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Preliminary results using a newly developed projection method to visualize vascular anatomy prior to DIEP flap breast reconstruction

S. Hummelink [a,b,*], M. Hameeteman [a], Y. Hoogeveen [b], C.H. Slump [c], D.J.O. Ulrich [a], L.J. Schultze Kool [b]

[a] *Plastic Surgery, Radboudumc, Nijmegen, The Netherlands*
[b] *Interventional Radiology, Radboudumc, Nijmegen, The Netherlands*
[c] *MIRA Institute for Biomedical Technology and Technical Medicine, University of Twente, Enschede, The Netherlands*

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Summary *Introduction:* In a deep inferior epigastric perforator (DIEP) flap breast reconstruction, computed tomography angiography (CTA) is currently considered as the gold standard in preoperative imaging for this procedure. Unidirectional Doppler ultrasound (US) is frequently used; however, this method does not distinguish the main axial vessels from perforator arteries at the height of the fascia, it has a limited penetration depth, and it cannot assess the branching patterns of the deep inferior arteries. A new method and system were developed, which consisted of a video projector preoperatively displaying the location and intramuscular course of the artery perforators and subcutaneous branching on the patient's abdomen.
Method: All patients ($n = 9$) underwent a standard protocol: a preoperative CTA was performed and the DIEPs were localized using a unidirectional Doppler probe. In addition, a three-dimensional (3D) reconstruction of the perforator locations based on CTA was projected on the abdomen of the patients. All projected perforator locations were assessed using a unidirectional Doppler probe. The intraoperative results were collected for comparison.
Results: A total of 88 locations were marked with the use of unidirectional Doppler and a total of 100 perforators were projected ($p = 0.38$). In 98 out of 100 projected perforator locations, a Doppler signal was audible. The intraoperative results demonstrate that 19 out of 34 transplanted perforators were correctly identified with unidirectional Doppler (56.9% ± 31.4%),

* Corresponding author. Radboud University Medical Center Nijmegen, Geert Grooteplein-Zuid 10, 6525 GA Nijmegen, The Netherlands.
E-mail address: stefan.hummelink@radboudumc.nl (S. Hummelink).

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where the projection method properly revealed 29 locations (84.3% $\pm$ 25.8%) ($p = 0.030$).
Conclusion: The projection method is not only capable of providing more information and identifying more perforators used for transplantation than unidirectional Doppler probing but also more accurate in pointing out the corresponding perforator found intraoperatively.

Introduction

In a deep inferior epigastric perforator (DIEP) flap breast reconstruction, an elliptic flap of abdominal skin and subcutaneous fat is elevated from the rectus fascia, leaving the rectus abdominis muscle in situ and largely intact with only an incision through the supraumbilical portion. The flap is perfused by one or more deep inferior epigastric artery perforators, and the selection of these perforators is crucial to ensure the viability of the flap.

Computed tomography angiography (CTA) is currently considered as the gold standard in preoperative imaging for DIEP flaps due to its high accuracy and low interobserver variability.[1–7] This imaging modality has been shown to be more accurate than other imaging modalities for the DIEP flap planning. Unidirectional Doppler ultrasound (US) is currently used to scan the entire lower abdomen. However, this method does not distinguish the main axial vessels from perforator arteries at the height of the fascia, it cannot assess the branching patterns of the deep inferior arteries, and it has a limited penetration depth although essential for obese patients.[8,9]

With the use of a video projector, the intramuscular course, perforating locations, and subcutaneous branching of the artery and perforators can be displayed preoperatively on the patient's abdomen, providing visual support. Only the marked perforators should be probed to ensure an accurate projection. This additional insight may lead to surgical benefits in DIEP flap breast reconstructions, including a reduced learning curve, a decrease in surgery time, an improved flap viability and thus patient safety, and decrease in operative stress.[7,10–13]

In this technical report, our initial experiences with preoperative projections onto the patient's abdominal wall using a Pico video projector are presented.

Materials and methods

Between January and April 2014, a total of nine female patients were included for projecting CTA planning data prior to DIEP flap breast reconstruction. A waiver from the medical ethical committee was obtained and these patients followed a standard protocol: (1) Preoperative CTA was performed to determine the vascular quality and (2) the DIEPs were localized using a unidirectional Doppler probe. The only addition to this protocol was a preoperative projection on the abdomen of the patients, based on a three-dimensional (3D) reconstruction of the CTA. This projection was always performed after the perforator mapping to prevent bias. All projected perforator locations were assessed with Doppler US for a pulsating sound.

The coordinates of all significant perforators were intraoperatively collected prior to incision of the abdominal fascia and noted on a metric grid using the umbilicus as the reference point. These include accessory submillimetric perforators accompanying larger perforators. All measurements were taken at the height of the abdominal fascia. The coordinates of only the intraoperatively used perforators were reviewed for detection using unidirectional Doppler US and projection perforator locations within a 1-cm radius, for these have the highest clinical relevance.

Double-sided paired *t*-tests were performed for the number of perforator locations estimated using Doppler US and the projection method and to evaluate the ratio

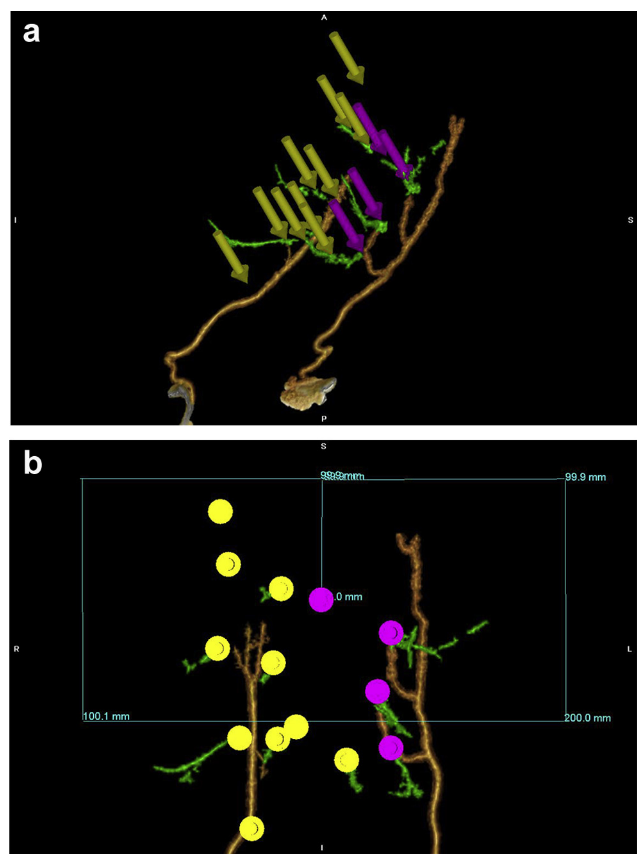

Figure 1 a) 3D reconstructed deep inferior epigastric artery and annotated perforators (yellow and purple arrows) with their subcutaneous branching pattern (green). b) Anterior-/posterior-oriented viewpoint with guidelines.

between the predicted perforator location and the transplanted perforator location. This test was also used to assess the distance between the Doppler US and the projected locations in relation to intraoperative perforator coordinates.

3D CTA reconstruction

Patients were scanned with a Toshiba Medical Systems Aquilion One 320 slice CT scanner (Toshiba Medical Systems, Tokyo, Japan). Using a VitreaAdvanced fX Workstation (Vital Images, Toshiba Medical Systems Group Company, Minnetonka, U.S.A), the abdominal vascular anatomy was reconstructed in 3D. The intramuscular trajectory of the deep inferior epigastric artery and its branches towards the perforators were highlighted in the Vitrea software. The umbilicus is indicated with a purple arrow and it represents the center of the 20 $\times$ 10-cm guidelines, essential for achieving a global orientation. All significant perforators (diameter $>$1 mm) were annotated with a yellow arrow, perpendicular to the CT table. The additional purple arrows indicate the most favorable perforators for transplantation. Consecutively, the 3D reconstruction is oriented from the anterior to posterior direction, displaying the annotation arrows as circles, as seen in Figure 1.

Projecting onto the patient

Preoperatively, the CT scan was performed with all patients in the supine position in bed. A handheld PicoPix PPX2480 Pico projector (Philips, Eindhoven, the Netherlands) was used to preoperatively display the previously described image onto the abdominal wall of the patient. Alignment of the purple circle corresponding with the umbilicus was achieved by moving the projector. The magnification of the image was corrected by altering the projector's height to match the predefined guidelines using a ruler. The rotation and skewing were removed by physical adjustments so the guidelines were projected horizontally and parallel to each other. The Doppler US markings and the subsequent projection are presented in Figure 2.

Results

In these preliminary results, Doppler US, projection, and intraoperative data were available for nine patients. A total of 88 locations were marked with the use of Doppler US and a total of 100 perforators were projected ($p = 0.38$). In these 100 projected perforator locations, a Doppler signal was audible at 98 locations.

In total, 34 perforators were transplanted and the total number of correctly identified perforators was 19 locations; 56.9% $\pm$ 31.4% using unidirectional Doppler US, whereas the projection method correctly revealed 29 locations; 84.3% $\pm$ 25.8% ($p = 0.030$).

The average distance from the intraoperative perforator for Doppler US and the projection method was respectively 7 $\pm$ 4 and 4 $\pm$ 3 mm ($p = 0.009$), although only the coordinates of the perforators within a 1-cm radius were reviewed.

Discussion

With unidirectional Doppler US alone, an arterial subcutaneous signal cannot be differentiated from a signal of the fascial penetration point. Projecting the intramuscular course of the deep inferior epigastric arteries and

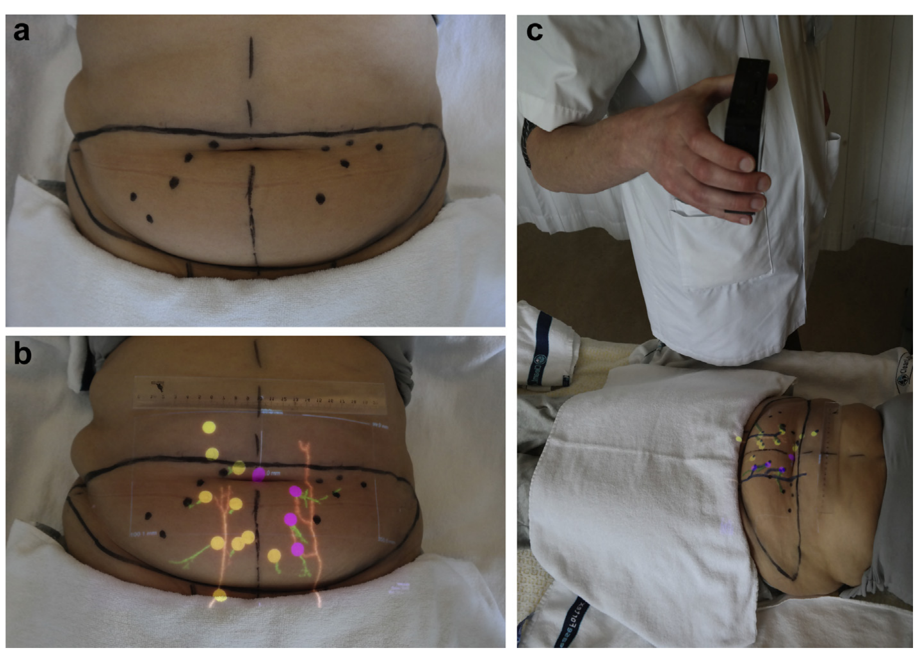

Figure 2 Handheld projection method. a) Black dots are determined following the standard Doppler protocol. b and c) The colored image is subsequently projected, showing the intramuscular (red) and subcutaneous (green) branching pattern of the DIEA with its perforators (yellow and purple). A ruler is used to ensure an accurate scaling of the projected image.

perforator locations onto the abdominal wall indicates the exact point of penetration of the perforator through the fascia. Not only would more information be available but also the time spent on preoperative planning might be lower with the projection technique. Performing the operations on the Vitrea fX Workstation takes only 15 min and the projection on the patient including confirming the locations with a unidirectional Doppler US probe takes around 2 min.

Obese patients may benefit from this technique; in this pilot study, two patients had a BMI >30 where the projection method showed the perforator locations more accurately than Doppler. A larger study cohort is necessary to investigate this.

The center of the umbilicus at the height of the fascia is not always obvious. Several transplanted perforators were submillimetric accompanied by a larger perforator, which were not specifically planned on CT but accounted for in the results. All transplanted major perforators were identified on CTA. Therefore, the previously mentioned 84.3% positive identification can be regarded an underestimated percentage.

The presented method is based on CTA images, whose quality should be sufficient for diagnostic purposes in order to produce a 3D reconstruction. Although in this study 3D reconstructions were created in Toshiba's VitreaAdvanced fX Workstation software, the 3D reconstruction method could be adapted to work with other 3D visualization software as well. A limitation in this study is that the projection method is operator dependent. The projector should remain perpendicular to the patient and centered at the umbilicus to avoid incorrect projections. During this process the operator of the projector inevitably introduces a tremor when holding the projector above the patient, which is disadvantageous for the accuracy. Other systems are capable of displaying anatomical data on the patient by using reflective markers and detectors, multiple cameras, or half-silvered mirrors.[14–18] However, this involves using an overcomplicated and bulky system, especially for the discussed procedure. We are therefore working on a simple minimalistic operating room compatible projection system with active feedback. This guarantees a steady, accurate projection onto the patient while remaining handheld and easy to use.

A minimalistic setup to reach preoperative augmented reality by projection on the abdomen is presented. However, the abdomen is not the only part of the body suitable for projection, as this method can be applied in other surgical fields as well for the visualization of important structures. These areas will be investigated on feasibility after the stabilized self-correcting handheld projection apparatus has been completed.

Conclusion

A new method of displaying vascular mapping essential for DIEP flap reconstructions onto the patient's abdomen is presented in this paper. The projection method is not only capable of correctly identifying more perforators used for transplantation than unidirectional Doppler US but also more accurate in pointing out the corresponding perforator found intraoperatively. Additionally, the intramuscular course and subcutaneous branching of the deep inferior epigastric arteries can be visualized.

Ethical approval

Not required.

Funding

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Conflicts of interest

None declared.

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