Using dynamic infrared thermography to optimize color Doppler ultrasound mapping of cutaneous perforators.

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Abstract

Aims: The high technical demands associated with perforator flaps demand a precise preoperative identification and evaluation of perforator vessels. Color Doppler Ultrasonography (CDU) and Dynamic Infrared Thermography (DIRT) are currently used for preoperative perforator mapping. Each individual technique has advantages and disadvantages. The purpose of this paper is to analyze the value of combining the two methods in order to optimize the process of preoperative perforator mapping. Material and methods: CDU and DIRT were used for preoperative perforator mapping in 10 pigs. The results were compared to intraoperative findings. Total number of perforators, localization, and identification of the dominant perforator was analyzed for each method. The examination time was recorded for each procedure. Results: Both methods had a high sensitivity in determining the number and localization of perforators when compared to those identified during surgery. DIRT produced a higher number of false positive results. CDU accurately identified the emergence of the perforators in the fascia in all cases. Both methods correctly identified the dominant perforator. The sensitivity, positive predictive value, and accuracy of CDU were 93.56%, 97%, and 91.30% respectively and for DIRT 95.05%, 80.67%, and 77.41% respectively. The average examination was 39.76 minutes for CDU and 10.24 minutes for DIRT. The average time taken into account for the analysis of a single perforator in order to confirm DIRT findings was 1.83 minutes. Conclusions: Preoperative perforator mapping has become a compulsory step in nearly all reconstructive procedures. In our study, both CDU and DIRT correctly identified the dominant perforator in all cases. By combining the two examinations overall mapping time can be reduced significantly. A reduced examination time translates into increased patient compliance and a lower procedure cost. The combined mapping technique facilitates the selection of the ideal perforator in all cases. Correctly identifying the dominant perforator preoperatively reduces operative time, lowers complication rates and ensures an overall better result.

Keywords: dynamic infrared thermography, color Doppler ultrasonography, perforator flap

Introduction

Surgical technique and flap design have evolved continuously over the last decades. In-depth understanding of the anatomy and physiology of the cutaneous circula-

 Received 18.07.2015 Accepted 15.09.2015

Med Ultrason
2015, Vol. 17, No 4, 503-508

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tion [1], allows surgeons to harvest flaps based on a single perforator, without sacrificing additional tissue. The introduction of perforator flaps has revolutionized reconstructive surgery, leading to reduced donor site morbidity, and the ability to tailor any flap to match the exact defect requirements [2].

Perforator flap surgery requires dissection of extremely small and fragile blood vessels, with a highly variable vascular anatomy [3]. Unlike conventional flaps, the high technical demands associated with perforator flaps require preoperative vessel identification and mapping, in order to reduce complications [4]. Preoperative perforator mapping optimizes flap design, reduces operating times, lowers complication rates, and provides an overall better result [5].
Color Doppler ultrasound (CDU) remains the most widely used method of preoperative perforator mapping, providing highly sensitive, predictive information regarding the emerging point, course, diameter and blood-flow characteristics of the cutaneous vessels [6]. The technique is noninvasive, safe, and has virtually no contraindications. Recent studies show no significant difference between Computer Tomography Angiography (CTA) and CDU in reducing operating times and lowering complication rates in patients undergoing breast reconstruction [7]. The main drawbacks associated with CDU are the long examination time and operator dependence [5].

Dynamic Infrared Thermography (DIRT) is a non-invasive monitoring technique recently introduced in reconstructive surgery. It provides dynamic, real-time, intraoperative information about vessel location, perfusion patterns and flap physiology [8]. It has been successfully used to map perforators, optimize flap design, assess blood flow and evaluate anastomosis patency [9].

Both CDU and DIRT are currently used for preoperative perforator mapping [10,11]. Each individual technique has advantages and disadvantages. The purpose of this paper is to analyze the value of combining the two methods in order to optimize the process of preoperative perforator mapping.

Material and methods

The experimental study was conducted under a protocol approved by the Ethics Committee of the University of Medicine and Pharmacy by decision no. 294/2015 at the Department of Surgery of the University of Agricultural Sciences and Veterinary Medicine between February – May 2015.

Animals

Animals were studied under the supervision of an approved institutional protocol. Ten PIC-FII-337 hybrid breed pigs, averaging 42.3 kg were used. This particular experimental model was chosen because of the similarity between human and porcine vascular architecture [12]. The animals were induced using (1-2 mg/kg IV) – Norfof (Norbrook Laboratories Limited, Northern Ireland), intubated, and maintained on 2% isoflurane (Baxter Healthcare Corp., Deerfield, IL). Electrocardiograph, respiratory rate, oxygen saturation, pulse, esophageal temperature, ETCO2, FiO2 and anesthetic gas concentration were monitored throughout the surgical procedure.

After the animals were anesthetized the abdominal area was prepared for mapping. A vertical line was drawn connecting the xiphoid appendix with the umbilicus. Horizontal lines were created, 10 cm apart, subdividing the upper abdominal region into four 10x10 cm quadrants.

Preoperative perforator mapping of each quadrant was performed, first using CDU and afterwards DIRT (fig 1).

CDU mapping

CDU mapping was performed using GE Logiq 9 Ultrasound machine (GE Healthcare, UK) using linear transducer with a preset frequency of 9 MHz, at PRF 1.4 kHz, WF 110Hz, CF frequency of 7.5 MHz and 2-3 cm depth.

The technique was identical in all cases. Each 10x10 cm quadrant was scanned individually, in two perpendicular directions, with an approximative speed of 3 mm/sec. The fascial layer was identified by adjusting the color sample Doppler at a corresponding depth level. All vessels that pierced de fascial layer and continued in a vertical or oblique trajectory towards the skin were analyzed. The arterial nature of each perforator was confirmed by visualizing the pulsating character of the Doppler curve.

To reduce the risk of artifacts, the position of each identified perforator was reconfirmed by a transversal scan. The cutaneous projection of the perforators was marked using a blue skin marker. After comparing all perforators in a given quadrant, the perforator with the greatest caliber was chosen as the dominant perforator. The dominant perforator was marked separately by adding a circle around the previously drawn point.

CDU mapping was performed by the same operator in all cases to avoid interobserver variability. The total procedure time and the time needed to analyze each individual perforator were recorded separately using a standard stopwatch.

DIRT mapping

DIRT perforator mapping was performed individually for each quadrant. After pulverizing alcohol over the region of interest, a fan was used to deliver air at room temperature directly over the quadrant, for 60 seconds. This achieved a uniform cooling effect, with skin temperature reaching 23-25°C. After the area cooled down, the thermography camera was used to visualize the rewarming pattern. A Testo 890 Handheld Thermal Imaging Camera (Testo AG, Lenzkirch, Germany) with a thermal sensitivity <40 mK and a standard lens was used to continuously monitor the area throughout the rewarming phase. The first areas that rewarm are the perforators and appear as “hot spots”.

Each identified “hot spot” was marked as a perforator using a green skin marker. The speed and progression of the rewarming pattern at the “hot spot” was used to determine the dominant perforator. The dominant perforator was the first to appear and had the largest “hot spot”. It was marked separately in each quadrant. The entire DIRT mapping process was timed using the same stopwatch.
Intraoperative phase

After completing the preoperative mapping each animal was prepared for surgery. All operative procedures were performed using the standard aseptic technique. Surgical exploration of the upper abdominal quadrants was performed in order to confirm the actual position of previously mapped perforators. A 20 cm incision was performed at the lateral border of the rectus muscle on each side of the abdominal wall. Dissection continued from lateral to medial in a plane above the muscle fascia. All perforators were identified and their emergence through the fascia was marked on the skin with red. After dissecting all the vessels in a quadrant, the perforator with the greatest caliber was chosen as the dominant perforator and marked separately (fig 2, fig 3).

Statistical analysis

Data was centralized using the SPSS v.17 software suite (SPSS Inc. Chicago, IL, USA) and analyzed using two types of continuous variables: examination time and number of identified perforator vessels per defined quadrant. For analyzing the quality of CDU and DIRT combined with CDU in mapping perforator vessels we used sensitivity (the number of true positive divided to the total number of positives) and positive predictive value (the number of true positives divided to the total number of positives at test). Accuracy was defined as the percentage of correctly classified perforators from the total analyzed ones. For analyzing possible differences in examination times, we used a two-tailed t-test for dependent means. The t-test for dependent means (also called a paired samples t-test, matched pairs t-test and matched samples t-test) is used to compare the means of two sets of scores that are directly related to each other. In this case it is used to test whether the total time required for preoperative perforator vein mapping is different under two conditions – first, using CDU; second, using the combined DIRT and CDU technique.

Results

Each quadrant was distinctly analyzed. The location and number of perforators identified by CDU and DIRT were compared with the intraoperative findings. The total number of perforators identified during surgery was 202. Preoperative CDU mapping identified 194 perforators, 189 of those being confirmed during surgery. DIRT visualized 238 perforators, with 192 confirmed by surgery. The sensitivity, positive predictive value, and accuracy of both methods are detailed in table I.

![Fig 1.](image1) a) CDU perforator mapping; b) DIRT visualization of “hot spots”; c) Intraoperative visualization of the previously mapped perforator

![Fig 2.](image2) A branching perforator, correctly identified by CDU (red star) (a) and visualized as two “hot spots” (white circle) with DIRT (b). Nipple areas (grey circles) were not analyzed.

![Fig 3.](image3) Visualization of an oblique perforator. The fascial emergence is correctly identified by the CDU (red star) (a). “Hot spots” (white circle) appear laterally with DIRT (b). Nipple areas (grey circles) were not analyzed.

<table>
<thead>
<tr>
<th>Test Indicator</th>
<th>CDU (95% CI)</th>
<th>DIRT (95% CI)</th>
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<tr>
<td>Sensitivity</td>
<td>93.56% (89.25%-96.53%)</td>
<td>95.05% (91.08%-97.60%)</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>97% (94.09%-99.16%)</td>
<td>80.67% (75.07%-85.49%)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>91.30%</td>
<td>77.41%</td>
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CDU- color Doppler ultrasonography; DIRT- dynamic infrared thermography
The emergence of the perforator through the fascia, as identified by CDU, was confirmed in 97.42% of cases during surgery. The mean duration of CDU mapping was 39.76 minutes (1.83 minutes average time necessary for each individual perforator analysis) and for DIRT mapping 10.24 minutes (mean difference between the two techniques: 27.69 minutes, \(t = -2.11, p \leq 0.05\)).

Superimposition of the images acquired during CDU and DIRT showed that the positions of “hot spots” on the skin were located within a mean radius of 0.9 cm (N=192) from the point where the perforator was observed to pierce the fascia.

The dominant perforator identified by both CDU and DIRT correlated with surgical findings in all cases.

Discussions

The ability to harvest any flap based solely on its cutaneous perforator, has transformed reconstructive surgery. The virtually infinite number of potential donor sites, with a highly variable vascular anatomy, requires preoperative visualization and mapping of perforators [13]. Preoperative perforator mapping optimizes flap design, reduces operating time and has become standard in certain areas of reconstructive surgery, such as breast reconstruction [5,14-19].

The currently available imaging techniques employed for preoperative mapping are handheld Doppler, CDU, CTA, and Magnetic Resonance Angiography. CTA is currently considered the “gold standard”, and has replaced color Doppler ultrasound in many institutions [20,21]. CTA has been shown to be accurate in demonstrating the location, size, and course of perforators as small as 0.3 mm and it has the ability to create 3-D reconstructions that can be easily interpreted by the surgeon [17]. However, the technique has some major disadvantages. It requires a separate hospital visit, administration of intravenous contrast, exposure to radiation, and cannot be used in patients with renal impairment or severe claustrophobia [18]. The high cost associated with the procedure limit its availability in many centers. CTA does not provide any information regarding tissue perfusion or vessel flow [22]. Often it fails to identify the dominant perforator because it does not account for both arterial and venous components of the perforator bundle [23]. Furthermore, CTA is unable to provide specific information regarding perforator location and course in regions with very thin adipose tissue (<8mm) [24].

CDU remains a safer, less expensive, and highly available alternative. It requires no intravenous contrast, and no radiation exposure. Unlike static imaging techniques such as CTA and MRI, CDU can provide dynamic information regarding vessel flow, damage caused by atherosclerosis, or blood vessel disorders [25]. Data obtained in our study confirms that CDU is highly sensitive, over 93%, when used for preoperative perforator mapping. These findings correlate well with other published data [26,27], showing the high level of reproducibility among various studies.

Preoperative imaging is an imperfect technique, particularly because the live surgical field changes as the surgery develops [28]. The need for systems that provide dynamic, real-time, intraoperative information about vessel location, perfusion patterns and flap physiology [29], has been addressed by the recent introduction of DIRT. DIRT implies using an infrared camera, which generates a color-coded map based on heat emitted by tissues. It is a safe, noninvasive procedure and has no contraindications. In current clinical practice DIRT is used to map perforators, optimize flap design, assess blood flow and evaluate Anastomosis patency [30]. The speed and progression of rewarming at the “hot spot” provides information regarding the caliber of the perforator and its surrounding vascular network [31]. Although our results show that DIRT has a lower sensitivity than CDU, it correctly identified the dominant perforator in all cases.

The precise mapping of all perforators is far less important than correctly identifying the dominant one [32]. The dominant perforator is the one selected in the vast majority of reconstructive cases, as it provides the best chance for flap survival [4]. If the ideal perforator is correctly identified preoperatively, the surgeon can sacrifice all other perforators, proceeding directly to the dominant one, significantly reducing operative time [7]. A shorter operative time lowers the risk of complications and the overall procedure cost [21].

The main drawbacks associated with CDU are the long examination time and the need for an experienced operator, which possesses detailed knowledge of perforator anatomy [33]. DIRT is a simple procedure, and does not require any experience. The examination time is very short, guaranteeing high patient compliance.

Both CDU and DIRT are currently used for perforator mapping. Our results show that DIRT has a lower positive predictive value than CDU and produces more false positive results, attributable to perforator branching at skin level. The position of “hot spots” was situated laterally to the fascial emergence of the perforators identified during surgery. The fascial emergence of perforators with a vertical trajectory appeared to align better with the visualization of “hot spots”, while oblique perforators were observed laterally during DIRT. Both methods correctly identified the dominant perforator in all cases.

Our results indicate that the time required to successfully identify a dominant perforator were significantly less using
the combined DIRT + CDU method, rather than CDU alone in our sample of 10 pigs. Using this combined approach, shorter examination times can be achieved while increasing patient compliance and lowering overall cost. DIRT can be used initially to identify the dominant perforator, which can then be confirmed and evaluated by CDU. CDU can also identify the point where the perforator emerges from the fascia and its arterial and venous characteristics.

One limitation of this study is the oversight of inter-operator variability. The same operator was used for all examinations. Another drawback is related to the research design that was limited to a sample of 10 pigs. While this offers highly valuable insight on the method’s potential, it can only provide descriptive empirical conclusions. For prevalence adjusted statistics and population level conclusions a larger study is required. Moreover, due to the nature of CDU and DIRT the specificity could not be calculated, in the absence of true negative examination outcomes. DIRT cannot establish which blood vessels are certainly not perforators because the technique is based on the observation of “hot spots” that are subsequently inferred to indicate the position of a dominant perforator. Hence, DIRT does not allow an exhaustive mapping of all blood vessels, rendering the calculation of specificity and negative predictive values impossible.

Conclusions

Preoperative perforator mapping has become a compulsory step in nearly every reconstructive procedure. In our study, all the dominant perforators identified by CDU and DIRT were confirmed at surgery. By combining the two examinations the overall mapping time can be significantly reduced. A reduced examination time translates in increased patient compliance and a lower procedure cost. The combined mapping technique facilitates the selection of the ideal perforator in all cases. Correctly identifying the dominant perforator preoperatively reduces operative time, lowers complication rates and ensures an overall better result.

Acknowledgement

The study was partially funded by the POSDRU 159/1.5/s/138776 grant.

Conflict of interest: none

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