CT-guided deep inferior epigastric perforator (DIEP) flap localization: a road-map for the onco-plastic surgeon

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Aims and objectives

The purpose of breast reconstruction after mastectomy for breast cancer (BC) is to restore the contour and size of the breast while minimizing the aesthetic impact [1] helping the woman to ease the trauma given by BC with positive effects on psychological recovery and self-esteem [2]. Surgery had encouraging evolution from radical mastectomy according to Halsted to 'conservative' reconstruction with adipocutaneous flap of the rectus abdominis muscle by Koshima and Soeda [3]. Vascularisation of the adipocutaneous rectus flap is due to Deep Inferior Epigastric Artery (DIEA), an external iliac artery's branch, distributed to the superficial area through Deep Inferior Epigastric Perforator (DIEP). Heitmann et al. demonstrated that DIEA is always present (average length of 10.3 cm) and one or two DIEP branches with caliber greater than 1 mm (72% in a ratio of 4 cm around the navel) are often identified from each side permitting theoretical good vascular supply to the adipocutaneous flap chosen for breast reconstruction [4].

Since the vascular anatomy of the DIEA and its DIEP branches present highly intra- and inter-individual variability [5] the correct identification of DIEA branching pattern, the location and course of DIEP branches in the single specific patient is mandatory to choose the best DIEP flap for breast reconstruction. Preoperative knowledge of this variable anatomy can definitely help the surgeon in better punctual management of the patient undergoing this complex intervention [6].

According to Moon and Taylor there are anatomical variants of DIEA, identified at the level of the arch of Douglas (Figure 1):

Type 1 (29%): there is only one intramuscular DIEA;

Type 2 (57%): DIEA divides into two intramuscular branches;

Type 3 (14%): DIEA is divided into three intramuscular branches;

Type 0: absence of DIEA.

The DIEP branches originate from DIEA which is usually located between the back face of the rectus abdominis muscle and its fascia, and then penetrate the posterior surface of the rectus abdominis and divide into variable intramuscular segments, than can have a variable subfascial and subcutaneous course.

The identified requirements for the ideal DIEP are:

- Medial localization, with a vascular territory that preferably extends beyond the midline to preserve the lateral innervations of the muscles;

- 0.9 mm is the minimum caliber suitable to nourish the flap;
- Short intramuscular path to facilitate dissection (arbitrarily classified <11 mm);

- Vascular distribution within the fat layer must match the design of the flap.

The use of preoperative imaging for the selection of the best perforator has been proposed as a method to counteract some difficulties associated with these flaps and lead to a reduction of the operative time with best final results [7]. Considering the great variability of vascular anatomy among patients and even between the two emiabdomen, it is essential to get a precise vessel map before the surgery to facilitate dissection and decrease vascular surgical complications [8].

CT-angiography of the abdominal wall is an emerging and accurate method to locate, characterize the piercing, define the branching pattern of the DIEA, the caliber of DIEP branches and the length of their intramuscular path [9, 10]. Autologous breast reconstruction with abdominal flap is an appropriate indication for abdominal CT-angiography that permit to reconstruct volumetric data acquired in a single breath-hold and get precise coordinates (indicated as x, y) shown on virtual surface rendering of patient's abdomen. The measures are then superimposed on the abdominal wall and allow precise preoperative marking of the patient for a targeted approach of the surgeon [1, 11, 12]. The aim of this study is to evaluate the accuracy of CT-angiography in identifying the dominant DIEP and therefore the most suitable abdominal flap for breast reconstruction with muscle sparing. The description of DIEA branching pattern and DIEP location, size and course was performed. Secondary aims were evaluate which post-processing CT method (Volume Rendering -VR- or Maximum Intensity Projection- MIP) allows better identification/characterization of DIEP in relation to iodine contrast concentration (measured as Hounsfield Unit, HU) and the impact of CT in patient management (identification of recipient vessel, operative time, complications at follow-up).
Fig. 1: Branching patterns of DIEA.

© Moon HK, Taylor GI. The vascular anatomy of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. Plast Reconstr Surg 1988;82:815e32
Methods and materials

Study population

Twenty-three patients (mean age 52±9,9 yr - age range 36-74 yr) underwent to CT-angiography. Among these patients there were 78% with infiltrating ductal carcinoma (3 patients with DCIS too), 13% with infiltrating lobular carcinoma (1 patient with DCIS too), 4% with DCIS and 4% with LCIS. In 33% of patients the reconstruction was immediate (Table 1).

CT-angiography technique

CT examinations were performed using a 64 detectors scanner (Lightspeed VCT, GE Medical Systems, Milwaukee, Wisconsin USA). Informed consent was obtained from each patient.

Acquisition and reconstruction parameters are reported in Table 2. The acquisition was performed in cranio-caudal direction during the administration of 100-130 mL of iodinated contrast material (Iomeron 300, Bracco, Milan, Italy). The contrast medium was injected at a speed of at least 3.5-4.5 mL/sec through an intravenous catheter inserted into an antecubital vein. The infusion of the medium contrast is followed by the injection of 30 mL of saline solution at the same rate of flow. The option Smart-Prep scanner, with ROI localized at aortic abdominal level, has been used to synchronize the scanning with the peak of artery opacification, using a densitometric threshold of +100 HU.

CT examination was completed by a pre-contrastografic acquisition and a venous phase in the case of specific clinical indication, for example for the staging purpose.

Data were then analyzed on a dedicated workstation (AW4.4, GE Healthcare, Milwaukee, Wisconsin, USA).

Post-processing of CT-angiography data

Images are first analyzed on axial plane form on which multiplanar reconstruction were performed. On axial view right common femoral artery was identified and the HU density was measured by a fixed ROI area (between 25 and 35 mm²) (Figure 2).

VR and MIP were secondary performed and analyzed (Figure 3).

DIEA vascular morphological data such as location, type, size and length size and course of DIEP were identified at emerging level and on the coronal plane the branching pattern of DIEA (type I, II, III) and its length are better studied (Figure 4).
Then we proceed to the evaluation of all piercing bilaterally and for each piercing its location, size and course were detected and divided into intramuscular, subfascial and subcutaneous path (Figure 5). In the abdominal headquarters x, y coordinates were given at the point of emergency from the rectus fascia in relation to the navel with reference to the superficial virtual plane drive (Figure 6).

One dominant perforator branch was identified at CT-angiography according to the characteristics described above (Figure 7). Pre-and intra-operative findings (Color-Doppler Ultrasound and surgery) were used as reference standard.

Quality of acquired images and of VR and MIP reconstructions were evaluated (score from 0-5) by two observer independently.

Eventual presence of Superficial Inferior Epigastric Artery (SIEA) was described.

Finally, through the thoracic volume acquired in the same CT-angiography, location, size and eventual anatomical abnormalities of the internal mammary artery (IMA) and the possible presence of IMA perforator (IMAp) for vascular anastomosis were studied (Figure 8).
Fig. 1: Branching patterns of DIEA.

© Moon HK, Taylor GI. The vascular anatomy of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. Plast Reconstr Surg 1988;82:815e32
Table 1: Table 1. Clinical characteristics of patients.

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<tr>
<th>Pt(age)</th>
<th>Tumor type</th>
<th>Surgery for BC</th>
<th>Reconstruction surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (41)</td>
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<td>Right mastectomy</td>
<td>Deferred</td>
</tr>
<tr>
<td>2 (44)</td>
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<td>Bilateral mastectomy</td>
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<tr>
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<tr>
<td>4 (40)</td>
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<td>Left mastectomy</td>
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<td>Right mastectomy</td>
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<td>6 (63)</td>
<td>Lobular Carcinoma In Situ (LCIS)</td>
<td>Right mastectomy</td>
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<tr>
<td>7 (64)</td>
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<td>Infiltrating ductal G3</td>
<td>Right mastectomy</td>
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</tr>
<tr>
<td>9 (42)</td>
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<td>Right mastectomy + left Supero-external quadrantectomy</td>
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</tr>
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<td>Combined</td>
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<td>Right mastectomy (Halsted)</td>
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CT-angiography:

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<table>
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<tr>
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<tr>
<td>Voltage</td>
<td>120 kV</td>
</tr>
<tr>
<td>Tube current</td>
<td>300-500 mA</td>
</tr>
<tr>
<td>Flow rate</td>
<td>3,5-4,5 mL/sec</td>
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</tbody>
</table>

Table 2: Table 2: Acquisition and reconstruction CT-angiography parameters.
**Fig. 2:** Figure 2: Example of evaluation of the density in HU in the right common femoral artery. a) patient number 20 (42 yr) with HU = 382 and image quality score of b) patient number 17 (39 yr) with HU score of 198 and image quality score of 2.

**Fig. 3:** Figura 3: a) axial image: 381,38 HU density in right common femoral artery measured with a ROI of 32,96 mm²; b) MIP coronal reconstruction: caliber of right (2,43 mm) and left (2,10 mm) DIEAs is measured at its ostium external iliac artery. c) VR reconstruction shows DIEAs of type I bilaterally d) SSD reconstruction of DIEA marked with black arrow.
**Fig. 4:** Figure 4: a) patient number 7 (64 yr) with symmetric DIEA type I branching b) patient number 13 (55 yr) with symmetric DIEA type II branching

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**Fig. 5:** Figure 5: Patient number 7 (64 yr). CT path of the dominant DIEP chosen in multiplanar views a) intramuscular b) subfascial c) subcutaneous.

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Fig. 6: Patients number 19 (56 yr): X,Y coordinates of dominant DIEP with its distance from the navel a) on Surface Shaded Display (SSD) and b) on the abdominal wall as drawn by the plastic surgeon.

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Fig. 7: Patient number 7 (64 yr) undergone combined intervention of right mastectomy for DCIS in outcomes of QUART. a) identification of the dominant DIEP in the left emiabdomen at CT angiography b) correlation with preoperative map on the abdominal wall as drawn by the plastic surgeon.

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Fig. 8: a) Identification and measurement of IMA’s caliber on the axial images; b) identification of emergency of IMA in the coronal plane; c) identification of the right and d) the left IMAs on VR reconstruction e) MIP coronal reconstruction showing IMA course in relation to the thoracic wall.
Results

One/23 patients was excluded for condrosternal necrosis as outcome of previous right mastectomy (Halsted) and RT; 15/23 underwent breast reconstruction. Thirteen/15 patients received DIEP-flap and 2/15 received Transverse Rectus Abdominus Myocutaneous (TRAM) flap (mean age 50±8.3 yr). Seven patients refused surgery and one patient is waiting for surgery. Five patients underwent a combined procedure of mastectomy and breast reconstruction with DIEP flap, in 10 patients (8 DIEP and 2 TRAM flaps) the reconstruction was instead deferred (figure 9). The time between CT angiography and surgery was on average 30 ± 15 days. Mean operative time was 8 hours and 30 '. The timing of CT reworking data are approximately 60±15 minutes. In 13/15 patients CT-angiography was accurate in characterizing dominant perforator and concordant with the final chosen DIEP (86,6%) but in the 2/15 undergone to TRAM-flap the indicated DIEP at CT angiography was not considered functional at color-Doppler Ultrasound direct evaluation at surgical time (figure 10).

DIEA vascular morphological data results are as follows:

- DIEA location: in 61% of patients it was observed symmetry between the two emiabdomen.

- DIEA type: in the left emiabdomen we found 13 DIEA of type 1 (59%), 9 of type 2 (41%) while in the right emiabdomen 16 of type 1 (73%), 5 of type 2 (23%) and 1 of type 3 (5%).

- DIEA average size was of 2.7 ± 0,56 mm and average length was 8.9 ± 3.6 cm, in agreement with the values reported in literature

Furthermore DIEP dominant branches morphological data results were as follows:

- DIEP location: all identified in the periumbilical region between 3-4 cm around the navel, as reported in the literature.

- DIEP size: the medium caliber of dominant DIEP chosen for implementation in our patients is 2,23 ± 0,56 mm, also in line with literature and in particular with caliber theoretically adequate for successful flap.

- DIEP course: all DIEP chosen by the plastic surgeon had a short intramuscular path (< 11 mm, as defined in literature to facilitate dissection).

SIEA of adequate size for transposition was never identified.

Image quality was excellent in all cases (score 4 to 5) and directly related to HU-density within femoral artery, in particular MIP reconstruction resulted to be the adequate post processing technique for the identification of the intramuscular course while for
subcutaneous and subfascial VR was preferred. A statistically significant correlation between the value of HU and the quality of axial MIP images is found (table 3).

Density HU values were then compared to the values of VR1 and MIP1 (first observer) and VR2 and MIP2 (second observer) and results are shown in table 4.

Statistically significant direct correlations were found between image quality score at post processing both VR and MIP and the value of HU. There is higher correlation with MIP technique for both observers, underlying a strong effect of the value of HU on image quality. Vascular contrast enhancement achieved is a fundamental parameter for image quality and in nowadays practice we improved it using 400 mgIodine/mL contrast.

We also analyzed the correlation between the two observers regarding the different post-processing techniques of VR and MIP. The correlation is stronger for MIP technique as shown in table 5.

Identification of eventual IMAp helped in preserving the main vessel in case of future bypass.
Fig. 9: Figure 9. Patient number 17 (39 yr) with infiltrating ductal carcinoma G3 subjected to delayed breast reconstruction surgery. a) identification of dominant DIEP at CT angiography in the right emiabdomen b) correlation on the abdominal surface as drawn by plastic surgeon c) images of surgical removal and d) outcomes of transposition of DIEP flap in mammary region.

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**Fig. 10:** Patient number 16 (36 yr) with infiltrating ductal carcinoma underwent delayed reconstruction surgery. Bilateral adequate piercing at CT-angiography with asymmetric DIEA (right type II and left type I). a) axial CT image b) Coronal MIP c) sagittal MIP of left DIEA. Discordant at Ultrasound evaluation, made TRAM flap.

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<table>
<thead>
<tr>
<th>Correlation test Image quality and HU</th>
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<tr>
<td>rs (Spearman coeff.)</td>
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<td>p</td>
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**Table 3:** Table 3: Spearman correlation test between image quality and HU density.

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<table>
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<table>
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<th>Correlation test MIP1 and HU</th>
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<table>
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<tr>
<th>Correlation test MIP2 and HU</th>
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<td>p</td>
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**Table 4:** Table 4: Spearman correlation test between image quality in VR and in MIP for the first and the second observer and HU density.

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Table 5: Analysis of the correlation between the two observers for the two post-processing techniques MIP and VR.

<table>
<thead>
<tr>
<th></th>
<th>K value</th>
<th>5-95% CI</th>
<th>SD</th>
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<tbody>
<tr>
<td>VR1 and VR2</td>
<td>0.478</td>
<td>0.1587-0.7973</td>
<td>0.1629</td>
</tr>
<tr>
<td>MIP1 and MIP2</td>
<td>0.7179</td>
<td>0.4679-0.9679</td>
<td>0.1276</td>
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Conclusion

The advent of abdominal DIEP flap has revolutionized breast reconstruction with minimal donor site morbidity. However, the extremely unpredictable vascular anatomy of the abdominal wall, not only between different individuals but also between the two emiabdomen of the same individual has meant that the collection of the DIEP flap is long and technically complicated.

DIEP flaps are vascularised by DIEA intramuscular perforators and their correct selection saves muscle and fascia in breast reconstruction with abdominal flap. Given the great variability of the vascular anatomy, plastic surgeons use the echo-Doppler to identify favorable perforating vessels but, despite the correlation between the volume of the audible signal and the diameter of the vessels is good, the results are imprecise and the number of false positive rate is high.

Preoperative CT-angiography performed with specific post-processing techniques allows to optimize surgical planning and improve the outcome of breast reconstruction (Figure 11, 12).

For this reason, CT-angiography has become the preoperative imaging gold standard for breast reconstruction with abdominal flap. By CT-angiography it is possible to define the location, size, course and anatomic abnormalities of vascular DIEP to eventually modify the pre-operative organization. CT-angiography is currently the most appropriate tool for supplying relevant information to the surgeon and to get a preoperative 'road map' of perforator vessels in the abdominal wall (up to 1 mm) that supply blood to the adipocutaneous tissue used for autologous free tissue transfer for breast reconstruction. CT-angiography showed a high degree of anatomical correlation with intra-operative color-Doppler Ultrasound findings and with intra-operative choice of the dominant DIEP for the transposition [13, 14].

In this study, 7 of 22 patients have not undergone surgery after it was carefully explained them the type of intervention, its duration and possible complications, although this emergent kind of surgery has positive results and with really reduced vascular complications.

Among the 15 patients who have undergone surgery for breast reconstruction with abdominal flap after preoperative CT-angiography, in 2 cases the surgeon did not choose the perforator vessel indicated at imaging due to the absence of pulsatility and opted then for a TRAM flap.

The success of the flap was in fact seen to be strongly linked to the identification of the dominant perforator vessel more suitable in terms of laterality, size, intramuscular course and pulsatility at direct Ultrasound evaluation.
The protocol for CT-angiography post processing reconstruction includes VR and MIP techniques, the first to locate subcutaneous and subfascial path of perforating with a reconstruction on the surface of the body where they are marked and their distance from the navel is measured. On these 3D reconstructions is also based preoperative design of abdominal wall that the plastic surgeon will perform before where the flap is drawn and dominant perforator vessels detected at CT-angiography is easily and quickly identified by echo-Doppler and marked with an X (Figure 13, 14).

Post-processing allows to analyze intramuscular path of perforator vessels in order to choose the DIEP with the shorter and less tortuous intramuscular course to reduce the rectus abdominis muscle dissection and decreasing the risk of postoperative complications due to muscle dissection such as partial, total or fat necrosis, abnormalities of the abdominal wall (hernia) or deficiency of muscle strength in the abdomen. MIP post-processing technique showed excellent intra- and inter- observer concordance and the highest quality score in our small sample size study in accordance to literature [1] and therefore should be used as the main post-processing technique in the analysis of perforating arteries [15].

Significant correlation was observed between HU and image quality, and of course increasing the enhancement, increases the quality of MIP images compared to other post-processing techniques. HU measured in the right common femoral artery of our patients ranging from 189.4 ± 40.9 [SD] to 382.3 ± 48.0 [SD], and values greater than 300 HU were correlated with excellent image quality, suggesting this value as a threshold for a better identification of perforating branches.

Currently also the use of medium contrast media with high concentration of Iodine (up to 400 mgI/ml), dedicated to CT-angiography evaluation, allows to obtain a greater intravascular density and therefore a better visualization of the distal perforating branches, with at the same time a reduction in the quantity of medium contrast administered.

Preoperative CT-angiography performed with specific post-processing techniques allows to optimize surgical planning and improve the outcome of breast reconstruction. Detailed information can be provided regarding the anatomy of the recipient site facilitating surgical approach [16].

The present study describes the importance of CT-angiography at our center where preoperative imaging is vital for planning breast reconstruction with DIEP-flap allowing a better global management of the patient.
Fig. 11: Figure 11. Patient number 19 (56 yr) undergone combined reconstruction surgery for infiltrating ductal carcinoma G2. a) CT-angiography SSD with X,Y coordinates of the dominant DIEP; b) correlation on abdominal flap map c) flap transposed into the mammary region at surgery time.

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Fig. 12: Figure 12: Patient number 18 (53 yr) undergone combined reconstruction surgery for mammary ductal carcinoma G2 + Ductal Carcinoma In Situ (DCIS); a) identification of dominant DIEP at CT-angiography; b) correlation on abdominal map c) images and surgical removal d) transposition of DIEP flap in mammary region.

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Fig. 13: Figure 13. Patient number 7 (64 yr) underwent combined surgery in outcome of QUART for DCIS. a) identification of the DIEP branch in the left emiabdomen at CT-angiography b) correlation with the preoperative abdominal map c, d) excellent results of breast reconstruction and abdominoplastic after 5 months

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Fig. 14: Figure 14. Patient number 13 (55 yr) underwent combined reconstruction surgery for mammary ductal carcinoma G3. a) identification of the dominant piercing branch in the left emiabdomen on axial and b) coronal MIP images. c) Correlation with the preoperative abdominal map d, e) identification and isolation of the adipo-cutaneous flap during surgery dissection f, g) results of breast reconstruction and abdominoplastic at f) 2 months and g) 5 months.

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Personal information

For information
federica.fiocchi@gmail.com
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