



Keystone Perforator Island Flaps in Major Head and Neck Surgery – The P.A.C.E. Perspectives

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Abstract

The four main characteristics of the Keystone Perforator Island Flap (KPIF) technique are repeated and visually evident in any reconstruction and we use the acronym P.A.C.E. to synopsise these characteristics:

Painless: The patient does not experience pain in any aspect of the reconstruction but it just feels initially tight.

Aesthetic: Using like for like creates the best match of tissue in any location compared with the non-matching of tissue texture in free flap reconstruction.

Complications: Are remote and the only problems related to tensional closure and wound breakdowns and not any relating to vascular insufficiency.

Economic: The timeframe of the procedure in one-to-two-hour units compares favorably with any microsurgical saga that might have a 10% return to theatre because of microscopic failure.

This article demonstrates the value of the Keystone Perforator Island Flap (KPIF) when applied for loco-regional reconstruction on various aspects of the head and neck. The cases all originated from the Peter MacCallum Cancer Institute where Professor Andrew Sizeland and Steve Kleid sourced the cases and appreciated the value of the KPIF.

Historically the keystone flap, a conjoined double V-Y flap which originally dates back to Dieffenbach 1845 and his V-Y flap in facial reconstruction. In 1995 the original KPIF was used which was a blend of two V-Y islands and the random circulation of the base was the principle of their success.

The local flap is based on the principles of applied anatomy of the dermatomal markouts and the physiology of a sympathectomy effect which results in hypervascularization once the island design is completed around the dermatomal outline. This principle is used in flap salvage to increase vascularization by incising the site of origin on the flap through the skin and epidermis only while leaving 1/3rd of deep attachment. It is similar in context to the 'pink foot' outcome following a lumbar sympathectomy in the day's past in any vascular unit. Thus this principle is used when the flap is not a standard KPIF design Types I and II but when loco-regional flaps are islanded adopting the principle of hypervascularity, this avoids flap necrosis whatever the location as long as they are dermatomally aligned. The KPIF technique compares favorably with any microsurgical closure of the defect.

Keywords: Dermatomal alignment; Keystone Perforator Island Flap; Head and neck oncological defects; Clinical observation; P.A.C.E. acronym

Introduction

The concept of the keystone flap first arose in 1973 when the senior author was a post-fellowship research fellow in London, studying the blood supply of skin. He introduced the concept of the Angiotome, a system of linked vessels with axial patterns in the dermatomal markouts of the head and neck and chest region. This was presented at the 6th International Congress of Plastic and Reconstructive Surgery in Paris, 1975. Professor William Manchester of Middlemore, Auckland came up to Dr Felix Behan, after the presentation saying "I do not know where you are coming from but keep it up" and urged him to persevere with this original thinking [1]. The basic concept of the keystone flap is that vessels in the integument follow nerves within the dermatomal alignments thus; to design flaps transversely crossing dermatomal alignments is wrong in principle in flap design in

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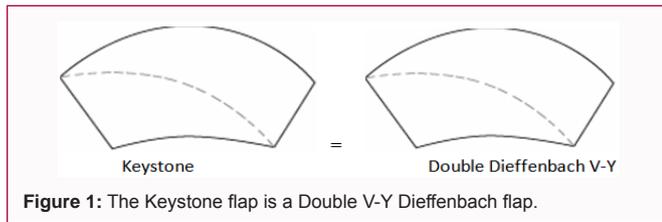


Figure 1: The Keystone flap is a Double V-Y Dieffenbach flap.

any situation. The flap is therefore based on random axial perforating vessels and as a neurovascular island flap is designed within the local dermatomal pattern, adjacent to the defect. The pioneering German surgeon Dieffenbach (1792 to 1847) described a V-Y advancement local flap concept in 1845, which has been refined over the last 150 years of modern surgery [2]. The senior author's keystone flap mirrored Dieffenbach's original concept but duplicated when one considers a diagonal across the keystone outlines a conjoined double V-Y advancement flap. Earlier work into design development resulted in a curvilinear V-Y flap which we call the Bézier. This allowed V-Y points to close defects rather than the flat triangular base, so characteristic of the original V-Y Dieffenbach design. The French mathematical engineer established the Bézier curves and this has been the design terminology when curvilinear designs are introduced into the V-Y flap. This original double V-Y arc flap was called keystone on the suggestion of a plastic surgeon, Alan Briedal FRACS of Melbourne. This recognizes the keystone architectural principle of the arc design in Moorish architecture which was eventually used in the Colosseum in Rome in 70 AD. The construction of bridges over a distance is based on arc design (Figure 1). Over the last nearly 50 years this design has been refined, developed and applied in various areas of reconstruction all over the body from a loco-regional perspective. One is fully aware that every aspect of embryological tissue is retained in the flaps including arteries, veins, nerves somatic and autonomic, lymphatic and even humoral factors. It is the basis integumentary pattern of the dermatome as long as there is 1/3 deep attachment in this fascial lined island flap. It compares favorably with any microsurgical free flap with only its artery and vein in the main [3-18].

The science behind the keystone flap

William Osler (1849 to 1919) the influential Canadian physician said that 'observation is the basis of scientific advancement'. The observational findings of the KPIF led him to search for the physiological basis for how they work. This was inspired by other research published in the surgical literature on angiogenesis, the increased blood supply in tissue-expanded flaps, concepts in endothelial stress. The static dimension in facial nerve repair with keystone closure gives a tonal appearance to the face which is far preferable to the facial palsy droop in spite of attempts of reconstruction.

The challenge was how to come up with a good research question from the clinical observations. The hypothesis behind any research principle as quoted by Professor Peter Doherty formulates questions considering:

1. A questioning mental attitude is the first step in the research process.
2. Research begins with that question which leads to the hypothesis.
3. Most quality research consists of comparisons.

4. By carefully selecting a comparison group or condition, the quality of the research can be improved.
5. The best questions come from the investigator's subject of interest.
6. The key is to start small and choose an experienced mentor.

Clinical signs and observational facts for the keystone flap

These can be categorized as arterial, venous and neural features.

1. The flap is a total island flap and for the lateral face region, is composed of skin, subcutaneous tissue, SMAS layer and platysma muscle. This is the basis of the myocutaneous island flap.
2. In Type IV versions of the flap, undermining of 40% to 50% occurs. This includes skin, fat and fascia often raised by blunt dissection.
3. The flap is planned within the dermatome and random perforators are not specifically located. The Doppler probe is not necessary.
4. The Red Dot Sign (point rouge) is a sign of hyperemia in the is-land flap as the perforator's vasodilate after approximately 15 min.
5. It is technically important to retain all venous draining tributaries. Even the external jugular vein is repaired, if damaged, in a neck clearance.
6. This blunt dissection facilitates undermining and stretching with movement around the limits of the flap and thus not dividing any filamentous neurovascular or lymphatic structures.
7. Flaps are closed under tension and the white lines of tension disappear as the vascular perfusion in the fascial base prevents any image of necrosis. Sometimes a secondary defect warrants a graft.
8. Postoperatively the pain is almost zero but the patient mentions that the tightness of the repair is evident. There is of course temporary denervation like that which is experienced in any clinical situation. This recovers in a few months.

Dermatomal precincts

The dermatomes are the compass markout becoming an aide memoire to define random perforator based fascial lined flaps. This KPIF principle of hypervascularization uses the dermatomes and is skinned to a delay procedure in loco-regional flaps. This increases the hyperdynamic perfusion as long as 1/3rd of deep attachment is maintained after the dermal/epidermal incisional markout creates the island pattern. Costly angiography is not required avoiding delay with such investigations. Intact nerve supply indicated intact blood supply. The KPIF flaps recover somatic sensation. The common dermatomes used in lateral face reconstruction are illustrated in Figure 2.

The clinical features of the keystone island perforator flap can be summarized in the acronym P.A.C.E.

Pain: The keystone flap reconstructions are relatively pain free, reducing the need for strong analgesia such as narcotics. There may be a feeling of tightness and loss of cutaneous sensation in the flap, which recovers in 3 months, like any surgical wound.

Aesthetics: The outcomes produce aesthetically acceptable reconstructive outcomes. It adheres to the Gillies's principle of using 'like for like'. Color mismatch is avoided when compared with

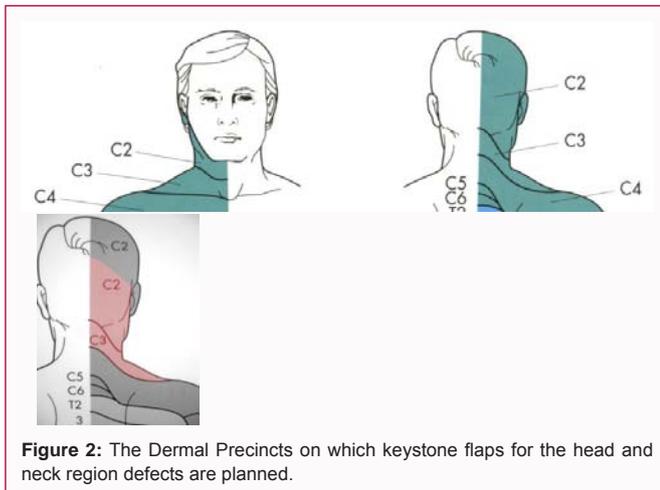


Figure 2: The Dermal Precincts on which keystone flaps for the head and neck region defects are planned.

microsurgical free flap repairs.

Complications: Vascular complications are rare and lines of white tension usually are eliminated when the subfascial circulation allows joint perfusion throughout. Tension sutures using a locking mattress technique are an essential for wound integrity and must stay in at least three weeks for fear of wound breakdown. At wound dressing for removal of sutures if any excess ooze develops it is a warning sign that healing is not complete and the wound should be brought back in a week.

Economics: Time is money is a standard financial quote and to reduce theatre time this has the advantage for the elderly patient in any reconstruction that can be executed in an expeditious manner. In microsurgery such principles do not universally apply.

Surgical principles for raising a keystone island flap

1. Using dermatomal alignment in the keystone shape the KPIF surrounds one side of the defect. The deep fascia along the curvilinear aspect of the flap must be divided to facilitate movement of this tissue bridge. At the limits of the flap skin subcutaneous tissue is provided to preserve the integrity of longitudinal running structures like veins and nerves.

2. The flap consists of skin/fat/fascia and all possible neurovascular connections, particularly superficial veins to eliminate venous stasis.

3. To facilitate rotation/advancement/transposition, the keystone flap can be undermined at the subcutaneous plane for up to 2/3rd of its dimension, with the remaining 1/3rd attached for random perforator perfusion.

4. When the loco-regional flaps do not match the design of the standard KPIF, islanding around the dermatomal markout is the lifeline to ensure hypervascularity while leaving 1/3rd of deep attachment.

Case Series

A series of 12 cases is illustrated to demonstrate the clinical and surgical application of the keystone island perforator loco-regional flap for patients with advanced cancers of the head and neck.

Case 1: Flap salvage by using the KPIF island principle of hypervascularization

This 77-year-old developed a secondary melanoma of the neck



Case 1:

over the (R) occiput region. His primary in the (R) parietal region was initially treated months before the secondary node development. The surgical excision including the posterior neck node mass created a defect 5 cm × 3 cm × 2 cm. The undermined flap for the anterior neck clearance (levels II, III, IV) is evident. To close this wound would have resulted in flap necrosis in its posterior limit. A KPIF in a C2/C3 dermatome was the means of closure and the is-land flap technique produced the hyperemic phase when the skin only (dermis and epidermis) is incised retaining 1/3rd deep attachment to ensure intact healing. This one characteristic of the KPIF is its hyperemic phase, which usually develops between 15 min to 20 min. This significant vascular perfusional dynamic to eliminate any cyanotic development which is a harbinger of potential necrosis. The undermining 2/3rd of the posterior island neck flap leaves an anterior attachment of approximately 1/3rd over sternomastoid to pick up random perforators. The timeframe of the documented images can calculate this development from a 4.14 pm timeframe to 4.18 pm to 4.25 pm which is the time for hyperemic development. This hyperemia is evident in the closed wound without lines of tension outlining tension which are controlled by this KPIF characteristic. The patient healed without complication or flap necrosis expediting the earlier treatment with XRT. The white arrows sit on the Red Dot Signs which is the epidermal manifestation at the suture point of the hypervascularity in the island flap. This occurs on the flap rather than the insert side. A Pain-free postoperative phase ensued and an Aesthetic reconstruction is evident - like for like and normal for normal a la Gillies. There were no wound complications and an economic timeframe (operating time approximately 1 h). Additionally, no flap necrosis, no recurrence at 18/12 and full facial nerve function.

Case 2: A standard KPIF reconstruction in the elderly with undermined tissue

This 80-year-old male developed a malignant mass of his (L) infraclavicular region and concurrently was recovering from a recent CVA. The oncological defect size with a periosteal strip of the (L)



Case 2:

clavicle created a hole 13 cm × 6 cm because of skin attachment. This was removed in association with a complete (L) sided neck clearance. The closure, using a KPIF, is indicated and sits along the intercostal dermatome of T4 at the level of the manubrium. The (L) middle finger shows the extent of undermining in the superior extreme, almost to the (L) mastoid. The KPIF along the T4/5 intercostal region is based on intercostal perforators to guarantee healing. The white arrows indicate the developing hyperemic phase to ensure healing by islanding the keystone design.

Single layer wound closure technique:

1. Tension locking mattress sutures are inserted at the prime tension points.

2. Mattress sutures complete the closure as this single layer.

3. A continuous nylon suture produces epidermal closure.

Wound dressing technique:

1. Cut the nylon loops at ten days.

2. Before some of the mattress sutures can be removed at two weeks.

3. Tension sutures stay in three weeks plus.

Case 3: Recurrent melanoma of the (l) conchal fossa – a standard submental KPIF

This 68-year-old male with a recurrent melanoma of the (L) conchal fossa warranted excision in association with a neck clearance and surgical closure of the 8 cm × 5 cm defect with a partial auriculectomy. The KPIF closure is a cervical submental flap in the C2/C3 dermatome from the submental region and turned at 90° into the auricular defect and 1/3 of the island flap is left intact over the (L) sternomastoid. The wound closure is completed and the black arrow is the point of maximum tension and this locking mattress suture must stay in at least three weeks. The postoperative appearance is an



Case 3:

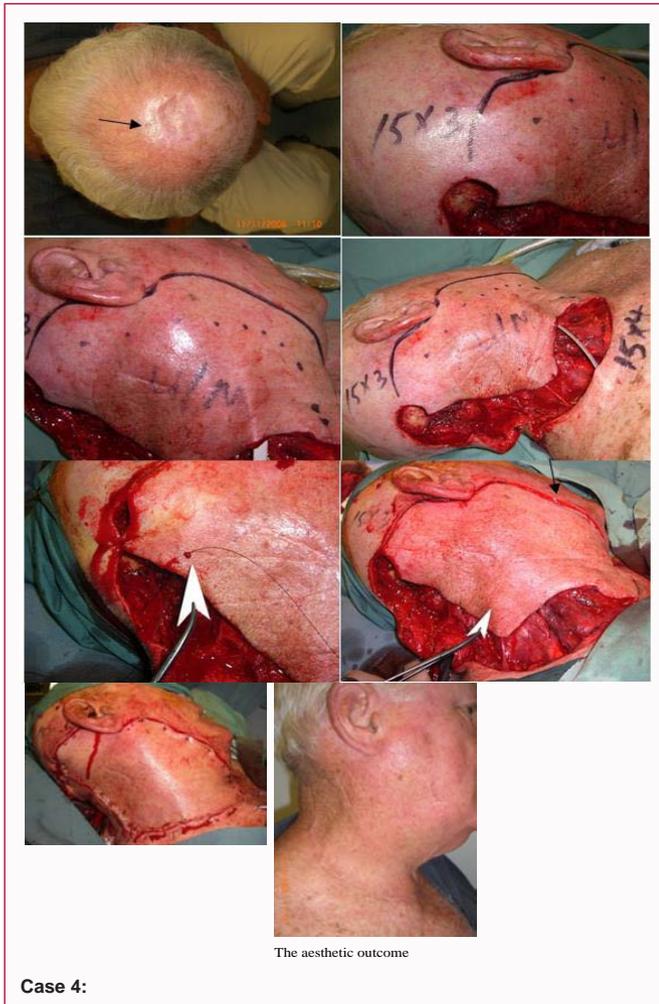
acceptable method of healing and notes his gleeful appearance and a small remnant of ear for his glasses. This technique is preferential to any microsurgical replacement.

Case 4: Creating the island flap of the neck to increase vascularity in a large loco-regional design using the KPIF principle

This 62-year-old male working in the corporate world (yet enjoying golf) sustained a melanoma of the posterior scalp which was excised and grafted approximately 2 years earlier (black arrowed). He developed an occipital mass of secondary melanoma. The occipital and neck clearance resulted in a defect measuring 15 cm in length and 4 cm more superiorly and 3 cm more inferiorly. The Redivac tubing is installed and the continuous line 3 cm beyond the excisional defect dotted indicates the deep attachment of a 1/3 of the size of the flap to tap into sternomastoid random perforators in the C2/C3 dermatomes. The epidermal incision to create an island flaps to hypervascularized the tissue. The white arrow indicates the point of the Red Dot Sign bleeding more on the KPIF site than the insertion site. The inferior white arrow is at the apex of the flap noting the hyperemia. The anterior limits of the flap again islanded but closed directly in repair, this ensures that the hyperemia preserves vascular integrity. This would be the site of necrosis if the KPIF hypervascularization technique was not applied. The wound closure with Redivac installed. The postoperative phase was pain free yet a feeling of tightness was evident. The postoperative appearance at three months with an acceptable aesthetic outcome, without complications in an economic timeframe. The patient was quite elated with the outcome when he saw alternatives.

Case 5: A standard type I KPIF to give an aesthetic repair in a lady's face regardless of age

This 63-year-old female with a Clark LII 1.2 mm of the (R) cheek over the (R) parotid. The defect created following a parotidectomy and upper neck clearance was 6 cm × 4 cm. A keystone around the



phase is developing and the direct closure of a single KPIF with deeper anterior attachments closes over to the preauricular groove. The white arrows indicate the Red Dot Sign and the timeframe is 9.54 am when the wound is totally closed at 10.25 am. Postoperatively the patient was pain free with an element of tightness in the closure, aesthetically normal without complications or facial nerve dysfunction and a timeframe was economical. The wound dressing technique of cutting the continuous nylon at seven days for a facial wound, some of the mattress at two weeks and the other tensional locking mattress sutures at three weeks. Appearance for eight days.

Case 6: Extremes of age is not a contraindication

This 99-year-old male with a Level II melanoma of the (L) jaw region was in a nursing home until he became a medical problem. The surgical defect of 6 cm x 7 cm was closed with an anterior KPIF in the same manner as Case 5. The timeframe for theatre was 1 h as on the date of photography and the patient was off the table, to everyone's satisfaction, expeditiously. The operation notes are included for verification and the case was done with the patient's permission to take digital imaging.

Case 7: Delayed reconstruction after pathology evaluation - the drape procedure

This 75-year-old farmer presented with a Malignant Melanoma in a Hutchinson's Melanomic Freckle. The Drape procedure applied (delayed reconstruction after pathology evaluation) and once the clearance had been obtained following repeat excisions a defect 10 cm x 6 cm over the (R) forehead eminence was the clinical problem. Applying keystone principles without keystone design we mobilized all the cheek tissues superficial to the SMAS layer, islanding the total area for the reconstruction which allowed the apex of the flap to reach across to the (R) glabella region. This design is not of the keystone outline but shows the keystone characteristics of hyperemia and is based on the V2 trigeminal dermatome. Note the outline of the epidermal/dermal incision only along the margins of the V2



anterior limits of the defect was based on perforators over the SMAS region and the 12 cm x 4 cm KPIF has been outlined. The hyperemic



Using the V2 dermatome of the trigeminal nerve and its vascular support to close the forehead defect with advancement and rotation



Case 7:



A 2-year appearance postoperatively of the reconstruction and with the static nerve facial reconstruction. The slight epiphora necessitated a delayed tarsorrhaphy which was not warranted initially.

Case 8:

dermatome is just incised and closed directly to facilitate the islanding and its resultant hyperemia in suspect flaps or flaps used under tension. The wound is closed directly including the nasolabial and mandibular incisions. These have only a minor part in the rotation advancement but the island incision is the basis for the hyperemic success.

The timeframe for the closure of 45 min is documented. The postoperative appearance at two days is noted as is the appearance at two years.

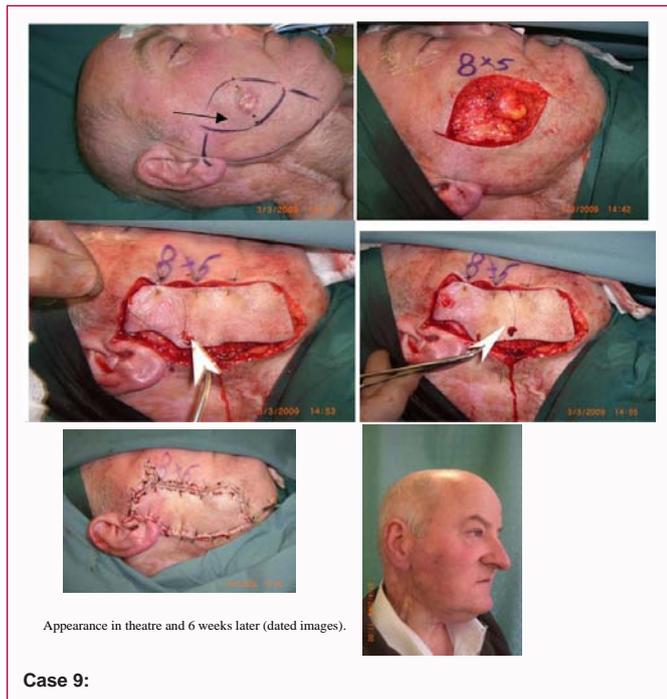
Case 8: Radical parotid excision including TMJ

This 68-year-old male farmer with a recurrent Melanoma of the (L) preauricular region as illustrated in images 1 and 2. The excision of the tumor mass involving the (L) TMJ meant the facial nerve had to be sacrificed with the neck dissection of level II, III, IV. The surgical defect was 10 cm × 6 cm over the (L) preauricular region including the zygomatic arch and cyanotic changes developed in the neck exploration flap. Note the external jugular vein not involved with any malignancy was preserved as a venous drainage lifeline should anything untoward occur with venous thrombosis which may have an effect on flap necrosis. The total area of the V2 dermatome is delineated surgically at the dermal epidermal level only to island this flap based on keystone principles. Such a reliable vascular change allows one to rotate the inferior limits of the neck flap into the apex of the preauricular groove to close the wound directly around the margins and inferiorly into the neck. The ‘dog ear’ is observed and with the reliability of the circulation the dermal epidermal excess is excised while the cervical fascia is retained. Direct closure is achieved under Redivac drainage. No facial nerve reconstruction is attempted and the benefits of grafting in time leave a lot to be desired. We have used the static factor of facial nerve palsy and the tensional closure eliminates any evidence of facial dysfunction. The effect on the eyelid is also enough and was only after two years, with a slight ectropion that a tarsorrhaphy was offered but the symptoms were minimal.

The nasolabial limits of the loco-regional neck flap are incised to convert to a full island flap outlining the V2 area. This part is not undermined but just closed directly confirming that islanding hypervascularizes tissue in the keystone manner. This allows the surgeon to advance, rotate and transpose, even under tension to close a surgical defect. The tightness avoids a tarsorrhaphy and even ‘dog ears’ can be excised (arrowed) at the epidermal/dermal level.

Case 9: Irradiated tissue is not a contraindication with the use of the KPIF

This 62-year-old barber and a smoker had a CA of the (R) tonsillar fossa treated with XRT. He developed radio necrotic changes in the (R) neck treated with PEC major flap which was successful. The radiation field reached to the level of the angle of the mouth and the globule of the ear and that lesion on the (R) cheek arrowed with a level II, III melanoma of 1.2 mm thickness. The excisional defect of 8 cm × 5 cm in the irradiated field was down to and preserving the integrity of the facial branches of the angle of the mouth. The buccal pad of fat is noted and the blue dots above and below have been the branches of the facial nerve preserved. The inferior based arc keystone is along the line of the mandible but in an irradiated field with random vascular input from the facial artery anteriorly and the superficial carotid posteriorly. The keystone is outlined at the dermal epidermal level without excessive undermining because of the concern of radiation vasculitis and potential for necrosis. However, the looser neck skin allowed direct apposition. The first



keystone image has a white arrow on the inferior limits of the island flap indicating a poorer vascular perfusion and the upper limits of the flap again, reflect this vascular impedance caused by radiation. The adjacent keystone image arrowed shows not a Red Dot Sign but one with a cyanotic changes again, confirming the slow vascular perfusion. The image on completion confirms the timeframe of 75 min and the completed picture shows an aesthetic outcome and the entire PACE characteristics were evident.

Case 10: Large defects are not a contraindication for the KPIF following oncological clearance

This 70-year-old female had an extensive level II melanoma of the (R) cheek with neck gland involvement and the excisional defect measured 10 cm x 9 cm. Note the preservation again of the external jugular vein to maintain venous drainage integrity. The (R) cervical neck flap of a modified keystone design is islanded 5 cm besides the undermined section which was part of the surgical clearance. It would be folly to create an island at the limit of the neck clearance. The islanding with deep attachment creates an incision along the line of the clavicle but with bending of the cervical spine into the area of the apex of the cervical flap, closure was achieved. A timeframe of 25 min has been documented and with Redivac clearance the hyperemic phase is evident throughout these cervical flaps. The postoperative appearance is evident at three days and at ten days the continuous nylon suture has been cut while the tension points stay in total three weeks at least. I bring to your attention the satisfied look on the patient who has had major surgery, who is pain free, who has retained her aesthetic appearance without undergoing any complications in a short timeframe the PACE characteristics are once more illustrated.

Alternative microsurgical techniques and limitations

Free flaps are the alternative options to close defects illustrated above. These are commonly practiced around the world. When the P.A.C.E. characteristics of the KPIF become appreciated this alternative reconstructive tool should be considered in most situations. Younger surgeons should be aware of this alternative reconstructive tool and while senior surgeons should encourage



training in this technique as well.

Cases 11 and 12: Non KPIF cases from other units

We will illustrate alternative methods of reconstruction using microsurgical repair which produce complications. This 88-year-old followed a free flap of the parotid. The forearm defect following a free flap harvest was still unhealed at four months in this octogenarian. He subsequently developed an ectropion. The thigh also was delayed in healing.

Note the disturbed aesthetic appearance after XRT of this large preauricular malignancy closed with a high volume latissimus dorsi microvascular free flap. He became a social recluse, embarrassed to go out in the street, even had to wear a beanie on hot summer days when outing.





Case 12:

Conclusion

The concept of the angiotome, from which the keystone flap evolved, began in 1973 whilst researching the blood supply of deltopectoral flaps at the College of Surgeons in London as part of a research program about vascular integrity in flaps. The keystone concept evolved over the years and the value of island flaps and their hypervascularity, even based on random perforators, was the conclusion after 30 years of surgery. The role of the dermatome precincts and the intrinsic neurocutaneous vascular supply of the human skin was the compass to guide, design in reconstruction. These flaps are robust all over the body and complications are rare even in older debilitated patients, diabetics, the immunosuppressed or the patients burdened with aggressive skin cancers. Contrary to standard practice, a single layered closure is a preferential method of wound apposition with tension locking mattress sutures at the key points followed by a simple mattress and finally a continuous nylon produces wound closure. As blood vessels and lymphatic vessels are intimately linked with the nerve supply, so the KPIFs based on random multiple arterial perforators with their vena comitantes provide the vascular networks for satisfactory healing. Division of the deep fascia is an essential pre-requisite in the keystone flap to protect the vascular layer in the suprafascial and infrafascial compartment and allows undermining up to 2/3^{rds} while not impairing vascular integrity. This technique, once mastered, could be described as sentinel in mastering difficult reconstructive surgical challenges. The avoidance of complex investigations in this surgical technique which could only be described as expeditious and noteworthy. The time-consuming activity and theatre exposure in the elderly and the risks thus entailed need no further elaboration as the death rate is directly proportional to the time rate. Whereas with the KPIF the inverse factor applies when considering time and loco-regional flap salvage by creating an island outlined by the dermatomes using the KPIF principle have all evolved from the number of cases done over the years which have exceeded 3000 over 20 years. Dr. Frederick J Menick wrote in 1998 about the interface of aesthetic and reconstructive surgery in facial reconstruction [19]. Distant tissue does not match facial skin in color, texture or thickness. Nor does it have facial shape. The subunit approach employing loco-regional tissue in contrast improves the aesthetic reconstructive result. Herein lies the useful option of the KIPF for facial reconstruction.

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