are less than 1mm, but several are in the medial row. Therefore on the left a 2 perforator DIEP is planned to improve flap perfusion and an msTRAM on the right, taking medial muscle only.

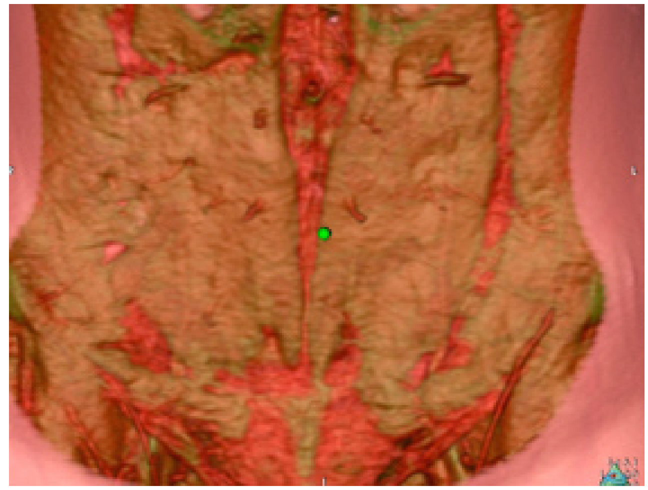

Figure 9: 3D reformat, case 1.

Case 2: a bilateral reconstruction with 50% of the abdomen is required. From the 3D reconstruction, on the right she has a 1.2mm perforator located 4cm lateral and 3cm below the umbilicus and another 1.1mm perforator located 1.5cm above the umbilicus (Figure 10). On the left, there are only two 0.8mm perforators; one is very medial and one very lateral. The SIEA on the left is 1.2mm and 0.5mm on the right. The flaps are therefore planned slightly higher than normal to incorporate the high perforator on the right; a 2 perforator DIEP is executed on the right and a full TRAM on the left.

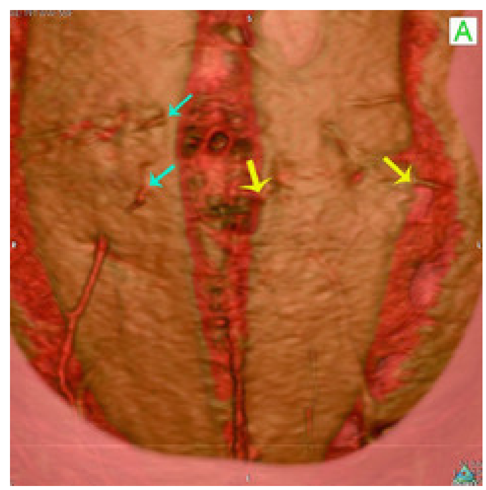

Figure 10: 3D reformat, case 2.

Case 3: a bilateral reconstruction is planned, requiring 50% of the abdomen from each side. On the 3D reformat, the right has a 1.5mm perforator, 3cm lateral and 4cm below the umbilicus. The rest of the perforators are all less than 1mm (Figure 11a). She has large 1.5mm SIEAs bilaterally shown on the SIEA 3D reformat (Figure 11b). On the left, an SIEA flap is planned and performed. On the right, a single perforator DIEP is planned.

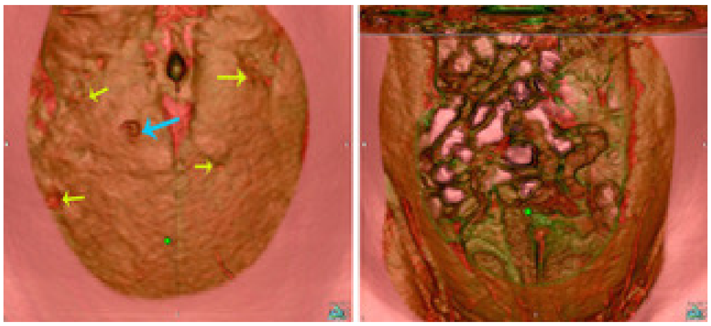

Figure 11: a left - 3D reformat, large perforator marked with blue arrow, case 3; **b right** - 3D reformat of SIEAs case 3, showing large left SIEA.

Results

350 abdominal based breast reconstructions have been performed over 9.5 years. CTA as a pre-operative standard was introduced 8 years ago, and the algorithm outlined in this paper has guided decision making since. Overall 85% of these cases have been DIEPs, 10% SIEAs and 5% TRAMs. Total flap loss rate was 2/350 (0.57%), partial flap loss rate was 1/350 (0.28%) and fat necrosis rate of 9/350 (2.57%).

The partial flap loss was in a flap raised before CTA was utilised; both total losses were in bilateral reconstructions. Both of these flaps had on table arterial clots needing anastomotic revision. Therapeutic heparin was started for both patients for presumed coagulopathies. One flap was lost at day 3 whilst on anti-coagulation. The other flap was lost at day 5 once the heparin was stopped, and aspirin commenced. Despite probable underlying coagulation disorders, none have been identified on testing either patient.

The fat necroses are particularly interesting and will be the subject of future studies. Four of the nine cases utilised single perforators; although the senior author rarely deviates from size and location criteria planned on the CTA, as the technique has evolved, the importance of the perforasome has been noted. It is postulated that the perforasome of these chosen perforators was inadequate to supply the whole flap reliably.

Discussion

Since CTA has been established as a reliable preoperative imaging modality for abdominal based free flap surgery [1-2,15], there have been many papers which have shown good correlation between imaging and operative findings of 82-100% [1,2,4,16-18] Studies have demonstrated operative time and post-operative complications have also been reduced [4-7]. Recent systematic reviews [19,20] have found a significant reduction in partial necrosis and flap loss rates in those studies utilising CTA compared to doppler ultrasonography, as well as donor site morbidity and cost [21].

Our study goes further than previous CTA papers. The modified "Navarro" criteria [22], for example list attributes which are desirable for optimal perforators including large caliber, central location, short intramuscular course and broad subcutaneous branching. Our work goes further to quantify the size of perforators and including the critical nature of the intraflap course or perforasome which is necessary to raise safe well vascularized flaps and provides a practical decision-making algorithm very useful to the surgeon. An elegant 'flap viability index' has been created by Pennington et al. [23] modelled on Pouseille's law, which predicts weight of flap which will reliably survive on chosen perforators according to their diameter. This mirrors our experience, except that perforators on the edge of the flap are assumed to have half the flow of those more centrally placed, rather than any attempt to look at perforasome, no mention is made of SIEA, msTRAMs or TRAMs, and flap weight itself is presented as key rather than percentage of abdomen required. Although related, this has not been our experience. Further studies of flow, such as that presented in a later paper by the same group, are welcomed [24].

Early in our series, microsurgical clamps were placed on smaller perforators to assess perfusion of the flap; this led to the algorithm for perforator choice based on size and position. During unit audits of other people's partial flap losses, retrospective review of the CTA also reinforced the perforasome concept. The utility of the system is backed up by the senior author's clinical results. This is in contrast to the study by Casares Santiago et al. 2014 [22] who do not correlate their approach with their complication profile. Our definitions of total and partial flap losses are easy to defend. It is well described that there are different ways of measuring fat necrosis including clinically and radiologically, and we recognize this is a limitation of our paper. The definition that we have used is clinical diagnosis only, gathered prospectively; we do not routinely do ultrasound follow-up in our patients.

It is often asked whether the CTA accurately reflects intra operative findings. In the study by Casares Santiago et al. [22] the perforators chosen in the pre-operative planning were used to raise the flap in 95.2% of cases. This is in some contrast to the paper by Keys et al. [17], who used 82% of the perforators marked pre-operatively using CTA to identify the largest perforators. Those that were not utilised based on CT criteria were reported as having an inadequate pre-operative CTA. In our experience the CTA is usually very accurate, although the perforator diameter measurements can be either all upsized or all downsized; however, the relative sizes remain the same. The reality is that the diameter of the CTA is a snapshot in time and can be changed in vivo due to changes in the patient's temperature and circulating catecholamines or exogenous inotropes. Intra-operatively if a perforator labelled as a 1.4 mm perforator is actually 1.7mm, then the plan may be changed from a two perforator to a single perforator DIEP for example. Equally a 1.2mm perforator may be actually less than 1mm, and the plan may be changed from a two perforator DIEP to a muscle sparing TRAM. Thus, we would also urge caution, as other authors suggest [17,22] in approaching the chosen perforators to allow a back-up plan should the perforators be smaller than envisaged on the CT scan.

In addition, we would caution the less experienced surgeon in choosing the superficial inferior epigastric system in preference to the deep, unless all criteria in our algorithm are satisfied. This means that the SIEA is the largest vessel on the abdomen, is central in the flap and has not been transected by prior surgery. It is well established that there is a learning curve with perforator flap surgery, as evidenced by Hofer et al. 2007 [25], who demonstrated a 40% complication rate in their first 30 DIEP cases compared to a 13.8% rate in the latter part of their 175-case series.

Conclusion

Our CTA algorithm is a logical stepwise approach to using the pre-operative imaging to its full potential and has resulted in rates of flap loss of 0.57%, partial flap loss 0.28% and fat necrosis 2.57%. The general guidelines include using the biggest perforator first and foremost. If there is choice, a medial row perforator is best for a unilateral reconstruction and lateral row perforators for bilateral. The perforators should ideally be central in the flap. If the perforators are less than 1.5mm, then usually more than one perforator is required; if this is the case, medial perforators are preferred as they require less damage to muscle and nerves. If all perforators are less than 1mm, then either a muscle sparing TRAM or TRAM is safest, with a TRAM used if the perforators are lateral. It is also paramount to leave a back-up plan when dissecting the pedicle.

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