Research Article

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Dynamic infrared thermography aiding in flaps

Abstract

Background: The selection of the best vessels is of utmost importance in reconstruction surgeries. This will reduce operative time, decrease complication rates, and ensure a better overall result. It is observed that dynamic infrared thermography (DIRT) has been increasingly used in reconstructive microsurgery to evaluate flap viability and locate perforators. DIRT measures the rate and patterns of rewarming after cooling. The sensor detects heat irradiation and forms a thermogram where the temperature of each spot can be recognized. This article aims to conduct a systematic review of the clinical applications of DIRT imaging in plastic surgery.

Methods: The search was performed in MEDLINE, LILACS, Cochrane, and Scielo databases using the following terms: "thermography", "thermometry", "surgical flaps", "reconstructive surgical procedures" and "microsurgery". Articles published from January 2006 to October 2021 were included. The primary search provided 115 matches in MEDLINE, 0 in LILACS, 6 in Cochrane, and 0 in Scielo. After removing duplicates, 115 articles were considered.

Results: After reading the titles and abstracts and removing duplicates, a total of 38 publications were found. These were read in full and evaluated against the inclusion and exclusion criteria. After full reading and analysis, a total of 25 publications met the inclusion criteria.

Conclusion: The use of DIRT shows promise for flap monitoring in reconstructions in Plastic Surgery.

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Introduction

For centuries, human body temperature has been measured through the skin to assess the physiological state of an individual,[1] and today it is one of the most widely used forms of clinical assessment in contemporary health care.[2] In environments with a stable temperature between 18 and 25 degrees Celsius (°C), the main way the human body enters into equilibrium with the external environment is through heat loss by electromagnetic waves. This energy is emitted mainly in the form of infrared radiation by the skin.[3]

Through the bloodstream, heat is transferred to the skin surface and emitted as infrared radiation.[4,5] The amount of emitted radiation results in incremental changes in skin temperature that can be differentiated using a color spectrum recorded by a thermogram.[4,6] Thus, measurement of this emitted energy can provide indirect information about skin perfusion.[7,8] This assessment becomes essential in flap reconstruction surgeries, in which flap perfusion and reperfusion are critical to the success of the procedure.

In flap reconstruction surgeries, the selected perfusion vessel is the only source of blood supply for the flap. The selection of the best vessels is of utmost importance in this procedure. This will reduce operative time, decrease complication rates, and ensure a better overall result. There are several methods to locate perforators: computed tomography angiography (CTA), Doppler ultrasound (CDU), magnetic resonance angiography (MRA), or dynamic infrared thermography (DIRT).[4,9,10] The current gold standard for this selection is CTA, in which the location and hemodynamic properties of the flaps can be reviewed.[9,11-13] This technique is often used because it is non-invasive and has a high spatial resolution, with visualization of the intramuscular course of vessels even as small as 0.3 mm.

Because it uses no radiation and no contrast agents, DIRT becomes less invasive, providing a rapidly obtainable image that is available pre-, intra-, and postoperatively. DIRT is relatively easy to interpret and has a low purchase cost. On the other hand, this technique only provides information about the physiology of the perforator and not the morphology. This means that the surgeon must have a thorough knowledge of vascular anatomy to interpret the results.[5]

It is observed that DIRT has been increasingly used in reconstructive microsurgery to evaluate flap viability and locate perforators.[14-16] In this technique, the skin must be subjected to a cold thermal challenge. DIRT measures the rate and patterns of rewarming after cooling. The sensor detects heat irradiation and forms a thermogram where the temperature of each spot can be recognized. The hotspots are defined as the regions of highest temperature in the thermogram and also represent areas with relatively more intense blood flow.[17] This procedure allows the dominant perforators and the area they perfuse to be identified.[18,19]

Flap failure in reconstructions is often due to technical failures during dissection of the perforator, failure of the anastomosis, or twisting or compression of the pedicle during flap insertion and shaping. These technical errors occur regardless of the surgeon's experience. Clinical monitoring of flaps is based on skin color and turgor, dermal border bleeding, and capillary filling. Such methods depend on the evaluator and are related to experience. In the intraoperative and postoperative periods, infrared thermography can also be a valuable monitoring tool.[20] This article aims to conduct a systematic review of the clinical applications of DIRT imaging in plastic surgery.

Methods

The search was performed in MEDLINE, LILACS, Cochrane, and Scielo databases using the following terms: "thermography", "thermometry", "surgical flaps", "reconstructive surgical procedures" and "microsurgery". The search was initially performed with the combination of the terms "thermography" and "thermometry" and, subsequently, with these terms plus the term "surgical flaps", the term "reconstructive surgical procedures", and the term "microsurgery", in separate searches, both connected by the Boolean AND. In the LILACS, Cochrane and Scielo databases, the same terms were used for the search in Portuguese: "termografia", "termometria", "retalhos cirúrgicos", "procedimentos cirúrgicos reconstrutivos" and "microcirurgia" and in Spanish: "Termografía", "Termometría", "Colgajos Quirúrgicos", "Procedimientos Quirúrgicos Reconstructivos" e "Microcirurgia".

Articles published from January 2006 to October 2021 were included. The primary search provided 115 matches in MEDLINE, 0 in LILACS, 6 in Cochrane, and 0 in Scielo. After removing duplicates, 115 articles were considered.

A reader reviewed the selected articles. All conflicting articles were discussed with two other independent readers until mutual agreement was found. 8 articles were immediately discarded based on languages (Mandarin, Japanese, Russian, German). In addition, 77 articles were excluded based on title and abstract.

The criteria used for the title and abstract inclusion were:

a. The article must contain the use of thermography in humans;
b. The included patients undergo flap reconstruction surgery;
c. The full text of the article be written in English, Portuguese, or Spanish.

If one of these criteria was not met, the study was not included. 38 abstracts met all criteria and were accepted for further review.

The electronic search using the criteria described revealed 121 articles. After reading the titles and abstracts and removing duplicates, a total of 38 publications were found. These were read in full and evaluated against the inclusion and exclusion criteria (Figure 1). After full reading and analysis, a total of 25 publications met the inclusion criteria.

Results

Use of dynamic infrared thermography (DIRT) in the evaluation and mapping of perforators in breast reconstructive surgeries

After reviewing the literature, 13 publications were analyzed. These included seven prospective studies, one systematic review, three case reports, one narrative review, and one pilot study. All of these studies use a similar type of digital infrared thermographic (DIRT) camera and analytical software, as described in Table 1.

De Weerd et al.,[21] used DIRT to monitor intraoperative reperfusion of 10 flaps in breast reconstruction surgery. They used fasciocutaneous flaps free of superficial inferior epigastric artery perforator (SIEP) or deep inferior epigastric artery perforator (DIEP). A comparison of the preoperative digital images with those obtained immediately before clamp release showed, in all cases, that the skin temperature of the lower abdominal flap dropped dramatically when not perfused. Six flaps showed a rapid appearance of a hotspot after clamp release, followed by more hotspots and an overall rewarming of the flap. Therefore, it was found that, although more research is needed, DIRT appears to be a valuable method for intraoperative flap monitoring.

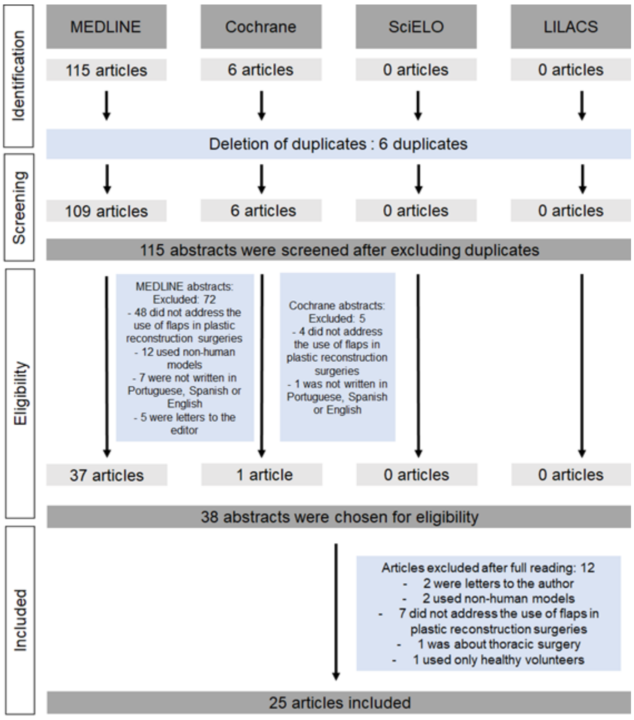

Figure 1 Literature review and flow of the selected articles.

Table 1 Articles reporting the use of dynamic infrared thermography in breast reconstructive surgery

Author, year of publication and Journal	Study modality	Participants	Modality of DIRT/ Software	Main considerations
De Weerd (2006)[21] Annals of Plastic Surgery	Prospective uncontrolled clinical study	N = 10 patients scheduled for secondary breast reconstruction with DIEP or SIEP flaps	Nikon Laird S270 ® / PicWin-IRIS ®	Although further research is necessary, dynamic IR thermography appears to be a valuable method for intraoperative monitoring of free tissue transfer.
Kalra (2007)[22] British Association of Plastic, Reconstructive and Aesthetic Surgeons	Case reports	N = 2 mastectomized patients scheduled for secondary breast reconstruction with DIEP flaps	Thermo TracerTM TH7102MV ®/MiKroSpec R/T TM and MikroSpec 2.9 TM ®	Thermobiological imaging can be a useful adjunct in the operating theatre as a tool to guide flap selection.
De Weerd (2009)[23] Annals of Plastic Surgery	Prospective uncontrolled clinical study	N = 20 patients scheduled for secondary autologous breast reconstruction with DIEP or SIEP flaps	Nikon Laird S270; FLIR ThermaCam S65 HS ®/ PicWin-IRIS; ThermaCam Researcher Pro 2.8 SR-1 ®	There is a stepwise progression of perfusion that proceedsfaster at the level of the subdermal plexus than at the subcutaneouslayer. For both flap types, the choke vessels at the midline form azone of larger resistance for circulation than the choke vesselsbetween the ipsilateral zones.

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Table Continued...

Author, year of publication and Journal	Study modality	Participants	Modality of DIRT/ Software	Main considerations
De Wereerd (2011)[5] Clinics in Plastic Surgery	Narrative review	Not applicable	Not applicable	DIRT provides information only on the physiology of the perforator and not on its morphology. It is therefore importante that the surgeon has a thorough knowledge on the flaps vascular anatomy and physiology When interpreting the results obtained from DIRT.
Tenorio (2011)[13] Annals of Plastic Surgery	Prospective uncontrolled clinical study	N = 10 patients scheduled for breast reconstruction with DIEP flap and N = 6 patients undergoing reconstruction of the mandible with a composite fibular flap	BioScan IR system ® /DIRI software ®	Although a limited number of patients have been included in this study, a potential application of DIRI in the preoperative planning of a reconstructive procedure using perforator free flaps has been successfully demonstrated.
Whitaker (2011)[35] British Association of Plastic, Reconstructive and Aesthetic Surgeons	Case report	N = 1 patient scheduled for breast reconstruction with DIEP flap	Thermo Tracer TH 7800, NEC Avio Infrared Technologies, Tokyo ® / Unquoted	DIRT allowed the authors to non-invasively assess the vasculature, plan surgery, and prepare the patient for a modified operation.
Weum (2016)[11] BMC Medicam Imaging	Prospective uncontrolled clinical study	N = 25 patients scheduled for breast reconstruction with DIEP flap	FLIR ThermaCAM S65 HS ® /Unquoted	This study confirms that perforators selected with DIRT have arterial Doppler sound, are clearly visible onCTA and provide adequate perfusion for DIEP breast reconstruction.
Hardwicke (2016)[25] Journal of the American Society of Plastic Surgeons	Case report	N=1 patient scheduled for mastectomy followed by breast reconstruction with DIEP flap	FLIR ONE ®/FLIR ONE application®	Preoperative, intraoperative, and postoperative ther-mograms can assist in the planning, execution, and monitoring of free flaps, and the FLIR ONE provides a low-cost adjunct that could be applied to other areas of burns and plastic surgery.
Kolacz (2017)[26] Journal of Surgical Research	Prospective uncontrolled clinical study	N=38 patients scheduled for breast reconstruction (N=10 with ipsilateral TRAM flap; N=10 with contralateral TRAM flap and N=18 with supercharged TRAM flap)	FLIR A320G ®/Unquoted	Cold stress and dynamic thermography can be a helpful additional tool to assess and monitor the blood supply to the flap skin both intraoperatively and postoperatively.
Thiessen (2019)[18] European Journal of Obstetrics and amp; Gynecology and Reproductive Biology	Systematic review	6 descriptive clinical studies, 3 case reports, 3 expert opinions/overview articles, and 2 systematic reviews	Not applicable	The data in the studies suggest that the use of DIRT is an additional tool that improves the results of free flap breast reconstructions and on top of that the examination is cheap, not invasive and does not harm the patient.
Thiessen (2020)[20] European Journal of Obstetrics & Gynecology and Reproductive Biology	Prospective uncontrolled clinical study	N=21 patients scheduled for breast reconstruction with DIEP flap	Unquoted	This feasibility study shows that DIRT is a promising technique for selecting perforators and monitoring flap perfusion, used during all phases of breast reconstructions with one standardized measurement setup.
Verstockt (2020)[27] Optical Society of America	Pilot study	N=1 patient scheduled for breast reconstruction with DIEP flap	Xenics Gobi 640 microbolometer 640-480 ® /Xeneth64 ®	Infrared thermography offers extra information on the location of theperforators and its vascularization pattern
Phillips (2021)[28] Plastic Surgery Research Council	Prospective uncontrolled clinical study	N=19 patients scheduled for breast reconstruction with DIEP flap	FLIR ONE device, iPhone 7 ® /FLIR software ®	Thermal imaging recognizes microanastomotic failure and is a practical adjunct in theevaluation of free flap perfusion.

Kalra et al.,[22] reported the cases of two patients mastectomized for invasive breast cancer who had breast reconstructions with DIEP flaps. A thermography engineer performed image capture during and immediately after surgery. The researchers successfully identified four main perforators supplying the flap - the lateral perforator, the intermediate perforator, the medial perforator, and the superomedial perforator. The lateral perforator was found to be the dominant perforator for this flap. The authors emphasized that thermobiological imaging technology has improved remarkably in the preceding years. This study attested that DIRT can be a useful tool in the operating room to guide flap selection.

In 2009, De Weerd et al.,[23] used DIRT to detect perforators in abdominal free flaps. A total of 20 patients were scheduled for secondary autologous breast reconstruction with DIEP or SIEP flaps. The perfusion dynamics of 16 DIEP flaps and four SIEP flaps were studied during the first, third, and sixth postoperative days using DIRT. Analysis of the images revealed individual variations in skin surface temperature. There was, however, clear reproducibility in the rate and pattern of rewarming for both flap types. It was found that there is a gradual progression of perfusion, which occurs more rapidly at the subdermal level than at the subcutaneous level. De Weerd et al., in 2011[5], also published an article illustrating how DIRT can provide the plastic surgeon with valuable information in breast reconstruction surgeries with DIEP flaps.

Tenorio et al.,[13] conducted a study comparing DIRT with portable Doppler in 16 patients undergoing reconstruction with a perforator flap. Ten of these patients underwent breast reconstruction with DIEP flap, while the other six patients underwent jaw reconstruction with compound fibular flap. The researchers found that the location of the perforators coincided at a distance of 0-15 millimeters (mm) in 67% of the cases. It was shown that while Doppler localized the perforators at a deeper level, where they exited the muscle fascia, thermography detected their location under the skin, and therefore both techniques complemented each other.

In 2011, Whitaker et al.[24] described the use of thermography in the surgical planning of a bilateral DIEP flap breast reconstruction compared with computed tomography angiography (CTA). Preoperative CTA showed a single adequate perforator supplying the right hemiabdome, with a diameter of 2 mm. The other perforators appeared insufficient to supply the flap. After ten minutes of a cold challenge using a 5°C water pack, thermal imaging showed the presence of a hotspot, confirming the presence of the dominant perforator on the right. Given the results of these tests, surgical planning was changed to a unilateral DIEP flap based on the right hemiabdome. This case exemplifies the need for more research on DIRT in preoperative imaging of the abdominal wall.

Weum et al.,[11] evaluated the use of DIRT as an alternative to CTA for perforator mapping in breast reconstructions. Twenty-five patients were scheduled for breast reconstruction with a DIEP flap. Preoperatively, the lower abdomen was examined with manual Doppler, DIRT, and CTA. The locations of the hotspots on DIRT were compared with the locations of the doppler sounds. The first hotspots that appeared were associated with sounds on Doppler arterial and perforating sounds visible on CTA. The hotspots on DIRT images were located laterally concerning the exit points of the associated perforators on CTA, and some periumbilical perforators were not related to hotspots. This study confirmed that the selected perforators with DIRT have Doppler sounds, are visible on CTA, and provide adequate perfusion for breast reconstruction with DIEP flaps.

To enable accurate excision of non-perfused or poorly perfused tissue, Hardwicke et al.,[25] used DIRT during the intraoperative period of right breast reconstruction with DIEP flap. Postoperatively, thermal imaging was also used as an adjunct to clinical monitoring of the flap. The patient progressed uneventfully and was discharged from the hospital on postoperative day 6.

Kolacz et al.,[26] evaluated 38 patients who underwent 10 breast reconstructive surgeries with ipsilateral transverse rectus abdominis myocutaneous (TRAM) flap, 10 patients with contralateral TRAM flap, and 18 patients with supercharged TRAM flap. In each operated patient, thermographic examinations were performed before surgery, after flap dissection, immediately after flap suturing, and during day 1 and day 7 after surgery. The collected data were processed to mathematically reproduce the results and to be compared with the clinical evaluation.

To evaluate the possible benefit of DIRT in breast reconstructions with DIEP flap, Thiessen et al.,[18] performed a systematic literature review with publications from January 1998 to November 2018. The search resulted in a total of 14 suitable articles: six descriptive clinical studies, three case reports, three expert opinion/overview articles, and two systematic reviews. It was realized that with the use of DIRT, it is possible to identify the dominant vessels preoperatively. The use of DIRT during the procedure allows for the adaptation of the surgery while postoperative use can identify vascularization problems at an early stage. Further studies are needed, but DIRT appeared to be a valuable tool for the pre, intra, and postoperative phases of DIEP flap reconstructions.

In 2020, Thiessen et al.[20] published a prospective clinical study to evaluate the use of DIRT in all phases of DIEP flap breast reconstructions. Before surgery, the 21 patients underwent a CTA to determine the location and intramuscular course of the perforators. Preoperatively, DIRT confirmed the location of the 69 perforators shown on the CTA. Intraoperatively, after dissection of the perforators, a cold challenge was performed to verify the patency of the dissected vessels. A total of 45 perforators were successfully dissected. The positioning of the dissected vessels was clinically associated with the location of the hotspots. Two flaps were successfully monitored postoperatively. This study showed that DIRT is a promising technique for perforator selection and flap perfusion monitoring.

To perform an investigation regarding the use of DIRT to select the most suitable perforators, Verstockt et al.,[27] performed a breast reconstruction using a DIEP flap. In this pilot study, measurements with external cooling were performed preoperatively to accurately predict the location of the dominant perforators. During the procedure, measurements were taken to map the influence of a specific perforator on the perfused areas of the abdominal flap. The perforators were sequentially closed and opened again to map the influence of that vessel on the vascularity of the flap. The thermal images obtained could help to decide which parts of the abdominal flap to use for reconstruction so that the chance of complications is reduced. In the postoperative stage, DIRT could visualize arterial and/or venous thrombosis before they become clinically evident.

In a prospective clinical study, Phillips et al.,[28] subjected 19 patients to 30 DIEP flaps for breast reconstruction. Thermographic images were obtained at all operative times (pre, intra, and post), particularly in cases of concern about flap viability or before any surgical re-exploration. Three groups were evaluated: normal DIEP flaps (FDN), flaps with arterial insufficiency (AI) and flaps with venous congestion (VC). With questionable flap viability, the temperatures of flaps with VC and AI were significantly cooler than the group with FDN. In these cases, DIRT was able to recognize microanastomotic failures and was shown to be a practical adjunct in assessing flap perfusion.

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Use of dynamic infrared thermography (DIRT) in the evaluation and mapping of perforators in lower limb reconstructive surgeries

After reviewing the literature, four publications were analyzed. These included four prospective studies. All of these studies use a similar type of digital infrared thermographic (DIRT) camera and analytical software, as described in Table 2.

Chen and Huang et al.,[14] evaluated the use of DIRT in 20 patients scheduled for fibular flap reconstruction after ablative surgery. Initially, the lower limbs were evaluated with a smartphone-compatible thermographic camera. During rewarming, hotspots were marked, and then patients were referred for CTA. In the donor limbs, the presence and location of skin perforators were identified during flap elevation and compared with preoperative findings. DIRT detected 42 of the 57 dominant perforators in 24 limbs, resulting in a sensitivity of 73.7% and a positive predictive value of 65.6%. For the low values found, smartphone-based DIRT could be used as an adjunctive tool in conjunction with other established imaging techniques.

Table 2 Articles reporting the use of dynamic infrared thermography in lower limb reconstructive surgery

Author, year of publication and Journal	Study modality	Participants	Modality of DIRT/Software	Main considerations
Chen and Huang (2019)[14] Head & Neck - Wiley Periodicals	Prospective uncontrolled clinical study	N=20 patients scheduled for fibular flap reconstruction	FLIR ONE PRO ®/FLIR Systems ®	The sensitivity and positive predictive value of the smartphone-based DIRT are low.
Afzal (2020)[29] Journal Of Ayub Medical College Abbottabad	Prospective uncontrolled clinical study	N=15 patients scheduled for lower limb reconstruction with a pedicled fasciocutaneous or musculocutaneous flap	FLIR ONE ® /Unquoted	Dynamic thermal imaging can be reliably used alone in planning of pedicled perforator flaps for lower limb reconstruction
Hallock (2020)[30] International Journal of the Care of the Injured	Prospective uncontrolled clinical study	N=10 patients considered for keystone flaps to avoid skin grafts or free flaps	FLIR ONE PRO ® / Unquoted	Thermal imaging provides a safe method for checking not only flap circulation, but also identification of "coldspots" or flap regions where means to augment advancement by deep fascia interruption or undermining will not interfere with flap perfusion.
Xiao (2020)[10] Annals of Plastic Surgery	Prospective uncontrolled clinical study	N=20 patients scheduled for free or pedicled ALT flaps	FOTRIC® 228s ® / Unquoted	Compared with CDU, infrared thermography can be used to locateperforators, in this case, the ALT perforators, with a high degree of consistency.

Afzal et al.,[29] also evaluated the utility of smartphone-compatible DIRT in detecting perforators in patients requiring fasciocutaneous or pedicled musculocutaneous flap for lower limb reconstruction. Thermal imaging and Doppler imaging were used to map the most appropriate perforators, which were confirmed intraoperatively. The ability to locate dominant perforators and the total time required was compared with portable doppler. The study included 15 patients, in whom 22 of 23 dominant perforators located with DIRT were confirmed intraoperatively (positive predictive value=95.7%) compared with 22 of 32 with doppler (positive predictive value=68.8%). The mean time required with DIRT was 598.47±192.94 compared to 591.27±252.48 seconds with a doppler. DIRT appeared to be more reliable in planning pedicled flaps for lower limb reconstruction compared to doppler.

Hallock[30] used a thermal camera attached to a smartphone to evaluate perforators in 10 patients considered for keystone flaps in the lower limb. All patients underwent a cold challenge followed by thermal recovery recorded by thermography to determine the location of hotspots, as well as their absence or cold spots. In one patient, inadequate hotspots were found in all adjacent donor regions that could have allowed for a keystone flap. Instead, a skin graft was more safely performed. The other nine patients underwent 10 flaps. Intraoperative thermographic images predicted 100% survival for nine flaps and marginal ischemia for 1 flap, being a correct assessment in all cases. Dehiscence occurred in the last flap, which healed by the second intention, while the remaining flaps healed uneventfully. The use of smartphones for thermography appeared to be a simple and fast means of evaluating the viability of keystone flaps in all surgical phases.

Xiao et al.,[10] conducted a prospective study aimed at comparing the application of doppler ultrasound and DIRT in preoperative perforator mapping in anterolateral thigh flap (ALT). Doppler and DIRT were applied in 20 patients to locate perforators originating from the lateral circumflex femoral artery preoperatively. The perforators identified in each modality were marked in the anterolateral region of the thigh. Fifty-three perforators were detected by doppler and 51 hotspots were identified by DIRT, where 50 hotspots matched the doppler, and the consistency test showed that the κ index was 0.712 ($P < 0.05$). DIRT showed a sensitivity of 94.3% and a specificity of 85.7% compared to doppler. Pearson's correlation coefficient was 0.84. Forty-four doppler-marked perforators were selected for flap design. The anatomical findings showed that the accuracy rate of doppler and DIRT was 93.2% (41 of 44) and 86.3% (38 of 44), respectively. There was no statistical difference ($P > 0.05$).

Use of dynamic infrared thermography (DIRT) in the evaluation and mapping of perforators in reconstructive head and neck surgery

After reviewing the literature, four publications were analyzed. These included one prospective study, two case reports, and one proof-of-concept study. All of these studies use a similar type of digital infrared thermographic (DIRT) camera and analytical software, as described in Table 3.

Table 3 Articles reporting the use of dynamic infrared thermography in head and neck reconstructive surgery

Author, year of publication and Journal	Study modality	Participants	Modality of DIRT / Software	Main considerations
Romansky (2019)[31] Journal of Neurological Surgery Part A	Case report	N=1 patient scheduled for reconstruction of the parietal region of the skull with a latissimus dorsi free myocutaneous flap.	Gobi384GigE ® / Unquoted	DIRT monitoring could add significant information to standard clinical observation in the field of plastic microsurgery.
Meyer (2020)[32] Head & Neck	Prospective uncontrolled clinical study	N=21 patients scheduled for head and neck reconstruction with microvascular free flap	FLIR ONE ® / FLIR ONE mobile application	Low cost, mobile smartphone devices such as the thermal camera may provide an objective method of monitoring microvascular free flaps.
Shokri (2021)[32] Head and Neck Medicine and Surgery.	Prospective uncontrolled clinical study	N=4 patients scheduled for pedicle reconstruction or free head and neck flap	FLIR ONE system ® / ThermaCAM Researcher Pro 2.8 SR-1 ®	Smartphone compatible thermal cameras may be used as an adjunct to clinical exam, as well as Other monitoring technologies,providing further information in not Only selection of perforators,in the operative setting, but also in the early detection of poor flap viability secondary to microvascular compromisse allowing for timely salvage.
Lutz (2021)[34] Plastic and Reconstructive Surgery - Global Open	Case report	N=1 patient scheduled for microvascular reconstruction of the face with a radial forearm flap	FLIR ONE PRO ® / Unquoted	DIRT is an especially useful tool in flap monitoring of the clinically non-assessable skin of the elderly patient.

Romansky et al.,[31] published the case of a 49-year-old patient with recurrent fibrosarcoma of the skin in the parietal skull region. Elective surgical intervention was performed with radical removal of the tumor, restoration of the bony structures with a titanium plate, and coverage of the defect with a free large dorsal myocutaneous flap. DIRT was used intraoperatively and postoperatively to verify revascularization at the intervention site. This case showed that DIRT can add significant information to standard clinical observation in the field of plastic microsurgery.

Meyer et al.,[32] evaluated the use of DIRT before, during, and after anastomosis in head and neck reconstructions with a microvascular free flap. Twenty-one patients were included, 15 male (71.4%) and 6 female (28.6%), with a mean age of 61 years. Most procedures were performed after surgical resection of a malignant neoplasm, most commonly squamous cell carcinoma (52.4%). The most commonly performed flap was the fibula (52.4%), followed by the anterolateral thigh (23.8%), scapula (14.3%), and forearm (9.5%). To eliminate confounding factors, the temperature difference (dT) between the flap surface and the normal surrounding tissue was calculated. The average dT for flaps intraoperatively before anastomosis was -11.47°F. For 20 patients, dT averaged between -0.30 and 0.12°F. One flap was inadequately perfused and the dT was -4.35°F.

In a proof-of-concept study, Shokri et al.,[33] evaluated the utility of DIRT in delineating angiosomes and monitoring tissue perfusion preoperatively, intraoperatively, and postoperatively. This technology was compared with indocyanine green fluorescence angiography (ICG-FA). Four patients undergoing pedicled or free flap reconstruction of the head and neck were selected. The study showed that in addition to the reproducibility of perfusion readings with the ICG-FA system, the use of DIRT successfully detected early vascular congestion in a free antebrachial flap, allowing successful salvage.

This indicates that infrared thermographic cameras can assess tissue perfusion in reconstructive procedures both in the preoperative mapping of the vascular pedicle and as an adjunct to clinical examination in postoperative monitoring of flap viability. Lutz et al.,[34] published the case of a 90-year-old woman who presented with an extensive squamous cell carcinoma in the right zygomatic and lateral orbital region. Next to the tumor, portions of the zygomatic bone, the lateral wall of the orbit, and the floor of the orbit were resected. The antebrachial flap was raised and anastomosis to the facial artery and vein and the external jugular vein was performed.

Thermographic images were obtained before the antebrachial flap lifting, intraoperatively and postoperatively. During flap elevation, the transplant temperature dropped from 32.7°C to 23.0°C. After

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reanastomosis of the flap to the recipient site, the temperature rose again but remained about 5°C below the initial temperature. During the use of DIRT for follow-up, the flap developed signs of hyperperfusion with temperatures up to 3°C above the initial temperature of the donor area, which may be explained by the higher blood flow and pressure in the external carotid branches relative to the peripheral forearm arteries.

Use of dynamic infrared thermography (DIRT) in the evaluation and mapping of perforators in reconstructive surgery - a miscellany

After reviewing the literature, four publications were analyzed. These included two case reports and two systematic reviews. All of these studies did not fit the other topics of this paper Table 4. Chubb et al.,[35] reported their experiences with DIRT in relation to CTA. The researchers performed CTA of a patient's abdominal wall vasculature, highlighting the location of the deep perforators of the inferior epigastric artery. Soon after, DIRT was used on the same patient, demonstrating agreement in the location of the perforators. It was found that the radiation emitted by the perforating arteries can highlight their locations and serve to map them in operative planning.

Yamamoto et al.,[36] published the result of postoperative monitoring with portable thermography of a perforating thoracodorsal artery flap. A large dorsal myocutaneous flap was transferred to the anterior chest region to cover the exposed costal bones. Thermographic imaging revealed that the temperature of the tip of the flap was lower than that of the central region. On a postoperative day 7, the flap tip became necrotic in the exact same region that showed low temperature on thermography.

Table 4 Other articles reporting the use of dynamic infrared thermography in reconstructive surgery

Author, year of publication and Journal	Study modality	Participants	Modality of DIRT / Software	Main considerations
Chubb (2011)[36] Annals of Plastic Surgery	Case report	N=1 patient	Unquoted	DIRT matches the accuracy for perforator localization of CTA.
Yamamoto (2012)[36] JPRAS	Case report	N=1 patient scheduled for latissimus dorsi myocutaneous flap transferred to the anterior region of the chest	Thermo Shot F30S ® / Unquoted	A handy thermography has a potential to be a useful accessory evaluation tool for flap circulation.
Lohman (2015)[37] Annals of Plastic Surgery	Systematic review	N=4 articles involving more than 5 flaps from 2 different main authors on intraoperative DIRT	Not applicable	DIRT was the least sensitive of the 3 methods evaluated for predicting overall complications, but it was 100% sensitive for anastomotic problems. With intraoperative DIRT, the rate of re-exploration was 0%, but 12.1% of all flaps were complicated by some degree of necrosis.
Smit (2018)[38] Microsurgery © Wiley Periodicals, LLC	Systematic review	N=2 articles on 26 flaps in 26 patients on DIRT	Not applicable	Although IRT seemed to provide valuable information on flap perfusion, measurements were easily influenced by internal factors as body temperature and external factors as room temperature.

Lohman et al.,[37] conducted a literature review on the techniques used for intraoperative flap evaluation. The authors discussed ICG, DIRT, and photo spectrometry to better define the sensitivity, specificity, expected outcomes, and possible complications associated with these techniques. Only studies that included at least 5 flaps were used for the analysis. The 95% confidence intervals for the statistics were calculated by the efficient scoring method with continuity correction. There were four articles involving more than five flaps on intraoperative DIRT. A total of 65 patients scheduled for breast reconstruction with TRAM, DIEP, or SIEP flaps were evaluated, and no complications specifically caused by DIRT were identified. The sensitivity of DIRT was 33% (95% CI: 11.3-64.6), specificity was 100% (95% CI: 84.8-100), and accuracy was 80% (95% CI: 71.2-89.7).

Smit et al.,[38] performed a systematic review with the aim of providing an overview of available methods for assessing tissue perfusion of free flaps intraoperatively. Sixty-four articles reporting 2369 procedures in 2009 patients were included. The methods reported were fluorescence imaging (FI), laser Doppler, oxygen saturation, ultrasound, DIRT, venous pressure, and microdialysis. DIRT was reported in two articles on 26 flaps in 26 patients. Although DIRT seemed to provide valuable information about flap perfusion, the measurements were easily influenced by internal factors, such as body temperature, and external factors, such as ambient temperature.

Discussion

During the planning of flap reconstructions, the selection and identification of a suitable perforator are necessary. Commonly used imaging techniques, such as computed tomography angiography (CTA) and indocyanine green angiography, expose the patient to radiation or contrast agents.[4,9,10] The trend is toward the use of a noninvasive, inexpensive, sensitive, and accurate tool with minimal or no adverse effects, such as dynamic infrared thermography (DIRT).[14-16]

Preoperative flap planning with imaging tools is an imperfect technique, since the operative field changes as the surgery unfolds.[39]

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The need for systems that provide dynamic, real-time information on perfusion patterns of the perforators has been addressed by the introduction of DIRT. According to the results reported by Muntean et al.[4], although DIRT has a lower positive predictive value than Doppler ultrasound (CDU), the time required to identify a dominant perforator is shorter when using the combined DIRT + CDU method. In contrast, the results obtained in our review showed a good correlation of DIRT findings with CTA.[11,14,20,24,35] These disagreements may have occurred because, while CDU locates the perforators at a deeper level, where they exit the muscle fascia, DIRT detects their locations under the skin.[18]

During surgical planning, the dissection with the lowest probability of complications seems to be associated with perforators with a perpendicular penetration pattern in the fascia and short intramuscular pathway.[19] Perforators located at tendon intersections have these characteristics and are reported to be larger than average, which may increase their quality.[40] These perforators are easily identified with DIRT, as the short, straight course facilitates rapid rewarming of the skin, causing an early hotspot, as demonstrated by Hennessy et al.[19]

In comparison to CTA, Chubb et al.,[35] reported in their preliminary results that the location of perforators with DIRT accurately matched the locations found with CTA. However, in a more recent study, Weum et al.,[11] showed that the hotspots were always located laterally relative to the exit point of the perforators identified by CTA. In another study, Cina et al.,[41] revealed that the sum of the diameter of the perforating artery and vein with the color Doppler was in agreement with the diameter of the presumed artery on CTA. The authors also showed that there was significant disagreement between the measured diameters of the arteries with color Doppler and CTA, as well as for CTA and intraoperative findings. Thus, the perforating artery measurement assumed on CTA may constitute the sum of the diameters of the perforating artery and vein. Mathes et al.,[42] warned against relying solely on perforator mapping with CTA, as they had to perform a significant number of intraoperative changes.

According to the review published by Lohman et al.[37], DIRT has a low sensitivity when compared to spectrophotometry and indocyanine green angiography, but has 100% sensitivity to detect intraoperative anastomoses perfusion problems. The results obtained by Smit et al.,[38] also showed that DIRT can provide valuable information on intraoperative flap perfusion. However, the measurements obtained can be easily influenced by internal factors, such as body temperature, and external factors, such as ambient temperature. In both analyses, there were a low number of studies included, which may mean that the calculations presented may not be very accurate.

The level of evidence for the use of DIRT in flap evaluation in plastic surgery is limited due to the lack of randomized clinical trials. The available data have shown that DIRT is a valuable resource for preoperative perforator selection, being a harmless, low-cost imaging tool that can quickly provide information on blood flow. Furthermore, by providing easy-to-interpret results in real-time, it becomes a useful tool also for intra- and post-operative monitoring. As more data becomes available, estimates of sensitivity, specificity, and accuracy can be refined. This effort will allow the discussion of thermal imaging technology to move away from expert opinion and toward numerical analysis. To facilitate this shift, microsurgeons should be encouraged to publish their experiences, especially regarding indications, costs, and complication rates.

Conclusion

The use of DIRT shows promise for flap monitoring in reconstructions in Plastic Surgery. The tool can be used in reconstructive surgery of the breast, head and neck, and lower limbs.

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Conflicts of interest

Authors declare that there is no conflict of interest.

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