An active intervention on flap vasculature: flap prefabrication by pedicle implantation, delay, pre-expansion, pre-grafting, tissue engineering, biomaterials and perforators surgery

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Abstract

The technology of flap prefabrications is a new, powerful tool in plastic and reconstructive surgery. It is based on an old idea, while applying the latest innovations in surgery. It involves any modification of a surgical flap done before its transfer to the final donor site, including surgical delay, pre-expansion, pre-grafting, the use of tissue engineering, biomaterials and perforators surgery, or the creation of a new pedicle by staged transfer of a vascular bundle. The different possibilities are discussed, with special reference to their biologic basis.
Key words: Microsurgery, surgical flaps, cytokines.

Riassunto

UN INTERVENTO ATTIVO SULLA VASCOLARIZZAZIONE DEL FLAP: PREFABBRICAZIONE DEL FLAP MEDIANTE IMPIANTO DEL PEDUNCOLO, ATTESA, PRE-ESPANSIONE, PRE-INNESTO, COSTRUZIONE DEL TESSUTO, BIOMATERIALI E CHIRURGIA CON PERFORATORI

Le tecnologie per la prefabbricazione di un lembo cutaneo è uno strumento nuovo ed efficace nella chirurgia plastica e ricostruttiva. Si basa su un principio già noto ed al quale sono state applicate le più recenti acquisizioni nel campo della chirurgia. Comprende tutte le possibili modificazioni apportabili al lembo cutaneo prima del suo trasferimento nella sua sede definitiva, inclusi i differimenti chirurgici, la pre-espansione, il pre-innesto, l'uso di tecniche di ingegnerizzazione dei tessuti, i biomateriali e la chirurgia con perforatori, attraverso la creazione di un nuovo peduncolo mediante trasferimento a tappe successive di un fascio vascolare.
In questa sede vengono discusse le varie possibilità, con particolare riferimento ai principi biologici cui si ispirano.
Parole chiave: Microchirurgia, lembo cutaneo chirurgico, citochine.

Introduction

Some pioneering experiments settled down the basis for the development of the technology of flap prefabrication. Since the early 30ies several authors succeeded in revascularizing an ischaemic hearth, implanting an internal mammary vessel or a pedicled muscle (3, 31). The same has been tried for bones (9), e.g. in Kienbock disease. Although such procedures didn't gain clinical acceptance, they opened the way for developing new reconstructive applications. Early experimental studies used the omentum to neovascularize the abdominal wall (33). The first prefa-bricated flap in Plastic Surgery was performed in 1976 by Erol, who reported the experimental grafting of skin on a femoral vessel in the rat, transforming a skin graft in a pedicled flap suitable for reconstruction (10). Finally, Shen introduced the term "prefabricated flap" to describe these procedures, in 1982 (27).

Basic principles

According to some authors (23) flap prefabrication consists in choosing a block of tissue that has no natural axial blood supply, and "creating" a new vascular pedicle. This is accomplished by the implantation of an arterovenous bundle that in a few weeks will "neovascularize" the selected block of tissue to constitute the future flap. The vascular bundle may or can not include a strip of fascia or a cuff of muscle at its end to increase the surface of contact. Subsequently, the flap will be transposed either

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as a pedicled or a free microvascular one. Thus these authors prefer to restrict the definition of prefabrication to the cases of "pedicle implantation", with staged transfer. Others (15) include any modification of the flap before its transfer, including delay procedures or pre-transfer grafting of the flap, with skin, mucosa, bone, etc. Spira (1) extended this concept including the use of biomaterials, of components derived from tissue engineering, or the use of growth factors and cytokines to improve the circulation of the flap.

Pre-transfer grafting has also been termed "pre-lamination" (23, 24) but we prefer to call it "pre-assembling".

Indeed, whatever the technique, the aim of flap prefabrication is to achieve an active intervention on the vascular structure of the flap. This may include neoangiogenesis from an implanted vascular pedicle, vascular enhancement by delay, drugs or pre-expansion, or creation of new vascular connections between a carrier flap and autografts, engineered tissues, or biomaterials.

to increase the surface of contact between the pedicle and the tissues to be vascularized. Khouri considered it the best solution and has described the u se of different fascial flaps, preferentially the free temporo-parietal fascia flap (13). Four weeks are necessary before the final transfer, and the dissection of the pedicle is usually easy at this stage. The viability of the flaps is good, but their venous drainage is often problematic. Some modifications have been investigated, including the implantation of a venous pedicle only (Total Venous Flap) (28), or a surgically created arterovenous fistula (16). Both histology and microangiogmphy indicate the formation of new vascular connections between the implanted pedicle and the recipient bed and blood flow has been confirmed by perfusion studies with 99-Tc radiolabeled red blood cells.

Neovascularization begins at the distal end of the implanted pedicle and then continues along the flap (22) and the new vessels derive both from the implanted pedicle and from the bed (11, 23).

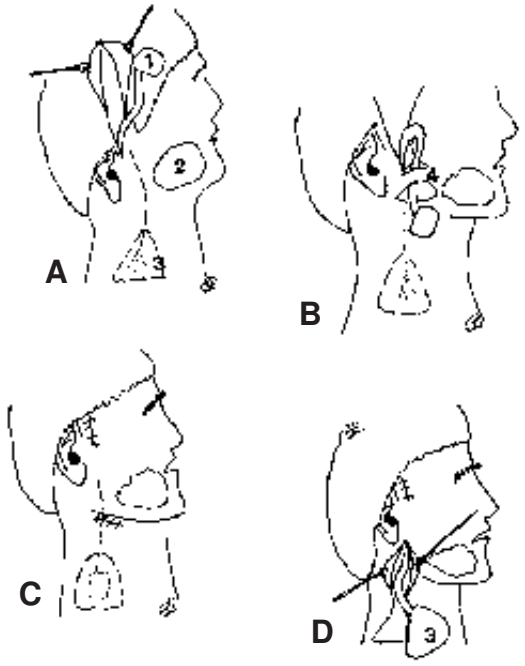

Fig. 1: Prefabricated flap of lower neck skin, transferred on a temporal pedicle for reconstruction of the cheek.
A) The temporal fascia flap (1) is raised. (2) is an hypertrophic scar on the cheek. The dotted line (3) shows the future flap and pedicle position. B)The pedicle is passed through a subcutaneous tunnel (4) towards the lower neck. C) The pedicle in place, under the skin. D) The prefabricated flap is raised after 6 weeks.

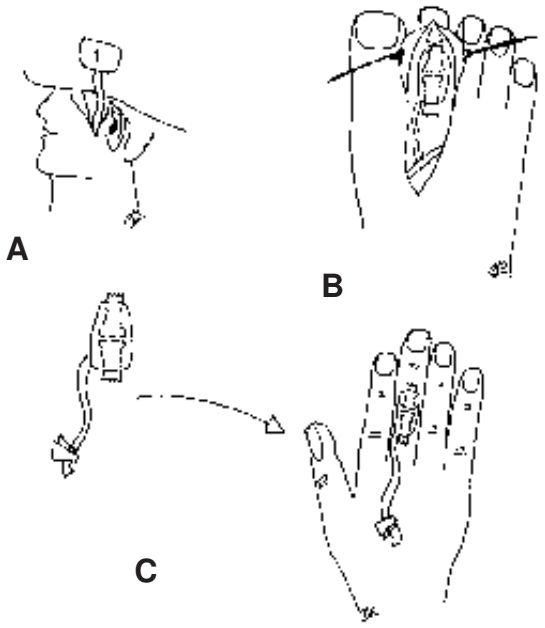

Fig. 2:Vascularized joint transfer from the second toe to the PIP joint of the 3rd finger.
A) The temporal fascia flap (1) is raised. B) Microvascular transfer to the foot. The fascia is wrapped around the joint of the second toe. C) After 6 weeks, microvascular transfer of the joint to the hand.

Biology and clinical applications

Pedicle implantation

The simplest pedicle to be implanted is an arterovenous bundle with its periadventitial connective tissue. A cuff of muscle or a strip of fascia can be kept with the vessels,

Delay and cytokines

No actual formation of new vessels by neoangiogenesis has been demonstrated. Anyway, dilatation of existing vessels and opening of choke vessels increase the blood supply of the flap. Adjacent angiosomes are recruited, contributing to the nutrition of the flap. All this results in better survival and higher resistance to infection (4, 30, 21).

Several cytokines, growth factors and other soluble substances are involved in this process and in neoangiogenesis. Some that have been investigated are TGF-beta, Basic FGF, PDGF, VEGF: their production seems to be induced first of all by ischaemia and surgical trauma. They have been administered topically to increase the viability of flaps or to shorten either the delay period or the prefabrication time, but results are not conclusive (12, 2, 19, 29, 25, 6).
Most experimental studies in flap prefabrication used histology, gross vascular anatomy, microangiography or perfusion with radiolabeled trackers: a better understanding of the molecular mechanisms of flap prefabrication may be useful.

Pre-expansion

Skin-expansion increase the surface of the flap, but also enhances its blood supply. There is a delay effect, due to the surgical dissection of the pocket under the flap. Furthermore, pressure and tension results in expansion and lengthening of the vascular pedicle, probably because ischaemia causes release of growth factors and cytokines (8, 20, 29).

Pre-assembling by grafting

It has been also called "flap prelamination" (23, 24). Additional tissue components are added to the carrier flap by conventional grafting techniques: bone, skin, cartilage, mucosa, tendons, etc. Sometimes tridimensional structures are pre-assembled, like a nose, an ear or a mandible (24). In these cases, the "take" of the graft involves the mechanisms of a usual skin or mucosal graft (26).

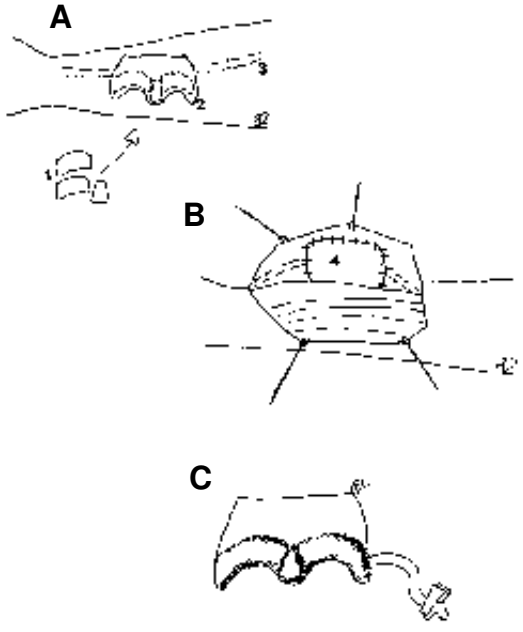

Fig. 3: Pre-laminated flap for total nose reconstruction ("Pre-assembling by grafting").
A) The flap outlined on the forearm skin. (1) Radial artery. (2) Cartilage grafts for alar rims and tip support.
B) The under surface of the flap, skin-grafted for vestibular lining.
C) The flap after 6 weeks, ready for microvascular transfer.

Pre-assembling by tissue engineering

The flap can be pre-grafted with cell cultures provided in films (e.g. sheets of keratinocytes), or seeded on tridimensional scaffolds (e.g. condrocytes or periostal cells on a readsorbable polymer). Another possibility is to use proteins or other substances able to induce the formation of bone, fat, or other tissues if applied on the carrier flap. This has been done applying Bone Morphogenetic Proteins (BMPs) on a muscle flap to induce the formation of bone (14, 7).

Pre-assembling with biomaterials

Porous materials implanted near a vascular pedicle, are surrounded and invaded by a fibrovascular tissue that allows later transposition as an axial flap (5). Experimental studies, anyway, have showed that the implant-host interface is relatively unstable (32).

Pre-assembling by perforators surgery

Flap prefabrication is usually intended as a staged procedure, requiring some weeks between the first stage of preparation of the flap and the final transfer. We would include among the different possibility of flap prefabrication also Koshima's chimeric flaps: a "carrier free-flap" is chosen (e.g. perforator flaps) and all the components needed (bone, skin pads, muscles, etc.) are added by the anastomosis of small perforator arteries and veins (caliber about 0.5 mm) using special instruments for "Supramicrosurgery" (17, 18). This can be considered a single-stage flap prefabrication.

Conclusions

Research in the biology of flap prefabrication is still at its beginning: a better understanding of the underlying mechanisms will probably allow making the process quicker and more effective. Furthermore, tissue engineering is evolving from cell cultures to the "in-vitro" prefabrication of composite tissues, toward the future goal of organ "prefabrication". Under an historical perspective, first early plastic surgeons started to apply the principles of classic anatomy. We have been subsequently involved in a new renaissance of anatomical studies with a revolution in the basic principles of flap design, with the introduction of musculocutaneous and fasciocutaneous flaps and of the concept of angiosomes. Now, flap prefabrication is pushing surgery beyond the limits of normal anatomy with the possibility of an active modification of the

vascular supply of living tissues, creating totally new flaps which include the tissue components needed, in the required amount and with the minimum of donor site morbidity.

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