Original Article

Comparative study of software techniques for 3D mapping of perforators in deep inferior epigastric artery perforator flap planning

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Background: Computed tomographic (CT) angiography (CTA) is widely considered the gold standard imaging modality for preoperative planning autologous breast reconstruction with deep inferior epigastric artery (DIEA) perforator (DIEP) flap. Improved anatomical understanding from CTA has translated to enhanced clinical outcomes. To achieve this, the use of appropriate CT hardware and software is vital. Various CT scanners and contrast materials have been demonstrated to consistently produce adequate scan data. However, the availability of affordable and easily accessible imaging software capable of generating 3D volume-rendered perforator images to clinically useful quality has been lacking. Osirix (Pixmeo, Geneva, Switzerland) is a free, readily available medical image processing software that shows promise. We have previously demonstrated in a case report the usefulness of Osirix in localizing perforators and their course.

Methods: In the current case series of 50 consecutive CTA scans, we compare the accuracy of Osirix to a commonly used proprietary 3D imaging software, Siemens Syngo InSpace 4D (Siemens, Erlangen, Germany), in identifying perforator number and location. Moreover, we compared both programs to intraoperative findings.

Results: We report a high rate of concordance with Osirix and Siemens Syngo InSpace 4D (99.6%). Both programs correlated closely with operative findings (92.2%). Most of the discrepancies were found in the lateral row perforators (90%).

Conclusions: In the current study, we report the accuracy of Osirix that is comparable to Siemens Syngo InSpace 4D, a proprietary software, in mapping perforators. However, it provides an added advantage of being free, easy-to-use, portable, and potentially a superior quality of 3D reconstructed image.

Keywords: Computed tomographic angiography (CTA); perforator imaging; Osirix; Siemens; accuracy

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Introduction

Currently, computed tomographic (CT) angiography (CTA) is widely considered the gold standard perforator imaging technique for preoperative planning an autologous breast reconstruction with deep inferior epigastric artery (DIEA) perforator (DIEP) flap (1,2). The scan data can be 3D reconstructed to produce a "perforator map" that assists surgeons in selecting an appropriate perforator, donor site, and the flap. A plethora of studies have demonstrated a high accuracy of CTA in detecting perforators, reporting a sensitivity and specificity close to 100% (3-12). In comparison to other perforator imaging modalities, such as Doppler ultrasound and magnetic resonance angiography (MRA), CTA has demonstrated superior visualization of the perforators and their subcutaneous course, respectively (7,10). While MRA may be evolving in this role, widespread outcome data is still lacking. The benefits of CTA have translated into improved clinical outcomes, such as increased flap survival, reduced donor site morbidity,

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and reduced operating time (5,6,10,12-24). To this end, appropriate use of hardware and software is essential to obtain optimal perforator data from CTA.

Through various scanner hardware brands (i.e., Siemens, Toshiba, and Philips), varying number of multi-detector rows (i.e., 4-slice to 320-slice scanners) and differing contrast media and volumes, all scanners and techniques are able to achieve high quality and clinically useful images (1,2). In addition, we have published optimized CTA scanning techniques that enhance perforator visualizations, such as initiating contrast bolus trigger at the common femoral artery, moving the computed tomography table caudo-cranially, and disabling the Siemens Care Dose 4D feature (10).

High cost and limited accessibility of 3D imaging softwares that generate 3D reconstructions suitable for clinical use have been challenging for hospitals with relatively limited resources. Most of the currently available proprietary softwares, such as Siemens Syngo InSpace 4D (Siemens, Erlangen, Germany) (25) and VoNaviX (IVS Technology, Chemnitz, Germany) (26) are expensive. Some are not readily accessible outside the institution where it was originally developed, such as virSSPA (University Hospitals Virgen del Rocio, Sevilla, Spain) (15). Furthermore, many programs available cannot provide adequate images, with some not able to visualize perforators to a clinically useful degree. One particular program that we have found that can achieve optimal images is Siemens Syngo InSpace 4D (10). The program enables users to assign color to various contrast values using color look-up table (CLUT) function, providing superior contrast resolution to the 3D reconstructions. Again however, the cost and availability are significant limitations. Previously, we have demonstrated the application of a free 3D imaging program, Osirix (Pixmeo, Geneva, Switzerland).

Osirix is a free imaging processing software, specifically designed for medical imaging by a radiologist, and is readily downloaded online for use unreservedly (27). It is able to produce the same or better images than the currently available programs on a user-friendly interface. Furthermore, Osirix can be readily operated on a laptop computer, which enables viewing in the operating theatre or at home. Similar to Siemens Syngo InSpace, Osirix enables the user to create 3D volume-rendered reconstructions and assign colors using an appropriate CLUT function to optimize visualization of perforators and their course, as demonstrated in our previous case report (28).

In the current study, we investigate the accuracy of the freely available 3D imaging software, Osirix, by comparing it to the proprietary program, Siemens Syngo InSpace 4D, and also comparing both softwares to the intraoperative findings.

Methods

The study design was a prospective case series. A total of 50 consecutive patients (i.e., 100 hemi-abdominal walls) underwent CTA prior to a DIEP flap breast reconstruction. All patients were aged between 30 and 60 years and spanned a wide range of body habitus. All imaging findings were recorded by a single operator and all intraoperative findings were recorded by the operating surgeon.

CTA technique

All scans were performed at a single institution (Future Medical Imaging Group, Melbourne, Australia) using a standardized protocol that has been modified and improved from the conventional CTA methodology in order to maximize the image quality and minimize radiation exposure (10,21). The computed tomography scanner used was a Siemens SOMATOM Sensation 64 multi-detector row computed tomography scanner (Siemens Medical Solutions, Erlangen, Germany) and the scan parameters are summarized in *Table 1*.

Patients were scanned in a position matching operative positioning: supine, with no clothing or straps to deform the abdominal contour. The scan range was limited to the tissue used intraoperatively and thus spanned from the pubic symphysis to 4 cm above the level of umbilicus. A bolus of 100 mL of intravenous omnipaque 350 was used for contrast, without oral contrast. We have previously described three major modifications introduced to the standard CTA protocol in order to enhance the arterial phase filling and the resolution of cutaneous vasculature (10). Briefly, the contrast bolus trigger to begin scanning was taken at the common femoral artery; the computed tomography table movement was reversed to scan caudo-cranially from the pubic symphysis to match the filling of DIEA; and the Siemens Care Dose 4D features was disabled, which maximized the abdominal wall signal-to-noise ratio.

Scan analysis

CTA scans were analyzed using both imaging softwares: Siemens Syngo InSpace 4D (Version 2006A; Siemens,

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Table 1 Computed tomographic scan parameters

Parameters	
Scanner	Siemens SOMATOM Sensation 64
Scan type	Helical multi detector row CT angiography
Slice thickness	64 detector row ×0.6 mm collimator width
Helical detector pitch	0.9
Gantry rotation speed	0.37 s
Tube potential	120 kV
Tube current	180 mA
Contrast	Omnipaque 350 100 mL IV injection 4 mL per second
Scanning range	Pubic symphysis to 4 cm above umbilicus
Scanning direction	Caudo-cranial
Bolus tracking	+100 HU from common femoral artery with minimal delay
Automatic dose modulation (Siemens Care Dose 4D)	Disabled
Imaging reconstruction	1 mm/0.7 mm overlapping axial images

CT, computed tomographic; HU, Hounsfield units.

Erlangen, Germany) and Osirix (Pixmeo, Geneva, Switzerland). The thin-slice (i.e., 1 mm or less) axial raw data were reformatted into 3D volume-rendered reconstructions and maximum intensity projections (MIPs) to identify the number and location of perforators, and the branching pattern of DIEA (29).

Perforator mapping

3D-reconstructed images of the abdominal wall perforators are generated using volume-rendering technique (VRT) and MIP techniques. VRT reconstructions required the use of the CLUT function found in both of the image processing softwares. Additionally in Osirix (Pixmeo, Geneva, Switzerland), we applied Gaussian blur to the final 3D reconstruction facilitating the removal of interference within the data (*Figures 1,2*). All infraumbilical perforators with diameter greater than 0.5 mm were identified and mapped on VRT reconstructions. Arrowheads were placed at the point of emergence of each perforator from the anterior rectus sheath. They were overlaid on to a 2D representation of each patient's abdominal wall with a grid of 4 mm squares applied to the image centered on the umbilicus as reference point. The transverse distances of each perforator from the midline were recorded to the closest 0.5 cm. The perforators were recorded as found in medial or lateral row. MIP reconstructions were used to illustrate intramuscular course of the perforators.

Intraoperative measurements

The perforator locations were compared with operative findings, where they were located on equivalent grids. Intraoperative grids were placed over the lower abdominal wall, with the umbilicus and midline as references, and the location of perforators was documented on it with sterile pens. A 0.5-cm margin of error was given for the location of each perforator. This was a conservative figure given as an estimate of the combined error associated with the calculation of concordance, and included the following factors: CTA error (e.g., patient movement, venous contamination), CTA reporting error (e.g., multiplanar reformatting error, reading error), intraoperative measurement error (e.g., limitation of measurement tool, reading error), and patient error (e.g., umbilical shift, abdominal pannus mobility). For the purpose of comparison, the operative findings were considered the standard.

All perforators were explored bilaterally, including the perforators not included in the flap. All perforators greater than 0.5 mm in diameter were included in the study and recorded in the manner described. As achieved during the CTA scan interpretation, the perforators identified intraoperatively comprised arterial perforators and not adjacent veins.

Statistical analysis

The perforator locations were recorded as exact values and the findings were compared between the two software

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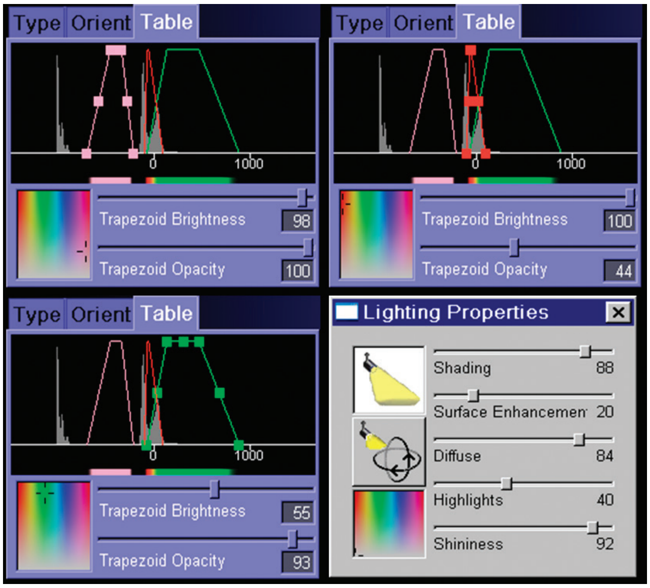

Figure 1 Color look-up table (CLUT) and ray cast lighting properties in Siemens Syngo InSpace 4D (Siemens, Erlangen, Germany). Reproduced with permission from Rozen *et al.* (25).

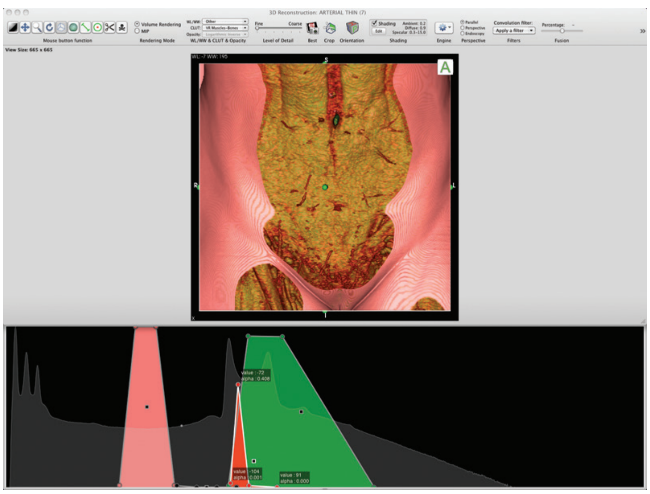

Figure 2 Color look-up table (CLUT) in Osirix (Pixmeo, Geneva, Switzerland), designed for perforator imaging. Reproduced with permission from Rozen *et al.* (28).

programs. In addition, the data from each program was compared to the operative findings. The comparative analysis was conducted using SPSS Statistics software package (IBM, Armonk, New York, USA) and the outcomes were analyzed using paired Student's *t*-test. A P value of <0.05 was accepted as statistically significant.

Results

A total of 50 CTA scans were performed in 50 consecutive cases (i.e., 100 hemi-abdominal walls) that identified 512 perforators of DIEA at an average of 5.12 perforators per hemi-abdomen. Concordance between Siemens Syngo InSpace 4D (version 2006A; Siemens, Erlangen, Germany) and Osirix (Pixmeo, Geneva, Switzerland) in accurately identifying perforator locations, and comparison between each of the software programs to intraoperative findings were evaluated.

Between Siemens Syngo InSpace 4D and Osirix, 510 out of 512 perforators (99.6%) had concordance. The two discordant perforators between the imaging programs were located in the lateral row and had only 0.5 cm of difference. Mean transverse distance from the midline using both software programs was 3.36 cm, with no statistical difference between them for measuring perforator location (*Table 2* and *Figure 3*).

Between each of the softwares and the operative findings, there was a mean difference of 0.7 mm per perforator using both programs (*Tables 3,4*). Although this difference was statistically significant (P<0.01), this was not a clinically significant difference (i.e., less than 1 mm).

An analysis of perforators that had a difference between imaging and intraoperative findings was undertaken, with 40 perforators (7.8%) discordant between imaging and operative findings (*Table 5*). Of 18 perforators that had 0.5 cm difference with operative findings, 7 were located in medial row and 11 in lateral row. Of 12 perforators that had 1 cm difference, 5 were located in medial row and 7 in lateral row. Of 8 perforators that had 1.5 cm difference,

Table 2 Mean transverse distance of DIEA perforators from the midline as identified using the 3D imaging softwares: Siemens Syngo InSpace 4D (Siemens, Erlangen, Germany) and Osirix (Pixmeo, Geneva, Switzerland)

	Siemens Syngo InSpace 4D	Osirix	Difference	P value
Perforator location, lateral-to-midline (mean)	3.36 cm	3.36 cm	0 cm	1

DIEA, deep inferior epigastric artery.

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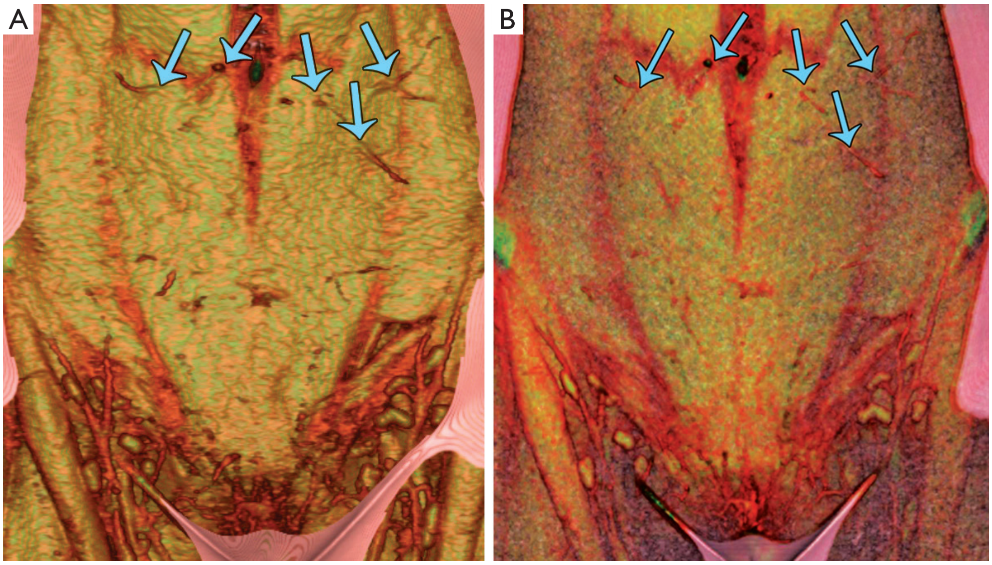

Figure 3 Preoperative computed tomography angiography (CTA), volume-rendered reconstruction of the abdominal wall vasculature with: (A) Osirix (Pixmeo, Geneva, Switzerland); and (B) Siemens Syngo InSpace 4D (Siemens, Erlangen, Germany). Both techniques clearly demonstrate several large periumbilical perforators (blue arrows), and highlight features of the abdominal wall soft-tissues. Reproduced with permission from Rozen *et al.* (28).

Table 3 Comparing the mean transverse distance of DIEA perforators from the midline calculated using Siemens Syngo InSpace 4D (Siemens, Erlangen, Germany) to the intraoperative measurements

	Siemens Syngo InSpace 4D	Operative findings	Difference	P value
Perforator location, lateral-to-midline (mean)	3.36 cm	3.43 cm	0.7 cm	<0.01

DIEA, deep inferior epigastric artery.

Table 4 Comparing the mean transverse distance of DIEA perforators from the midline calculated using Osirix (Pixmeo, Geneva, Switzerland) to the intraoperative measurements

	Osirix	Operative findings	Difference	P value
Perforator location, lateral-to-midline (mean)	3.36 cm	3.43 cm	0.7 cm	<0.01

DIEA, deep inferior epigastric artery.

Table 5 Analysis of discrepancy found in the perforator localization between imaging and operative findings and their distribution between medial and lateral rows

	Medial row	Lateral row	Total
Imaging: operative discrepancy 0.5 cm (number of perforators)	7	11	18
Imaging: operative discrepancy 1.0 cm (number of perforators)	5	7	12
Imaging: operative discrepancy 1.5 cm (number of perforators)	1	7	8
Imaging: operative discrepancy 2.0 cm (number of perforators)	0	2	2
Total	13	27	40

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1 was located in medial row and 7 in lateral row. Of 2 perforators that had 2 cm difference, none were located in medial row and 2 in lateral row. Medial row perforators accounted for 13 out of 40 discordant results (32.5%) and lateral row 27 out of 40 (67.5%). Hence, imaging was more accurate when assessing medial row perforators (32.5% *vs.* 67.5%). Furthermore, when specifically assessing the larger discrepancies (>1 cm), medial row accounted for only 1 out of 10 (10%) and lateral row 9 out of 10 (90%).

Discussion

An improved understanding of the DIEA and its perforators from CTA has assisted reconstructive surgeons in the selection of the appropriate donor site, perforator, and hemi-abdominal wall of choice for reconstruction, which has translated to significant improvements in clinical outcomes (5,6,10,12-24). To achieve this, the use of appropriate hardware and software is vital. For CTA hardware, CT scanners from various brands using different multi-detector rows with varying IV contrast materials and volumes have demonstrated in the literature to deliver consistently sufficient scan data (1,3,5,10,12,15). In contrast, the high cost and limited accessibility of image processing software that can produce clinically useful 3D volume-rendered reconstructions have limited a wide application of CTA. To this effect, Osirix, a medical imaging program available for free online, have been useful. It is capable of producing the same or superior quality 3D reconstructions than the proprietary softwares and has added advantages of user-friendly interface and portability.

We have previously described the potential utility of Osirix for preoperatively planning a DIEP flap breast reconstruction in a case report (28). In the current case series, we demonstrate that Osirix is as accurate as the commonly used proprietary software, Siemens Syngo InSpace 4D, in identifying perforator number and location (99.6%). Furthermore, the measurements from both programs closely correlated to the operative findings (92.2%). The discordance between imaging and operative findings was most pronounced in assessing lateral row perforators (90% *vs.* 10%). For the purpose of the current study, we forewent comparing perforator diameters since these measurements can be made on standard axial slices of a CTA, regardless of the software program.

In addition to its accuracy in perforator localization, Osirix has the potential to yield superior quality 3D images than Siemens Syngo InSpace 4D due to its 16-bit CLUT function and the capacity to apply Gaussian blur after the 3D reconstruction to reduce interference. Furthermore, Osirix exhibits an easy-to-navigate user interface that is readily accessible to clinicians without technological background and it is compatible on Mac operating system. As a result, surgeons can access the 3D reconstructed images on their portable computer in the operating theatre or at home.

Of note, although free for the basic version, there is a cost to the fully functional version that allows more images to be processed and your own presets to be used. Even this version offers a widely affordable option for most institutions compared to other options.

One of the limitations of the current study is our relatively small sample size. A larger randomized study with greater sample size will be required to further validate our findings. Moreover, a future study may consider comparing Osirix to a host of other proprietary softwares, such as VoNaviX, and their impact on clinical outcomes. For the purpose of this study, the comparative analysis was performed in cases of autologous breast reconstruction with DIEP flap. However, validating Osirix in assessing other free flap options for autologous breast reconstruction may be of value.

Conclusions

This comparative analysis demonstrates that the accuracy of Osirix, a freely available medical image processing software, is concordant with Siemens Syngo InSpace 4D, a commonly utilized proprietary software, in localizing perforators for autologous breast reconstruction with DIEP flaps. Measurements from both programs correlated equally to the intraoperative findings. Most of the discrepancies arose in the lateral row perforators.

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None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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