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CASE REPORT

THE ANGIOSOMAL CONCEPT: AN OVERVIEW AND 3 ILLUSTRATIVE CASES

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Summary

The angiosomal theory and its clinical application is not the latest science discovery. Nevertheless, its importance in plastic reconstructive surgery is still often underestimated when planning surgical procedures. Knowing and understanding the main problem can be useful not only for planning the flap design but also for survival of large flaps and also the wound healing process. Learning more about the complexity of skin and soft tissue anatomy and the vasculatory system can be beneficial for a variety of medical subspecialities. The article is divided into two parts. Part one is an introduction to the history, anatomy and physiology of angiosomes and perforator flaps. The second part describes practical applications in 3 various cases treated at the Department of Plastic and Esthetic Surgery, University Hospital Olomouc.

Key words: angiosome; perforator; flap; delay phenomenon; choke and true anastomosis; chronic wound healing

Introduction

It has been more than 30 years since G.I. Taylor and J.H. Palmer first introduced the angiosomal model in the fundamental work The Vascular Territories (Angiosomes) of the Body: Experimental Study and Clinical Applications (1). This revolutionary piece of art influenced plastic surgeons around the world and contributed to the development of many important reconstruction procedures. We would like to review and bring back this significant historical keynote with presentation of some clinical outcomes in our department as well as the state-of-art of potential applications.

Definition

The meaning of the term angiosome comes from the translation of Greek words “angenion” which means vein and “somite” by another name part of the body. The angiosome is a three-dimensional block of tissue supplied

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by a defined source vessel with its boundary outlined either by an anastomotic perimeter of reduced-caliber choke vessels or by true anastomoses with no reduction of vessel caliber (1). In addition, the angiosome is formed by an artery, vein, nerve, and surrounding tissues with a variety of interconnection to the neighboring angiosome. Technically, we can also describe an arteriosome, venosome, neurosome and lymphosome to be more accurate.

History

Historically, the first who described skin territories with their own arterial supply was Carl Manchot in 1889 (2). He defined 40 territories in the human body without usage of the X-ray, discovered by Wilhelm Röntgen in 1895. Manchot used a mixture containing lead oxide to map the tiny arteries in fresh cadavers to explain and better understand the viability of local flaps with regards to their vascularization. However, this work remained unknown for a long time. In 1893, Werner Spalteholz (3) described the vascular structure of the skin more specifically, based on gelatin and pigment cadaveric injection studies. He divided the peripheral arteries into 2 groups. Direct perforators whose main purpose is to supply predominantly the skin and indirect perforators which mostly supply the deeper tissue, especially muscles. The next major acknowledgment was found almost one hundred years later by Michael Salmon in 1936 (4). He used X-ray angiography with a lead oxide mixture to define almost 80 territories of the skin supplied by only one specific artery and in the same vein he referred to the hypovascular and hyper-vascular zones of the skin. Until now, it is not certain if Salmon knew about the work of Manchot and based on his study and using radiography upgraded this thesis. William D. Morains' English translation (3) of Manchot work is dated in 1983. This is almost one hundred years after it was first written. Prior to this, the study was almost unknown. However, the final extension of those works was made in the previously mentioned year 1987 by Taylor and Palmer (1), who introduced the elaboration on the skin's vasculatory by radiographic studies on fresh cadavers and animal models. As a result of this work, it was finally agreed, that the human body is divided anatomically into three-dimensional networks with almost 400 parts called angiosomes, which vary in size but are practically constant. Each of these territories is fed by one source artery and accompanying vein with plenty of interconnections. This structure became defined by medical term the angiosome. In other words, it is a composite block of tissue, embracing skin, subcutaneous tissue, fascia, muscles and bone. This fundamental statement started to be crucial for reconstructive surgery and local as well as free flaps planning. Only a few years later, in 1989 George C. Cormack and George H. Lamberty came with work The Arterial Anatomy of the Skin Flaps (5), where they explained the microcirculation of the skin on the basis of superficial and subdermal plexus. All of these historically important findings and the ana-tomical renaissance in 1970s led to better understanding of the com-prehensive vascular anatomy of the body and simultaneously to the big boom in the plastic reconstructive microsurgery approach.

Anatomical and Physiological Background

The anatomical angiosome as a three-dimensional unit of the human body is supplied by one specific and sort of constant artery with accompanying vein with the main source in a bigger branch artery which can be easily defined. For clinical application, the angiosomal artery is usually called "perforator". The functional angiosome is basically bigger than the anatomical one, and includes all of the interconnections between the next surrounding angiosomes (2) (Figure 1). This principle and understanding of variety of interconnections is important for the flap design and harvesting. There are 2 kinds of interconnections between adjacent angiosomes. The first are the true artery-arterial anastomoses constant in caliber and blood flow. The more frequent second ones are the choke arteries, with reduced caliber and capacity to change the thickness of their wall and diameter of the lumen (Figure 2). This ability is important in so called delay phenomenon in the clinical application (6). An analogous principle is observed on the venous side with avalvular bi-directional oscillating veins. The space between neighboring angiosomes is seen on angiograms as so called watershed zones which contain mainly the choke arteries.

As mentioned above, it is important to understand the delay phenomenon for clinical practice in reconstructive surgery planning: how to facilitate the survival of flaps, increase the length-to-breadth ratio in random pattern flaps, and ensure the reliable transfer of larger volumes in axial pattern flaps. The length and volume of the flap depend on the distance between the central and the next dominant angiosome. Without accepting the delay concept during a flap incision making which incorporates more than one angiosome, necrosis occurs in the watershed area (6). (Figure 3) However, once a large-volume-flap is necessary, it is possible to use the tube-pedicle flap with a random tip

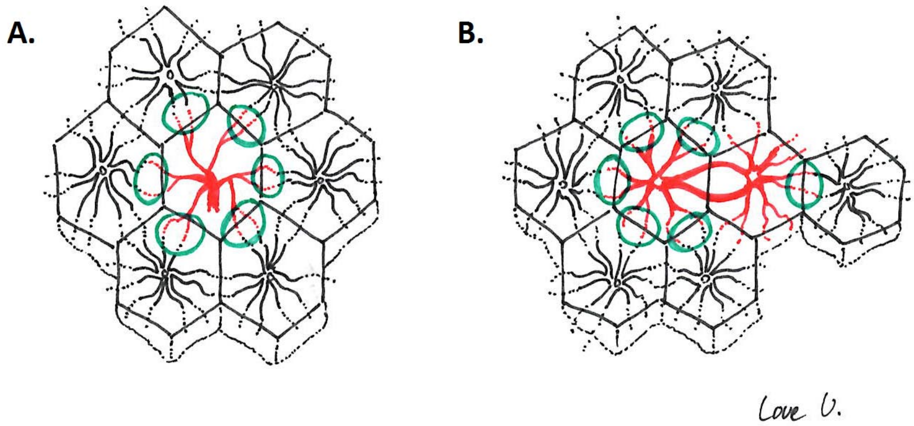

Figure 1. The safe clinical territory of a cutaneous perforator in the functional angiosome where (A) viable adjacent perforator angiosomes have been captured radially on the perforator when connected by choke anastomoses, with necrosis occurring at the next choke vessel interface around the perimeter, and (B) a larger angiosome that has survived where several perforator angiosomes are connected by true anastomoses.

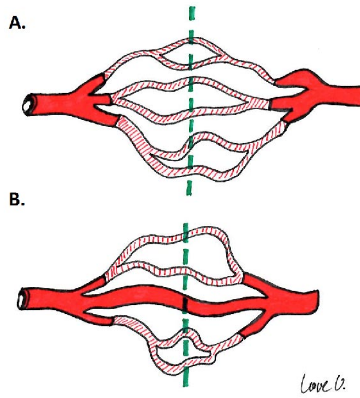

Figure 2. The schematic of choke anastomoses (A) and true anastomoses (B) between adjacent arteries.

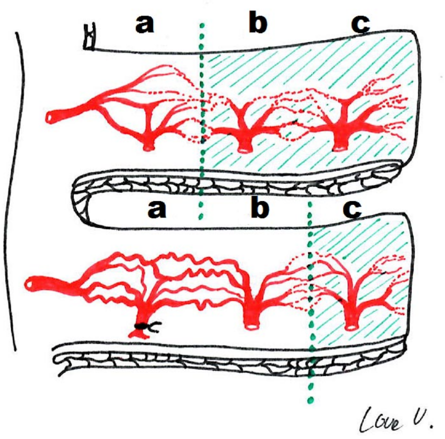

Figure 3. The schematic diagram illustrates two situations of the same flap raised with- and without a surgical delay to illustrate the necrosis line and the changes in the choke vessels. (Above) The adjacent territory (a) is captured safely, and the necrosis line occurs at the choke-vessel interface with vessel (b) or the one beyond. (Below) Vessel (a) has been delayed before raising the flap and the necrosis developed far away in part (c) as well as a dilatation and hypertrophy of the vessel is seen.

preserving in the first surgery. It ensures opening and hypertrophy of the choke arteries with previously reduced caliber. These arteries dilate and rebuild they wall by increasing the number (proliferation) of smooth muscle cells due to variety of regulators growing factors and cytokine cascade. This process takes approximately seven days, after that the changes are irreversible and stable. The maximum alteration occurs within 48-72 hours (6). (Figure 4) In the second stage surgery it is possible to raise the flap from the local area and transfer it somewhere else with required size.

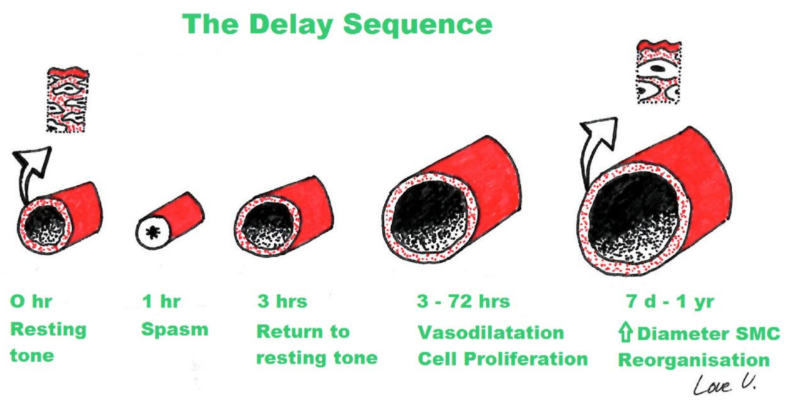

Figure 4. The delay sequence. A diagrammatic summary of results.

Clinical Application

Bearing in mind the existing angiosomes and their importance enables plastic surgeons to choose the best option for the wound cover, considering the localization and the size of the defect. Since the angiosomal phenomenon discovery, random pattern skin flaps were mainly used such as rotation- , advancement- and transposition flaps (e.g. Limberg flap, V-Y flap, bi-lobed flap, keystone flap, nasolabial flap etc.).Those flaps are very useful for covering especially smaller-size defects. The major problem is limited mobility and lack of rotation possibility. The next group includes commonly used myocutaneous- or fasciocutaneous flaps elevated locally on a well-defined axial artery (e.g. forearm flap, latissimus dorsi flap, sural flap etc.). Also this group of flaps is still very popular, thanks to their optimal size for covering medium up to large defects, and generally fast and relatively easy preparation. Though, there is often a bulky side-effect, sometimes with the need of other surgeries in order to achieve desirable esthetic result. The free flaps (such as DIEP - Deep Inferior Epigastric Perforator flap, TRAM - Transverse Rectus Abdominis Muscle flap, ALT - Anterolateral Tight flap, free fibula bone flap etc.) represent another group of flaps, placed on the virtual top in hierarchy of plastic reconstructive surgery. Their biggest advantage is the opportunity to choose from a number of possible flaps and placing them basically anywhere on the body. Even though the feeding artery in these flaps is mostly constant and preoperatively verified on CT (Computed Tomography) angiography or by Doppler probe. Nonetheless, single harvesting is demanding, time-consuming and needs some experience. Simultaneously, it involves performing of very delicate vessel anastomosis (with diameter of several millimeters) which requires microsurgery skills and proper equipment.

Finally, a specific group contains the perforator flaps. Perforator is defined by Salmon (7) as any vessel that perforates the other layer of the deep fascia to supply the overlying subcutaneous tissue and skin. In another words, the perforator flap could be equivalent to one or more angiosomes, which is an area of the tissue and skin fed by one specific perforator. There are two different groups of perforators. The first one (about 40 %) is the direct perforator, which goes through the septum directly to the skin and the main purpose is to supply the skin. We can call them septocutaneous perforators and find them mostly on extremities, where the perforating vessels are long and go through the septum to the skin. The other group (around 60 %) contains the indirect perforators which first penetrate some tissue such as muscle, bone, tendon, cartilage, before reaching the skin (8). They are called musculocutaneous perforators and are anatomically predominantly localized on the trunk, dorsum and abdomen. There are the large plane muscles and the perforating vessel has a short course there. Unfortunately, the terminology of the direct and the indirect perforator flaps is often confusing. The indirect flaps are mostly called according to the perforated muscle e.g. DIEP, ALT, TRAM etc. (8).

Surgical approach

In the surgical approach, when planning usage of perforator flaps for covering a variety of wounds, perfect knowledge of anatomy of the donor and recipient sites and choosing the most suitable flap is of the greatest importance . We can find and verify the proper perforator preoperatively by duplex sonography, CT- angio scans or both. Considering the size, number, diameter, centralization, density, 3D arborisation and course of the perforators as well as the maximal possible area and capacity of rotation of the harvested flap is very important (9). It is essential to decide whether the flap will be used as a local free style perforator flap, pedicle- or free flap. In large defects, we can also consider delay procedure or using tissue expansion to cover all of the necessary recipient area. Preoperatively, it is crucial not only to find the most fitting perforator, but also marking it on the skin, drawing the optimal shape of the flap in the proper position of the body before and after harvesting the flap. The situation can be different when the patient is lying on the operation table and when moving and using the underlying muscle of the composite flap. During the surgical procedure itself, the wide bloodless operation field, usage of magnifying loupes or microscope when needed and smooth anesthesia conducting optimal blood pressure, temperature, relaxation are extremely important. In most cases, the incision down to the fascia on one side is performed first, followed by very gently raising the flap until defining the right perforator. During preparation of the perforator, avoiding twisting, shaking and stretching of the pedicle is crucial, as well as consistent ligation or coagulation far away from the main trunk. After preparing the perforator, we can more or less easily continue to raise the rest of the flap. At the beginning, it is useful to define more than one suitable perforator in case something happens or we change the surgical strategy for a different reason. For example, we can perform the local transposition free style flap or free flap or start the delay procedure. Postoperative intensive monitoring and adequate medication are important parts of the complex care as well.

There are plenty of advantages of choosing the perforator flap instead of conventional flaps in reconstructive surgery. One of the biggest positive aspects is a variety of different local- or distant flaps we can use with the optimal perforator. By understanding the delay phenomenon, we can prepare larger flaps for bigger wounds with or without using tissue expansion. When raising only a tiny skin flap on a specific perforator, we can save the muscle and underlying tissue and also spare the muscle function. The donor side can then be smaller, closed by direct suture. We can also avoid the unaesthetic "bulky" effect when using the volume size musculocutaneous flap (10). Identifying the most suitable perforators gives us a good chance of longer vessel pedicle with better flexibility and possibility of rotation. However, there are some disadvantages as well, especially demanding and time-consuming preparation, performing microanastomosis of vessels with a diameter lower than one millimeter, etc. The risk of venostasis and thrombosis of the flap in the early postoperative period is also very problematic and regular flap monitoring in first days following the surgery is necessary as well as a standard anticoagulants regime (e.g. Fraxiparine® 0,3 - 0,6 ml 1-2 x per day). This pertains to free flaps with vascular anastomosis with continual intravenous heparin infusion 5-10 000 IU (International Units) for the first 2-5 postoperative days. Sometimes it may be combined with long-lasting therapy of antiaggregants (e.g. Anopyrin® 100mg) or vasodilatants (e.g. Trental® 300 mg), depending on the department protocol. However, the most recent trend is against complex pharmacotherapy regimes and is supported by many authors.

Case reports

Versatile applications of angiosomal concept in plastic surgery are described in three case reports. The first case report shows one of the most common usage of this principle in breast reconstruction following oncological surgery as an alternative to breast implants or other reconstruction procedures. Despite the fact that the results using only autologous tissue are very natural, the ideal candidates for this procedure must be chosen by specific criteria; thus this particular procedure involves several hours under the general anesthesia, longer recovery including flap monitoring in ICU (Intensive Care Unit), long term anticoagulant therapy and often also additional surgeries to ensure bilateral breast symmetry. The similar principle of the angiosonal application is seen in post-oncological orofacial reconstruction. The second case depicts posttraumatical reconstruction as a plastic surgery approach following usually several weeks after the primary injury. This is often complicated by the general critical health condition in severely injured patients and postponed reconstruction resulting in local infection and osteomyelitis. Therefore, for many patients, it is the last alternative to cover the chronic wound, often resulting with bone or osteosynthetic material exposure and without the adequate defect coverage, thus resulting in the worst scenario with limb amputation. However, similarly like in the previous case, this reconstruction needs complex long-lasting therapy and additional surgeries to be performed in the future. The last case, on the other hand, describes possible acute usage in an acute trauma performed within the first emergency surgical care. In fact all small local flaps are used with a defined vessel. Even this procedure is an elegant option and does not need any particular equipment or other additional therapy, it is more technically complicated than the classical random flaps and needs more preparation time and sufficient experience. The advantage is functionally better and the end esthetic result as well as possible coverage larger defects especially on the hand.

Case report 1

A 50-year-old woman after mastectomy of the left breast and axillary lymphadenectomy due to ductal carcinoma G2, pT2N1, M0, HER2 negative, BRCA (Breast Cancer gene) negative, hormonal dependent. Postoperatively she underwent adjuvant chemotherapy, radiotherapy and when undergoing reconstructive surgery, she was on hormonal therapy. Based on oncological recommendation, she was also indicated for prophylactic mastectomy of the right breast due to positive family medical history. One stage bilateral reconstructive surgery with prophylactic right subcutaneous mastectomy was performed. The breast reconstruction was performed with the DIEP flap on the right side and mini TRAM free flap on the left side. The anastomosis was performed bilaterally on the mammary artery and one vein using Prolen 9/0 microsurgical suture. The procedure was performed by two surgical teams working together; the time of surgery being 10 hours and 45 minutes. The patient was observed on ICU (Intensive Care Unit) for the first post-operative day, with full heparinization, anti-edematous therapy, prophylactic antibiotic application. The flaps were checked every hour clinically and by the Doppler probe. The course was without any com-plications. The patient was discharged from the hospital on the 10th post-operative day. Within a 2-year period consequent to the reconstructive surgery, she underwent three additional procedures - lipografting in the left hy-potrophic breast with total amount of 375 ml of purified autologous fat, bilateral areolomamilar complex reconstruction using a dermo-epidermal graft, scar revision and flap correction under the general anesthesia. (Figure 5)

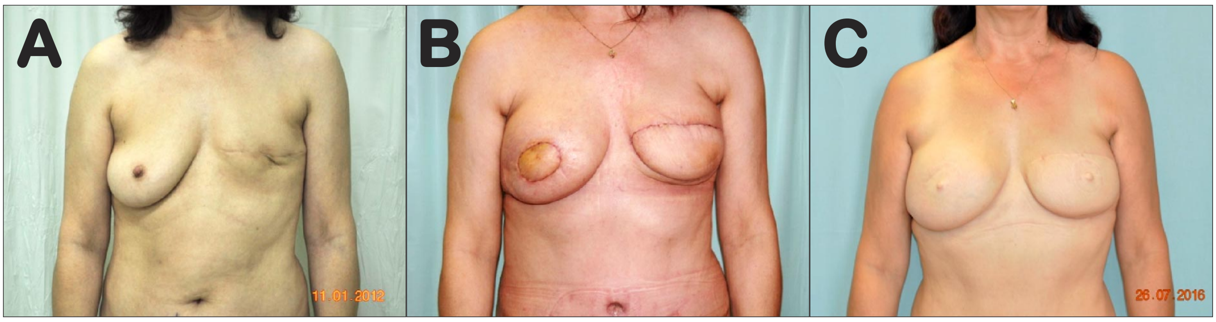

Figure 5. A. Status before reconstruction, B. Status after bilateral reconstruction, C. Final result after 4 years.

Case report 2

A 74-year-old man with diabetes on PAD (Peroral Antidiabetic Drugs) experienced an accident by a branch shredder machine. He was recommended to our department one month after the accident for a non-healing wound on his right crura. Primarily, there was a skin laceration on the ventral part with tibia bone exposure. The VAC (Vacuum Assisted Closure therapy) system, antibiotic, insulin and anticoagulant therapy were introduced. Preoperatively, negative bacteriological cultivation was verified and CT angiography was performed finding good blood flow in all three main arteries of the crura. With regards to these examinations, the patient was indicated for propeller perforator flap reconstructive surgery. The entire defect was 10 x 7 x 2 cm in size, with tibia bone exposure of around 10 x 5 mm, with granulation and no inflammation in the surrounding area. Debridement and partial bone prominence ablation was performed. Two perforators were found 2 and 7 cm distally from the defect. The perforator flap on one dominant proximal perforator was then harvested and rotated 180º to the defect.

The secondary wound was covered by a dermo-epidermal skin graft from the left thigh. Foil wound dressing was used. The total time of the surgery was 2 hours and 17 minutes. After one day of observation on ICU, the patient was hospitalized for 7 more days and then released. There was complete flap survival with skin graft healing without complication. The patient was fully recovered 2 months after the surgery. (Figure 6)

Figure 6. A. Crural defect before reconstruction, B. Flap harvesting, C. Flap placement and skin grafting of the donor side, D. Final result after two months.

Case report 3

A 24-year-old man suffered a finger injury at work by putting his hand into the printer rubber roller. The degloving injury involved partial loss of the skin and subcutaneous tissue of the distal and medial part of the middle and ring finger with loss of the nail of the index finger on the left non-dominant hand. There was no bone fracture and just a small exposure of flexor tendons of the fingers. The periphery was vital with suitable capillary bleeding. Reconstructive surgery was performed under regional anesthesia by a wrist block with 1% Mesocain and 0,5% Marcain 1:1. A V-Y local transfer was used for closing the defect on the apex of the middle finger and a homodigital arterial flap on the digital artery was harvested and moved to the defect on the ring finger. For the secondary defects, a thin dermo-epidermal skin graft obtained from the thigh was used. Wound dressing and dorsal gypsum were applied. The total time of surgery was 1 hour and 25 minutes. One day observation in the hospital followed with discharge on the 2nd day. Regular checks-ups on outpatient basis including proper rehabilitation continued up to 3 weeks and the patient fully recovered. (Figure 7)

Figure 7. A. Degloving injury of the hand, B. Immediate reconstruction, C. Result after 2 weeks.

Chronic Wound Healing

In addition, the angiosome concept is increasingly discussed in the chronic wound healing application. More than 12-20 % of patients older than 65 years are suffering from PAD (Peripherial Arterial Disease) and/or CLI (Critical Limb Ischemia) (11). The biggest contributing factor is diabetic neuroischemic disease as a source of chronic pain, ulceration and gangrene, very often resulting in amputation. In the case of verified limb ischemia, an arterial bypass or revascularization procedure on the best useful vessel, which is less damaged, is generally performed. Nevertheless, still almost 18 % of revascularized extremities end in high, low- or below-knee amputation, without revascularization 40 % respectively (11). According to the angiosome theory, we can presume the healing potential of direct revascularization on the specific perforating vessel in the area of hypoxia. On the contrary to the conventional indirect revascularization on the best vessel, where the volume concept plays the main role. For example O'Neal reported by Sumpio et al. determines the diabetes end-artery occlusive disease theory, where he states that this process is in diabetes a combination of atherosclerosis, acute septic thrombosis and destruction of collateral arterial system; that is the reason for the direct revascularisaton of a specific local vessel (12). Even though this strategy seems to be promising, the comparative efficacy of angiosome-directed and indirect revascularisation strategies to aid healing of chronic foot wounds in patients with co-morbid diabetes mellitus and critical limb ischemia is, however, still not conclusive (10, 11). Therefore more additional multidisciplinary studies and research in this area are needed and would be beneficial to confirm or refuse the direct revascularisation respecting the angiosomal model in reconstructive surgery for successful global patient management.

Conclusion

For more than 30 years since its first introduction, the angiosomal concept has been an attractive scientific topic not only in plastic reconstructive surgery. Considering vascular territories of the body should be a standard approach in flap reconstruction planning or in chronic wound healing.

Many varieties of new free style perforator flaps appear wherever on the body as well as growing applications of tissue expanders in pre-expanded super-thin skin flaps (8). In addition, another potential field represent trials carried-out in robotic assisted surgery in free flaps harvesting or mini-perforator flaps using an extracorporeal perfusion etc (13).

Disclosure statement

The authors proclaim that they have no competing interests.

Conflict of Interest Statement

None declared.

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