

# Keystone flap as a reconstructive option in complex posterior midline defects

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## Abstract

Local flaps or based on a single perforator have great utility in reconstructive surgery, however, its use is complicated posterior midline due to the characteristics of the tissues, the keystone flap described in 2003 has become one of the main options for reconstruction due to safety, easy reproducibility, shorter surgical time, and shorter learning curve, there are three cases of posterior midline defects where the characteristics of the patient required a shorter recovery time with adequate functional and esthetic results.

**Keywords:** Keystone flap. Posterior midline defect. Perforator flap.

## Introduction

Posterior midline defects due to pathologies in the spine represent a great challenge for the plastic and reconstructive surgeon. Due to the nature of the adjacent soft tissues, management with local flaps gives limited coverage options with the need to perform multiple procedures; this does not always lead to adequate functional and esthetic results, which generates frustration for the surgeon and the patient. Management with microsurgical options has become the gold standard for the coverage of these defects, however, this option is not feasible in all hospital centers worldwide, due to the lack of adequate optical and instrumental equipment, as well as the training and the necessary curve of a microsurgeon.

Since its first description in 2003 by Behan on the reconstruction of skin defects in the face and trunk region, studies have been carried out demonstrating

the usefulness of the keystone-type flap, in its many modifications, for coverage of defects that are difficult to manage, such as the trunk, limbs, or periarticular region with adequate results.

Behan's original technique indicates the elliptical excision of the defect parallel to the vascular perforators, this consists of taking the side adjacent to the defect with greater laxity, followed by an incision at 90° at each end of the defect with a length ratio of 1:1 (with the maximum width of the defect and joining parallel to the ellipse of the defect). If the defect is greater than 2 cm, a blunt dissection can be performed on the edges of the flap to facilitate advancement, respecting the ipsilateral edge of the defect. Scheme (A) Elliptical Defect (B) Keystone Flap Design, Trapezoidal shape with 90 degrees angles and width of flap at same ratio as the defect.

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This manuscript presents three cases of the use of the keystone flap for the management of defects that are difficult to manage due to their dimensions, characteristics such as bony projections, or exposure of the spinal cord in the posterior midline with adequate functional and esthetic evolution.

### Case 1

A 40-year-old male patient with a history of spinal instrumentation. He subsequently presented a surgical site infection that conditioned multiple surgical toilets with surgical wound dehiscence secondary to poor general conditions of the wound edges and high tension in the primary closure. After this, surgical cleaning of the wound, antibiotic impregnation locally, remodeling of non-viable wound edges with a resulting bloody area of approximately 18 × 9 cm with bone exposure, and osteosynthesis material are performed in conjunction with the neurosurgery service. Coverage is performed with a bilateral keystone type flap (Type 3) with adequate coverage of bone protrusions, edges are faced with closure in three planes, placing closed drainage type drenovack. The patient presents partial superficial dehiscence of the advancing edge in VY which improves with local care, with removal of the drain 7 days after surgery (Fig. 1).



**Figure 1.** Total closure of the keystone flap with Monocryl suture and placement of Nylon suture to decrease tension, without vascular compromise.

### Case 2

A 57-year-old male patient with increased volume in the lumbosacral region and a diagnosis of probable chordoma. He presents partial resorption of the vertebral column at the lumbosacral level as well as spinal cord injury conditioning paraplegia. In the first surgical stage, the tumor was resected by neurosurgery, obtaining a surgical piece of approximately 20 × 18 × 18 cm, with a resulting bloody area of 20 × 17 cm; bilateral keystone flap (Type 3) is implemented and the edges adjacent to the wound are de-epithelialized to obliterate the dead space and cover bone protrusions. Afterward, a closed drenovack-type drainage is placed, obtaining closure in three planes without tension, presenting adequate evolution without wound dehiscence or some other minor or major complication during post-surgical consultations, however with a subsequent increase in volume at approximately 6 months of follow-up secondary to recurrence of chordoma, for which palliative management is performed due to lineage (Figs. 2 and 3).



**Figure 2.** Resulting wound of 20x17 cm with vertebral exposure and loss of paravertebral muscle anatomy.



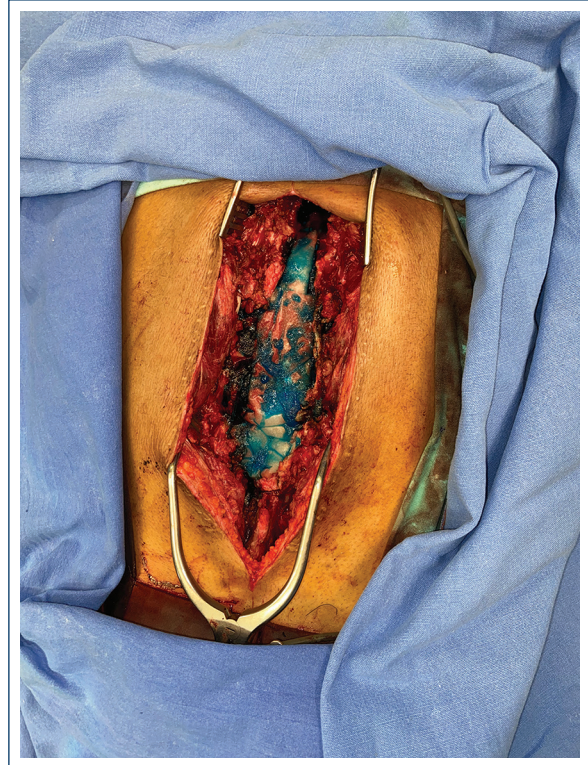
**Figure 3.** Bilateral keystone flap with de-epithelialization for space obliteration, closure with Monocryl suture and placement of Nylon suture to decrease tension, without vascular compromise.

### Case 3

A 45-year-old male patient presented with an increase in volume in the region of the spinal cord at the thoracolumbar level that caused bone resorption and paraplegia. Resection was performed by neurosurgery, obtaining a tumor of approximately 25 × 15 × 8 cm and a resulting bloody area of 22 × 12 cm with bone and spinal cord exposure. A gelfoam-type hemostatic plug and fibrin sealant are placed by neurosurgery; subsequently, coverage is performed with a bilateral keystone flap (Type 3), with de-epithelialization of the edges for adequate coverage of bone protrusions, closed drainage type drenovack is placed, it is faced in three planes, achieving adequate closure without tension, with adequate post-surgical evolution without presenting major or minor complications with current favorable follow up at 3 months (Fig. 4) (Fig. 5).

### Discussion

During the history of reconstructive surgery, different options have been developed for the management of defect coverage. Koshima and Soeda described a musculocutaneous flap with skin island based on the inferior epigastric artery for the reconstruction of defects, Kroll and Rosenfield conducted studies on perforator flaps showing vascular reliability comparable to that of musculocutaneous flaps, but with decreased morbidity of the donor site by avoiding the extraction of muscle; evolving into propeller flaps first in 1991 by Hyakusoku



**Figure 4.** Resulting wound of 22x12 cm with bone and spinal cord exposure, after placement of gelfoam hemostatic and fibrin sealant for spinal cord coverage.

et al., and later modifications by Hallock and Teo. Taylor and Palmer studied and introduced the concept of angiosome, about the static vascular territories of each vessel with its perforators, and later, Saint-Cyr introduced the concept of perforator vascular territories distinct from individual perforators, which have significant interactions with adjacent perforators<sup>1</sup>.

The keystone flap described by Behan in 2003 is a flap with a trapezoidal design and curvilinear shape. It is essentially two V-Y flaps from one side to the other. The curvilinear shape adapts well to the contour of the body and is designed within the dermatomes adjacent to the defect, originally described for the reconstruction of defects after excision of skin cancer, beginning its use in head-and-neck reconstruction with subsequent use in trunk and extremities, presenting high flap survival rates, low risk of both minor and major complications, decreased pain, and faster post-operative recovery<sup>2</sup>.

In relation to its movement, this is an advancement flap based on random fasciocutaneous or musculocutaneous perforators through the transfer of adjacent tissue with adequate soft-tissue laxity. This flap can be



**Figure 5.** Bilateral keystone flap with de-epithelialization for space obliteration, after placement of closed drain, closure with Monocryl suture and placement of Nylon suture to decrease tension, without vascular compromise.

a primary reconstructive option or planned as a complement for supplementary soft-tissue coverage, requiring knowledge of hot spots or hot spots that allow skin islands to survive through known musculocutaneous and fasciocutaneous perforators. It may be necessary to visually identify it intraoperatively, thus reducing operative times. The distribution of perforators is relatively predictable, with almost 400 perforators found in the body, and although Doppler marking is not mandatory, knowledge of these zones or hot spots ensures that the flaps are centered on them and that the axis of the flap is oriented to include dominant connecting vessels between them<sup>3</sup>.

Named after the cornerstone of an arch in Roman architecture, the keystone flap typically has a long axis to short axis ratio of 3:1, planning the long axis of the flap parallel to the distribution of cutaneous nerves, veins, and known perforators to allow possible preservation of cutaneous sensation and to maintain as much axially as possible of the flow of the dominant perforators. Advancement of the flap into the defect along the short axis creates redundancy and subsequent

soft-tissue laxity in the long axis of the flap, resulting in an increase in the length of the flap along its short axis, which is the area of greatest stress during closure. VY advancement should be performed at each end of the flap in the long axis to further decrease the size of the donor site defect by lowering the tension of defect closure<sup>4</sup>.

Originally, the short axis of the keystone flap was designed to have a 1:1 relationship to the short axis of the defect, and the flap extremities were angled 90° to the long axis of the defect. Modifications in flap design and harvesting give the reconstructive surgeon greater freedom to maximize tissue use and decrease the risk of complications. Modifications include an increase in the ratio between the size of the flap and the size of the defect, de-epithelialization of a segment for obliteration of the dead space, circumferential incision of the deep fascia, keystone flap with a distal or proximal base, bilateral flap, and angulation asymmetric limb to avoid critical structures. Modifications include maintaining a skin bridge, partial undermining, folding the flap into an “omega,” or rotating it in a bilateral “ying-yang” configuration; de-epithelializing a portion of the flap is important for space obliteration along with progressive tension sutures for final closure. The degree of contour deformity is generally less than that associated with propeller flaps<sup>(5)</sup>. The flaps, when initially dissected, appear hyperemic perhaps due to denervation or vasodilation of the vessels, attributing it to a sympathetic response<sup>5</sup>.

Four types of keystone flaps have been described in the literature:

- Type I: Standard flap design without division of the deep fascia
- Type II: The deep fascia on the convex face of the flap is sectioned to improve mobility, with the management of the secondary defect by primary closure (Type II a), or coverage by skin grafting (Type II b)
- Type III: Bilateral flap to facilitate closure of large defects
- Type IV: Subcutaneous dissection of up to two-thirds of the flap to maximize its mobilization<sup>6</sup>.

A Moncrieff modification to the keystone flap is to maintain a skin bridge, whose function is to improve the venous and lymphatic drainage of the flap without restricting mobility. This consists of an incision of the fascia under the tunneled skin bridge that allows advancement and avoids deep dissection of the structures<sup>7</sup>.

The keystone flap sometimes has problems such as excessive tension and restriction in the closure of the

donor area, skin contractures due to straight scars in the joints and other mobile areas. Therefore, one of its described variants has been the design of an additional V shape in the lateral curve of the flap, further reducing the tension of the closure and the adjacent tissues, with the use of said modification in extremity joints<sup>3</sup>. Some disadvantages of this flap despite its versatile nature are its use with caution in trauma areas where the underlying perforators may be damaged. Therefore, it is necessary in such cases to use a Doppler that not only indicates the exact location of the perforators but also indicates the strength of the flow within said perforator<sup>8</sup>.

The keystone flap has many advantages over free flap-based microsurgical reconstruction, including:

1. Shorter surgical times than the free flap or the single perforator flap, with faster elevation and insertion of the flap (2-3 h)
2. Avoid the technical demands of perforator dissection
3. High reproducibility, technically easy flap elevation, and reliable vascularity
4. Single region donor site, which allows for superior esthetic compatibility by advancing adjacent tissue with similar characteristics.
5. Ideal for patients with multiple comorbidities that make patients not candidates for microsurgical or long-term procedures
6. Avoid the need for post-operative monitoring of the flap
7. Decreased post-operative pain in relation to musculocutaneous flaps, earlier ambulation of the patient and shorter duration of hospitalization.

The lower extremities are another area where this flap has been widely used and provides an excellent option for traumatic defects where microsurgical reconstruction is not possible, as well as the possibility for immediate management of defect coverage<sup>9</sup>. In a series conducted by Lee et al. of 12 cases of non-oncological periarticular defects, adequate results and flap survival were obtained for defect coverage, obtaining thin, flexible, and durable tissues through flap reconstruction to withstand constant movement with tensile forces of multiple vectors, shear, and external pressure<sup>10</sup>.

In a study by Mohan et al., multiple options associated with this flap in locoregional reconstruction are highlighted: use of bilateral opposing trapezoidal flaps; incorporation of advance, rotation and transposition; obliteration of dead space; and combination with other local flaps. Allowing greater utility in more complex wounds and in the context of large oncological resections and fundus radiotherapy, traditionally contraindicated for locoregional flaps<sup>11</sup>.

Some of the uses of the flap described in the literature is for the management of myelomeningocele, this being the most common and serious pathology of the open spine compatible with life, using multiple reconstructive options such as primary closure, local flaps, and transposition flaps. Throughout history, a high incidence of complications such as partial or total loss of the flap, wound dehiscence, cerebrospinal fluid fistula, and soft-tissue infection has been described in 2-20% of the series. Minor complications (seromas or peripheral and partial dehiscence) occur in about 20% of cases. Primary closure and transposition flaps are the procedures with the highest rates of complications<sup>5</sup>, which is why this flap has begun to be implemented with promising results, such as a success rate of up to 97% and a reduction in the need for multiple surgical interventions newborn<sup>12</sup>.

A solution to reduce the tension in the closure is to use a keystone-type flap with fenestrae. Once the flap mobilized toward the defect has been designed, when excessive tension is noted, several horizontal cuts or fenestrations are made, perpendicular to the lines of maximum tension and distributed throughout the entire flap, to increase its surface, and with this cover a larger surface and reduce tension. This modification of the last step is made by making the decision according to the surgeon's experience to predict the tightness of the closure, it does not require much time, it is very easy to perform, and it produces minimal bleeding, with acceptable esthetic and functional results during follow-up. The most common complications are typically minor, involving wound dehiscence, and delayed wound healing, which are treated conservatively with local wound care. The risk of wound complications increases with a history of active smoking as well as pre-operative irradiation. Major complications such as vascular compromise of the flap resulting in partial or total loss of the flap are rare, observed in <10% of cases<sup>13</sup>.

In our cases presented, the decision to perform this type of flap was due to the characteristics of the patient that made it difficult to perform and survive a microsurgical flap as well as its subsequent care, the keystone flap presented adequate coverage, with less surgical time, care in home reproducible by caregiver and adequate evolution, in one of our cases, I presented superficial partial dehiscence in the edges of greatest tension, which is described in the literature as a higher risk area that required only general care such as any wound with adequate evolution at medium and long term.

## Conclusions

The keystone flap remains an adequate reconstructive option in areas that are difficult to manage with the coverage options used conventionally with local flaps, as well as areas where, due to the characteristics of the injury or the patient in general, it is impossible to perform flaps based on a perforator or microsurgical flaps, having the advantage of a shorter surgical time, a shorter learning curve with respect to perforator or microsurgical flaps, and also a greater ease of reproducing the procedures later.

An adequate evaluation of both the defect to be covered and the general characteristics of the patient are always necessary to make the appropriate decision as to which of the keystone flap modifications is correct for that patient, as well as adequate knowledge of the anatomy and planning and flap dissection to ensure the highest success rate of the procedures.

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## Conflicts of interest

The authors declare that they have no conflicts of interest.

## Ethical disclosures

**Protection of human and animal subjects.** The authors declare that no experiments were performed on humans or animals for this study.

**Confidentiality of data.** The authors declare that they have followed the protocols of their work center on the publication of patient data.

**Right to privacy and informed consent.** The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

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