

SIMPLE METRIC MEASUREMENT TO CHOOSE A KEYSTONE FLAP DESIGN ON EXTREMITIES: A CADAVERIC STUDY

Hariwangsa N.T.^{1*}, Sudjtmiko G.²

1. Universitas Indonesia, Department of Surgery, Division of Plastic Reconstructive and Aesthetic Surgery, RSUPN Cipto Mangunkusumo, Jakarta, Indonesia
2. Universitas Indonesia, Department of Surgery, Division of Plastic Reconstructive and Aesthetic Surgery, RSUPN Cipto Mangunkusumo, Jakarta, Indonesia

ABSTRACT

Background: Closing defect on extremities can be challenging because of limited donor area in order to obtain similar quality, color, texture, and adequate size with the defect. The keystone flap has gained popularity as a tool for local reconstruction because of its simple design, short operative time, good aesthetic outcome, and cost-effective wound closure. The aim of this study is to introduce a method in choosing a keystone flap design based on simple metric measurement resulting in lower tension..

Methods: Four circular defects were created on 4 different regions of a fresh cadaver's upper limbs. Diameters were 5 cm for upper arms and 3 cm for lower arms. Two options of keystone flaps designs were introduced. The keystone could be advanced in longitudinal manner or in transversal manner according to limb's axis. We then calculated the percentage of the skin required to stretch, in order to close the defects. The less percentage of skin required to stretch between the two manners indicated the lower tension of the keystone flap.

Results: Measurements in all of 4 regions of upper limbs showed that the percentage of skin stretch in closing the defects was lower in longitudinal advancement keystone flap compared to transversal advancement (19.88% versus 27.8% for upper arms and 15.71% versus 21.67% for lower arms)

Conclusion: Simple metric measurements in choosing a keystone flap can be applied to defects on extremities. With less tension when raising the keystone flap, acceptable scar is expected and the occurrence of contracture and flap necrosis can be reduced.

Keyword: *Keystone flap, tension, extremities*

Latar Belakang : Menutup defek pada ekstremitas merupakan suatu tantangan karena ketersediaan donor dengan kualitas, warna, tekstur dan ukuran yang memadai terbatas. Popularitas flap keystone untuk menutup defek di daerah ini meningkat karena desain yang sederhana, waktu operasi yang singkat, hasil yang memuaskan dan ekonomis. Tujuan dari tulisan ini adalah memperkenalkan cara memilih flap keystone berdasarkan pengukuran metric untuk mengurangi tegangan.

Metodologi : Empat defek sirkular dibuat pada 4 daerah yang berbeda di ekstremitas atas cadaver. Diameter yang digunakan adalah 5 cm untuk lengan atas dan 3 cm untuk lengan bawah. Dua cara membuat desain flap keystone diperkenalkan, yaitu pergerakan secara longitudinal dan transversal terhadap sumbu lengan. Kemudian diukur persentase dari kulit yang diregangkan untuk menutup defek. Persentase yang rendah menunjukkan tegangan yang lebih rendah.

Hasil : Pengukuran pada ke-4 bagian ekstremitas atas menunjukkan persentase kulit yang teregang lebih rendah pada flap dengan longitudinal advancement dibanding transversal advancement (19.88% vs 27.8% pada lengan atas dan 15.71% vs 21.67% pada lengan bawah).

Kesimpulan : Pengukuran metric sederhana untuk memilih desain flap keystone dapat diterapkan untuk menutup defek pada ekstremitas. Dengan tegangan yang lebih rendah diharapkan angka kejadian parut, kontraktur dan nekrosis flap dapat berkurang.

Kata Kunci : *Keystone flap, tension, extremities*

Received: 17 Februari 2016, Revised: 30 Maret 2016, Accepted: 25 April 2016.

ISSN 2089-6492 ; E-ISSN 2089-9734

This Article can be viewed at www.jprjournal.com

INTRODUCTION

Defects or wounds on the human body requires reconstruction because they may cause chronic pain, restriction of activity, high medical expenses, and lower quality of life. Tendons and surgeons are skin graft and flaps. Surgeons are required to obtain a donor tissue of similar quality to the lost tissue in regards to its color, texture and size, with close proximity of donor to the defect. Options of closure methods range from grafts, local flaps, regional flaps, and the more recently favored distant tissue transfer with microvascular anastomosis. free tissue transfers are technically more demanding, takes longer time, more cost, and does not always bones that exposed become necrotic and blood vessels may rupture and are prone to infection.¹ Main strategies of wound reconstructions for provide the same tissue quality that compares to neighboring tissue.²

The keystone island flap was described by Behan in 2003. Based on fasciocutaneous perforators, the keystone island flap offers both the robust vascularity of perforator flaps and relatively easy and fast local tissue reconstruction. Behan et al. have demonstrated this technique to be versatile and reliable for reconstruction of defects in the head and neck, trunk, and extremities. Other advantages of this technique include short operative times, high reproducibility, ease of use, and local tissue aesthetic similarities.^{3,4}

The flap design described in detail by Behan, is essentially a curvilinear trapezoid sharing one margin with the original wound, resulting in the flap being shaped like a “keystone” seen in architectural elements (figure 1). The ratio between width of the excision and width of the flap is usually one to one. However this ratio may be widened to accommodate any undermining that may occur in traumatic cases. The viability of the flap is then supported by random the subcutaneous vascular network and fascial and muscular perforators.^{4,5}

Behan described 4 types of keystone flap. Type I: The lateral deep fascia margin may be left intact. Type II: Deep fascia is divided to obtain adequate advancement of the flap. Type III: for larger defects, two identical opposing keystone flaps may be mobilised. Type IV: The area underneath the flap is never undermined in types I, II and III. However, up to 50% of the flap can be undermined subfascially (to maintain the perforator support) to facilitate its rotation.⁴

Given the universal distribution of perforators with the subcutaneous vascular support, the keystone flap is potentially suitable for all areas of the body from head to foot.⁶⁻⁸ However, difficulties are still encountered in reconstructing defects on extremities. Blood supply is becoming sparse as it goes distally, as well as the venous return which may be inadequate. Furthermore, achieving permanent closure may be problematic due to limited donor area and less tissue redundancy which create wound tension.⁹

Tension has been shown to be a key factor in the healing and scarring processes following local tissue reconstruction. Acutely, local stress concentrations may cause vascular insufficiency and localized flap necrosis. Chronically, local stress concentrations may induce excessive wound tension, resulting in wound dehiscence and hypertrophic scarring.^{10,11}

The aim of this study is to introduce a method in choosing a keystone flap design on extremities based on simple metric measurement. The objective is to achieve local tissue reconstruction with lower tension. We introduce two design options of raising the keystone flap by advancing the flap longitudinally or transversally, according to the limb’s axis. A cadaveric study is conducted to determine which of the two designs is suitable for raising keystone flap on extremities with lower tension. The less skin required to stretch indicates the lower tension of the keystone flap.

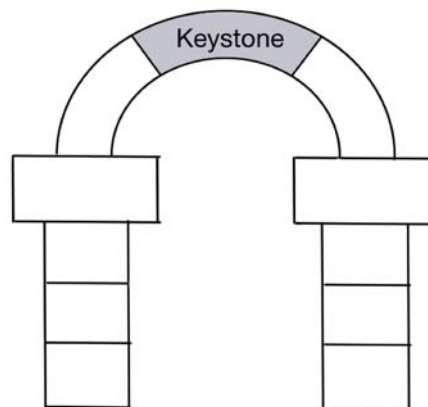


Figure 1. The architectural shape of a keystone

Disclosure: The authors have no financial interest to disclose.

METHOD

Cutaneous Markings

One fresh cadaver was used for this study. The study was conducted in the Forensic Laboratory of Forensic Department Cipto Mangunkusumo Hospital on January 31st 2015. We used the upper limbs of the cadaver to make the measurements and raise the keystone flap.

We divided the upper limbs into 4 different regions; right upper arm, left upper arm, right lower arm, and left lower arm. Cutaneous markings were created as borders of each region. We used acromion process as the proximal border of upper arm, imaginary line between medial and lateral epicondyles of humeri as border between upper and lower arm, and distal wrist crease as the distal border of lower arm (Figure 2 and 3). These 4 regions would be the measurement areas of the study. Four circular defects were created on each region of upper limb. Diameters of the defects were 5 cm for upper arms and 3 cm for lower arms. We placed the defects on volar side and exactly on the center of each region (Figure 2 and 3).



Figure 2. Cutaneous marking of the borders of upper arm regions with defects sized 5 cm in diameter



Figure 3. Cutaneous markings of the borders of lower arm regions with circular defects sized 3 cm in diameter

Keystone Flap Design

In this study we used the type III keystone flap where two identical opposing keystone flaps were mobilized. The defect was made circular and the edge of the defects reflected the inner edge of the flap. The lateral edges were two lines perpendicular to the inner edge. The outer edge paralleled the inner one with a 1:1 ratio between defect and flap widths. A 90° angle was created between the defect and the flap’s side edge which created the “keystone” or arch (Figure 4).

Two options of method in raising the double keystone flap in this study were introduced. First, the keystone flap could be advanced in longitudinal manner in the direction of the limb’s longitudinal axis. Second, the keystone flap could be advanced in transversal manner perpendicular to the limb’s longitudinal axis (Figure 5). The goal was to determine which of the two designs was the better one in achieving defect closure with lower tension. We determined this by measuring the length of skin, which had to be stretched in order to close the defect

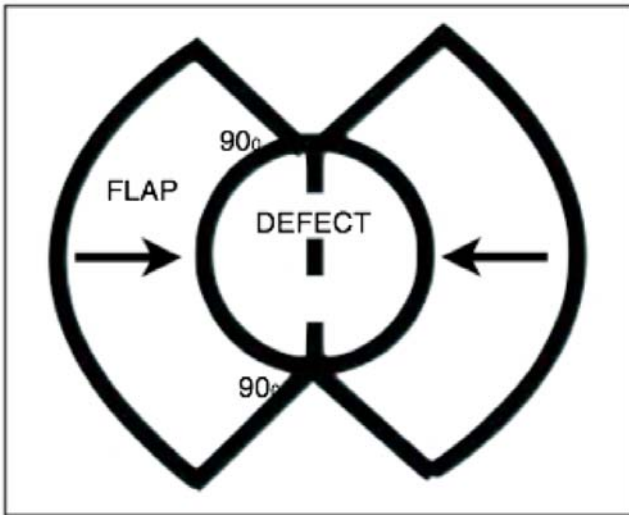


Figure 4. Type III: Two identical opposing keystone flaps are designed to create a double keystone flap.



Figure 5. Type III: Two identical opposing keystone flaps are designed to create a double keystone flap.

Measurements

We made measurements for each of the 4 regions of the cadaver. The goal was to compare the percentage of skin required to stretch to close the defect between the longitudinal advancement and the transversal advancement. The less percentage of skin required to stretch between the two manners indicated the lower tension of the keystone flap thus became the preferred method in raising the keystone flap.

Each region represented a measurement area. For each region we measured as the following; first we measured the longitudinal length of the limb A-B = LL and D = diameter of the defect. The length of skin available for closing the defect was calculated by subtracting the diameter of the defect from the longitudinal length of the limb (LL - D). Then the percentage of the skin required to stretch longitudinally was calculated using this equation.

Percentage of the skin required to stretch longitudinally (% LS) :

$$\frac{D}{LL - D} \times 100\%$$

Secondly we measured the circumference of the limb C and D = diameter of the defect. The length of skin available for closing the defect was calculated by subtracting the diameter of the defect from the circumference of the limb (C - D). Then the percentage of the skin required to stretch transversally was calculated using this equation. Percentage of the skin required to stretch transversally (% TS):

$$\frac{C}{C - D} \times 100\%$$

We compared % LS and % TS on each region of measurement. Lower percentage described the less skin stretch to close the defect. Less skin stretch would then indicate the lower tension of the keystone flap. All measurements were made using simple measuring tape.

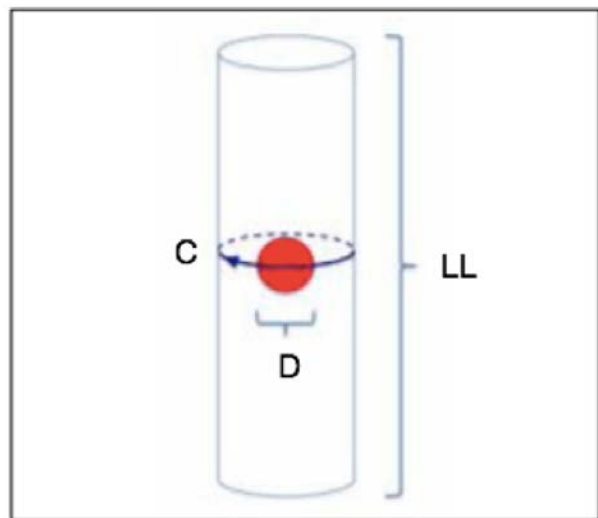


Figure 6. Modelling of a measurement area of a region on upper limb with L = longitudinal length, C = circumference, D = diameter of the defect.

Keystone Flap Elevation

After the measurement had been made, we raised the keystone flap on the cadaver. The design of the keystone flap was determined by the measurement, which gave the lower tension. Once the skin is incised, fibrous subcutaneous septa were gently divided by blunt dissection in order to preserve subcutaneous arteries and veins as much as possible. The procedure was identical on the lateral and outer edges of the flap. Approximating mattress sutures were used to close the defect with each end aligned with VY apposition.

RESULT

Measurements were done on 4 regions of cadaver's upper limb. For upper arm regions, average percentage of skin required to stretch longitudinally was 19.88% (range: 19.76-20%) and transversally was 27.8% (range: 27.03-28.57%).

For lower arm regions, average percentage of skin required to stretch longitudinally was 15.71% (range: 15.63-15.79%) and transversally was 21.67% (range: 21.43-21.9%).

Based on the measurement, the preferred design for closing the defects on all 4 regions was the longitudinal advancement keystone flap. Lower percentage showed that the skin was less stretched to close the defect. Less skin stretch would then indicate the lower tension of the keystone flap. We then raised the keystone flap on all of the 4 regions of measurement. We raised 2 longitudinal advancement keystone flaps as the favorable designs and methods and 2 transversal advancement keystone flaps as the unfavorable ones (Figure 7 and 8).

Table 1. Result of measurement on upper and lower arms

No	Regions	Diameter of defects (D)	Length of skin		Skin available for closing the defect		Percentage of skin stretching required to close the defects	
			Longitudinal (LL)	Transversal (C)	Longitudinal (LL-D)	Transversal (C-D)	Longitudinal (%LS)	Transversal (%TS)
1	Right Upper Arm	5 cm	30.3 cm	23.5 cm	25.3 cm	18.5 cm	19.76%	27.03%
2	Left Upper Arm	5 cm	30 cm	22.5 cm	25 cm	17.5 cm	20%	28.57%
3	Right Lower Arm	3 cm	22 cm	17 cm	19 cm	14 cm	15.79%	21.43%
4	Left Lower Arm	3 cm	22.2 cm	16.7 cm	19.2 cm	13.7 cm	15.63%	21.9%



Figure 7. Favorable design of keystone flap where the flaps were



Figure 8. Unfavorable design of keystone flap where the flaps were advanced transversally.

DISCUSSION

Keystone flap has gained popularity as a tool for local reconstruction because of its simple design, short operative time, good aesthetic outcome, and cost-effective wound closure. However, limitation still occurs in the reconstruction of the defects on extremities.^{3,4,5} Area of the limbs have sparse vascularity as it goes distally and it has limited donor skin in terms of local reconstruction.⁹ Keystone flap plays a role in reconstruction of the extremities due to its particular design; (1) Because it is an island flap, there is no cutaneous bridge to restrict mobility. (2) The flap is designed within dermatomal precincts, including superficial and deep veins, fascial and muscular perforators or cutaneous nerves, for the best possible vascularization. (3) The curvilinear trapezoidal design of the keystone integrates two V-Y advancement flaps oriented end to side. The advancement of the flap, which is necessary for wound closure, opens a lateral defect that is long and narrow. Suturing the angles in a V-Y fashion further reduces the surface to be closed and locks the flaps into their final positions.¹²

Our study proposes a method in choosing a keystone flap design based on simple metric measurements of the limbs. The benefit is twofold. First, we consider the limbs as a two-dimensional plane with 2 axis, longitudinal and transversal, then we compare the length between those 2 axis using a simple metric measurements.

We consider this method of determining a keystone flap design to be simple and easy. Second, this method is applied to achieve the result of lower tension for keystone flap.

We estimate this by measuring the availability of skin as the donor to close the defect then we measure how much the skin has to be stretched in order to close the defect. The less skin available, the more it has to stretch thus the more tension it creates. We consider that this method is able to accommodate achieving the result of lower skin tension after defect closure.

Measurements in all of 4 regions of upper limbs showed that the percentage of skin stretch in closing the defects was lower in longitudinal advancement keystone flap compared to transversal advancement (19.88% versus 27.8% for upper arms and 15.71% versus 21.67% for lower arms). Based on the measurements, the preferred design for closing the defects on all 4 regions was the longitudinal advancement keystone flap.

Nevertheless, our study has many limitations. It does not take into account the viscoelastic behavior of the skin and the relation between keystone flap advancement and the relaxed skin tension lines. Our study focuses on introducing an easy method on choosing a keystone flap design resulting in lower tension. Furthermore, It does not evaluate the keystone flap after the defect closure. We consider that the final appearance of the keystone flap on cadaver can only predict the tension and stretch that it produces. Further study on actual patients is needed to evaluate long term outcome of keystone flap on extremities, including long term evaluation of resulting tension and scar.

CONCLUSION

Simple metric measurement of the extremities can be applied in choosing the suitable design for keystone flap resulting in lower tension. Although many factors play roles in affecting tension of skin and flap, this method may help surgeon to choose a keystone flap design on extremities to achieve better outcome. With less tension when raising the keystone flap, acceptable scar is expected and the occurrence of contracture and flap necrosis can be reduced.

Corresponding author :

Narottama Tunjung Hariwangsa
tommyhariwangsa@hotmail.com

REFERENCES

1. Parret BM, Pribaz JJ. Lower extremity reconstruction. *Rev Med Clin Condes*. 2010; 21(1): 66 – 75.
2. Sudjatmiko G, Pribadi S, Supit L. Random perforator flap: some experiences with keystone flap. *Jurnal Plastik Rekonstruksi*. 2013; 2(2): 42-46.
3. Behan FC. The keystone design perforator island flap in reconstructive surgery. *ANZ J Surg*. 2003;73:112-20.
4. Pelissier P, Santoul M, Pinsolle V, Casoli V, Behan F. The keystone design perforator island flap. Part I: anatomic study. *J Plast Reconstr Aesthet Surg* 2007;60:883-7.
5. Pelissier P, Gardet H, Pinsolle V, Santoul M, Behan FC. The keystone design perforator island flap. Part II: clinical applications. *J Plast Reconstr Aesthet Surg* 2007;60:888-91.
6. Behan FC, Sizeland A, Porcedu S, Somia N, Wilson J. Keystone island flap: An alternative reconstructive option to free flaps in irradiated tissue. *ANZ J Surg*. 2006;76:407-413.
7. Moncrieff MD, Bowen F, Thompson JF, et al. Keystone flap reconstruction of primary melanoma excision defects of the leg: The end of the skin graft? *Ann Surg Oncol*. 2008;15:2867-2873.
8. Peters LJ. Keystone island flaps: A radiation oncologist's perspective. *ANZ J Surg*. 2006;76:1127.
9. Khouri JS, Egeland BM, Daily SD, Harake MS, Kwon S, Neligan PC, Kuzon WM Jr. The keystone island flap: use in large defects of the trunk and extremities in soft-tissue reconstruction. *Plast Reconstr Surg*. 2011;127:1212-21.
10. Arnold MG, Chu EA, Odland RM. Chapter 78: Skin flap physiology and wound healing. *Stell and Maran Textbook of Head and Neck Surgery and Oncology Part VI*. Lippincott Williams & Wilkins. Philadelphia. 2013;1124-36.
11. Buganza-Tepole A, Steinberg JP, Kuhl E, Gosain AK. Application of Finite Element Modeling to Optimize Flap Design with Tissue Expansion. *Plast Reconstr Surg*. 2014;134(4): 785-92.
12. Pauchot J, Chambert J, Remache D, Elkhyat A, Jacquet E. Geometrical analysis of the V-Y advancement flap applied to a keystone flap. *J Plast Reconstr Aesthet Surg* 2012;65:1087-95.