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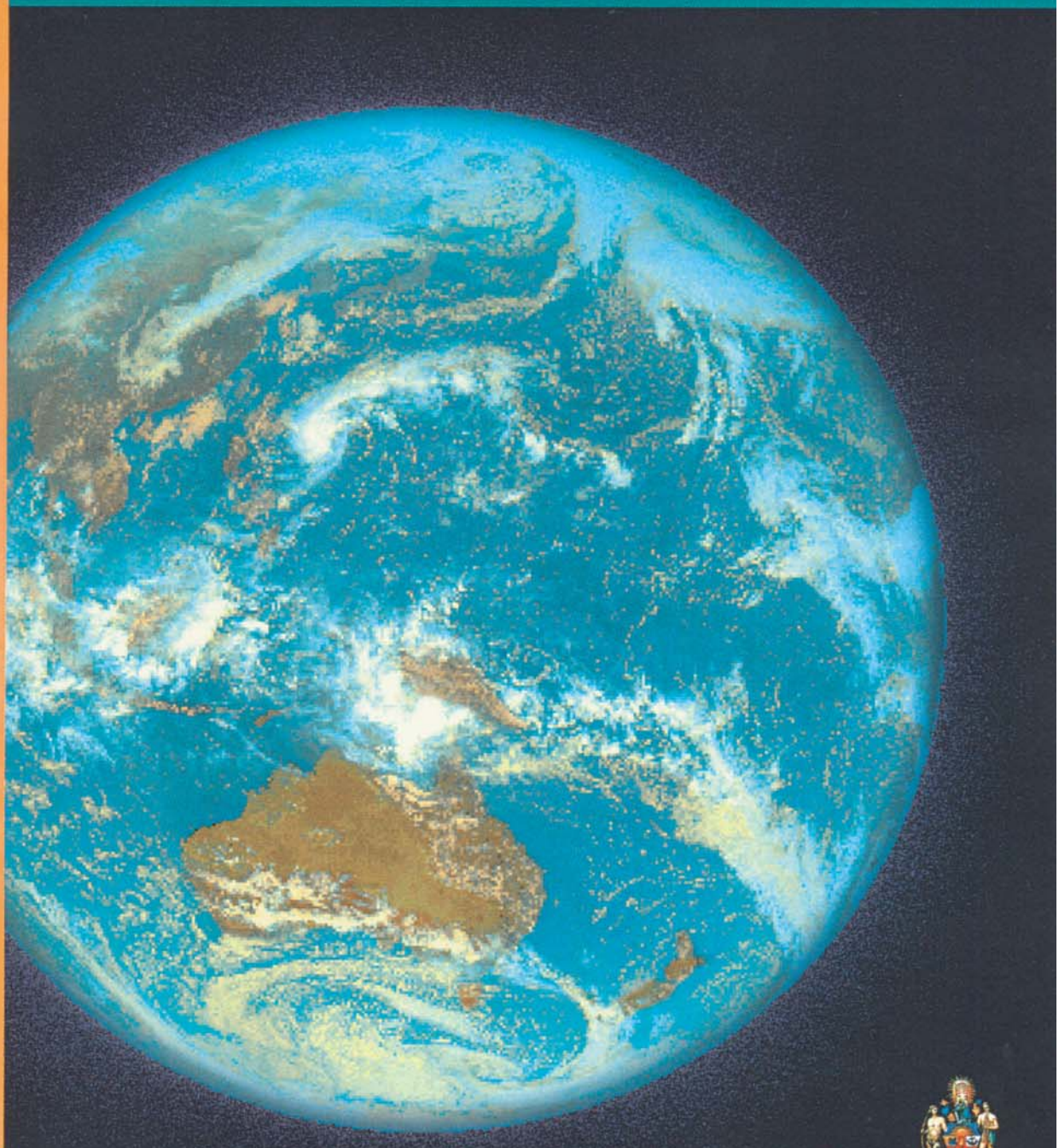

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Contents:

COMMENTARY

THE KEYSTONE DESIGN PERFORATOR ISLAND FLAP IN RECONSTRUCTIVE SURGERY

It is a pleasure for me to discuss the keystone design perforator island flap which Felix Behan has developed.[1] When one initially looks at this flap, one's feeling is that, if you can close the defect with this flap, you could have closed the defect directly. With a little further thought, it becomes obvious that the situation is not quite as simple as it seems. What Behan has done, is to achieve the blood supply which comes through the subdermal plexus, and he captures this by making a very cleverly designed island flap. The flap is a continuation of the distal excision line laterally. This continues out in a one-to-one ratio to the width of the defect laterally, a curved line is made which parallels the edge of the defect. Therefore, the design of the flap is well established and is related to the defect size; of course this is the art of making any type of flap, whether it be a transposition flap or whether it be an island flap, as is the keystone flap. What we are looking at now is an island which needs to be mobilized. This is then carried out and the mobilization continues until the flap will advance and close the primary defect. It is obviously very important that no undermining whatsoever be carried out in the area of the flap, and as little damage as possible should be inflicted on soft tissue around the flap in order to maintain not just vascularity but also lymphatic drainage. It is particularly important, as with all flaps, to maintain venous drainage.[2]

In what is called the type II keystone, the lateral fascia is released deeply. When the flap is moved into the defect, there are three mechanisms at work. First, is advancement of the flap, second is advancement of the skin lateral to the flap, and third is V-to-Y closure of defects at either end of the flap. There is no doubt that with a flap such as this, one does, to some extent, rely on the viscoelastic properties of the surrounding tissue. These are mobilized as the sutures are placed around the flap, both laterally and proximally and distally. It is in the lateral areas of the V-to-Y where advancement is achieved. It is important that no undermining is performed deep to the flap, and in some patients it may be necessary to leave a raw area which would be closed with a skin graft, be allowed to close directly or closed by secondary suture.

Further varieties of this flap can be used, not just a single flap but also double flaps. If a large move is required, then the deep fascia is divided laterally and this will allow somewhat more advancement to be achieved.

In modern literature, nomenclature and classification is almost mandatory, and with this flap Behan has met the modern challenge. Type I is a standard flap design, and this allows closure of defects up to 2 cm almost in any area. In type IIA, the deep fascia is divided, but of course this can be something that could be done routinely just to give a little more security to the flap. Type IIB requires a skin graft to the secondary defect, and this is necessary in areas of 'anatomical tightness'. Type III refers to double keystone flaps, and type IV is a variety of rotation advancement.

This keystone flap falls well within the concepts of flap creation. There are multiple perforators which come to the skin through fascia, through muscle, and occasionally through nerves. This flap takes advantage of all of these, and what should be appreciated is that, in addition to tiny arterials coming to the flap, small veins are draining the flap. Once the flap is raised, all dissection should be blunt in order to retain the vascular supply. It is also obvious that two flaps can be used if necessary when the defect is large. This will probably require special care.

I believe that this flap is greatly superior to a bipedicled flap in that it eliminates the inevitable tension which occurs due to the movement of the central part of the bipedicled flap where, because of the tension, the central portion will often run into vascular difficulty. This is not the case with the keystone flap where the tension is equally distributed all around the flap. Felix Behan brings up an interesting question, and that is, are island flaps sympathectomized?[3] Is this why they have a better blood supply and are more dependable? An area for new research?

This is the type of flap that, as one uses it more applications will be found. It is important, however, that the design is correct and that the flap edges are free of tension. One worry would be pincushioning, but apparently this does not occur. I feel that this is a flap which requires to be examined, tried, and reported on if it turns out to be as good as it seems or as its originator claims. As Felix Behan is a well respected, enthusiastic and objective assessor, I would expect that the flap would be cleared on all counts.

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ANZ J. Surg. 2003; **73**: 112–120

ORIGINAL ARTICLE

THE KEYSTONE DESIGN PERFORATOR ISLAND FLAP IN RECONSTRUCTIVE SURGERY

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Background: A surgical technique for closing skin defects following skin cancer (particularly melanoma) removal is described in the present paper. Its use is illustrated in five patients. The technique has been used in 300 cases over the past 7 years and is suitable for all areas of the body from scalp to foot.

We have coined the term Keystone Design Perforator Island Flap (KDPIF) because of its curvilinear shaped trapezoidal design borrowed from architectural terminology. It is essentially elliptical in shape with its long axis adjacent to the long axis of the defect. The flap is based on randomly located vascular perforators. The wound is closed directly, the mid-line area is the line of maximum tension and by V-Y advancement of each end of the flap, the 'islanded' flap fills the defect. This allows the secondary defect on the opposite side to be closed, exploiting the mobility of the adjacent surrounding tissue. The importance of blunt dissection is emphasized in raising these perforator island flaps as it preserves the vascular integrity of the musculocutaneous and fasciocutaneous perforators together with venous and neural connections. The keystone flap minimizes the need for skin grafting in the majority of cases and produces excellent aesthetic results. Four types of flaps are described: Type I (direct closure), Type II (with or without grafting), Type III (employs a double island flap technique), and Type IV (involves rotation and advancement with or without grafting). The patient is almost pain free in the postoperative phase. Early mobilization is possible, allowing this technique to be used in short stay patients.

Results: In a series of 300 patients with flaps situated over the extremities, trunk and facial region, primary wound healing was achieved in 99.6% with one out of 300 developing partial necrosis of the flap.

Conclusions: The technique described in the present article offers a simple and effective method of wound closure in situations that would otherwise have required complex flap closure or skin grafting particularly for melanoma.

Key words: aesthetic results, Keystone Design Perforator Island Flaps, melanoma, pain.

Abbreviation: KDPIF, Keystone Design Perforator Island Flap.

INTRODUCTION

Closure of the skin defect following excision of skin cancers is ideally achieved by transposing local tissues of similar qualities. In this regard flaps are generally preferable to skin grafts because they have better colour and contour and are associated with the reduction of donor site morbidity. Small defects are effectively closed by local transposition or V-Y subcutaneous or fasciocutaneous perforator flaps. But larger defects pose a problem. Free flap reconstruction seems an overtreatment and requires expertize, time and resources. We describe a new local flap – the Keystone Design Perforator Island Flap (KDPIF) to reconstruct soft tissue defects and avoid complex reconstruction.

The KDPIF is a curvilinear shaped trapezoidal design flap. It is essentially two V-Y flaps end to side. The curvilinear shape of the flap fits well into body contours. The principle of the island flap repair has a long history[1–5] The KDPIF is designed within the dermatomal segments or precincts (Fig. 1) and straddles longitudinal running structures,[6,7] for example cutaneous nerves and superficial veins[8] which are incorporated in the flap. Aligning the flaps, where possible, along the cutaneous nerve supply incorporates the perforators that accompany the peripheral nerves.[8,9] These are in addition to the subcutaneous, fascial and muscular perforators that support the viability of the flap.[10] Blunt dissection allows the retention of the majority of venous communications.[8]

Doppler localization techniques have not been used preoperatively or intraoperatively.

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WHY KEYSTONE?

Architecturally speaking, to support the tremendous weight of the Roman arches it was necessary to design a stone called a keystone – a way of locking the arch through gravity. This wedge shaped stone was designed to lie in such a manner that it produced arch support. Similarly the shape of the flap seems to lock into the defect and provide structural advantages. Initially called an 'arc' flap, then colloquially an 'arcade' and finally, keystone (A. Breidahl, pers. comm., 1997) became the accepted terminology.

The present paper describes the use of an island flap that is effective in many areas of the body, provides effective skin cover and achieves excellent aesthetic results (Fig. 2).

METHODS

Flap design

The surgical lesion should be excised in an elliptical manner with its axis parallel to the line of cutaneous nerves, veins and/or

known vascular perforators. In the upper and lower limbs this location is generally longitudinally placed (Fig. 1). The side of the defect that has the greater laxity is chosen for the flap site. In the lower leg where these flaps are particularly well suited, the flap is best sited posterior to the defect so that the increasing laxity of skin over the posterior compartment can be exploited to close the secondary defect (e.g., upper, middle and lower calf areas in the lower limb). In the upper limb these techniques are well applied to the bicep and tricep areas of the upper arm, and the proximal flexor and extensor areas of the forearm. An incision at 90 degrees at either end of the defect meets the curvilinear line of the flap markout. This curvature or keystone shape is then mobilized. The width of the flap equals the width of the defect (Fig. 3). Its length is governed by the size of the elliptical excision.

Flap elevation and defect closure

Once the excisional defect is created after the removal of a lesion, the KDPIF has a ratio 1 : 1 for the width of the defect to the width of the flap. The length of the flap is determined by the size of the excisional defect. A right angle is created at the limits of the excision to create the keystone design (Fig. 3a, b).

Blunt dissection allows mobilization of the surrounding tissue while advancing the flap to facilitate wound approximation (Fig. 4a). Careful teasing of the circumferential tissues is performed without any flap undermining so as to preserve the integrity of perforators. Where possible all subcutaneous longitudinal venous and neural structures which support the flap should also be retained within the limits of the surgical procedure. Any inadvertent trauma to the venous drainage system is repaired. The deep fascia is left intact for smaller lesions up to 2 cm (Type I keystone). Where increased mobilization is required, the lateral deep fascial margin is released particularly in the areas of the calf, thigh, forearm and upper arm (Type II keystone).

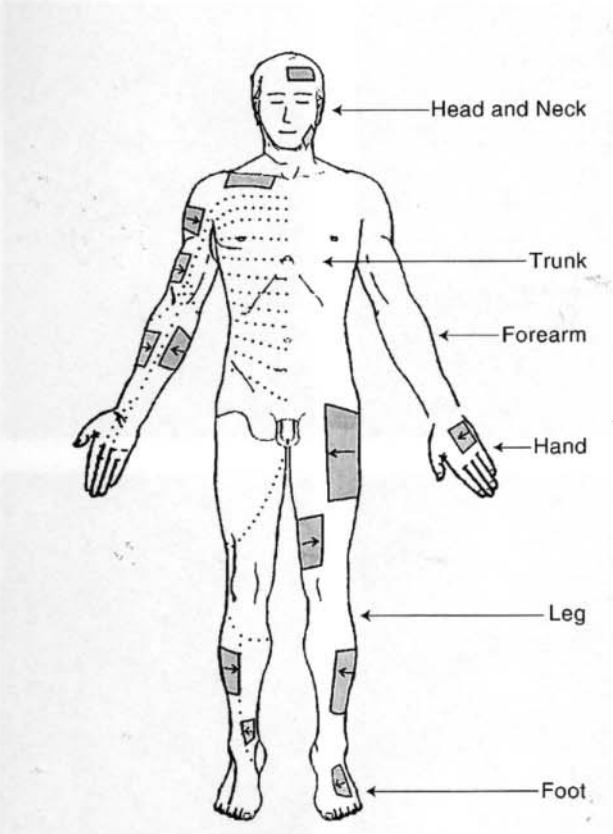

Fig. 1. Keystone Design Perforator Island Flaps designed along the dermatomal segments. The longitudinal axis of the flap sits along the dermatomal segment, and superimposes on septocutaneous, musculocutaneous and fasciocutaneous perforator vessels that ensure the viability of the flap.

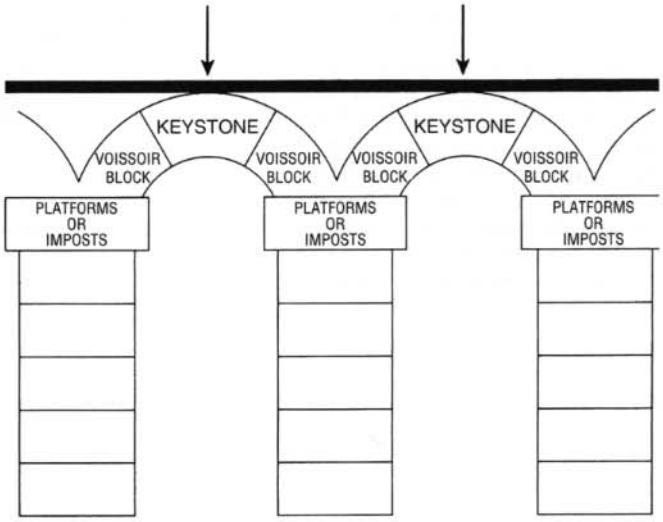

Fig. 2. Architectural nomenclature.

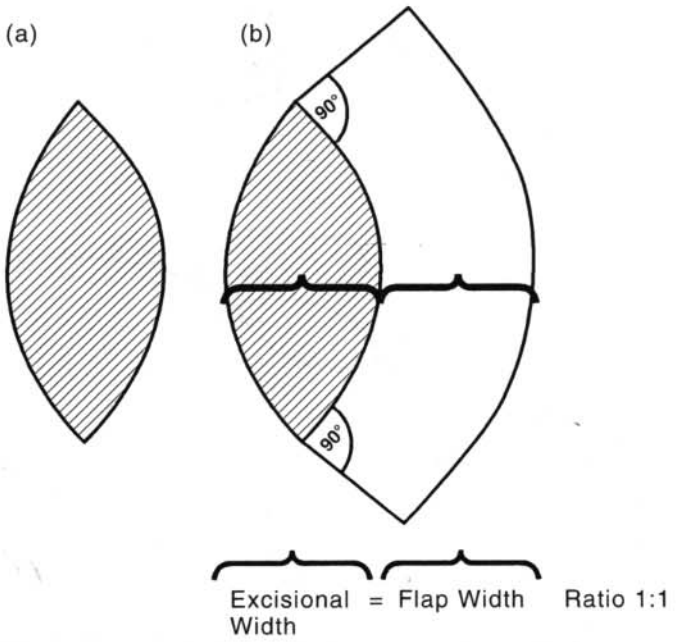

Fig. 3. (a) Mitotic lesion or traumatic defect excized with clearance; (b) Keystone Design Perforator Island Flap. The trapezoidal shaped flap is contoured along the side of the excisional defect with 90° angle at the limits of the island flap.

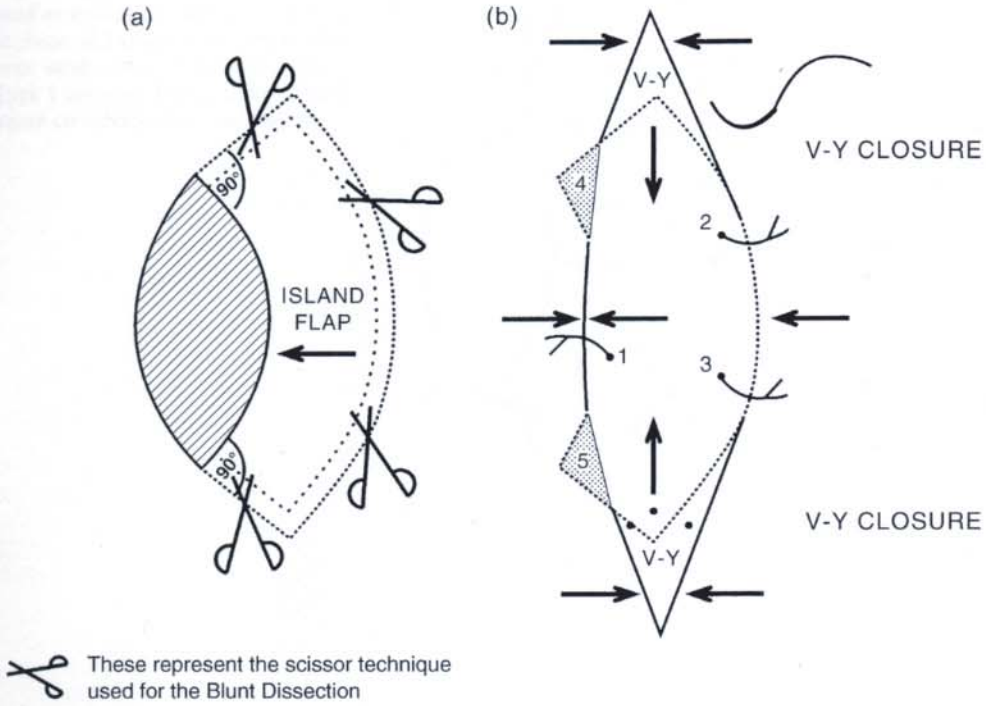

Fig. 4. (a) Blunt dissection mobilization around the limits of the flap. Note: no dissection is done beneath the island flap to preserve the integrity of the perforators while retaining, if possible, all longitudinal venous and neural structures which support the flap. The deep fascia is divided along the outer curvilinear line in Types IIA, IIB, III and IV where the undue tension exists. No deep fascia is divided beneath the flap canopy, the site of the random perforator. (b) The Keystone Island Flap in position. Interrupted sutures (1–3) bring the flap into alignment creating lines of tension. Closure of the double V-Y apposition points at the limits of the flap creates a relative redundancy in the central portion of the flap and relaxes the horizontal tension. The shaded areas (4, 5) are redundant and are excised. The wound closure is completed with the Hemming suture.

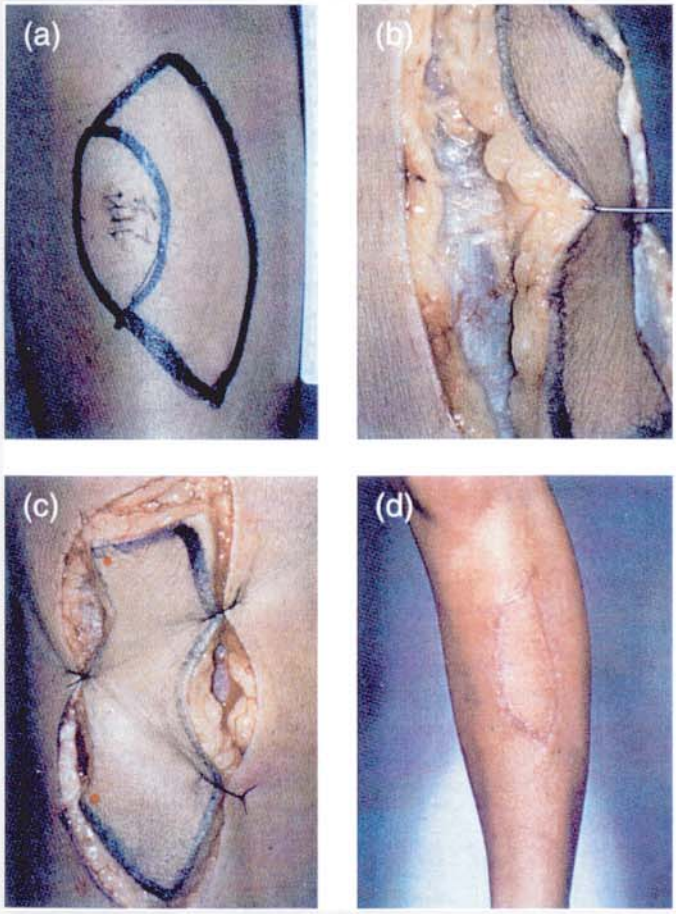

Fig. 5. (a)–(d) Illustrate the use of a Type IIA keystone flap to reconstruct a 5 × 2.6 cm soft tissue defect on the lower leg following a wide local excision for a level II malignant melanoma.

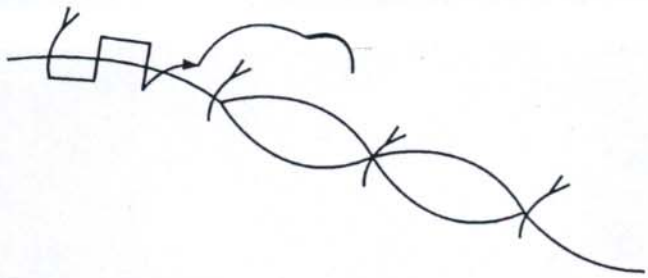

Fig. 6. Wound closure is achieved in three steps: (i) the stay sutures (using 3/0, 4/0, 5/0 nylon) approximate the wound at the points of tension; (ii) the Hemming suture is used to close the limits of the flaps. This is a single layer **H**orizontal **E**verting **M**attress **M**ethod of Sutur-**ING** which ensures dermal and epidermal apposition; (iii) Steri-strips are used to reinforce epidermal appostion.

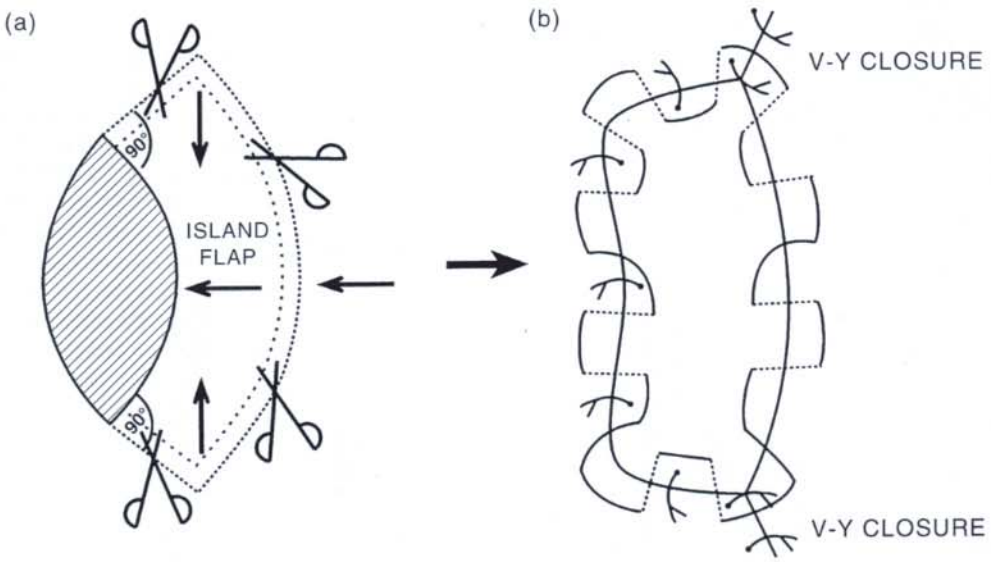

Fig. 7. (a) and (b) show Type I: used to reconstruct defects following excision of lesions up to 2 cm in size over most areas of the body. They Type I keystone flap is a skin island based on subcutaneous perforators.

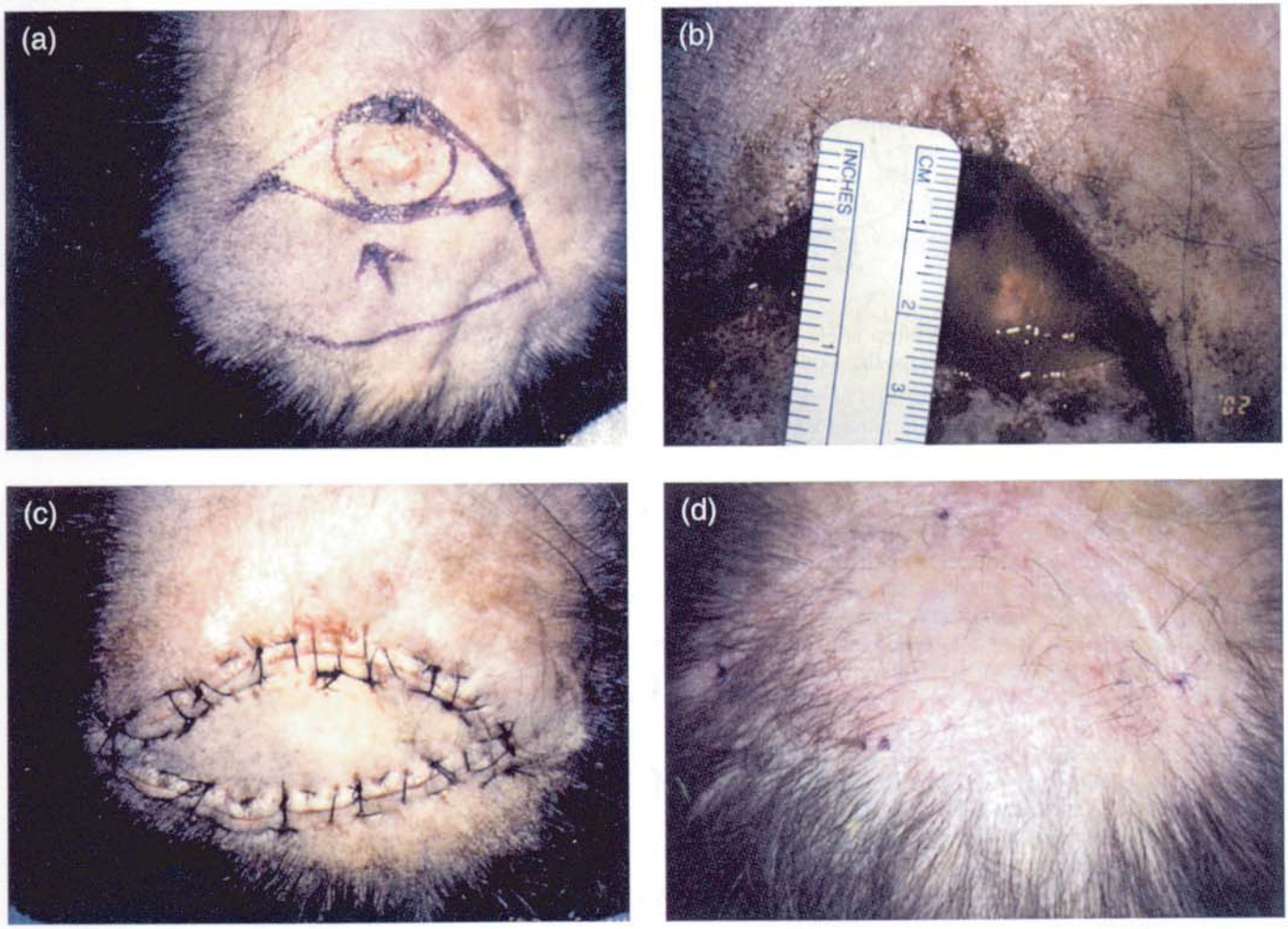

Fig. 8. Illustrates the use of a Type IIA keystone flap to reconstruct a 4 × 2.5 cm soft tissue defect in the scalp following excision of a SCC.

The first step in wound closure is direct apposition of the defect with interrupted single layer nylon sutures (Fig. 5c). Depending on the size of the defect, that may be two, three or four stay sutures in this single layer closure technique. Then the V-Y advancement of each end of the flap in the longitudinal axis is completed (Fig. 4b). This creates redundancy and laxity in the flap tissue at the right angle points of the flap which are excized. This also serves to narrow the whole defect. The wound closure of the relaxed keystone flap can now be completed using the hemming suture (Fig. 6) advanced in the horizontal axis into the original defect and sutured. Further undermining and release allows even distribution of tension and facilitates circumferential wound closure. A continuous everting horizontal mattress suture also helps to distribute tension evenly around the flap margins (B. Courtice, pers. comm., 1968).

To close the V-Y points initially may reduce tension. However, our technique of direct closure of the mid point helps to determine the need for a graft if undue tension exists and, therefore, employ a Type IIB technique. Stay sutures must be left intact for 14–17 days to prevent wound dehiscence.

Flap subtypes

Type I

The standard flap design and closure is suitable for defects over most areas of the body up to 2 cm in width (Figs 7a,b and 8a–d).

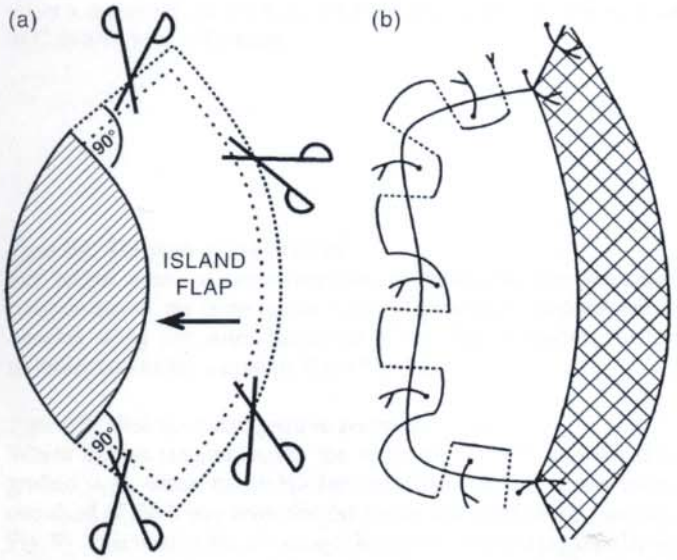

Fig. 9. (a) Type IIA: Division of the deep fascia along the outer curvilinear line to facilitate closure; (b) Type IIB: Skin graft to the secondary defect when undue tension exists.

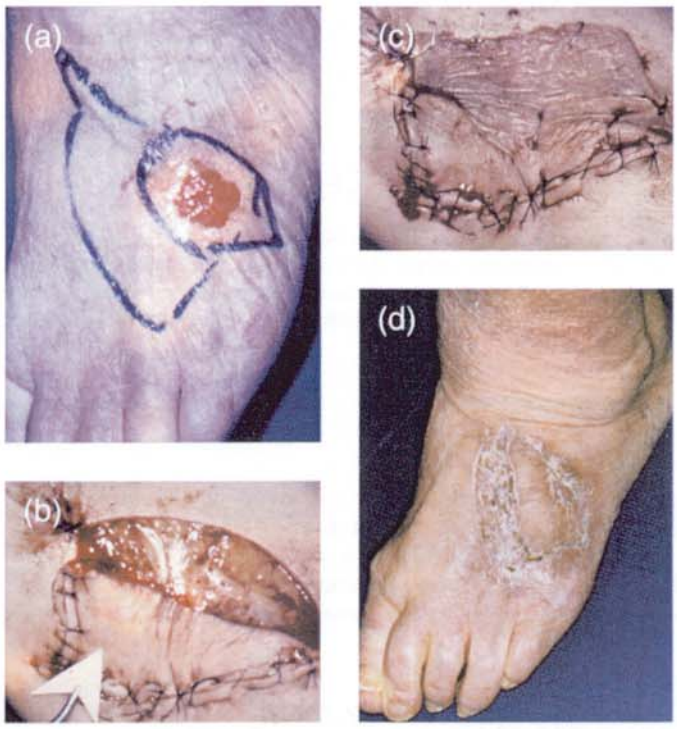

Fig. 10. (a)–(d) Illustrate the use of a Type IIB keystone flap and split skin graft to reconstruct a 4×2.2 cm soft tissue defect with exposed extensor tendons on the foot of a 78-year-old diabetic.

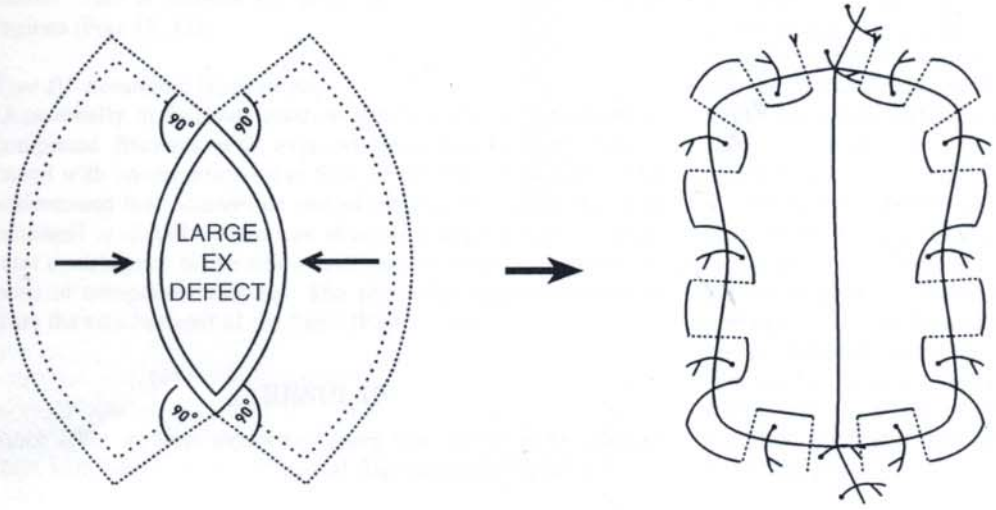

Fig. 11. Type III: Two identical opposing keystone flaps are designed to create a double keystone flap.

Fig. 12. This illustrates the use of a Type III double KDPIF to reconstruct a defect 8.5 cm × 6.5 cm × 1.5 cm following an excision of an SCC in a 68-year-old patient.

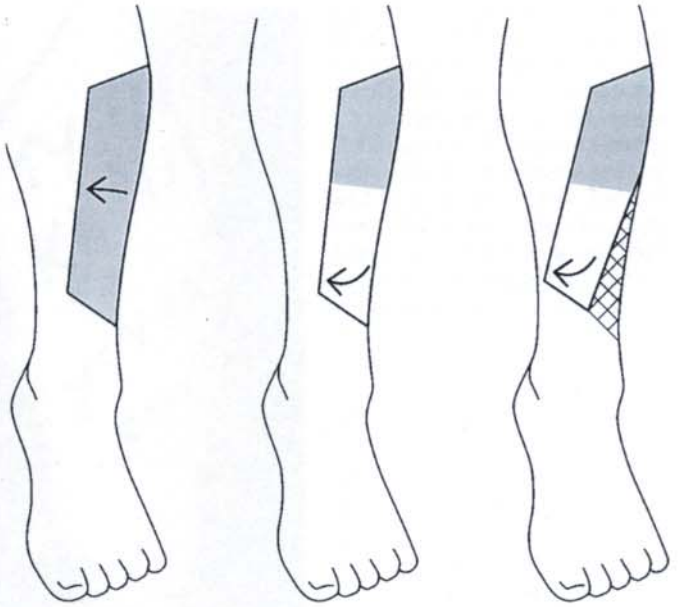

Fig. 13. Type IV: This KDPIF variant is particularly useful for compound fractures of the lower limb without reverting to free flap reconstructive techniques. Additionally it covers the bony defect with sensate tissue with a minor SSG donor site.

Type IIA: Division of deep fascia
For larger areas of reconstruction, located over the muscular compartments, the deep fascia over the muscular compartment is divided along the outer curvature of the flap to permit further mobilization of the keystone flap (Fig. 9a).

Type IIB: With split skin graft to secondary defect
Where excess tension exists, the secondary defect may be skin grafted (e.g., where tissue has limited elastic stretch on the lower one-third of the lower limb and the lower one-third of the forearm; Fig. 9). This retains the advantage, however, of allowing the flap to cover vital structures while the graft allows wound healing (Fig. 10).

Type III: Double keystone flaps
For considerably larger defects (5–10 cm) a double keystone design can be done to exploit maximum laxity of the surrounding tissues. This is suitable for large defects in the calf or sacral regions (Figs 11, 12).

Type IV: Rotational keystone flap
Occasionally to facilitate rotation across a joint contractures or compound fractures with exposed bone, the keystone flap is raised with undermining up to 50% of the flap subfascially. The undermined fasciocutaneous part of the flap that could be either proximal or distally based can then be transposed across large joint contractures of the elbow and knee or to cover the exposed bone in compound fractures. The perforator support is derived from the attached part of the flap[11] (Figs 13, 14).

RESULTS

Since 1995 we have performed more than 300 keystone design flaps with only one case of partial flap necrosis. Superficial flap necrosis occurred in the leg of a 78-year-old diabetic patient. Thus the flap survival rate in this whole series has been 99.6%. The procedure has been associated with excellent healing, minimal postoperative pain, minimal postoperative oedema and superior aesthetics. Six representative cases are illustrated in Figs 5, 8, 10, 12, 14, 15.

DISCUSSION

The vascular basis of this keystone flap is essentially fasciocutaneous perforator in type and has been well described by us and others.[1–5] Hence we use the terminology Keystone Design Perforator Island Flap. It is really an extension of the angiotome principle, designed as an island based on axial perforators from the underlying structures. However, to design a flap the same width as the primary defect immediately adjacent to it that has essentially the same mobility characteristics and to expect this to not only close that defect but also to permit direct closure of its own larger secondary defect seems empirically daring. What is it about the design that enables this to occur when the rules of length/breadth ratio seem to be over-ruled?[12] It was S. H. Milton in 1971 on the experimental studies on island flaps who said, 'an island is safer than a peninsula'.[13]

The flap has certain characteristics of a bipedicled flap,[6,7] yet this keystone flap is really two V-Y flaps side by side but facing opposite directions. In a conventional bipedicled design the secondary defect is usually larger than the primary and is not closeable without grafting. By converting this bipedicled flap into an island with V-Y advancement at each end, the longitudinal tension in the flap is released thus creating laxity and redundancy in its mid-portion that can then be moved further in a horizontal

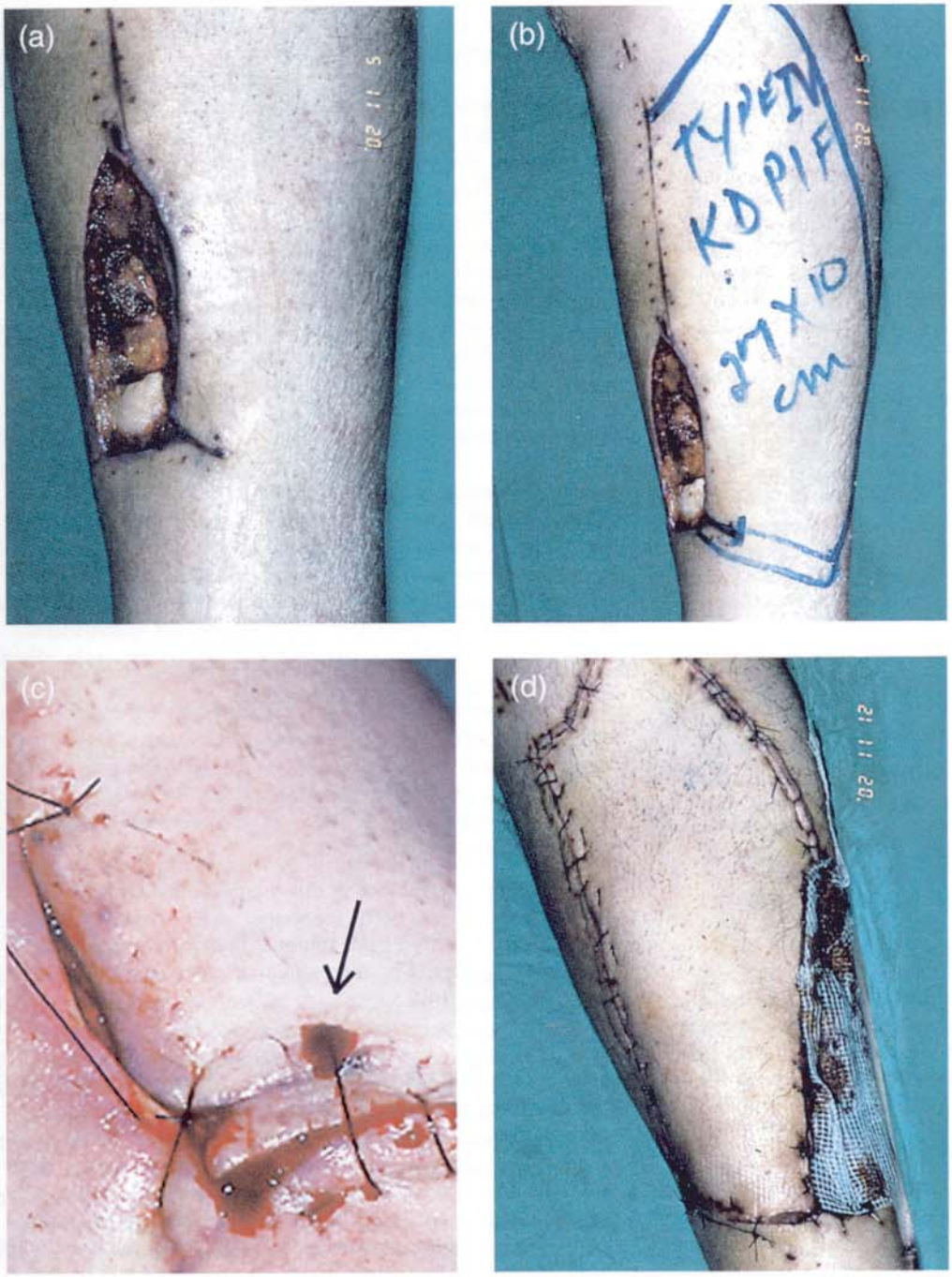

Fig. 14. Compound fracture of the tibia and fibula with a large soft tissue defect. Type IV KDPIF based on the peroneal compartment (L5 dermatome) in the distribution of the superficial peroneal nerve is really a fascio cutaneous island flap used to cover the skeletal and soft tissue deficiency. The secondary defect is covered with an SSG. (d) Shows appearance at 6 days – no flap necrosis.

direction towards the defect. Closure of the V-Y defects at each end narrows the whole defect complex so that the flap does not have to move so far horizontally (Fig. 4a,b). Similarly the secondary defect on the opposite side of the flap is reduced by this manoeuvre. Wide blunt dissection preserving neurovascular structures and teasing of the surrounding tissue facilitates their centripetal movement inwards circumferentially around the flap. Although there is considerable tension peripherally, the central portion of the flap does not move excessively relative to its underlying vertical perforators. These are consequently not subjected to the same tension.

Flaps when initially islanded appear hyperaemic perhaps because of denervation or vessel vasodilatation as confirmed by Doppler ultrasound (O. Hennessey and Morrison, pers. comm., 2001) at 14 days of their perforating vessels. It is conjectured that this is a sympathetic response and a sympathectomy is being performed to the small vessels via the blunt dissection. We have observed striking vascular changes in these island flaps. This may make them intrinsically more robust than skin based flaps which rely on horizontal blood flow and are more subject to tensional forces.[4,5,8,10] The *red dot sign* at a suture point is where arterial blood oozes on the

with the overlying skin compared with the tighter fascial or periosteal beds of the anterolateral aspect that allows very little direct advancement of overlying skin.

The perforating skin vessels of the lax muscle compartment are also longer and more stretchable than the short tighter vessel of the anterior region. In this sense the design is somewhat akin to the principle of the bilobed flap where the first flap closes the main defect while the smaller second flap – because it is now taken from laxer tissues – is able to close the secondary defect. In this case however, the second flap is direct advancement.

Postoperative pain is negligible and narcotics are rarely needed. The reason for minimal pain is presumably a result of the division of the cutaneous branches of the surrounding nerves in the dermis due to temporary denervation. When healing is complete the surrounding nerve supply usually returns to normal though some do complain of mild dysaesthesia particularly in the large flaps in the front of the thigh.

Somewhat surprisingly postoperative pin cushion type flap oedema has been minimal despite the islanded flap design. No doubt the underlying perforator support plays a role as well as the relatively large size of the flaps, including the possible stimulation of lymphangiogenesis associated with the island flap design.

Aesthetically the results have been pleasing. The ability to totally close relatively large defects with flap tissue from the immediate vicinity maximizes the aesthetic appearance compared with grafts or distant flaps which suffer from poor colour match, poor contour and secondary deformity. The nature of the curvilinear design of the keystone flap fits well into body contour dimensions (i.e., straight lines stand out, curves fit into the creases). Could this be the clinical application of Laplace's Law (tension inversely proportionate to radius) where the larger the arc, the less the tension.

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