University of Groningen

An overview of methods for vascular mapping in the planning of free flaps

Smit, Jeroen M.; Klein, Steven; Werker, Paul M. N.

Published in:
Journal of Plastic Reconstructive and Aesthetic Surgery

DOI:
[10.1016/j.bjps.2010.06.013](https://doi.org/10.1016/j.bjps.2010.06.013)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2010

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Smit, J. M., Klein, S., & Werker, P. M. N. (2010). An overview of methods for vascular mapping in the planning of free flaps. *Journal of Plastic Reconstructive and Aesthetic Surgery*, 63(9), e674-e682. <https://doi.org/10.1016/j.bjps.2010.06.013>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

REVIEW

An overview of methods for vascular mapping in the planning of free flaps

Jeroen M. Smit ^a, Steven Klein ^a, Paul M.N. Werker^{*}

Department of Plastic Surgery, University Medical Centre Groningen, PO Box 30.001, 9700 RB Groningen, The Netherlands

Received 21 April 2010; accepted 9 June 2010

KEYWORDS

Free flap;
Hand-held Doppler;
Colour duplex
sonography;
Digital subtraction
angiography;
Computed tomography
angiography;
Magnetic resonance
angiography

Summary *Introduction:* The aim of this overview is to describe the various methods for vascular mapping of flaps together with their advantages and drawbacks.

Materials and methods: The PubMed database was used. Relevant search terms included 'flap' in combination with 'hand-held Doppler' (HHD), 'colour duplex sonography' (CDS), 'digital subtraction angiography' (DSA), 'computed tomography angiography' (CTA) and 'magnetic resonance angiography' (MRA). All studies found between January 2000 and January 2010 was evaluated.

Results: A total of 72 articles were found. Of these, 62 were usable for this overview. Recommendations could not be found for all types of flaps. Therefore, no uniform guidelines can be provided; some findings are, however, unequivocal. In general, HHD is cheap and easy to use, but relatively unreliable in determining the exact site of emergence at fascia level of perforators. CTA and MRA provide the best three-dimensional images. CTA offers more detailed images, MRA has the advantage however of not using radiation. CDS can be of value to offer information about the amount of flow in vessels or in cases in which CTA or MRA are contraindicated. DSA appears to be fading out slowly.

Conclusion: CTA and MRA are currently the best methods available to map the vasculature of donor sites of perforator flaps with variable anatomy such as anterolateral thigh (ALT) and deep inferior epigastric perforator (DIEP). In flaps with standard anatomy and superficial vasculature, HHD or no mapping at all remains the method of choice.

© 2010 British Association of Plastic, Reconstructive and Aesthetic Surgeons. Published by Elsevier Ltd. All rights reserved.

* Corresponding author. Tel.: +31 (0) 50 3618840; fax: +31 (0) 50 3613043.

E-mail address: p.m.n.werker@plchir.umcg.nl (P.M.N. Werker).

^a Both authors share first authorship as equal efforts were made.

Introduction

Reconstructive surgery has seen great development since the early 1960s, when the concept of axial vessels became mainstay.^{1–10} The first generation of axial pattern flaps was based on well-known vessels from the anatomy book, such as the radial artery for the radial forearm flap and the thoracodorsal vessels for the latissimus dorsi flap. The harvest of these flaps, although in that time revolutionary, is nowadays looked upon as relatively straightforward, due to their constant anatomy. Only in instances where previous surgery or trauma might have damaged the vascular pedicle, further investigation of the vasculature is deemed indicated. In the past 20 years, enormous progress has been made in flap design and more and more flaps are based on perforating vessels that branch off and are traced back to well-known vessels, thereby limiting donor-site morbidity. The exact location of perforators, however, varies significantly, and preoperative vascular mapping has been introduced to help identify the dominant perforator and its course and, as such, speed up flap harvest.

A variety of methods is available for this purpose, the most commonly used being hand-held Doppler (HHD),^{2–4} colour duplex sonography (CDS),^{5,11–13} digital subtraction angiography (DSA),^{14,15} computed tomography angiography (CTA)^{6–8,16} and magnetic resonance angiography (MRA).^{8,9,17} HHD was already reported in the planning of flaps in 1975, when it was described for the localisation of the donor and recipient vessels in facial reconstructions.¹⁸ Around the same period, angiography, later replaced by DSA, was introduced to assess the vascular anatomy of flaps, mainly in the lower extremities.^{19,20} The use of CDS in the planning of flaps was first described in the 1980s and became a common mapping method in the 1990s.^{21,22} In the last decade, major progress has been made in the applicability of, especially, CTA and MRA. The purpose of this overview is to describe the various vascular mapping systems in detail, together with their advantages and drawbacks to assist beginning micro-surgeons in their planning of free flaps.

Although other mapping methods such as indocyanine green²³ and near infrared imaging²⁴ exist, these can only be used for intra-operative flap design and are therefore beyond the scope of this overview.

Materials and methods

A literature search was conducted, using the PubMed database. The following search terms were used: 'flap' in combination with 'hand-held Doppler', 'colour duplex sonography', 'digital subtraction angiography', 'computed tomography angiography' and 'magnetic resonance angiography'. All studies found between January 2000 and January 2010 was evaluated. Only studies written in the English language were included. Manual cross-referencing was also performed. For historical and technical backgrounds, reports prior to 2000 were used whenever necessary.

In selecting data regarding the reliability of the mapping method, studies with the highest level of evidence were preferred over others.

Results

Our query led to 18 studies on HHD, eight on CDS, 10 on DSA, 31 on CTA and 12 on MRA.

Hand-held Doppler sonography (HHD)

A pencil-type Doppler probe registers moving erythrocytes by sending out and detecting reflected ultrasound. Depending on the depth and the diameter of the vessels to be investigated, various probes with different frequencies can be used. The two most commonly used frequencies, 8 and 10 MHz, have a peak sensitivity of only 20 and 15 mm, respectively. Gel must be used at the interface of skin and the probe to improve ultrasound conduction. When searching for perforators, it has been advised to vary the amount of pressure applied with the Doppler probe to the skin surface. If the detected sound comes from a perforator that runs directly towards the HHD, the loudness of the pulsating sound will reduce with increasing pressure.²⁵

Reported advantages of the HHD are its non-invasiveness, small size, low costs, portability and the ease to perform the examination. In addition, there are special probes available, which can be sterilised, making the technique available intra-operatively to finalise the planning and check the pulsation of a vessel during the surgical procedure.^{2,4,25,26}

The main disadvantages of the most widely used Doppler probe (8 MHz) is that it only detects vessels to a depth of 20 mm. This makes the technique less reliable for the detection of the site of emergence of perforators through the fascia, whenever the thickness of skin and subcutaneous tissue exceeds this amount.² Besides, one can never know for sure what vessel is producing the Doppler signal picked up by the HHD. Furthermore, this technique does not create a three-dimensional (3D) image of the vasculature and its surrounding anatomy than can be stored and retrieved later.

The use of HHD has predominantly been reported to locate perforators on the trunk and extremities.^{2–4,28} A relatively new field in reconstructive surgery, in which the HHD is being used, is in free-style perforator free flaps^{27,29–33} and in pedicled perforator flaps.^{34–36}

The use of HHD has been reported with variable success: In the study by Yu and Youssef² of 2006, in which they included 100 patients undergoing an anterolateral thigh (ALT) reconstruction, the locations of HHD signals of an 8-MHz and a 10-MHz probe were compared to the intra-operative findings. The positive predictive value for the 8-MHz probe in detecting the perforator was 89%, while no false-negative results were found. For the 10-MHz probe, a positive predictive value of 94% and negative predictive value of 43% were found. The study by Shaw et al.²⁸ compared HHD to intra-operative findings in 30 patients undergoing an ALT reconstruction. They found a large underestimate (30%) to an overestimate (150%) for the HHD findings. In a study of 32 deep inferior epigastric perforator (DIEP) and eight superior gluteal artery perforator (SGAP) flaps in which HHD findings were compared with intra-operative findings, a positive predictive value of only 52.4% was found for DIEP and SGAP flaps combined.⁴

Colour duplex sonography (CDS)

CDS relies on the same working principle as HHD. Blood flow in vessels is detected by the physical principle of a direct relationship between the recorded Doppler frequency shift and blood-flow velocity. In addition, different velocities and directions of moving blood streams can be displayed on a screen in the colour duplex mode. As such, CDS does not only offer information about the internal vessel diameter and their course, but also depicts the 3D footprint of the perivascular anatomy.³⁷ As with HHD, gel must be used at the interface of skin and the probe to improve ultrasound conduction.

Similar to HHD, CDS is non-invasive. An advantage compared with the HHD is its ability to offer more information about anatomy of the vessel and its perforators in reference to its surrounding tissues, and it can quantitatively analyse which perforator is the dominant one.³⁸

The disadvantage of CDS is, however, that the investigation can only be performed by skilled personnel, who also have knowledge of free-flap anatomy. In addition, it is less reproducible because of its real-life dynamics. Another disadvantage in comparison to CTA, MRA and DSA is that CDS – just as HHD – does not reproduce a 2D or 3D image of the complete vascular anatomy, which can be used by the surgeon during flap design or flap elevation.^{7,8,16}

CDS has been successfully used to preoperatively assess flaps for reconstructions in the head and neck, trunk^{5,11,13,38,40} and extremities.^{12,37} Tsukino et al.^{37,39} investigated the reliability of CDS in 10 patients prior to ALT flap harvesting. Comparison of CDS findings to intra-operative findings showed a concordance of 100%. This was confirmed for DIEP flaps in a report of six cases.¹¹ CDS has been found to be of value in cases in which the perforating vessels might have been damaged, for example, after liposuction, as it can give information about the amount of flow in vessels or in cases where the radiation dose of CTA is undesirable.¹¹

Digital subtraction angiography (DSA)

In traditional angiography, an iodine-containing contrast medium is administered intra-arterially while X-rays are taken. In DSA, these contrast-enhanced pictures are digitally subtracted from the pre-contrast mask X-ray to depict the vascular anatomy (Figure 1). This investigation technique generates 2D images and, therefore, generally has to be performed in two directions.

The reported advantages of DSA include the facts that it gives an image of the intraluminal vascular anatomy and information about atherosclerotic changes. A disadvantage of DSA is that it is a time-consuming, invasive technique necessitating the use of iodine-contrast medium, which may cause vascular or renal damage as well as allergic reactions.⁴¹ In addition, there is a radiation dose to be considered.^{6,42–45} Another disadvantage is the vasoconstricting effect of the contrast medium, making exact measurement of the vascular diameter and the assessment of small-calibre vessels unreliable. Furthermore, the patient has to stay in supine position after the angiography for several hours, to allow the puncture site to heal. This makes hospital admission often mandatory and this imaging modality relatively expensive. Finally, there is a 4.5% chance for the development of false aneurysms at the puncture site.⁴⁶

Figure 1 Digital subtraction angiography imaging of the left lower leg, showing a normal branching pattern of the vessels.

DSA in free-flap planning is predominantly reported in fibula flaps, where it is essential to be informed about the continuity of the three lower leg vessels, the level of bifurcation of the tibiofibular trunk and about arteriosclerotic plaques.^{15,42,43} Angiography has been found to provide a more accurate assessment of the patency of vessels compared with conventional tests such as ankle–arm index and HHD examination.^{15,42,43,47}

The use of DSA has also been reported in the planning of transverse⁴⁵ and oblique⁴⁴ rectus abdominis musculocutaneous flaps. It has been reported to have been used during surgery to visualise the vascular architecture of a flap after its harvest. This can show its perforator and its connection to the axial flap vessel, which can help the surgeon to safely thin and separate the flap during secondary procedures.^{44,45} This is, however, not a commonly reported technique.

Computed tomography angiography (CTA)

CTA combines the use of X-rays with computerised 3D analysis of the images. The number of detector rows decide how fast a scan can be performed and to what extent details can be revealed. A great variety of CT scanners and software is currently available, making a comparison of the results of various studies difficult. The number of multi-detector rows used in different studies varies from 4¹⁶ to 64,⁴⁸ enabling the generation of slices of approximately 1 mm or thinner, depending on the CT scanner used. The actual scan is performed in concert with a high-speed venous contrast-medium injection to enhance the staining

of vessels. A bolus of 80–100 ml of contrast medium is given intravenously at a rate of 4 ml s^{-1} . After the scanning, the data need to be processed into maximum intensity projection and 3D volume-rendered reconstructions. A great variety of software packages are available for this purpose (e.g., Siemens InSpace,⁴⁸ Vitrea version 3.0.1,⁷ VoNavix⁴⁹ VirSSPA⁵⁰ and Virtual Place 21⁵¹). Based on the software used, 2D pictures in three planes or 3D reconstruction in multiple planes can be provided. The processing of the images by the radiologist and the preoperative selection of the right vessels/perforators by the surgeon has been reported to take up to 30 min in perforator flaps.^{16,49}

The advantage CTA offers is that it provides an image with accurate visual details on the calibre and course of the vessels and their relationships with other anatomic structures (Figures 2 and 3). This allows surgeons to develop a dissection strategy and opt for a certain perforator prior to surgery, making the actual dissection safer and swifter.^{7,8,16,49,52–54}

The disadvantages of CTA are its radiation dose, which is reported to be 5.6 mSv,⁷ and the necessity to use iodinated contrast medium with its previously listed disadvantages.^{7,16} Especially, the vasospastic action is a serious drawback, because it can make the accurate assessment of small-calibre vessels difficult.⁵⁵

CTA has been predominantly used in the planning of perforator flaps in breast reconstructions (DIEP and SGAP),^{7,8,16,48,49,56,57} and has also been reported to assess the vasculature of ALT flaps^{54,58} and fibula flaps.⁶

Figure 3 3D CTA image of a deep inferior epigastric perforator flap through which can be scrolled, which enables the user to view the vasculature from any direction. The direction of viewing is predominantly cranial as indicated by the green cube on the bottom left. The trunk of the umbilicus and the rectus abdominis muscles can be seen. On the left side of the umbilicus a perforator can be seen going medially around the rectus muscle and branching off towards the skin.

Figure 2 Reconstructions of CTA images in the sagittal, coronal and axial planes (right), and the VRT coronal image of a deep inferior epigastric perforator flap.

Furthermore, it has been described to map the internal mammary artery perforator⁵⁹ and the deep circumflex iliac artery perforator flap⁶⁰ in cadaver studies. CTA may also have additive value to preoperatively assess the recipient site.^{6,61,62} However, the spurting test should be used in addition to confirm blood flow in the recipient site. In the initial reports of Masia et al.⁷ and Alonso-Burgos et al.¹⁶ regarding CTA in DIEP breast reconstructions, a 100% correlation was found between the CTA findings and the intra-operative findings. This included the location of the perforators, their estimated size, the course of the pedicle and its relationship with other anatomic structures. This was later confirmed by other studies.^{8,48,56,57} Compared with MRA, the depiction of smaller perforators is more accurate with CTA (vessels up to 0.3 mm in CTA vs. 1.0 mm in MRA).^{63,64} The introduction of CTA in DIEP in breast reconstructions led to a reduction of operating times of 90–100 min in flaps previously examined by HHD,^{8,57,65} and 76 min in flaps previously mapped by CDS.⁵⁶ In the planning of ALT flaps, a 100% correlation was found between CTA findings and intra-operative findings as well.⁵⁸

Magnetic resonance angiography (MRA)

MRA imaging uses a powerful magnetic field to align the nuclear magnetisation of hydrogen nuclei in the body. Radio-frequency pulses are used to tip the alignment of the hydrogen nuclei away from the main magnetic field, causing the hydrogen nuclei to produce a radio-frequency signal that is detectable by the scanner. Analysed by a computer, this yields detailed pictures of organs, soft tissues, bone and virtually all other internal body structures. By injection of a paramagnetic contrast agent (gadolinium), the vessels enhance. Since magnetic resonance imaging (MRI) has no radiation exposure, a picture of the vessels is typically obtained in the arterial phase and subsequently in the blood-pool phase to selectively visualise only arteries and to also see the larger artery/vein combination. Recently, a new blood-pool gadolinium contrast agent, gadofosveset trisodium, has become available that is optimised for imaging both the arterial and blood-pool phases of contrast enhancement without interference from soft-tissue enhancement. There is also the possibility to visualise vessels without the injection of contrast, albeit with lower resolution.⁶⁶

Just as with CTA, a great variety of magnetic resonance scanners and software are being used, making comparison of the results of different studies once again difficult. The scanners used varied from 1.5^{63,68–70} to 3 T.^{9,17} However, in recent perforator flap studies, the 1.5-T scanners are preferred over 3 T because of the better image quality. The 1.5-T scanners suppress signals from fat more homogeneously than the 3-T machines.^{66,69,70} The contrast medium administered varied from none⁶⁶ to 60 ml⁶⁷ per scan. With the introduction of newer devices, the procedure time of an MRA scan has been reduced to approximately 20 min, and with actual scan acquisition times of about 20 s.⁶⁸

There are several advantages of MRA. It works with magnetism instead of radiation and, depending on the software used, can be used without a non-iodine contrast medium, making it a relatively safe procedure for the patient.⁶⁷ MRA produces a 3D image, which allows surgeons

to accurately assess the course and diameter of the vessels and their relation to other surrounding structures, prior to surgery (Figure 4).^{9,10,67,71} MRA can be obtained both prone and supine to have images in which the normal contours of the abdominal and buttock fat are not distorted by the pressure of lying against a flat surface.

The reported disadvantages of MRA are its relatively high costs. Besides, it cannot be used in claustrophobic patients or patients with implants containing ferrous metals because these produce scattering or can cause severe damage to the scanner, if they are magnetic. Further, compared with CTA, the depiction of smaller perforators is less accurate with MRA (vessels up to 1.0 mm in MRA vs. 0.3 mm in CTA).^{63,64}

MRA has predominantly been used in the planning for free fibula flaps^{9,10,67,72} but more recently for the mapping of perforator flaps in breast reconstructions as well.^{17,63,66,68–70} MRA, as a single test in the planning of fibula flaps, has been reported to provide all the goals addressed by Doppler, combined with conventional angiography. Furthermore, it adds important data concerning the septocutaneous perforators that neither test can provide.¹⁰

For DIEP flaps, Masia et al.⁶⁶ found a 100% correlation between MRA and intra-operative findings in a study including 56 patients. Greenspun et al.⁷⁰ reported a positive predictive value of 100% but a negative predictive value of 96% in a series including 31 patients and using MRA

Figure 4 MRA image of the lower legs, showing a normal branching pattern of the vessels.

with contrast. For fibula flaps, it is unfortunately more difficult to draw conclusions about the positive and negative predictive values based on currently available literature. The reports that correlate the preoperative images to operative findings consist of only small populations and are not unambiguous.^{10,63,64,67,68,71}

Table 1 summarises all the characteristics found in the literature of the individual mapping methods such as use of radiation, invasive nature of the investigation and the type of vessels they are able to image.

Discussion

This study was undertaken to create a contemporary overview of the preoperative mapping methods for (free) flap planning. A serious limitation of this study is that the use of the discussed methods of mapping has not been reported for all currently used flaps. Therefore, only an extrapolation of the findings in this study to other flaps can be given. Furthermore, the studies found were mostly large case series and have low levels of evidence. For this reason, it is not possible to draw concrete conclusions based on the current literature; nevertheless, some findings are unequivocal and guidelines for clinical practice can be distilled.

While interpreting these data, it is important to realise that anatomical knowledge still remains the cornerstone to successful flap harvest and that preoperative mapping methods only serve as an adjunct to surgery. Furthermore, with some of the methods described above, it might be difficult to detect discrepancies between the perforating artery and the committante vein. Therefore, it is always good to have a back-up plan. In addition, readers should be aware that most studies took place in specialised units and the achieved results might not be obtainable in less specialised units in which a specific mapping method might not be available. Finally, it is important to realise that collective collaboration between radiologist and surgeon is key in order to maximally exploit the more advanced preoperative mapping possibilities.

This report shows that, in such settings, CTA^{7,8,16,48,49,56,57} and MRA^{9,10,41,67,71} can produce the best 3D image of the vessels and their surrounding structures.

The advantage of CTA over MRA is that it is able to depict small vessels and especially perforators more accurately.^{63,64} This is why CTA, at present, is predominantly being used in the scanning of perforator flaps, in which the size and the course of the perforators are of great importance for surgery.^{7,8,16,48,49,56,57} The main advantages of MRA over CTA are its lack of exposure of the patient to ionising radiation and the necessity to use a potentially nephrotoxic contrast medium (if used at all).^{66,67}

Although HHD has proven to be less accurate in locating perforators compared with CDS^{2,3} and CTA,^{7,16,26,48} it will probably remain of importance in clinical practice. This is because the device is portable and the examination inexpensive and relatively easy to perform and interpret. In contrast to most other mapping methods, it can be made available during surgery.^{2,4,25,26} Furthermore, it can be used as primary mapping device in thin flaps and in flaps, which do not rely on a specific perforator such as the radial forearm flap or as a complementary device to CTA or MRA in the planning of, for example, DIEP and fibula flaps.

CDS is a readily available non-invasive mapping device in most vascular units that, to some extent, also offers information about the 3D anatomy around the vasculature.³⁷ The disadvantage of CDS is that the investigation can only be performed by skilled personnel, who also need to have knowledge of flap surgery. In addition, it is less reproducible because of its real-life dynamics.^{8,9} This is why we believe CDS should only be used as primary mapping modality in selected cases, as for instance, in cases in which CTA or MRA are contraindicated or in which there is a special interest in flow within the vessels.

With the introduction of CTA, MRA and CDS, the need for DSA in free-flap planning as a primary mapping device seems to fade. Compared with CDS and MRA, it is more invasive, necessitates a radiation dose and the use of iodinate-contrast medium. Furthermore, the images it produces are only 2D and finally, false aneurysms may occur.

Future developments in the planning of free flaps should focus on the refining of 3D reconstructions and in a further elimination of the use of invasive diagnostic tests that rely on contrast media, which may cause co-morbidity. Because MRA has most of these characteristics, we believe that MRA has the greatest potential for the future, especially if

Table 1 The characteristics of each mapping method compared to one other

Feature	HHD	CDS	DSA	CTA	MRA
Three-dimensional imaging	–	–	–	+	+
Operator dependant	+	+	–	+	+
Use of radiation	–	–	+	+	–
Invasiveness	–	–	A	V	V/–
Images superficial vessels/perforators	+	+	–	+	+
Images vessels in deeper layers	–	+	+	+	+
Reproducibility	–	–	+	+	+
Information on surrounding tissues and anatomy	–	+	–	+	+
Additional costs per investigation ^a	–	€75	€325 ^b	€250	€250

HHD; hand-held doppler, CDS; colour duplex sonography, DSA; digital subtraction angiography, CTA; computed tomography angiography, MRA; Magnetic resonance angiography, A; arterial, V; venous.

^a The prices given in this overview only represent a rough indication; prices can vary between countries and hospitals.

^b The costs of the hospital admission often mandatory are not included.

Figure 5 MRA image in the axial plane of a deep inferior epigastric perforator flap. Showing a perforator left from the centre and its course through the muscle.

future developments make it as accurate as CTA. Nevertheless, HHD will always keep a place in (free) flap planning because of its ease of use and intra-operative availability.

Future research should also focus on the comparison between the different mapping methods and should prospectively compare the findings of the diagnostic tests with intra-operative findings.

CTA and MRA are currently the best methods available to map the vasculature of flaps that rely on perforators and their surrounding anatomy. In the planning of thin pedicled flaps that are planned close to a defect, in flaps with a more straightforward anatomy and for intra-operative use, the HHD remains to be mapping method of choice. DSA is slowly fading out and CDS can be used as an alternative, whenever there are contra-indications to the use of the other methods of investigation.

Acknowledgement

The authors like to thank Dr. Martin Prince, Columbia and Cornell Universities, New York, USA, for his critical reading of the manuscript.

The following people are acknowledged for providing the figures: Dr. Nicholas Waughlock, Uppsala University Hospital, Uppsala, Sweden (Figure 3), Dr. Derek Lohan, University of California Los Angeles, Los Angeles, USA (Figure 4) and Dr. Julie Vasile, Center for Microsurgical Breast Reconstruction, New York, USA (Figure 5).

Financial disclosure

There are no potential or actual, personal, political or financial interests by any of the authors in the material, information or techniques described in the paper. This project was financially supported by the NutsOhra Foundation, Amsterdam, the Netherlands.

References

1. Smit JM, Acosta R, Zeebregts CJ, et al. Early reintervention of compromised free flaps improves success rate. *Microsurgery* 2007;27:612–6.
2. Yu P, Youssef A. Efficacy of the handheld Doppler in preoperative identification of the cutaneous perforators in the anterolateral thigh flap. *Plast Reconstr Surg* 2006;118:928–35.
3. Khan UD, Miller JG. Reliability of handheld Doppler in planning local perforator-based flaps for extremities. *Aesthetic Plast Surg* 2007;31:521–5.
4. Giunta RE, Geisweid A, Feller AM. The value of preoperative Doppler sonography for planning free perforator flaps. *Plast Reconstr Surg* 2000;105:2381–6.
5. Heitland AS, Markowicz M, Koellensperger E, et al. Duplex ultrasound imaging in free transverse rectus abdominis muscle, deep inferior epigastric artery perforator, and superior gluteal artery perforator flaps: early and long-term comparison of perfusion changes in free flaps following breast reconstruction. *Ann Plast Surg* 2005;55:117–21.
6. Klein MB, Karanas YL, Chow LC, et al. Early experience with computed tomographic angiography in microsurgical reconstruction. *Plast Reconstr Surg* 2003;112:498–503.
7. Masia J, Clavero JA, Larrañaga JR, et al. Multidetector-row computed tomography in the planning of abdominal perforator flaps. *J Plast Reconstr Aesthet Surg* 2006;59:594–9.
8. Smit JM, Dimopoulou A, Liss AG, et al. Preoperative CT angiography reduces surgery time in perforator flap reconstruction. *J Plast Reconstr Aesthet Surg* 2009;62:1112–7.
9. Lohan DG, Tomasian A, Krishnam M, et al. MR angiography of lower extremities at 3T: presurgical planning of fibular free flap transfer for facial reconstruction. *Am J Roentgenol* 2008;190:770–6.
10. Fukaya E, Grossman RF, Saloner D, et al. Magnetic resonance angiography for free fibula flap transfer. *J Reconstr Microsurg* 2007;23:205–11.
11. De Frene B, Van Landuyt K, Hamdi M, et al. Free DIEAP and SGAP flap breast reconstruction after abdominal/gluteal liposuction. *J Plast Reconstr Aesthet Surg* 2006;59:1031–6.
12. Futran ND, Stack Jr BC, Payne LP. Use of color Doppler flow imaging for preoperative assessment in fibular osteoseptocutaneous free tissue transfer. *Otolaryngol Head and Neck Surg* 1997;117:660–3.
13. Yano K, Hosokawa K, Nakai K, et al. A rare variant of the deep inferior epigastric perforator: importance of preoperative color-flow duplex scanning assessment. *Plast Reconstr Surg* 2003;111:1578–9.
14. Smith RB, Thomas RD, Funk GF. Fibula free flaps: the role of angiography in patients with abnormal results on preoperative color flow Doppler studies. *Arch Otolaryngol Head Neck Surg* 2003;129:712–5.
15. Klein S, Hage JJ, van der Horst CM, et al. Ankle-arm index versus angiography for the preassessment of the fibula free flap. *Plast Reconstr Surg* 2003;111:735–43.
16. Alonso-Burgos A, García-Tutor E, Bastarrika G, et al. Preoperative planning of deep inferior epigastric artery perforator flap reconstruction with multislice-CT angiography: imaging findings and initial experience. *J Plast Reconstr Aesthet Surg* 2006;59:585–93.
17. Alonso-Burgos A, García-Tutor E, Bastarrika G, et al. Preoperative planning of DIEP and SGAP flaps: preliminary experience with magnetic resonance angiography using 3-tesla equipment and blood-pool contrast medium. *J Plast Reconstr Aesthet Surg* 2010;63:298–304.
18. Aoyagi F, Fujino T, Ohshiro T. Detection of small vessels for microsurgery by a Doppler flowmeter. *Plast Reconstr Surg* 1975;55:372–3.
19. Gerlock Jr AJ, Perry PE, Goncharenko V, et al. Evaluation of the dorsalis pedis free flap donor site by angiography. *Radiology* 1979;130:341–3.

20. May Jr JW, Athanasoulis CA, Donelan MB. Preoperative magnification angiography of donor and recipient sites for clinical free transfer of flaps or digits. *Plast Reconstr Surg* 1979;64:483–90.
21. Merritt CR. Doppler color flow imaging. *J Clin Ultrasound* 1987; 15:591–7.
22. Hutchinson DT. Color duplex imaging. Applications to upper-extremity and microvascular surgery. *Hand Clin* 1993;9:47–57.
23. Komorowska-Timek E, Gurtner GC. Intraoperative perfusion mapping with laser-assisted indocyanine green imaging can predict and prevent complications in immediate breast reconstruction. *Plast Reconstr Surg* 2010;125:1065–73.
24. Matsui A, Lee BT, Winer JH, et al. Image-guided perforator flap design using invisible near-infrared light and validation with x-ray angiography. *Ann Plast Surg* 2009;63:327–30.
25. Mun GH, Jeon BJ. An efficient method to increase specificity of acoustic Doppler sonography for planning a perforator flap: perforator compression test. *Plast Reconstr Surg* 2006;118: 296–7.
26. Puri V, Mahendru S, Rana R. Posterior interosseous artery flap, fasciosubcutaneous pedicle technique: a study of 25 cases. *J Plast Reconstr Aesthet Surg* 2007;60:1331–7.
27. Ahmad N, Kordestani R, Panchal J, et al. The role of donor site angiography before mandibular reconstruction utilizing free flap. *J Reconstr Microsurg* 2007 May;23:199–204.
28. Shaw RJ, Batstone MD, Blackburn TK, et al. Preoperative Doppler assessment of perforator anatomy in the anterolateral thigh flap. *Br J Oral Maxillofac Surg*; 2009 Sep 15 [Epub ahead of print].
29. Chang CC, Wong CH, Wei FC. Free-style free flap. *Injury* 2008; 39:S57–61.
30. D'Arpa S, Cordova A, Pirrello R, et al. Free style facial artery perforator flap for one stage reconstruction of the nasal ala. *J Plast Reconstr Aesthet Surg* 2009;62:36–42.
31. Hamdi M, Van Landuyt K, Monstrey S, et al. Pedicled perforator flaps in breast reconstruction: a new concept. *Br J Plast Surg* 2004 Sep;57:531–9.
32. Niranjan NS, Price RD, Govilkar P. Fascial feeder and perforator-based V–Y advancement flaps in the reconstruction of lower limb defects. *Br J Plast Surg* 2000;53:679–89.
33. Demirtas Y, Ozturk N, Kelahmetoglu O, et al. Pedicled perforator flaps. *Ann Plast Surg* 2009;63:179–83.
34. Pignatti M, Pasqualini M, Governa M, et al. Propeller flaps for leg reconstruction. *J Plast Reconstr Aesthet Surg* 2008;61:777–83.
35. Jakubietz RG, Jakubietz MG, Gruenert JG, et al. The 180-degree perforator-based propeller flap for soft tissue coverage of the distal, lower extremity: a new method to achieve reliable coverage of the distal lower extremity with a local, fasciocutaneous perforator flap. *Ann Plast Surg* 2007;59:667–71.
36. Misra A, Niranjan NS. Fasciocutaneous flaps based on fascial feeder and perforator vessels for defects in the patellar and peripatellar regions. *Plast Reconstr Surg* 2005;115: 1625–32.
37. Tsukino A, Kurachi K, Inamiya T, et al. Preoperative color Doppler assessment in planning of anterolateral thigh flaps. *Plast Reconstr Surg* 2004;113:241–6.
38. Ogawa R, Hyakusoku H, Murakami M. Color Doppler ultrasonography in the planning of microvascular augmented “super-thin” flaps. *Plast Reconstr Surg* 2003;112:822–8.
39. Michlits W, Papp C, Hörmann M, et al. Nose reconstruction by chondrocutaneous preauricular free flaps: anatomical basis and clinical results. *Plast Reconstr Surg* 2004;113:839–46.
40. Chen JJ, Giese S, Jeffrey RB, et al. Treatment and stabilization of complex wounds involving the pelvic bone, groin, and femur with the inferiorly based rectus abdominis musculocutaneous flap and the use of power color Doppler imaging in preoperative evaluation. *Ann Plast Surg* 1999 Nov; 43:494–8.
41. Valentini V, Agrillo A, Battisti A, et al. Surgical planning in reconstruction of mandibular defect with fibula free flap: 15 patients. *J Craniofac Surg* 2005;16:601–7.
42. Monaghan AM, Dover MS. Assessment of free fibula flaps: a cautionary note. *Br J Oral Maxillofac Surg* 2002;40:258–9.
43. Seres L, Csaszar J, Voros E, et al. Donor site angiography before mandibular reconstruction with fibula free flap. *J Craniofac Surg* 2001;12:608–13.
44. Ohjimi H, Era K, Tanahashi S, et al. Ex vivo intraoperative angiography for rectus abdominis musculocutaneous free flaps. *Plast Reconstr Surg* 2002;109:2247–56.
45. Ohjimi H, Era K, Fujita T, et al. Analyzing the vascular architecture of the free TRAM flap using intraoperative ex vivo angiography. *Plast Reconstr Surg* 2005;116:106–13.
46. Gabriel M, Pawlaczyk K, Waliszewski K, et al. Location of femoral artery puncture site and the risk of postcatheterization pseudoaneurysm formation. *Int J Cardiol* 2007;120:167–71.
47. Monstrey SJ. Ankle-arm index versus angiography for preassessment of the fibula free flap. *Plast Reconstr Surg* 2003;112:710–1.
48. Rozen WM, Phillips TJ, Ashton MW, et al. Preoperative imaging for DIEA perforator flaps: a comparative study of computed tomographic angiography and Doppler ultrasound. *Plast Reconstr Surg* 2008;121:9–16.
49. Pacifico MD, See MS, Cavale N, et al. Preoperative planning for DIEP breast reconstruction: early experience of the use of computerised tomography angiography with VoNavix 3D software for perforator navigation. *J Plast Reconstr Aesthet Surg* 2009;62:1464–9.
50. Gacto-Sánchez P, Sicilia-Castro D, Gómez-Cía T, et al. Use of a three-dimensional virtual reality model for preoperative imaging in DIEP flap breast reconstruction. *J Surg Res*; 2009 Feb 21 [Epub ahead of print].
51. Imai R, Matsumura H, Tanaka K, et al. Comparison of Doppler sonography and multidetector-row computed tomography in the imaging findings of the deep inferior epigastric perforator artery. *Ann Plast Surg* 2008;61:94–8.
52. Rozen WM, Ashton MW, Grinsell D, et al. Establishing the case for CT angiography in the preoperative imaging of abdominal wall perforators. *Microsurgery* 2008;28:306–13.
53. Rozen WM, Ashton MW. The “limited rectus sheath incisions” technique for DIEP flaps using preoperative CT angiography. *Microsurgery* 2009;29:525–8.
54. Ribuffo D, Atzeni M, Saba L, et al. Angio computed tomography preoperative evaluation for anterolateral thigh flap harvesting. *Ann Plast Surg* 2009;62:368–71.
55. Singh J, Daftary A. Iodinated contrast media and their adverse reactions. *J Nucl Med Technol* 2008;36:69–77.
56. Uppal RS, Casaer B, Van Landuyt K, et al. The efficacy of preoperative mapping of perforators in reducing operative times and complications in perforator flap breast reconstruction. *J Plast Reconstr Aesthet Surg* 2009;62:859–64.
57. Clavero JA, Masia J, Larrañaga J, et al. MDCT in the preoperative planning of abdominal perforator surgery for postmastectomy breast reconstruction. *Am J Roentgenol* 2008;191:670–6.
58. Rozen WM, Ashton MW, Pan WR, et al. Anatomical variations in the harvest of anterolateral thigh flap perforators: a cadaveric and clinical study. *Microsurgery* 2009;29:16–23.
59. Wong C, Saint-Cyr M, Rasko Y, et al. Three- and four-dimensional arterial and venous perforasomes of the internal mammary artery perforator flap. *Plast Reconstr Surg* 2009; 124:1759–69.
60. Ting JW, Rozen WM, Grinsell D, et al. The in vivo anatomy of the deep circumflex iliac artery perforators: defining the role for the DCIA perforator flap. *Microsurgery* 2009;29:326–9.
61. Demirtas Y, Cifci M, Kelahmetoglu O, et al. Three-dimensional multislice spiral computed tomographic angiography: a potentially useful tool for safer free tissue transfer to complicated regions. *Microsurgery* 2009;29:536–40.

62. Duymaz A, Karabekmez FE, Vrtiska TJ, et al. Free tissue transfer for lower extremity reconstruction: a study of the role of computed angiography in the planning of free tissue transfer in the posttraumatic setting. *Plast Reconstr Surg* 2009;**124**: 523–9.
63. Rozen WM, Stella DL, Bowden J, et al. Advances in the pre-operative planning of deep inferior epigastric artery perforator flaps: magnetic resonance angiography. *Microsurgery* 2009;**29**:119–23.
64. Rozen WM, Ashton MW, Stella DL, et al. Magnetic resonance angiography and computed tomographic angiography for free fibular flap transfer. *J Reconstr Microsurg* 2008;**24**:457–8.
65. Casey 3rd WJ, Chew RT, Rebecca AM, et al. Advantages of preoperative computed tomography in deep inferior epigastric artery perforator flap breast reconstruction. *Plast Reconstr Surg* 2009;**123**:1148–55.
66. Masia J, Kosutic D, Cervelli D, et al. In search of the ideal method in perforator mapping: noncontrast magnetic resonance imaging. *J Reconstr Microsurg* 2010;**26**:29–35.
67. Kelly AM, Cronin P, Hussain HK, et al. Preoperative MR angiography in free fibula flap transfer for head and neck cancer: clinical application and influence on surgical decision making. *Am J Roentgenol* 2007;**188**:268–74.
68. Neil-Dwyer JG, Ludman CN, Schaverien M, et al. Magnetic resonance angiography in preoperative planning of deep inferior epigastric artery perforator flaps. *J Plast Reconstr Aesthet Surg* 2009;**62**:1661–5.
69. Vasile JV, Newman T, Rusch DG, et al. Anatomic imaging of gluteal perforator flaps without ionizing radiation: seeing is believing with magnetic resonance angiography. *J Reconstr Microsurg* 2010;**26**:45–57.
70. Greenspun D, Vasile J, Levine JL, et al. Anatomic imaging of abdominal perforator flaps without ionizing radiation: seeing is believing with magnetic resonance imaging angiography. *J Reconstr Microsurg* 2010;**26**:37–44.
71. Mast BA. Comparison of magnetic resonance angiography and digital subtraction angiography for visualization of lower extremity arteries. *Ann Plast Surg* 2001;**46**:261–4.
72. Lorenz RR, Esclamado R. Preoperative magnetic resonance angiography in fibular-free flap reconstruction of head and neck defects. *Head Neck* 2001;**23**:844–50.