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Review

DYNAMIC PERFUSION ASSESSMENT DURING PERFORATOR FLAP SURGERY: AN UP-TO-DATE

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Abstract

Flap monitoring technology has progressed alongside flap design. The highly variable vascular anatomy and the complexity associated with modern perforator flaps demands dynamic, real-time, intraoperative information about the vessel location, perfusion patterns and flap physiology.

Although most surgeons still assess flap perfusion and viability based solely on clinical experience, studies have shown that results may be highly variable and often misleading. Poor judgment of intraoperative perfusion leads to major complications. Employing dynamic perfusion imaging during flap reconstruction has led to a reduced complication rate, lower morbidity, shorter hospital stay, and an overall better result.

With the emergence of multiple systems capable of intraoperative flap evaluation, the purpose of this article is to review the two systems that have been widely accepted and are currently used by plastic surgeons: Indocyanine green angiography (ICGA) and dynamic infrared thermography (DIRT).

Keywords: perforator flap, indocyanine green, thermography

Introduction

Perforator flaps represent the pinnacle of flap design. They are a result of decades of research pioneered by Manchot, Salmon, Cormack and Lamberty, and Taylor and Palmer [1], that have led to a better understanding of the vascular anatomy and physiology of the cutaneous circulation. This evolution has allowed surgeons to harvest flaps based on a single cutaneous perforator leading to reduced donor site morbidity, preservation of underlying structures and the ability to tailor any flap to match the exact defect requirements [2].

Flap monitoring technology has progressed alongside flap design. Preoperative imaging for perforator mapping is standard in some areas of reconstructive surgery, like breast reconstruction [3-9]. Preoperative imaging, using CTA or MRI, has the ability to create a vascular map of the flap but it fails to deliver dynamic, intraoperative information regarding the physiology and the perfusion pattern of certain vessels [10].

The virtually infinite number of potential donor sites, highly variable vascular anatomy and the complexity associated with dissecting increasingly smaller and more fragile blood vessels are the drawbacks of this evolutionary process [11]. The increased technical demands of these flaps have hailed the need for systems that provide dynamic, real-time, intraoperative information about vessel location, perfusion patterns and flap physiology [12].

The last decade has seen the emergence of multiple systems capable of intraoperative flap evaluation. The purpose of this article is to review the two systems that have been widely accepted and are currently used by plastic surgeons: Indocyanine green angiography (ICGA) and

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dynamic infrared thermography (DIRT).

Indocyanine Green Angiography (ICGA)

Indocyanine green was first discovered in 1957, and was initially used in ophthalmology to assess retinal vessels [13]. It's introduction in plastic surgery is relatively recent. It is currently being used to monitor free and pedicle flaps, assess micro-vascular anastomosis, map perforators and evaluate burn depth [14].

The dye is injected in bolus trough a peripheral vein. Using an overhead laser (Pi =0.16W - λ=780 nm) the dye is excited and it emits fluorescence with a maximum at 835 nm. The images are visualized on a video monitor [12]. The light in the near infrared spectrum (NIR) is minimally absorbed by water and hemoglobin, and is not dispersed by the tissues. This allows for an excellent visualization of blood vessels up to 2 cm underneath the skin [15].

ICG binds to plasma proteins so it's presence in the extravascular space is minimal. Unlike fluorescein, ICG does not cause tissues staining. The dye has a plasma half life of about 3-5 minutes in humans which allows for multiple injections during the same procedure, to a maximum dose of 5 mg/kgc [16]. After 10-20 seconds post-injection the dye appears in the arterioles of the flap, with a maximum fluorescence at 30 seconds [17]. Because ICG has a very rapid biliary excretion, the angiography can be repeated every 10 minutes [18].

The raw image is viewed as a gray scale, but software processing can be used to calculate florescence percentages [19]. ICGA can be used to monitor all types of flaps, including skin flaps, muscle, fascia and bone [17,20,21].

Perforator mapping

ICGA is used for perforator mapping in the preoperative stage. Unlike CTA it does not require ionizing radiation or a separate hospital visit [22]. Several authors reported using ICGA for perforator mapping and optimizing flap design [16]. Sacks et al. used ICGA to center the flap over the dominant perforator after anterior thigh mapping [23]. The authors concluded that ICGA is superior to Doppler in identifying the dominant perforator, alleviating the need for exploration of different perforators. This reduces operating time and donor site morbidity.

Onoda et al. reported using ICGA for perforator mapping, but found it useful only in flaps with a thickness of ≤2 cm [24]. In thicker flaps they observed a diffuse staining of the tissue after injecting the dye, with no clearly visible perforators. In sites with a thin layer of subcutaneous fat, like the head and neck region, the trunk, and the extremities, perforators and their course are easily visualized and ICGA is regularly used for flap planning and evaluation [25] as reported by Pestana et al.

Perfusion assessment

ICGA has been used to evaluate perfusion in ophthalmology [26], cardiac [27], vascular [28] and transplantation surgery [29]. It is successfully used by plastic surgeons to assess flap perfusion and guide resection of necrotic tissue [14,30,31].

Several authors have reported excellent results with intraoperative soft tissue perfusion evaluation using ICGA. Pestana et al. used fluorescence angiography to monitor perfusion in 29 patients with breast reconstruction. ICGA identified ischemic tissue and guided resection in 50% of patients, with one total flap loss correctly identified by the technique [17]. Holm et al. studied a group of 25 patients with breast reconstruction. They used fluorescence angiography to evaluate the vascular territories of bots SIEA and DIEA. ICGA changed the preoperative plan in 44% of patients [32].

Assessing perfusion by clinical judgment alone is extremely difficult even for experienced surgeons. Newman et al. used ICGA to monitor mastectomy flaps in 20 patients. The study showed a 95% correlation between intraoperative fluorescent angiography and clinical course with a 100% sensitivity and 91% specificity [33]. Phillips et al. found similar results in their study involving 32 mastectomy patients. ICGA had a 90% sensibility and 100% specificity in predicting mastectomy flap necrosis [34].

A meta-analysis published in 2014 by Lohman et al. evaluated a total of 11 articles from 9 lead authors describing intraoperative use of ICGA. A number of 244 patients and 253 flaps were analyzed. Calculated sensitivity was estimated at 90.9% (95% CI: 77.5Y100) with a P value for heterogeneity of 0.93 (Q=0.79), accuracy: 98.6% (95% CI: 97.6Y99.7), with a P value for heterogeneity of 0.77 (Q=5.75). Specificity was 98.6% (95% CI: 94.5Y99.8). The rate of re-exploration was 11.1% (95% CI: 7.4Y16.3), and intraoperative revision because of a positive ICGA study was 13.3% (95% CI: 9.1Y18.5). In 9 flaps the surgeon chose not to act in spite of anastomotic problems or filling defects revealed by ICGA. This resulted in 2 cases of complete flap loss, 6 partial and a complication rate of at least 89% [35].

Vascular anastomosis

Indocyanine green angiography is used to confirm the patency of micro-vascular anastomosis [20,36]. Once the anastomosis is completed, ICGA can evaluate flow through the pedicle. Fluorescence angiography can also differentiate between an arterial or venous thrombosis [12]. In case of an arterial occlusion, there is no visible dye in the flap. If there is a venous outflow problem, the dye does not exit the flap and the flap remains colored after the adjacent tissue has lost florescence [37]. This imaging test can also be used to assess venous drainage in perforator flaps and reveals the need for a second venous pathway.

ICGA provides real-time assessment of tissue perfusion that has been correlated with clinical outcomes [12] and guides surgical decision making, such as flap design, intraoperative tissue resection, and assessment of micro-vascular anastomois. ICG has an excellent safety profile (1 in 42.000 allergic reactions) and short plasma half-life, allowing for repeat evaluations during the same operative procedure.

Dynamic infrared thermography (DIRT)

Monitoring flaps using DIRT implies using an infrared camera, which generates a color-coded map based on the heat emitted by tissues. Warm areas appear red, while cold areas are shown in blue. As a result thermography can be used to assess flap vascularization. Areas with increased blood flow and ischemic areas easily differentiated.

In current clinical practice DIRT is used to map perforators, optimize flap design, assess blood flow and evaluate anastomosis patency [38]. Thermography is mainly used to monitor skin flaps but the technique can be applied to every type of flap [39].

Perforator mapping

Thermography visualizes perforators as areas of high temperature "hot spots" and allows them to be clearly differentiated from the surrounding tissue [40]. For perforator mapping the area of interest has to be cooled down first. This is achieved either by cold air, or a metal plate applied directly over the flap. After the area has cooled down, the thermography camera is used to visualize the rewarming pattern [41]. The first areas that rewarm are the perforators and appear as "hot spots". The speed of rewarming and the progression of rewarming at the "hot spot" provides information regarding the caliber of the perforator and it's surrounding vascular network [42]. De Weer et al. used DIRT for perforator mapping in 27 patients undergoing breast reconstruction. They concluded that preoperative thermography correctly identified the dominant perforator in all cases [43].

Perforators mapped using thermography overlap with those identified by Doppler ultrasound and correlate well with perforators on CTA. Giunta et al. showed that the Doppler signal recorded at skin level is situated at a mean distance of 0.8 cm from the actual fascial emergence of the perforator [44]. Septal perforators, which have a short course and follow a perpendicular direction towards the skin [45] are easily identified because they appear first and have the strongest signal.

Optimizing flap design

DIRT can be used to differentiate between direct and indirect connections between perforator angiosomes. True or direct connections between perforator angiosomes usually occur alongside venous or nervous pedicles [46]. These true connections are ideal because they permit harvesting multiple perforator angiosomes with a low risk of necrosis [47]. By identifying directly linked perforator angiosomes, DIRT is used for optimizing flap design. The flap is redrawn to encompass as many directly connected perforator angiosomes as possible [48]. This allows harvesting of bigger flaps and reduces complications.

Assessing flap flow and anastomosis patency

DIRT can monitor dynamic changes in flap perfusion. Visualization of "hot spots" in the perforator area of the harvested flap confirms the integrity of the vascular pedicle, after dissection of the perforator or after the flap has been inset at the level of the defect [43].

Dynamic thermography monitoring after de-clamping can differentiate between arterial or venous problems. If the flap temperature does not rise after the cold challenge, and there are no visible hot spots, there is a problem with the arterial inflow. If the flap is diffusely warm with no visible hotspots, there is a venous drainage insufficiency [39]. This allows the surgeon to reevaluate the flap pedicle prior to final closure.

Perforator flaps have a high risk of developing circulation problems during harvesting and flap inset [49]. The perforator pedicle doesn't have a protective muscle cuff, making it more susceptible to injury or torsion. DIRT can identify external compression, kinking, vasospasm or venous insufficiency, altering the operative plan accordingly [50].

Dynamic infrared thermography can assess perfusion dynamics, map perforators, confirm pedicle patency and optimize flap design. It does not require intravenous contrast or ionizing radiation. It is a safe, noninvasive and without complications. The procedure can be repeated countless times in each patient.

Conclusion

Both ICGA and DIRT provide real time perfusion assessment, optimize flap design, allow perforator mapping and intraoperative flap monitoring. Published data confirm that these systems have a high sensitivity and specificity in facilitating flap planning, dissection and inset. Most surgeons still assess flap perfusion and viability based solely on clinical experience, which can often be misleading. Employing dynamic perfusion imaging during flap reconstruction has led to a reduced complication rate, lower morbidity, shorter hospital stay, and an overall better result. As the technology becomes more available in the near future, perfusion imaging will be a mandatory step in any reconstructive procedure.

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