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Reconstructive

The Value of Dynamic Infrared Thermography in Pedicled Thoracodorsal Artery Perforator Flap Surgery

Thomas Sjøberg, MD*†
James B. Mercer, PhD†‡
Sven Weum, MD, PhD†‡
Louis de Weerd, MD, PhD*†

Background: Dynamic infrared thermography (DIRT) is a noninvasive imaging technique that can provide indirect and real-time information on skin perfusion by measuring skin temperature. Although used in flap surgery, there are no reports on its value in procedures using a pedicled thoracodorsal artery perforator (TDAP) flap. The aim of this study was to assess the usefulness of DIRT in preoperative perforator mapping and in monitoring intra- and postoperative flap perfusion of pedicled TDAP flaps.

Methods: This prospective study comprised 21 patients (21 flaps) scheduled for reconstructive surgery with a TDAP flap. Perforator mapping was done by DIRT, handheld unidirectional Doppler ultrasound, and computer tomography angiography. Intra- and postoperative flap perfusion was assessed by clinical signs and with the use of DIRT and handheld unidirectional Doppler ultrasound.

Results: Perforator mapping with DIRT showed that first-appearing bright hotspots were always associated with arterial Doppler sounds and suitable perforators intraoperatively. Computer tomography angiography presented useful information on the thoracodorsal artery branching pattern but was less beneficial for perforator mapping. Intra- and postoperative flap monitoring with DIRT was more useful than handheld unidirectional Doppler ultrasound and clinical signs to detect early arterial and venous perfusion problems. DIRT demonstrated that TDAP flap perfusion is a dynamic process with an increase in perfusion during the first operative days. Nineteen flaps survived, of which 3 sustained distal necrosis. Two flaps were lost due to inadequate blood perfusion.

Conclusion: DIRT provides valuable real-time information for perforator mapping and for monitoring TDAP flap perfusion intra- and postoperatively. *(Plast Reconstr Surg Glob Open 2020;8:e2799; doi: 10.1097/GOX.0000000000002799; Published online 15 July 2020.)*

INTRODUCTION

The thoracodorsal artery perforator (TDAP) flap is a frequently used pedicled flap in breast reconstruction.[1] Unlike the myocutaneous latissimus dorsi flap, no muscle is harvested, and donor site morbidity is thereby reduced.[2] However, abandoning the muscle comes at the expense of less robust blood flow. Preoperative perforator mapping to locate dominant perforators and to optimize perforator flap design can be helpful to ensure adequate tissue perfusion.[3,4] The most frequently reported mapping techniques are handheld unidirectional Doppler ultrasound, computer tomography angiography (CTA), and color Doppler ultrasound. Intra- and postoperative assessment of flap perfusion is commonly accomplished by clinical examination and handheld unidirectional Doppler ultrasound.[5]

Thermography is widely used in medicine as a noninvasive technique to measure skin temperature.[6] Dynamic infrared thermography (DIRT) is based on the relationship between dermal perfusion and the rate and pattern

*From the *Department of Plastic and Reconstructive Surgery, University Hospital of North Norway, Tromsø, Norway; †Medical Imaging Research Group, Department of Clinical Medicine, UiT The Arctic University of Norway, Tromsø, Norway; and ‡Department of Radiology, University Hospital of North Norway, Tromsø, Norway.*

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Table 1. Local Protocol for Preoperative TDAP Flap CTA

Scanner: Siemens Somatom Definition Flash
Slice thickness: 128 detector row × 0.6 mm, pitch 1.3
Rotation speed: 0.5 s
Contrast medium: Ominpaque 350 mg I/mL
Flow rate: 4 mL/s
Total volume: 80 mL contrast medium + 50 mL saline
Scanning range: Clavicle to xiphoid process
Scanning direction: Cranial to caudal
Bolus tracking: >100 HU at aortic arch with 5 s delay
Image reconstruction: 0.4 mm overlapping axial images

Patient in supine position with arms stretched above the head.
HU, Hounsfield units.

of skin rewarming following a cold challenge. The use of DIRT has been reported in flap surgery.[7,8] To our knowledge, however, there are no reports on DIRT in reconstructive surgery using pedicled TDAP flaps. The aim of this study is to assess the usefulness of DIRT in preoperative perforator mapping, as well as in intra- and postoperative monitoring of perfusion in TDAP flaps.

MATERIALS AND METHODS

This prospective study was performed in accordance with the principles outlined in the Declaration of Helsinki and in-house rules of the University Hospital of North Norway. All patients were nonsmokers or had stopped smoking at least 3 months before surgery and consented to participate in the study.

Preoperative Assessment of Flap Perfusion

Preoperative perforator mapping was done by CTA, handheld unidirectional Doppler ultrasound, and DIRT. The CTA protocol is presented in Table 1. Doppler ultrasound and DIRT examinations were performed in the lateral decubitus position, similar to during flap harvest. Arterial perforator sounds were detected using a handheld 8 MHz unidirectional Doppler ultrasound (Multi Dopplex II; Huntleigh Healthcare, Cardiff, United Kingdom) and marked with a red dot on the skin (Fig. 1). DIRT was performed in a dedicated laboratory (room temperature 21°C–23°C) using an infrared camera (FLIR ThermaCAM S65 HS or FLIR T 420; FLIR Systems, Boston, Mass.) with thermal emissivity set to 0.98. After a 10-minute acclimatization period, the donor site was exposed to a mild cold challenge for 2 minutes using a desktop fan blowing air at room temperature over the skin surface. The rate and pattern of skin rewarming were registered for 3 minutes. First-appearing hotspots were marked with a black cross (Fig. 1). All data were electronically stored for analysis using designated software (FLIR Research IR, ver. 3.0.11; FLIR Systems).

Surgical Technique

Our surgical technique followed previously established methods.[9,10] In short, the patient was operated on in a lateral decubitus position, with the ipsilateral arm abducted and supported by an arm table. The deep fascia was included in the flap. A propeller flap design was used in the majority of cases.[11] If a longer pedicle was needed, the perforator was mobilized further by including a small muscle cuff surrounding the vessels. Most frequently, the skin bridge between donor and recipient site was divided to avoid compression on the pedicle, although subcutaneous tunneling was used in a few cases. In breast reconstructions, TDAP flaps were combined with submuscular implants in all but 2 patients.

Intraoperative Assessment of Flap Perfusion

Flap perfusion was evaluated by clinical signs (color, refill, and temperature), Doppler ultrasound, and DIRT. The intraoperative cold challenge was effectuated by washing the flap surface for 30 seconds with gauze soaked in saline at room temperature (22°C–23°C), after which the skin was dried with a gauze.

At first, DIRT was repeated to confirm the preoperative findings regarding the rate and pattern of skin rewarming of the flap at the donor site. After flap and perforator dissection, skin perfusion by each potentially suitable perforator was assessed, leaving the selected perforator open, while the other perforators were temporarily closed using microclamps. After flap transposition and at the end of the surgery, flap perfusion was evaluated again.

Postoperative Assessment of Flap Perfusion

Postoperative flap monitoring was done by clinical evaluation, Doppler ultrasound, and DIRT. Clinical signs and Doppler ultrasound were checked every 2 hours

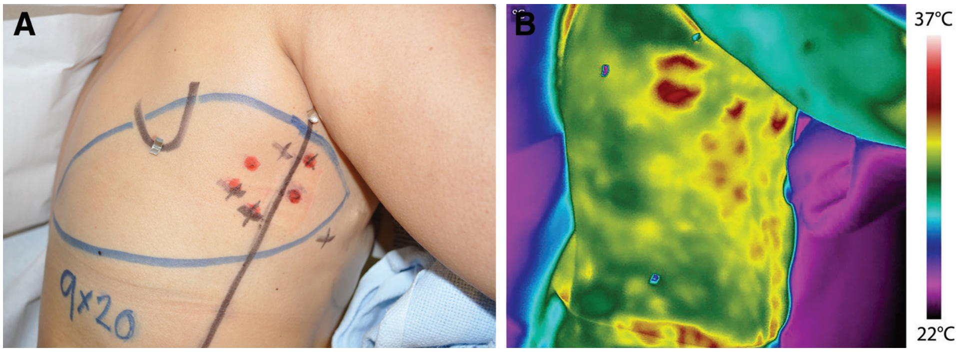

Fig. 1. Routine procedure for preoperative perforator mapping. A, Perforators localized by Doppler ultrasound (red dots) and DIRT (black crosses). B, Thermal image showing several hotspots (bright red color) representing the localized heat radiation conveyed by the subcutaneous perforators. Note the scale on the right side of the image explaining the relation between temperatures and color.

during the first 24 hours and every 6 hours thereafter for 2 days. DIRT was done on postoperative days 1, 2, 3, and 6.

RESULTS

Twenty-one patients (1 male), mean age 50 years (21–65 years) and mean body mass index 23.0 kg/m^2 (17.4–30.3 kg/m^2), were included. Nineteen female patients were scheduled for secondary breast reconstruction. Twelve of these had received adjuvant radiochemotherapy, whereas 5 had received radiotherapy only. The average time interval between radiotherapy and TDAP flap surgery was 59 months (median, 39 months; range, 11–209 months). One female patient required scar release due to childhood flame burns to the axilla and thorax. The male patient had a scar contracture in the axilla following surgery for hidradenitis.

Preoperative Findings

Preoperative CTA was accomplished in all but 5 patients, whereas DIRT and Doppler ultrasound were performed in all patients. CTA visualized the thoracodorsal artery (TDA) and its branching pattern in all patients. Although intramuscular perforators could be visualized on CTA in many patients, the continuation of an intramuscular perforator into the subcutaneous layer could be detected in only one. This result did not change when using maximum intensity projection reconstructions with a slice thickness of 10 mm. DIRT showed large variability in the locations and numbers of hotspots between patients. Rapidly appearing hotspots with progressive rewarming were always associated with arterial Doppler sounds. In some patients, arterial Doppler sounds were detected on locations without a hotspot on DIRT.

Intraoperative Findings

The results of perforator mapping with DIRT were similar intra- and preoperatively. Surgery confirmed that the locations of selected hotspots corresponded with the locations of suitable perforators. In 7 flaps, intramuscular dissection was required to obtain a longer pedicle to optimize flap transposition. The mean flap length was 19 cm (15–24 cm) and the mean width was 9 cm (7–10 cm). In 17 breast reconstructions, 6 silicone implants [mean volume, 283 mL (200–355 mL)] and 11 expander implants (range, 300–450 mL) (Mentor Worldwide LLC, Santa Barbara, Calif.) were used.

Analyses of the rate and pattern of rewarming at each hotspot showed that the brightest hotspot, with the largest rewarming area, was always associated with a suitable perforator. Rewarming always started at the brightest hotspot with an increase in temperature of the surrounding area. Other hotspots then appeared near the first-appearing hotspot in the area where the vascular pedicle entered the flap. The distal part of the flap showed a slower, more homogenous rewarming without hotspots (Fig. 2).

Although the pattern of hotspots remained largely unchanged directly after flap transposition, the observed rewarming at the hotspot(s) was somewhat slower. In cases of a major decrease in rewarming, repositioning the flap to its donor site resulted in an increased rate of rewarming and brighter hotspots within approximately 3 minutes. Repeated transposition and reposition appeared to enhance flap perfusion in general. Such a cycle of transposition and reposition and back to the recipient site took approximately 6 minutes.

In some cases, flap transposition resulted in a colder flap and the disappearing of hotspots within a few minutes. Such findings were also associated with less audible or loss of arterial Doppler sounds and were related to impaired arterial inflow, caused by kinking, torsion, tension, or compression on the pedicle. DIRT and ultrasound findings always preceded clinical signs of a pale flap (Fig. 3). After proper adjustments were made, rewarming improved and hotspots reappeared.

In some cases, DIRT showed a homogenous rewarming pattern without a clear pattern of hotspots after flap transposition. The arterial Doppler sounds gradually weakened. Clinically, the flap showed a bluish discoloration. This pattern of rewarming was always related to venous congestion. Manipulation of the pedicle or, in one case, removal of the implant normalized the flap perfusion.

Postoperative Findings

Two flaps were lost due to insufficient flap perfusion postoperatively. In both patients, the preoperative CTA showed a thin TDA. Although DIRT and Doppler investigations at the end of surgery indicated normal perfusion, postoperative DIRT showed a slow rate of rewarming at the hotspots and in the periphery. Finally, the hotspots and arterial Doppler sounds disappeared, the flaps became pale, and the skin temperature dropped on DIRT. Both patients had received adjuvant radiotherapy as part of their prior cancer treatment.

Clinical signs of venous congestion and a diffuse homogeneous rewarming pattern on DIRT, with no hotspots, were observed in 2 other breast reconstructions. Implant removal, on postoperative days 1 and 2, respectively, immediately resulted in a rewarming pattern with hotspots and a gradual return of normal skin color (Fig. 4). Both flaps survived, although 1 developed necrosis at the distal end. Partial tip necrosis also occurred in 2 other patients. One of these flaps was a bi-lobed flap used to correct burn scars. In these cases, DIRT results indicated a normal flap perfusion, apart from the most distal part, which was slightly colder after the surgery. The remaining patients had complete flap survival. There were no donor site complications.

DISCUSSION

Adequate tissue perfusion is essential in perforator flap surgery. Preoperative imaging can provide information on the location and quality of perforators. Such information can simplify the surgical procedure and reduce operating time.[12] This is particularly important in anatomical locations with large interindividual variability in vascular anatomy and in cases where previous surgery may have altered the normal anatomy. Handheld unidirectional Doppler ultrasound is the most commonly used technique in perforator mapping due to its easy handling and availability. However,

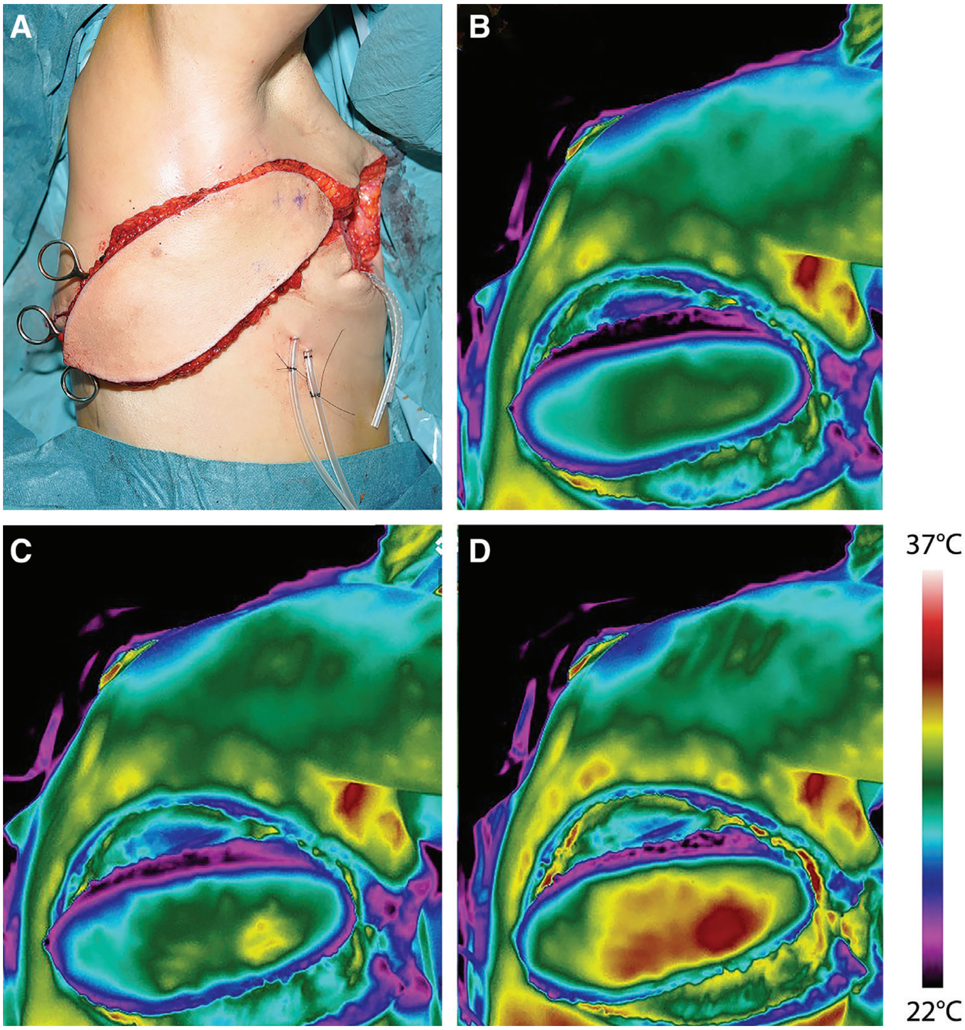

Fig. 2. Intraoperative images of a TDAP flap raised and isolated on a perforator, illustrating the information gained from the cold challenge. A, Isolated flap. B, Thermal image immediately after the cold challenge with reduced heat radiation and no hotspots. C, Thermal image 3 minutes after the cold challenge with increased heat radiation and a bright hotspot at the proximal end of the flap. D, Thermal image after complete rewarming of the flap. Note reduced heat radiation at the distal end of the flap.

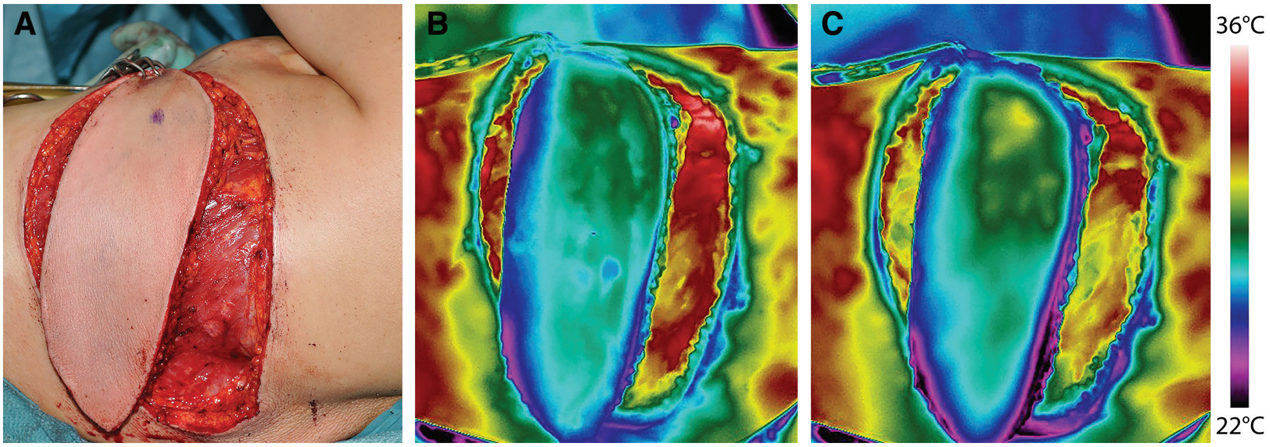

Fig. 3. DIRT revealing impaired flap perfusion before clinical signs are visible. A, This flap cooled down after transfer to the recipient site and was therefore relocated to the donor site. The thermal image shows the flap immediately after return to the donor site. B, The flap at the donor site showing no clinical signs of impaired perfusion. C, Thermal image 2 minutes after figure A, with reappearance of hotspots in the proximal part of the flap, confirming perfusion through the perforator.

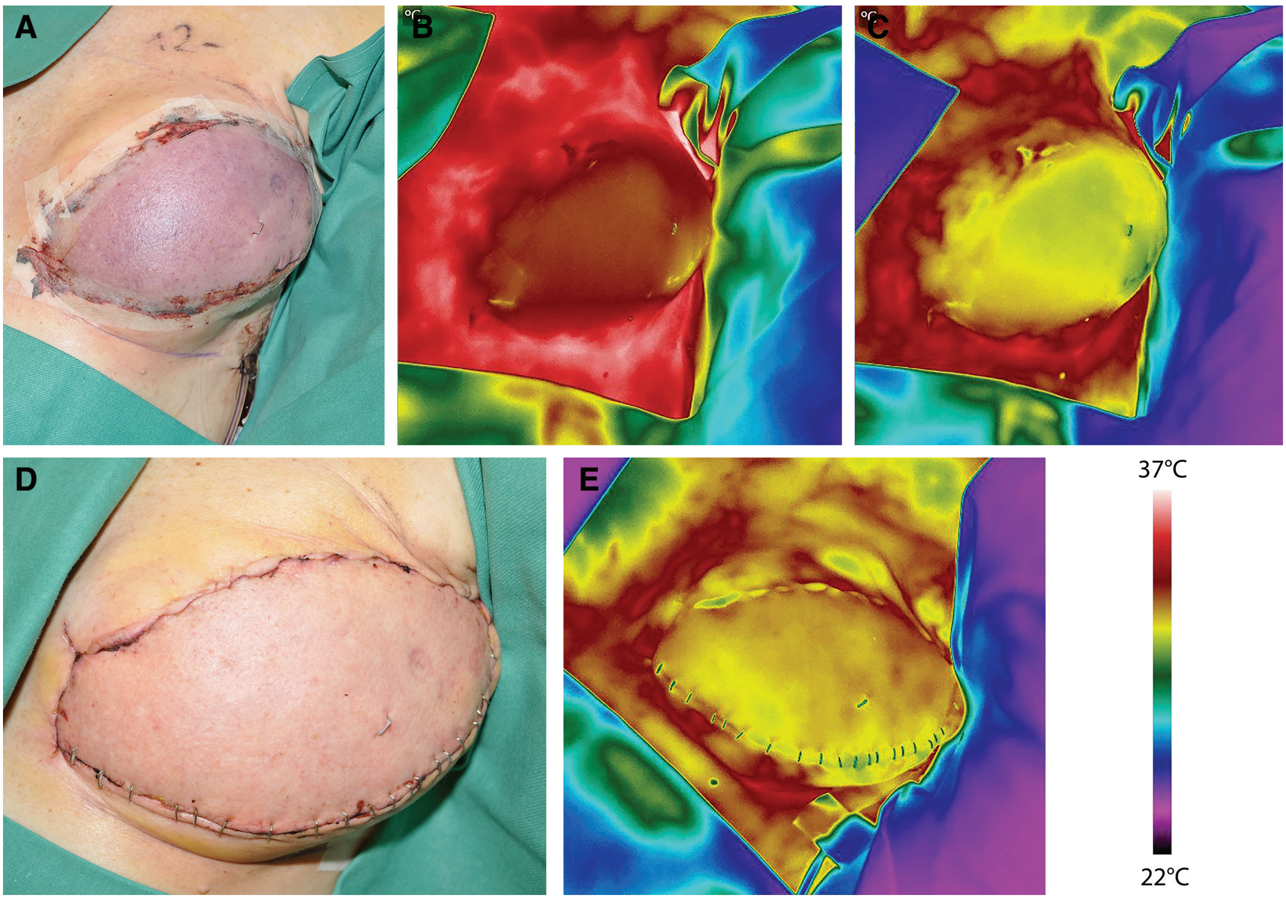

Fig. 4. This series of images shows venous congestion of the flap caused by a breast implant. A, The flap shows clinical signs of venous congestion. B, The thermal image shows a homogenous temperature pattern. C, Thermal image of the congested flap 3 minutes after the cold challenge shows no hotspots. D, The flap after removal of the implant showing normal skin color. E, Thermal image following implant removal showing re-appearing hotspots within few minutes after the cold challenge.

Stekelenburg et al[13] found poor interobserver reliability and almost 50% false-positive results when handheld unidirectional Doppler ultrasound was compared with color Doppler ultrasound. The false-positive results were mainly related to axial or intramuscular vessels. This could explain why the location of some arterial Doppler sounds could not be correlated to hotspots in our preoperative assessment. However, the perforators that were detectable by both DIRT and Doppler ultrasound preoperatively were all associated with perforators on surgical exploration. Hence, DIRT can enhance the reliability of perforator mapping with handheld unidirectional Doppler ultrasound. Furthermore, perforator mapping with DIRT produced reproducible results, as the preoperative results were identical to those obtained immediately before flap harvest.

Skin rewarming after a cold challenge is related to the quality of the perforator. First-appearing hotspots with a progressive, rapid skin rewarming are related to transport of warm blood through perforators with a large diameter and well-developed vascular network. The cold challenge makes it easier to locate such perforators and assess their ability to rewarm the skin.[14,15] Although Theuvenet et al[16] already in 1986 published an article on thermographic assessment of perforating arteries using a cold challenge, it was not until recently that DIRT has gained popularity in perforator mapping. Our results show that DIRT can also be used for perforator mapping of TDAP flaps. A disadvantage of DIRT, in comparison to CTA, is that it cannot provide detailed information on the anatomical course of the perforator.[17] A few studies support the use of CTA in TDAP flap surgery.[3,4,18] However, TDAPs are smaller, and the overlying subcutaneous layer is often thinner compared with, for example, deep inferior epigastric artery perforators and abdominal flaps, where CTA is a commonly used imaging technique. This can make the interpretation of the CTA more challenging in TDAP flap surgery.[4] Indeed, Feng et al[19] reported on perforator mapping in the lower extremities, where the thickness of the subcutaneous layer often resembles that of the back, and found that color Doppler ultrasound was superior to CTA. In our study, CTA was not very useful for TDAP mapping, although the protocol was similar to those in previous studies.[3,4,18] However, CTA clearly demonstrated the branching pattern of the TDA and, to some extent, its intramuscular course. Elzawawy et al[20] showed that the branching pattern of the TDA varies considerably among patients. Information on detailed vascular anatomy may therefore still be useful when intramuscular dissection is required. In addition, a TDA with a small caliber on CTA might be associated with reduced flap perfusion. We had the impression that the TDA as seen in 2 of our patients with total flap loss had a small caliber. The intramuscular course of perforators can perhaps be used to estimate the location of perforators in the subcutaneous tissue, even without detectable subcutaneous continuation. However, different patient positions during CTA and surgery may reduce the reliability of CTA for perforator mapping.

Intraoperative evaluation of the perforator is most frequently done with a handheld unidirectional Doppler ultrasound despite the mentioned limitations. Our results show that assessment of tissue perfusion after flap dissection can be easily performed with DIRT, allowing for selective quality assessment of individual perforators by clamping other possible perforators. This technique was described by Kalra et al[21] for intraoperative selection of a dominant deep inferior epigastric artery perforator.

Perforator flap surgery demands meticulous surgical technique, as inadvertent damage to the perforator can easily occur. Torsion, kinking, or external compression of the pedicle may cause impaired flap perfusion after flap transposition. In our study, DIRT revealed these events even before clinical signs of impaired flap perfusion became visible. The rate of rewarming at the hotspot overlying the perforator rapidly decreased in case of reduced inflow. Repositioning the flap back to its donor site improved the rate of rewarming at the hotspot and the flap. After correcting the obstruction, the flap could be relocated to its recipient site without affecting the normal rewarming. Interestingly, in some flaps, this procedure had to be repeated more than once, but flap perfusion improved every time as if some flap preconditioning occurred. While an arterial inflow problem became visible by a decreased rate of rewarming or disappearance of hotspots, venous outflow problems were characterized by a homogenous rewarming pattern without hotspots. This may be explained by the pooling of warm blood in the flap due to venous congestion.

Following flap transposition, the number of hotspots at the proximal part of the flap gradually increased, while the distal part of the flap showed a homogeneous rewarming pattern without hotspots and was cooler than the proximal part. Hotspots became visible in the distal part only during consecutive postoperative days. In cases with partial flap necrosis, this always occurred in the distal part of the flap. A possible explanation may be found in the angiosome concept by Taylor and Palmer.[22] Perforators within the same angiosome are linked by direct vascular connections, whereas adjacent angiosomes are connected by choke vessels that can open on demand to increase the vascular territory of each source vessel. The TDA is the dominant blood supply to the latissimus dorsi muscle and its overlying skin.[23] However, at its most medial extension, blood supply to the skin territory is provided by intercostal arteries.[24] A horizontal TDAP flap design up to the midline therefore consists of 2 angiosomes. The TDAP flaps for breast reconstructions in our study were designed with a horizontal orientation to conceal the scar under the bra strap. At the end of the surgery, hotspots were only seen in the angiosome corresponding with the TDA. However, during the consecutive postoperative days, hotspots became visible in the adjacent angiosome of the intercostal arteries. In such case, DIRT revealed that the perfusion of the TDAP flap is a dynamic process, explained by the opening of choke vessels between the angiosomes, resulting in gradually expanding perfusion of perforators in the distal part of the TDAP flap. Flap necrosis is most likely to occur in this distal part, as was seen in several TDAP flaps. As reported by others, designing the TDAP flap over the vertical angiosome of the descending branch of the TDA may reduce the risk for such complications.[25–27]

In 2 cases, the flaps showed a bluish discoloration within hours after the operation, and DIRT showed a homogenous rewarming pattern without hotspots. We assumed that the venous congestion resulted from compression by the breast implants. Flap perfusion improved rapidly with re-emerging hotspots on DIRT and normalized flap color after implant removal. The 2 flaps that failed had initially audible Doppler sounds, but a slow rewarming pattern during the first postoperative days. During the following days, DIRT showed a progressive decrease in flap temperature starting at the periphery; the Doppler sounds became gradually weaker and finally disappeared. The vascular pedicle in one of these flaps was dissected over a rather long distance through the muscle and might have been injured. Both flaps had a small caliber TDA on CTA. Although no intraoperative explanation was obvious in the other case of total flap failure, this was probably caused by injury to the perforators following dissection or postoperative tension on the pedicle.

One of the limitations of DIRT is that it only provides indirect information on skin perfusion. However, Miland et al[28] showed a good correlation between the results from DIRT and direct visualization of blood vessels using indocyanine-green fluorescence angiography (ICG-FA). Nevertheless, an animal study using DIRT and ICG-FA to predict partial flap necrosis in a pedicled flap demonstrated that intraoperative DIRT findings overestimated flap survival by 5%–6%, while intraoperative images of ICG-FA underestimated flap survival by 6%–10%.[29] When this limitation is acknowledged, DIRT may be useful to assess distal flap perfusion. Unlike CTA and ICG-FA, DIRT does not require intravenous injection or exposure to ionizing radiation. Furthermore, DIRT provides real-time information on skin perfusion without the need for physical contact with the patient. Recently, low-cost handheld thermal cameras and thermal cameras for smartphones have shown to be promising alternatives to expensive cameras in perforator mapping, making DIRT available at a lower cost.[30,31]

In summary, this study showed that DIRT was useful for perforator mapping in pedicled TDAP flaps, as it provides valuable information on the hemodynamic quality of perforators and their location. DIRT was also useful for intraoperative and postoperative monitoring of TDAP flap perfusion. DIRT provided more accurate information on inadequate flap circulation than clinical judgment or handheld Doppler ultrasound. DIRT showed that flap perfusion of the transversely designed TDAP flap is a dynamic process with a progression of perfusion during the first postoperative days.

Professor Louis de Weerd, MD, PhD
Department of Plastic and Reconstructive Surgery
University Hospital of North Norway
Sykehusveien 38
9038 Tromsø
Norway
E-mail: louis.deweerd@unn.no

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