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CTA in preoperative planning for DIEP breast reconstruction: what the reconstructive surgeon wants to know. A modified Delphi study☆

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AIM: To gather expert reconstructive surgical opinion to define and rank the surgically most important anatomy and provide guidance for report content to radiologists when reading a preoperative computed tomography angiography (CTA).

MATERIALS AND METHODS: A modified Delphi approach was used, involving a panel of 13 microsurgery experts across North America. Data from three consecutive online surveys were collected and returned to the respondents in the subsequent survey, allowing each respondent to see the range of opinions from other field experts.

RESULTS: Response rates were 62%, 77%, and 69% for each of the three survey rounds, respectively. The panel identified that the most important perforator characteristics in selecting the optimal perforator are diameter of the vein, perforator location within the flap, and diameter of the artery, respectively. The stated preference was for perforators located below the umbilicus. If no suitable perforator was located below the umbilicus, the panel would consider perforators up to 2 cm above the umbilicus. The most important considerations for the preoperative radiology planning report are: the size of the perforator vein, perforator location relative to landmarks, and the size of the perforator artery.

DISCUSSION: Based on the panel of expert reconstructive microsurgeons, the most surgically important anatomical considerations to be assessed and included in preoperative CTA reports for DIEP flap breast reconstruction were determined. The recommendations for reporting of preoperative DIEP breast reconstructions are presented, which, in consultation with local surgeons, can be used to form a template for reporting.

Introduction

Following total mastectomy, the deep inferior epigastric perforator (DIEP) procedure is the most common choice for patients who prefer autologous reconstruction[1] and have adequate abdominal tissue. Autologous tissue is shown to have very good longevity in patients who have received prior radiation. It is a good option for patients undergoing mastectomy for an immediate reconstruction, and can be performed in a patient with an existing defect from a prior mastectomy[2] (delayed reconstruction). In the DIEP flap breast reconstruction, skin and subcutaneous tissue from the abdomen is taken along with one or more supplying perforating vessels from the inferior epigastric vessels. The

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goal is to preserve the rectus muscles during the dissection as the perforator vessel is traced back through the muscle to the main inferior epigastric vascular pedicle. The deep inferior epigastric artery (DIEA) branches originate from the terminal end of the external iliac artery.[1] The DIEA ascends from the lateral parts of the rectus abdominis and penetrates the muscle at its posterior aspect, with three to seven perforator branches supplying the overlying tissue.[1] The vein travels with the perforating artery as a vena comitans. The venous drainage of the lower abdominal flap is primarily through these small vein perforators in the anterior rectus sheath, which drain into the deep inferior epigastric veins (DIEVs), followed by the external iliac vein3. The superficial inferior epigastric vein (SIEV) connects to the DIEV perforator system through anastomoses, and contributes to draining the subcutaneous anterior abdominal wall.[3] The lower abdominal tissue can be anatomically subdivided into four zones based on perforator distribution and perfusion.[4] In designing a flap, the most "dominant" perforator is selected based on certain clinical and anatomical features, which will best support the flap's viability.[2] The required subcutaneous tissue and skin is subsequently dissected and transferred to the recipient breast and anastomosed with the associated internal mammary vessel, or less commonly, the thoracodorsal vessels.[2] This tissue is then used to recreate a natural appearing breast.

The vascular anatomy of the lower anterior abdominal wall varies widely between patients. Computed tomographic angiography (CTA) and three-dimensional (3D) post-processing can be used to illustrate the size, number, course, and location of the available DIEA perforators for use in the tissue flap[5] (Fig 1). Preoperative imaging can be used

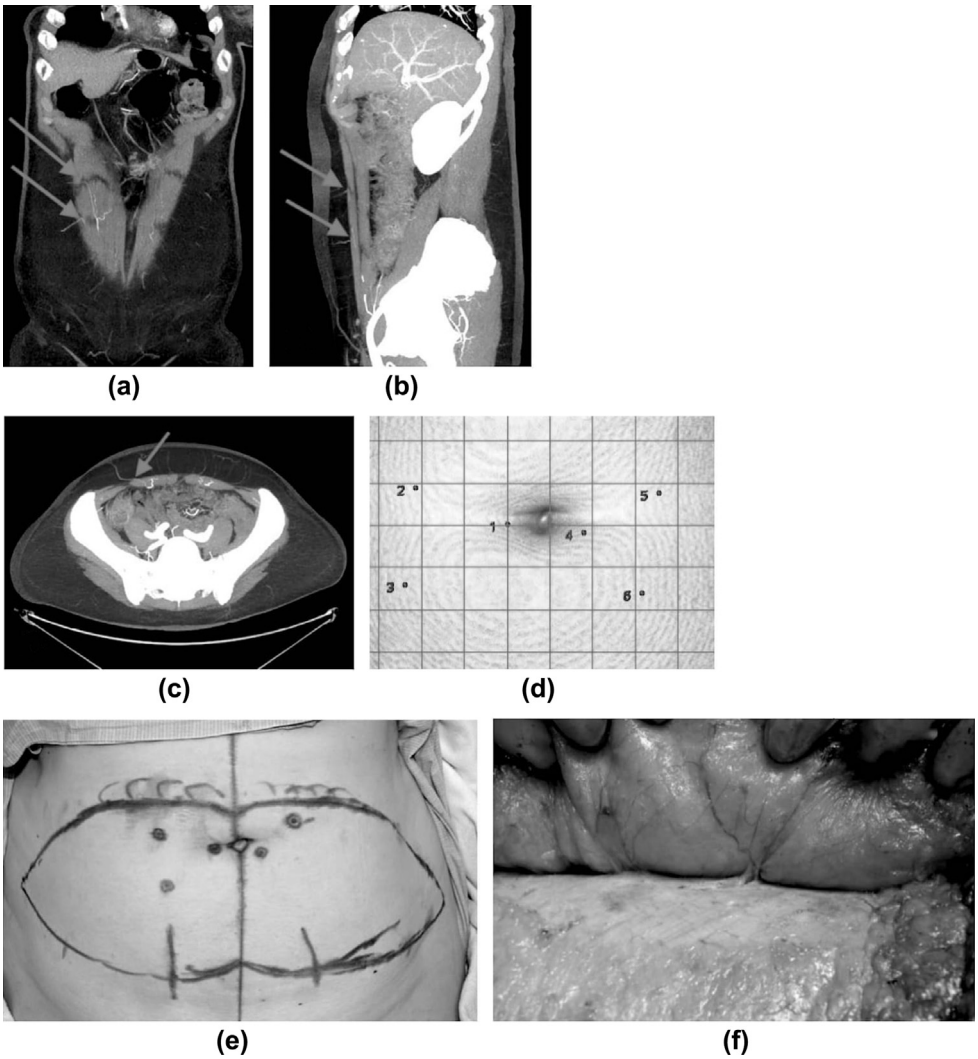

Figure 1 A 66-year-old woman requiring left mastectomy with immediate DIEP free flap reconstruction. Example of the utility of CTA in preoperative planning. (a) Coronal, (b) sagittal, and (c) axial abdominal 50 mm MIP reconstructions, demonstrating two lateral row right-sided perforators. (d) Surface rendered reconstruction demonstrating perforator position relative to umbilicus with 20 mm overlay grid. (e,f) Three perforators on the right hemi-abdomen, of which the two lateral row perforators were used for the DIEP flap. The SIEV was also connected in this case to augment the venous outflow at the time of anastomosis. (e) It is marked on each hemi-abdomen with a vertical line across the inferior incision. All images are of the same patient with their consent.

to assist in planning for microvascular breast reconstruction, and has been demonstrated to reduce the length of time for flap harvest and overall operative times, and to improve outcomes.[4,5] Given the utility of CTA in planning for DIEP breast reconstruction, the aim of the present study was to gather expert reconstructive surgical opinion to define and rank the surgically most important anatomical features to help guide report content for radiologists reading these preoperative CTA examinations.

The purpose of this study was to arrive at an expert consensus as to what is surgically the most relevant anatomical information from preoperative CTA prior to DIEP breast reconstruction. This will provide guidance for radiologists to improve the surgical relevancy of radiology reports and benefit interdisciplinary communication in microvascular breast reconstruction.

Materials and methods

Study design

A modified Delphi approach was used, involving a panel of microsurgery experts. The Delphi survey method aims to build consensus by collecting data from field experts through a series of questionnaires.[6] Data from each survey were collected and returned to the respondents in the subsequent survey, allowing each respondent to see the range of opinions from other field experts.[6] This feedback process allowed respondents to reassess their survey answers, and encouraged consensus building through integrating different viewpoints.[6] It also provided anonymity, permitting respondents to give their expert opinions without group-think bias. No institutional review board approval was required for this study.

Expert panel

Thirteen reconstructive staff microsurgeons were invited via email to participate in the present three-part survey. The surgeons were selected based on their expertise in autologous breast reconstruction and were known to the authors of this present study. The panel consisted of 11 microsurgeons working across Canada and the United States. The represented institutions included University of Manitoba, Mayo Clinic, McMaster University, Memorial Sloan Kettering Cancer Center, New York University Langone Medical Center, University of Ottawa, and University of Toronto. Participants' identities and survey responses were held anonymous to each other.

Questionnaire development and consensus building

Online survey tools (Survey Monkey, Survey Planet) were used to collect data (Fig 2). In the first round, participants shared their general preferences for preoperative imaging and perforator characteristics. Open-ended questions were used to gather a wide range of opinions (Table 1). In round 2, participants responded to and commented on themes that emerged from the results of round 1, and ranked their perforator selection priorities (Table 2). In the final round, consensus was sought by asking participants to comment on and agree or disagree with the survey findings (Tables 3 and 4). A qualitative coding approach was used to interpret and analyse the survey responses. This information has enabled content guidance for radiologist reporting of preoperative CTA to be proposed and clarified.

Results

Among the 13 reconstructive microsurgeons invited to the study, 11 participated in at least one of the survey rounds. There were eight (62%), 10 (77%), and nine (69%) respondents for each of the three survey rounds, respectively. The panel reported using preoperative CTA or magnetic resonance angiography (MRA) in an average of 66% of DIEP breast reconstruction cases. A summary of the final results from the surveys is described below.

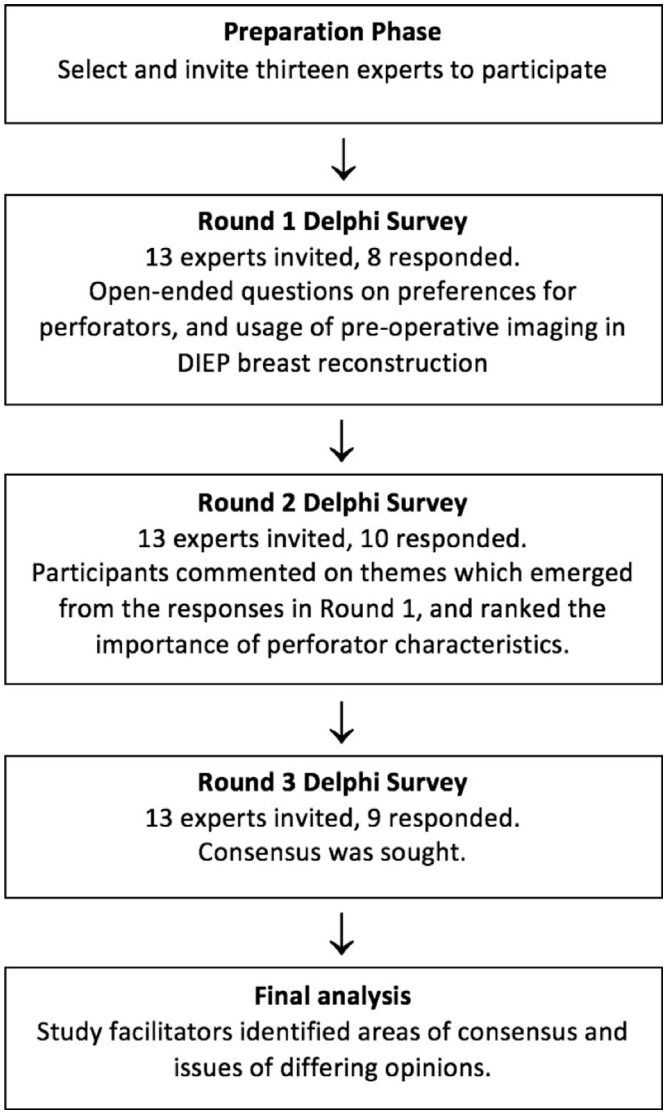

Figure 2 Modified Delphi survey process.

Table 1
Round 1: survey questions and responses.

No.	Survey questions	Summarised responses[a]
1	Do you give preference to medial row or lateral row perforators? Why or why not?	- "Medial row for unilateral to perfuse across midline better and possibly less nerve disruption; no preference for bilateral" - "Medial row. Due to proximity to edge of the flap and perfusion" - "Lateral. Mainly due to ease of dissection" - "Medial, most bulk of the flap, potential to be closer to midline, less critical for damage to muscle innervation if more medial" - "No. Selection of row is based on the best perfusion of the flap" - "Depends if a bilateral or unilateral reconstruction" - "Medial row; better perfusion across midline" - "No, I don't believe it makes a difference"
2	What characteristics makes a perforator desirable for DIEP breast reconstruction?	- "Largest territory of perfusion" - "Venous outflow, then arterial inflow, proximity to edge of flap" - "Larger size, shorter intramuscular/septal course, position in the flap, total length of the pedicle" - "Venous diameter" - "Large size and reasonable location" - "Size, course, physiology (i.e., how much of the flap it perfuses)" - "Large calibre, shortest intramuscular course" - "Adequate flap perfusion"
3	Does location relative to the umbilicus affect your opinion of a perforator? In what way?	- "Medial row for unilateral to perfuse across midline better and possibly less nerve disruption; no preference for bilateral" - "Yes as it is close to the edge of a hemi-abdomen flap" - "Usually good size but can be off centre" - "No" ×3 - "I prefer a perforator more centrally located in the flap" - "Prefer to dissect perforators away from the umbilicus (easier), but the pups are usually the ones with the best perfusion"
4	Does intramuscular course affect your opinion of a perforator? In what way?	- "Not really if it's the best perfusing perforator" ×2 - "No. But it makes damage to the venous system more likely" - "Yes. Shorter path is better option" - "Yes. Long intramuscular dissection means long surgery, risk of denervation of muscle and risk of injury to the perforator" - "For ease of dissection I prefer a shorter intramuscular course" - "Somewhat, it can be a more challenging dissection" - "Yes, we try to dissect the one with less intramuscular course to preserve muscle integrity and speed up process"
5	Is there a minimum lumen size of perforator that you would use for a single vessel perforator DIEP?	- "No" ×3 - "About 1.5 mm and with palpable pulse" - "1.5 mm" - "I do not have a number in term of size. If appears small, not sounds load with Doppler" - "For vein … I prefer at least 2 mm" - "Not really … I will assess the perfusion of the flap clinically …"
6	What percentage of cases do you like to use preoperative CTA or MRA imaging in DIEP breast reconstruction?	- "10%" - "2%" - "95%" - "100%" ×2 - "90%"
7	Which characteristics of perforators do you look for with preoperative imaging?	- "Size, location, course" - "Presence of a perforator" - "Size and the course under and within the muscle" ×3 - "Size, position, relationship to each other" - "I select a better perforator based on venous drainage on magnetic resonance venography, no arterial inflow"
8	For your planning purposes, what do you want a radiologist to include in their report?	- "If there is a vein, if veins cross midline or connect with superficial system" - "Nothing. I look at the images myself" ×3 - "Landmark measurements where the perforator exits the muscle in reference to a stable location such as umbilicus" - "Size/location of perforator, intramuscular course, tortuosity" - "Size and location of perforator veins"
9	How many perforator vessels on each side of the abdomen do you like to be included in a radiology report?	- "Only the best 1 or 2" - "It does not matter what the report says" ×3 - "As many 1 mm and above vessels that are seen at and below the umbilicus level." - "Usually 2 or 3 is enough" ×2

[a] Some responses have been summarised and abbreviated to meet page requirements.

Table 2
Round 2: survey questions and responses.

No.	Survey questions	Summarised responses[a]
1	How would you compare the difficulty in dissecting the medial versus lateral row perforator in a DIEP dissection?	- 70% responded "More difficult for medial row" - 0% responded "More difficult for lateral row" - 30% of experts responded "Equal between medial and lateral rows"
2	In your experience, which perforator dissection (medial versus lateral row) is associated with greater morbidity of the rectus abdominus muscle/abdominal wall donor site?	- 40% responded "Lateral row perforator dissection is less morbid" - 40% responded "There is no difference in morbidity" - 20% responded "Medial row perforator dissection is less morbid"
3a	In unilateral reconstruction, do you prefer the medial or lateral row?	- 40% responded "Medial row" - 20% responded "Lateral row" - 40% responded "No preference based on medial or lateral row perforator"
3b	In bilateral DIEP flap breast reconstruction, do you prefer the medial or lateral row?	- 30% responded "Medial row" - 30% responded "Lateral row" - 40% responded "No preference based on medial or lateral row perforator"
3c	In patients with a higher BMI/thicker DIEP flap, do you prefer the medial or lateral row perforator?	- 30% responded "Medial row" - 10% responded "Lateral row" - 60% responded "No preference based on medial or lateral row perforator"
4	Please rank the following perforator characteristics in order of importance, when selecting a perforator for a DIEP flap:	Summed ranking by order of importance: 1) Diameter of vein 2) Location within flap 3) Diameter of artery 4) Territory of perfusion of vessels 5) Intramuscular course distance (short versus long) 6) Length of pedicle 7) Sub-fascial course 8) Medial versus lateral row perforator
5	For radiologists to use a reference point for perforator location, please rank the following radiologic/clinical reference points:	Summed ranking by order of importance: 1) Umbilicus 2) Pubic symphysis 3) ASIS 4) Xiphoid
6	In your opinion, should the length and course of an intramuscular perforator be included in the report?	- 70% responded "Yes" - 30% responded "No"
7	For when a radiologist is preparing a preoperative planning report, please rank the following considerations in order of importance:	Summed ranking by order of importance: 1) Size of perforator vein 2) Perforator location relative to landmarks 3) Size of perforator artery 4) Anatomy (type 1, 2, 3) and epigastric course (single, double, multiple rows 5) Connection of perforator vein with superficial vein system 6) Location of superficial epigastric vein
8	Regarding the superficial inferior epigastric vein, what information from the radiology report would you like to know?	- "Location in relation to pubic symphysis and calibre: - "Presence and location" - "Only presence" ×5 - "Location and interconnection with DIEV" - "Size" - "Distance from midline and communication with deep system"
9	With regard to perforator artery position on preoperative imaging, how much would you value volume-rendered 3D reconstructions with the perforator position marked by a radiologist?	- 40% responded "Somewhat helpful" - 30% responded "Of little importance" - 30% responded "Unnecessary" - 0% responded "Essential"
10	Would you choose a more superiorly located flap based on a favourable perforator above the umbilicus on preoperative imaging?	- 30% responded "Often" - 40% responded "Only if there are no other reasonable perforators" - 30% responded "No"

[a] Some responses have been summarised and abbreviated to meet page requirements.

Considerations in selecting ideal perforators and preoperative planning

The most important perforator characteristic that the panel of experts look for in selecting the optimal perforator is the diameter of the vein. This is closely followed by the perforator's location within the flap, and the diameter of the artery, respectively (Fig 3). In terms of location, the stated preference was for perforators located below the umbilicus. If no suitable perforator was located below the umbilicus, the panel was willing to consider suitable perforators up to 2 cm above the umbilicus. Although territory of perfusion

Table 3
Round 3: survey questions.

No.	Survey questions
1–10	Experts were invited to comment on the following collective results from the second survey *(Questions from the second survey are in quotations, and the collective results are in italics)* 1) "Which perforators are easier to dissect – medial row or lateral row perforators?" → *30% of experts responded "No difference", 70% responded "Easier for lateral row", and 0% responded "Easier for medial row"* 2) "Which perforators (medial versus lateral row) are associated with less morbidity in dissection?" → *20% of experts responded "Medial row", 40% responded "Lateral row", and 40% responded "No difference"* 3) "Which perforators (medial or lateral) are preferred in: • unilateral reconstruction?" → *40% responded "Medial row", 20% responded "Lateral row", and 40% responded "No preference"* • bilateral reconstruction?" → *30% responded "Medial row", 30% responded "Lateral row",* and *40% responded "No preference"* • thicker flap reconstruction?" → *30% responded "Medial row", 10% responded "Lateral row",* and *60% responded "No preference"* 4. "What are the most important perforator characteristics when selecting a perforator for a DIEP flap?" → *1) Diameter of vein, 2) Location within flap, 3) Diameter of artery, 4) Territory of perfusion of vessels, 5) Intramuscular course distance (short versus long), 6) Length of pedicle, 7) Subfascial course, and 8) Medial versus lateral row perforator* 5. "How many perforator vessels should be included on the radiology report?" → *The experts prefer having 1–3 perforator vessels reported on each side of the abdomen* 6. "What are the most important radiologic/clinical reference points for perforator location?" → *1) Umbilicus, 2) Pubic symphysis, 3) ASIS, and 4) Xiphoid* 7. "What are the most important considerations in a radiology preoperative planning report?" → *1) Size of perforator vein, 2) Perforator location relative to landmarks, 3) Size of perforator artery, 4) Anatomy (type 1, 2, 3) and epigastric course (single, double, multiple rows), 5) Connection of perforator vein with superficial vein system, and 6) Location of superficial epigastric vein)* 8. "What information from the radiology report would you like to know about the superficial inferior epigastric vein?" → *50% responded "Presence only", 30% responded "Presence and location", 10% responded "Presence and size", and 10% responded "Presence, location, and size"* 9. "What is the importance of having volume-rendered 3D reconstruction of perforator position on preoperative imaging?" → *The experts have said that it is somewhat helpful, but not essential* 10. "Would you choose a more superiorly-located flap based on a favourable perforator above the umbilicus on preoperative imaging? → *30% responded "No", 30% responded "Often", and 40% responded "Only if there are no other reasonable perforators"*
11	The lateral row perforator generally has a shorter length of dissection than the medial row perforator. → *Agree or Disagree? Comments?*
12	Lateral row perforator dissection poses greater risk to the motor nerve innervating the rectus muscle than medial row dissection. → *Agree or Disagree? Comments?*
13	When taking abdominal tissue in a single flap across midline (zone 3), a medial row perforator is preferred. → *Agree or Disagree? Comments?*

was arguably the most important consideration for the panel of experts, it was acknowledged that this value is difficult to ascertain from CTA/MRA, and is usually inferred based on the perforator's location within the flap.

Commonly, the deep inferior epigastric vessels split into medial and lateral rows at some point throughout their course. The panel did not consider the presence of the perforator in the medial or lateral row to be an essential consideration in preoperative surgical planning. There were split preferences in selecting between medial and lateral perforators. Medial row perforators were preferred over lateral perforators in unilateral reconstruction (40% of experts versus 20%), as there is a perceived greater perfusion across the midline to zone 3 (the skin and subcutaneous tissue overlying the contralateral rectus abdominis muscle) from the pedicle.[1] There was no clear consensus on preference for medial or lateral perforators in bilateral reconstructions (30% versus 30%). Interestingly, the majority of the panel (87.5%) agreed that medial row perforators have a longer length of dissection and are associated with more potential for muscle damage, but are associated with less potential for motor nerve damage compared to lateral row dissections (75%). Ultimately, the decision between choosing a perforator from the medial or lateral row was not an essential consideration for the panel (Fig 3). With respect to the SIEV, 100% of the panel reported interest in knowing that it was present, whereas the location and size of the SIEV was not deemed as important (Fig 4).

Preferences for the radiology preoperative planning report

The panel's preferences for the radiology preoperative planning report closely reflect the most important considerations in selecting a perforator. According to the panel of experts, the most important considerations for the preoperative radiology planning report are, in order of descending importance: the size of the perforator vein, perforator location relative to landmarks, and the size of the perforator artery (Fig 5). The umbilicus was reported by 90% of the panel to be the most important reference point from which to map the perforators. The next most significant radiological reference points were the pubic symphysis, and the anterior superior iliac spine, respectively. The course of the perforator within the muscle was also reported as a significant consideration. Although the preference is for perforators located below the umbilicus, 70% of the panel reported considering a more superiorly located flap based on a more favourable perforator above the umbilicus on preoperative imaging. Thus, the experts agreed that at least one to three perforator vessels should be reported on each side of the abdomen, preferably below the umbilicus, but up to 2 cm above if adequate perforators were not identified below.

Volume-rendered 3D reconstruction of the perforator artery position on preoperative imaging was regarded as somewhat helpful by the panel, but not essential. In total,

Table 4
Round 3: survey responses.

Survey questions	Summarised responses[a]
Questions 1–10. Experts were invited to comment on the results from round 2 *(refer to Table 3 for the full question stems and summary of round 2 responses)*	
1. "Which perforators are easier to dissect: medial row or lateral row perforators?"	- "Lateral row perforators tend to involve less length of dissection … because the main pedicle is usually closer" - "Depends if type 1–3 vascular anatomy" - "Agree, the lateral ones are usually easier" ×3
2. "Which perforators (medial versus lateral row) are associated with less morbidity in dissection?"	- "The lateral row dissection puts motor branches at more risk to the remaining muscle, but otherwise there is not really a difference in morbidity" - "Usually lateral row is a bit better …" ×2 - "No difference" - "Depends on the intramuscular course"
3. "Which perforators (medial or lateral) are preferred in: a) unilateral reconstruction?"b) bilateral reconstruction?" c) thicker flap reconstruction?"	- "This shows that medial versus lateral row is not essential for a healthy flap. Perforator characteristics are more important" - "Agree. I also look at the venous branching pattern if I am considering using a lateral row perforator" - "Bilateral I like lateral row" - "Unilateral: medial row usually has better perfusion across midline, but not always. Bilateral: no preference – abdomen being split in half, so perfusion across midline not important. Thicker flap: no preference" - "Always the largest vein"
4. "What are the most important perforator characteristics when selecting a perforator for a DIEP flap?"	- "The perforator vein/artery as it exits the fascia are the most important. Location and distance that the vessel spends from exiting the fascia, before it exits the muscle, are also important - "Territory of perfusion should be potentially more important but difficult to know beforehand" ×4 - "Location within flap can correspond to perfusion. The decision must be made clinically … Intramuscular course is very important"
5. "How many perforator vessels should be included on the radiology report?"	- "Agree … ideally below the umbilicus, but up to 2 cm above can be included" ×2 - "Usually 3" - "I read CTA by myself" - "In my opinion those which measure greater than 0.3 mm are relevant reported"
6. "What are the most important radiological/clinical reference points for perforator location?"	- "Umbilicus should be the reference point" ×2 - "Agree"
7. "What are the most important considerations in a radiology pre-operative planning report?"	- "Presence of superficial vein is still important, exact location is not, though helpful to know" - "Agree" - "Area of perfusion would be most interesting" - "Perforator location; size of perforator vein/artery; anatomy of system as this can correlate with intramuscular course but not always; SIEV usually in the same spot" - "Radiologists frequently misinterpret the anatomy as type 1, 2, or 3"
8. "What information from the radiology report would you like to know about the superficial inferior epigastric vein?"	- "Yes I agree. I think that some people do not routinely use SIEV as bailout for DIEP flap. It should be commented on in the report" - "I agree" ×2 - "I believe vast majority of Canadian surgeons do not use SIEA/E system" - "Location implies presence and gives more information"
9. "What is the importance of having volume-rendered 3D reconstruction of perforator position on preoperative imaging?"	- "I think that many of the experts do not have this capacity in their centres. I think everyone would love to have it if they could, but it is not essential" ×2 - "Not that helpful for me" - "Agree" - "Agree. It is often underestimated on DIEP flaps and overestimated in thigh-base reconstructions"
10. "Would you choose a more superiorly located flap based on a favourable perforator above the umbilicus on preoperative imaging?	- "yes I agree. Again best to stay within a couple centimetres above the umbilicus as a rule" - "Yes I agree" ×2 - "Agree, radiologists should comment on perforators above the umbilicus to a point, maybe a few centimetres above it at most" - "Once they are above 2 cm from the umbilicus, I will disregard them"

(*continued on next page*)

Table 4 (*continued*)

Survey questions	Summarised responses[a]
The lateral row perforator generally has a shorter length of dissection than the medial row perforator.	- 87.5% responded "Agree" - 12.5% responded "Disagree"
Lateral row perforator dissection poses greater risk to the motor nerve innervating the rectus muscle than medial row dissection.	- 75% responded "Disagree" - 25% responded "Agree"
When taking abdominal tissue in a single flap across midline (zone 3), a medial row perforator is preferred.	- 100% responded "Agree" - 0% responded "Disagree"

[a] Some responses have been summarised and abbreviated to meet page requirements.

40% of respondents felt that these reconstructions were somewhat helpful and 30% stated that these were unnecessary (Table 2 question 9).

Discussion

Selecting the ideal perforator for a DIEP breast reconstruction involves optimising arterial inflow and venous drainage of the flap whilst minimising injury to the abdominal wall donor site. The present study provides a consensus of expert surgical opinion to the most surgically relevant information that should be included in the reporting of preoperative CTA examinations for DIEP breast reconstruction. This will guide radiologists to the most important anatomical information to be assessed and allow for more standardised and surgically relevant reporting. To this goal, guidance for reporting of these examinations has been summarised, which, in consultation with local surgeons, can be used to form a template for reporting (Electronic Supplementary Material Appendix S1).

Among these recommendations, the template report should comment on the DIEA branching pattern on each side of the abdomen.[7] Perforators with long intramuscular courses (>4 cm) through the rectus muscle require more care to avoid vessel and muscular injury.[8] Likewise, perforators with a sub-fascial segment just beneath the anterior fascia of the rectus sheath can be at risk of perforator injury if not recognised due to their superficial location.[8] It can be a challenge to dissect perforators that course through or near the tendinous intersections of the rectus muscle (muscle inscriptions).[8] Thus, the vascular anatomy and epigastric perforator course is an important consideration for the preoperative planning radiology report.

The report should label one to three perforators on each side of the abdomen from most to least favourable, based on size and location. Each perforator should have an accompanying description indicating its position relative to the umbilical root, the length of intramuscular and subfascial course, and calibre of the perforator as it exits the deep fascia (Figs 6 and 7). These characteristics are known to correlate with the territory of perfusion of the

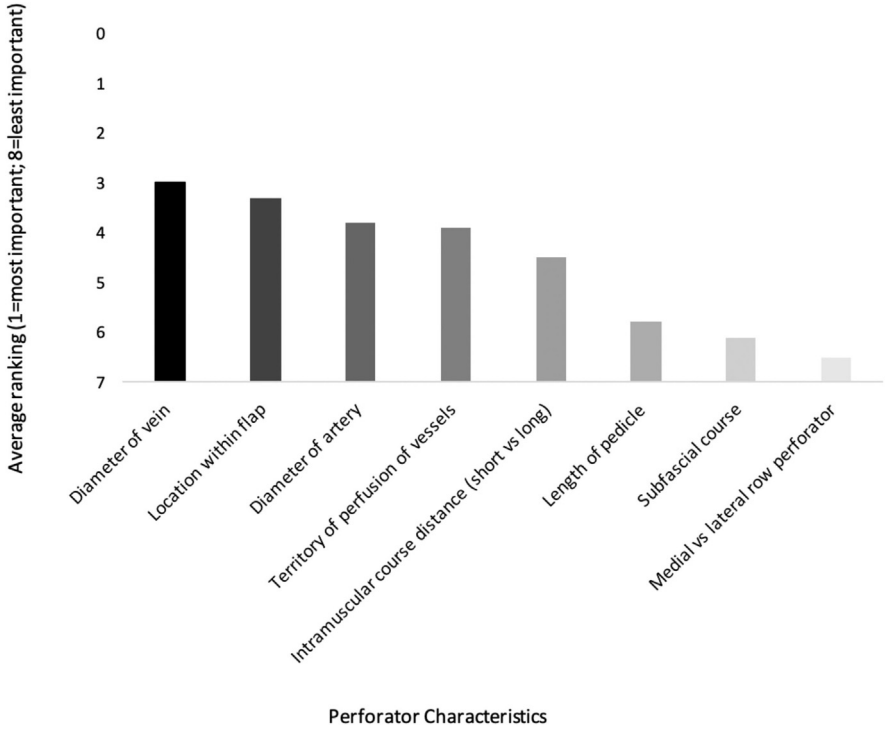

Figure 3 Most important perforator characteristics in selecting a perforator for a DIEP flap.

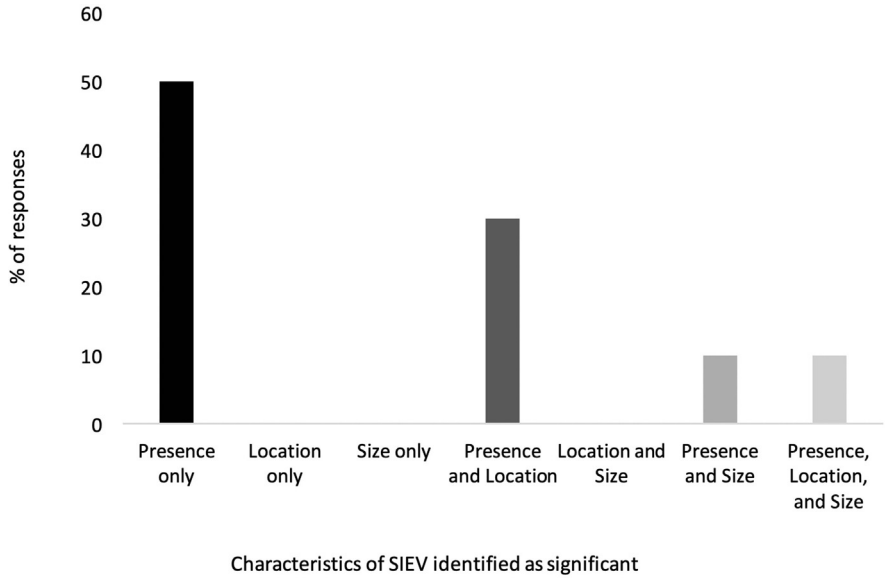

Figure 4 Distribution of responses to the survey question, "What would you like to know about the Superficial Inferior Epigastric Vein (SIEV)?"

perforator, and accordingly, the future viability of the flap.[1] Interestingly, the most important characteristic of a perforator stated by a number of the experts was size of vein rather than size of artery. This is likely due to surgical concern that poor venous outflow from a graft is the primary cause of failure. The enhanced artery and paired non-enhanced vein run close together as they exit the fascia. At this site, due to their small size and average volume effect, the two cannot be clearly differentiated from one another on either CTA or MRA. Therefore, the size measured results from the sum of the calibres of the both artery and accompanying vein2.

The radiology report should include a description of the presence and position of the superficial epigastric vein. Venous congestion is a major complication affecting 2–10.9% of DIEP flaps[9] due to drainage insufficiency; following DIEP dissection, the venous outflow redirects from the dominant superficial system to the deep system.[9] The presence of a direct venous connection of the DIEP vein to the SIEV has been reported to correlate with improved outcomes,[9] although this has been debated within the literature.[9] The presence of the SIEV in the flap may also permit for additional venous anastomosis to increase venous drainage,[9] and is connected to the deep inferior epigastric system in 38–100% of all patients.[9,10] Increased degree of midline crossover by the SIEV has been associated with improved flap drainage.[11] Crossover of the SIEV branches across the midline may be present in approximately 23–64% of cases.[9,10] In 3% of cases, there may be a perforating SIEV anomaly detected with preoperative CTA, where the SIEV originates from the DIEA and perforates the rectus abdominis muscle between the umbilicus and arcuate line.[12] An example of bilateral SIEV imaged on CTA is shown in Fig 8.

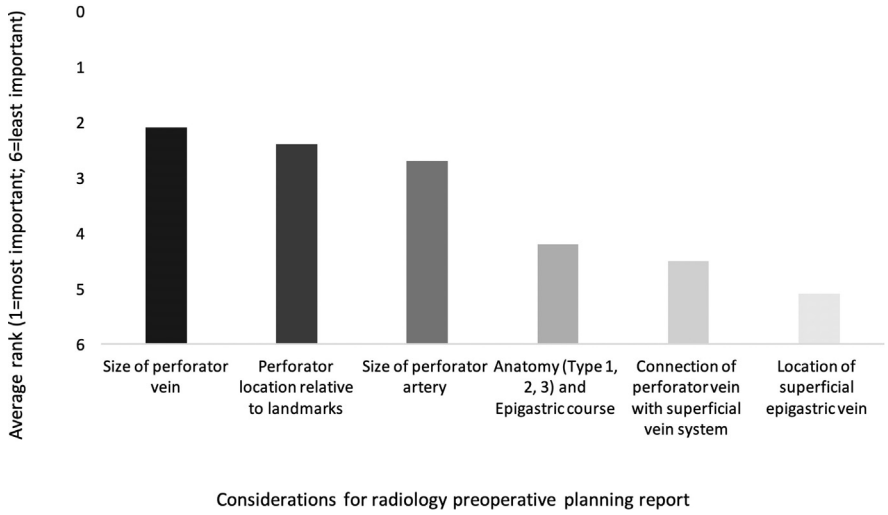

Figure 5 Most important considerations in a radiology preoperative planning report.

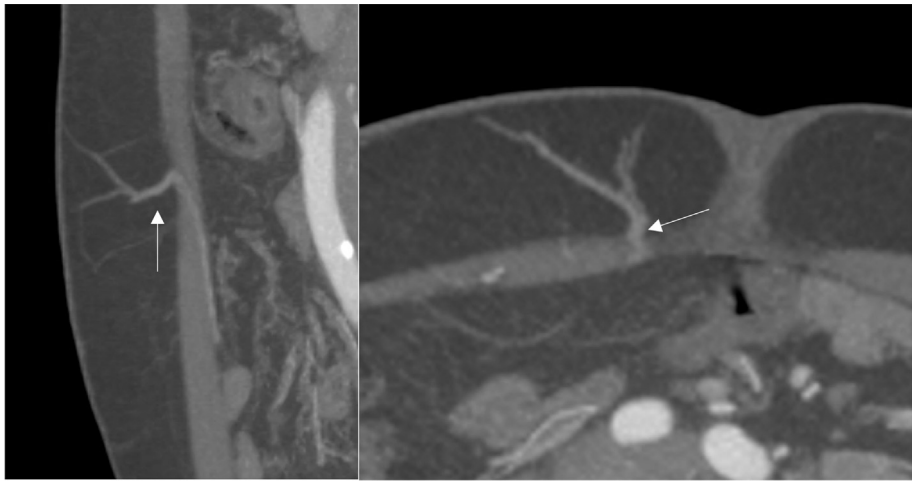

Figure 6 Sagittal and axial 5 mm MIP reconstructions from CTA of a 38-year-old woman demonstrating a good calibre right paramedian perforator (arising medial to the right rectus abdominus) measuring 2 mm in diameter (white arrows).

Interesting comments that did not reach consensus and may warrant further investigation are that medial perforators may have more direct, perpendicular paths through the rectus muscle compared to those of lateral perforators.[13] Medial row perforators can be associated with greater territory of perfusion across the midline to zone 3. In addition, medial row perforator dissection has the potential for less motor nerve damage. Interestingly, the decision between a medial or lateral row perforator was ranked as the least important of the considerations in selecting an optimal perforator (Fig 3).

Volume-rendered 3D reconstruction of the perforator artery position on preoperative imaging was overall regarded as non-essential with varying opinions regarding its importance. Heterogeneity of opinion in this respect highlights the need for close interdisciplinary communication between the local surgeon and radiologist to guide local post-processing and reconstructions.

Although this study focused on the utility of CTA, MRA is used in many centres for the preoperative assessment of DIEP anatomy. Potential advantages include the elimination of radiation exposure and decreased risk of contrast reaction. MRA has been shown to be comparable to CTA for identification of the dominant perforator and close in accuracy for three best perforator identification an intramuscular course assessment (reference - Planning DIEP flaps for Breast reconstruction[14]: a comparison between MD CT and MRA); however, disadvantages include decreased spatial resolution, a longer scan time, more limited accessibility and MRI contraindications.[14]

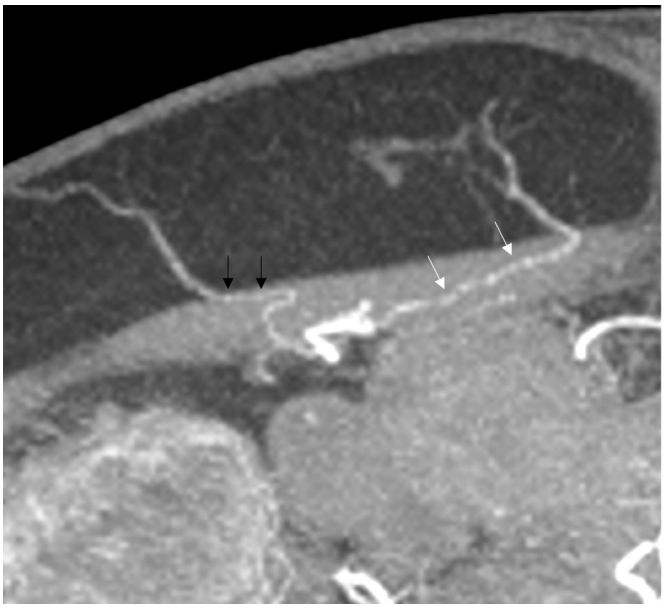

Figure 7 Axial 5 mm MIP reconstruction from CTA demonstrating two right-sided DIEPs. The more medial perforator has a relatively long intramuscular course (white arrows) measuring >3 cm, but no significant subfascial course. The more lateral perforator demonstrates a short intramuscular course and 15 mm subfascial course (black arrows).

Study limitations

The present study is limited by the total number of reconstructive surgical experts. This is somewhat mitigated by the multicentre practice settings of the 13 participating experts that in total represent six different healthcare institutions across Canada and the United States. Additionally, a number of questions remained unanswered by individual experts, reducing the overall strength of consensus.

In conclusion, Preoperative CTA provides surgeons with a roadmap for perforator selection. Understanding the surgical procedure and important aspects of perforator anatomy enable radiologists to focus their reporting to the most surgically relevant findings. Based on the present

Figure 8 A 66-year-old woman requiring left mastectomy with immediate DIEP free flap reconstruction. Bilateral SIEVs on 5 mm axial MIP CTA slice, 2 cm superior to the pubic symphysis. The SIEVs are measured from the midline (lines 2 and 4) and from the skin surface (lines 3 and 5).

panel of expert reconstructive microsurgeons, this study identified that the three most important considerations for a preoperative radiology report are in order of importance: size of perforator vein, perforator location relative to anatomical landmark, and size of perforator artery. Preoperative radiology reports should identify one to three perforator vessels located below the umbilicus on each side of the abdomen, and up to 2 cm above the umbilicus in patients with questionable infra-umbilical perforator vessels. The umbilicus can be used as the radiological reference point. The presence or absence of the superficial inferior epigastric vein should be stated. The findings of the present study demonstrate that preoperative volume-rendered 3D reconstructions of perforator artery position may be somewhat helpful to microsurgeons, but are not considered essential. Dialogue between reporting radiologists and local surgeons is essential in order to tailor a local radiology service that meets the expectations and needs of local referrers.

Conflict of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crad.2019.07.016.

References

1. Hamdi M, Rebecca A. The deep inferior epigastric artery perforator flap (DIEAP) in breast reconstruction. *Semin Plast Surg* 2006;**20**(2):95–102.
2. Cina A, Salgarello M, Barone-Adesi L, *et al*. Planning breast reconstruction with deep inferior epigastric artery perforating vessels: multidetector CT angiography versus color Doppler US. *Radiology* 2010;**255**(3):979–87.
3. Gagnon A, Blondeell P. Deep and superficial inferior epigastric artery perforator flaps. *Cir Plást Ibero-Latinoamericana*. 2006;**32**(4):1–7.
4. Lee KT, Mun GH. Perfusion of the DIEP flaps: a systematic review with meta-analysis. *Microsurgery* 2018;**38**(1):98–108.
5. O'Connor EF, Rozen WM, Chowdhry M, *et al*. Preoperative computed tomography angiography for planning DIEP flap breast reconstruction reduces operative time and overall complications. *Gland Surg* 2016;**5**(2):93–8.
6. Hsu CC, Sandford BA. The Delphi technique: making sense of consensus. *Pract Assess Res Eval* 2007 Aug;**12**(10):1–8.
7. Moon HK, Taylor GI. The vascular anatomy of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. *Plast Reconstr Surg* 1988;**82**:815–32.
8. Lam DL, Mitsumori LM, Neligan PC, *et al*. Preoperative CT angiography and three-dimensional image post processing for deep inferior epigastric perforator flap breast reconstructive surgery. *Br J Radiol* 2012;**85**(1020):e1293–7.
9. Ruiz-Moya A, Lopez-Garcia RA, Sicilia-Castro D, *et al*. Anatomical features associated with venous congestion in DIEP flap using CT

angiography with three-dimensional reconstruction. *Plast Aesthet Res* 2017;**4**:127–34.
10. Blondeel PN, Arnstein M, Verstraete K, *et al*. Venous congestion and blood flow in free transverse rectus abdominis myocutaneous and deep inferior epigastric perforator flaps. *Plast Reconstr Surg* 2000;**106**(6):1295–9.
11. Rozen WM, Chubb D, Whitaker IS, *et al*. The importance of the superficial venous anatomy of the abdominal wall in planning a superficial inferior epigastric artery (SIEA) flap: case report and clinical study. *Microsurgery* 2011;**6**:454–7.
12. Rozen WM, Grinsell D, Ashton MW. The perforating superficial inferior epigastric vein: a new anatomical variant detected with computed tomographic angiography. *Plast Reconstr Surg* 2010;**124**(3):119e–20e.
13. Schaverian MV, Ludman CN, Neil-Dwyer J, *et al*. Relationship between venous congestion and intraflap venous anatomy in DIEP flaps using contrast-enhanced magnetic resonance angiography. *Plast Reconstr Surg* 2010;**126**(2):385–92.
14. Cina A, Barone-Adesi L, Rinaldi P, *et al*. Planning deep inferior epigastric perforator flaps for breast reconstruction: a comparison between multidetector computed tomography and magnetic resonance angiography. *Eur Radiol* 2013;**23**(8):2333–43.