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The Use of Keystone Flaps for Lower Limb Defects

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Abstract

Background: Local flap reconstruction uses local "like" tissue more effectively and takes less time during surgery than free tissue transfer.

Objective: To assess the keystone flap as a versatile and reproducible coverage option for small and medium-sized lower limb defects, irrespective of the aetiology. Additionally, we aim to reduce the rate of complications by conducting a preoperative dual assessment of the number of perforators, diameter, and peak systolic velocity in the suggested flap.

Patients and Methods: This was a case series study conducted on 20 patients with small to medium-sized lower limb defects due to different aetiologies at Kasr Al-Ainy Hospital between January 2022 and January 2023.

Results: Out of 20 patients, 25% experienced complications, including failure, infection, wound dehiscence, and superficial sloughing. Treatment for complications included secondary sutures, repeated dressing, flap advancement, skin grafting, and debridement. Patients with complications had significantly more exposed structures in the distal tibia and other sites compared to those without complications. Patients with complications had a lower mean number of perforators and smaller average perforator diameter. The mean average perforator PSV was also lower in cases with complications. Nevertheless, there was insignificant variance in the mean defect-nearest perforator distance between the two groups.

Conclusion: The keystone flap provides a stable, reproducible, and versatile solution for lower limb defects, with a simple, timesaving, single-stage procedure that minimizes complications compared to more sophisticated flaps, thanks to pre-operative duplex and perforator mapping.

Key Words: *Keystone flaps – Lower limb defects – Complications.*

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Introduction

A variety of methods for lower limb restoration are now feasible because more knowledge regarding perforators is now available [1]. The idea of the reconstructive ladder was put up to close wounds effectively using a step-by-step progression from straight forward to intricate techniques. Instead of a step-by-step ascent up the ladder. The reconstructive elevator takes innovative thinking and careful consideration of numerous factors to create the greatest form and function [1]. The ideal lower limb reconstruction should replace the lost tissues with similar stable ones and minimize morbidity to the donor site, achieving the best possible aesthetic and functional outcome. In addition to reducing the hospital stay and resuming daily life in an efficient manner [2]. The keystone flap, which was first used in 2003 by Behan, it is a multi-perforator advancement flap that produces dependable and adaptable vascularization [3]. It was mentioned that it is imperative to use a doppler which not only shows the exact location of the perforator but also gives an indication about the flow strength within the perforator. A perforator demonstrating a good audio signal off the doppler is usually considered for flap location [4].

This study aimed to assess the keystone flap as a versatile and reproducible coverage option for medium and small-sized lower limb defects, irrespective of the aetiology. As well as minimizing the complications rate through preoperative duplex evaluation of perforator number, diameter, and peak systolic velocity within the proposed flap.

Patients and Methods

This was a case series investigation performed on twenty cases with small to medium-sized lower limb defects due to different etiologies at Kasr Al-Ainy Hospital in the period of time starting from January 2022 to January 2023.

Inclusion criteria: Patients suffering of post–traumatic, post-skin lesion excision or after different types of malignancies excision. Lower limb defects of small to medium size, and patients suffering of chronic lower limb ulcers.

Exclusion criteria: Defects that could be primarily closed, large or complex defects that couldn't be covered by local flaps, undetermined safety margins after different types of malignancies excision, patients with uncontrolled chronic comorbidities, including autoimmune diseases, peripheral vascular insufficiencies, and immunosuppressed patients, and patients refusing to participate in the study.

Methods:

The following was applied to all patients:

Preoperative preparation:

After proper selection of the candidates for the procedure according to the previously mentioned inclusion and exclusion criteria, the patients were prepared for the procedure through the following protocol: History taking: Proper full history taking and examination: General examination and local examination: Examination of skin lesions involves character, lymph node assessment, defect assessment, site, size, debridement need, visible scars, anatomical structures exposed, and post-traumatic injuries.

Investigations:

Preoperative labs included blood count, renal, liver, bleeding profile, and HbA1C. Plain X-rays were used to diagnose orthopedic injuries, and culture and sensitivity were obtained from infected wounds. Arteriovenous duplex was performed for the affected limb, with perforator mapping and skin marking. Written consent was obtained from patients after explaining the procedure and its advantages and complications. Preoperative pictures were taken.

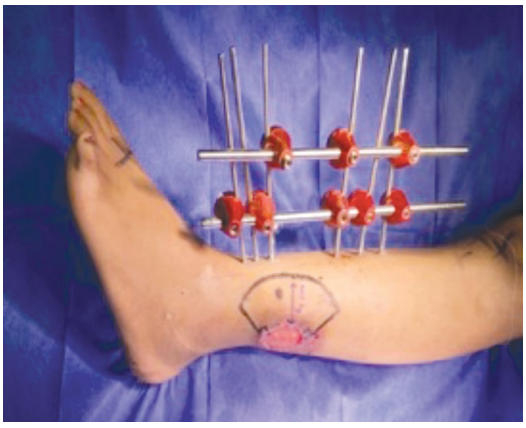

Fig. (1): Keystone flap design showing the perforator suppling the flap after being mapped by arteriovenous duplex.

Operative details: After general or spinal anaesthesia, proper sterilization and toweling of the patient's wound were done.

Recipient site preparation:

In cases of post-skin lesion excision: Marking of the resection border of the lesion and ensuring a suitable surgical safety margin according to published guidelines. The lesion was then excised with the previously marked safety margins in a circular or elliptical shape based on initial lesion presentation, then marking of the specimen was done which was immediately sent for frozen section histopathological examination of the safety margin all around the edges and the depth of the excised tissue in cases of malignant lesions. Once the safety margins were confirmed to be free by the frozen section examination, then the process of flap reconstruction can be carried out in the same session. In cases of post-traumatic defects or chronic ulcers, any associated vascular and/or orthopaedic injuries were managed accordingly by vascular and orthopaedics teams in post-traumatic cases. Debridement of any necrotic tissues and refreshment of defect edges was done on the first day of presentation with a second look and reassessment after 48 hours for the possible need of further sessions of debridement. NPWT was applied to some patients after 48 hours of the first session of debridement (to be changed every 48 hours with further wound reassessment) as a temporary dressing until the raw area was ready for coverage (free of necrotic tissue) and the perforator mapping was done.

Flap coverage:

Flap design: The recipient raw area was prepared for coverage after skin lesion excision or final debridement. The side with greater laxity has been chosen for the flap site to use the increasing skin laxity to close the donor site. Adjacent perforators were re-checked and marked by a handheld ultrasound Doppler device. The defect had been examined in two dimensions: the longest dimension was length, and its perpendicular axis was width. A longitudinally curvilinear flap with a width that is either slightly larger than or equal to the width of the defect has been developed by designing a keystone flap at ninety degrees angles from the corners of the defect. Two opposing keystone openings (type III) were occasionally designed to facilitate closure in cases with insufficient local tissue laxity. Flap dissection and in setting: A skin incision was made along the flap to open the epidermis and dermis, creating an island-shaped flap using a monopolar diathermy device. If increased mobilization was needed, the deep fascia was partially in-

cised along the convex border of the flap, releasing it from surrounding tissues. Flap movement was accomplished by advancing over the defect, with minimal undermining of the flap margin to preserve perforators integrity. If superficial veins and sensory nerves have been discovered throughout the division of the deep fascia, they have been isolated and preserved to preserve the vascularity and sensation of the flap. To evaluate tension and identify if more dissection has been required, flap inset has been carried out with stay sutures. The central portion of the flap on the defect side has been closed, and the lateral 'V' flaps have been aligned and closed in a V-Y pattern. An omega variant modification (type IV) was used to reduce tension during flap inset and provide further flap movement. Donor site closure: The donor site has been closed without skin grafting or split-thickness skin graft if excess tension exists, allowing the flap to cover vital structures while the graft allows wound healing. Penrose drains have been positioned under the flap and donor site, and compressive dressing or incisional NPWT was applied for large flaps. Temporary immobilization was achieved through splintage for 1 week postoperatively.

Postoperative follow-up:

After the surgery, the flap has been observed for any changes in colour or temperature, as well as the time it took for capillaries to refill. All the patients received postoperative oral antibiotics, analgesics, antio-edematous measures, and proper hydration. Lower limb elevation was done. The patients were discharged after 1 week & returned for follow-up. After being discharged, the patients returned for follow-up at 7 days and then at 1, 3, and 6 months.

Results

The mean age of the cases was 36.00±16.17 years, with a median age of 33.50 years (interquartile range: 22.00-48.00). Most of the cases were male (75.0%), and 50.0% reported a history of smoking. Comorbidities were present in 30.0% of the patients, with 15.0% having hypertension and 15.0% having diabetes mellitus. (Table 1).

Most of the patients (55.0%) had defects that were caused by trauma, followed by post-excision tumours (20.0%) and post-excision benign skin lesions (15.0%). Only 10.0% of the patients had defects caused by post-initial debridement of trochanteric bed sores. (Table 2).

The mean length of the defect was 5.20±1.53 centimeters, with a median length of 5.00 centimeters (interquartile range: 4.00-6.00 cm). The mean width of the defect was 3.28±0.91 cm, with a median width of 3.00 cm (interquartile range: 3.00-4.00 centimeters). The mean surface area of the defect was 18.13±9.21 cm^2, with a median surface area of 16.25 cm^2 (interquartile range: 12.00-24.00 cm^2). The mean length of the flap used for reconstruction was 9.58±3.88 cm, with a median length of 9.00 centimeters (interquartile range: 7.00-12.00 cm). The mean width of the flap was 5.35±1.69 cm, with a median width of 5.00 centimeters (interquartile range: 4.00-6.00 cm). The mean surface area of the flap was 56.13±37.29 cm^2, with a median surface area of 45.00 cm^2 (interquartile range: 28.00-72.00 cm^2). (Table 3).

The most widespread type of flap used was Type IIA (45%), followed by Type I (30%). Type III and type IV were used in 10%, while type IIB was used in only one case (5%). The donor site was primarily closed in 18 cases (90%), while split-thickness skin graft (STSG) was used in two cases (10%). (Table 4).

Table (1): Demographics in the study patients.

Variables	Patients (n = 20)	
Age:		
Mean ± SD	36.00±16.17	
Median (IQR)	33.50 (22.00-48.00)	
	N	%
Gender:		
Male	15	75.0
Female	5	25.0
Comorbidities:		
HTN	3	15.0
DM	3	15.0
Smoking	10	50.0

IQR: Inter quartile range.

SD: Standard deviation.

Table (2): Cause of defect in the study patients.

Variables	Patients (n = 20)	
	N	%
Post excision tumor	4	20.0
Post excision benign skin lesion	3	15.0
Post traumatic	11	55.0
Post initial debridement of bed sores	2	10.0

Table (3): Measurements of defect and flap parameters in the study patients.

Variables	Patients (n = 20)
Size of defect (length) (cm):	
Mean ± Standard deviation	5.20±1.53
Median (IQR)	5.00 (4.00-6.00)
Size of defect (width) (cm):	
Mean ± Standard deviation	3.28±0.91
Median (IQR)	3.00 (3.00-4.00)
Defect SA (cm^2):	
Mean ± Standard deviation	18.13±9.21
Median (IQR)	16.25 (12.00-24.00)
Size of flap (length) (cm):	
Mean ± Standard deviation	9.58±3.88
Median (IQR)	9.00 (7.00-12.00)
Size of flap (width) (cm):	
Mean ± Standard deviation	5.35±1.69
Median (IQR)	5.00 (4.00-6.00)
Flap SA (cm^2):	
Mean ± Standard deviation	56.13±37.29
Median (IQR)	45.00 (28.00-72.00)

IQR: Inter quartile range. SD: Standard deviation.

Table (4): Type of flap and donor site parameters in the study patients.

Variables	Patients (n = 20)	
	N	%
Type of flap:		
I	6	30
IIA	9	45
IIB	1	5
III	2	10
Type IV	2	10
Donor site:		
1ry closure	18	90%
STSG	2	10%

Out of 20 patients, 5 (25%) experienced complications, including failure, infection, wound dehiscence, and superficial sloughing and flap congestion. Regarding the treatment of complications, 1 patient (20%) received secondary sutures, 2 patients (40%) underwent repeated dressing, 1 patient underwent flap advancement and skin grafting (20%), and 1 patient (20%) underwent debridement, vacuum-assisted closure, and skin grafting. (Table 5).

60.0% of patients with complications had exposed structures in the distal tibia, which was significantly higher compared to those without complications (0.0%). Furthermore, 40.0% of patients with complications had exposed structures at other sites, compared to 100.0% of patients without complications. The *p*-value for the difference in the distribution of exposed structures in the distal tibia between the groups was 0.009, indicating a statistically significant difference. (Table 6).

Cases with complications had a significantly lower mean number of perforators (1.20±0.45) compared to those without complications (2.13± 0.99), with a significant *p*-value of 0.033*. Additionally, patients with complications had a significantly smaller average perforator diameter (0.88±0.04 mm) compared to those without complications (1.45±0.36 mm), with a significant *p*-value of 0.002*. Moreover, the mean average perforator PSV was significantly lower in patients with complications (20.60±1.95 cm/sec) than in those without complications (28.67±6.77 cm/sec), with a significant *p*-value of 0.001*. Nevertheless, there was insignificant variation in the mean defect-nearest perforator distance among the two groups (*p*=0.933). (Table 7).

Table (5): Complication types and its treatments in the study patients.

Variables	Patients (n = 20)	
	N	%
Complications	5	25.0
Types of complications:		
Failure rate	1	5.0
Regarding Infection	1	5.0
Regarding wound dehiscence	2	10.0
Superficial sloughing & flap congestion	1	5.0
Treatment of complications:		
2ry sutures	1	20
Flap advancement & STSG	1	20
Repeated dressing	2	40.0
Debridement & VAC & STSG	1	20

Table (6): The rate of flap complications in relation to the site.

Variables	Complication				*p*-value
	Yes (n=5)		No (n=15)		
	N	%	N	%	
Distal tibia	3	60.0	0	0.0	0.009*
Other site	2	40.0	15	100.0	

p: *p*-value for comparing between the two studied groups.

Table (7): Perforators data in the study groups according complication.

Variables	Complication		*p*-value
	Yes (n=5)	No (n=15)	
Number of perforators: - Mean ± Standard deviation	1.20±0.45	2.13±0.99	0.033*
Average Perforator diameter(mm): - Mean ± Standard deviation	0.88±0.04	1.45±0.36	0.002*
Average Perforator PSV (cm/sec): - Mean ± Standard deviation.	20.60±1.95	28.67±6.77	0.001*
Defect-nearest perforator distance (cm): - Mean ± Standard deviation.	3.20±0.84	3.20±1.03	0.933

Case presentation:

Case (1): A 42-year-old male patient, controlled hypertensive, presented with two pigmented skin lesions with an irregular surface of 3*2 and 4*5cm in dimensions, occupying the lower 1/3 of the antero-medial and medial aspects of the right leg above the medial malleolous. They appeared at the age of 4 years old as pigmented lesions that underwent a recent, slowly progressive course of 2 years duration and irregular transformation of their surface. A preoperative punch biopsy revealed verrucous hemangioma. We performed an arterio-venous duplex on the right leg, identifying a patent arterio-venous vasculature with a perforator measuring 0.8mm in diameter and a PSV of 19cm/sec. The lesion was surgically removed, resulting in a defect measuring 5*3cm in diameter. A Type IIA keystone flap was designed to cover the defect, and STSG was used to cover the other defect. The flap size has been determined to be 7*4cm, including one perforator confirmed by hand doppler, and the donor site was primarily closed.

Fig. (2): 42-year-old male patient with verrucous hemangioma affecting the right leg, (A) Intraoperative excision marking and flap planning, (B) Intraoperative lesion excision and flap dissection, (C) Flap in setting and 1ry closure of donor site, (D) One week postoperative, (E) 3 weeks postoperative, (F) 2 months postoperative.

Case (2): 21-year-old male patient, medically free, presented to Kasr Al-Ainy ER after motor bike accident, trauma survey was done for proper resuscitation and exclusion of life-threatening injuries, the patient was found to have isolated trauma of left leg with open fracture proximal tibia without vascular injury, The patient underwent external fixation & debridement on admission, resulting in a defect of 5*3cm in diameter with exposed proximal tibia. After 48 hours, type IIA keystone flap was designed to cover the defect. The flap size was determined to be 6*4cm, including one perforator confirmed by hand doppler & the donor site was primarily closed after rubber drain insertion. Arterio-venous duplex was done for the right leg: patent arterio-venous vasculature with marking of 1 perforator with 0.6mm diameter & 19cm/sec PSV.

Wound dehiscence started 4 days postoperative, then after 1 week more dehiscence occurred for which flap advancement and STSG was done.

Fig. (3): Intra operative pictures showing:(A) Exposed left proximal tibia and keystone flap design. (B,C,D&E) Steps of flap dissection, advancement, insetting & 1ry closure of donor site. (F) Four days postoperative starting wound dehiscence. (G) One week post operative showing wound dehiscence in the same original site of the defect. (H) Flap advancement and STSG. (I) One week post flap advancement & STSG.

Case (3): 16-year-old female patient, medically free, presented to Kasr Al-Ainy ER after road traffic accident, trauma survey was done for proper resuscitation and exclusion of life-threatening injuries, the patient was found to have isolated trauma of left leg with open fracture distal tibia without vascular injury.

- The patient underwent external fixation & debridement on admission, resulting in a defect of 3*4cm in diameter over the lateral side of distal left leg above the lateral malleolus with exposed peronei tendons.
- After 48 hours, type VI (Ω variant) keystone flap performed to cover the defect.
- The flap size was determined to be 8*4cm, including three perforators confirmed by hand doppler & the donor site was primarily closed.
- Arterio-venous duplex was done for the right leg: patent arterio-venous vasculature with marking of 1 perforator with 1mm diameter & 22cm/sec PSV.
- On day 4, minimal wound dehiscence occurred at one side of the flap and was managed by repeated dressings.

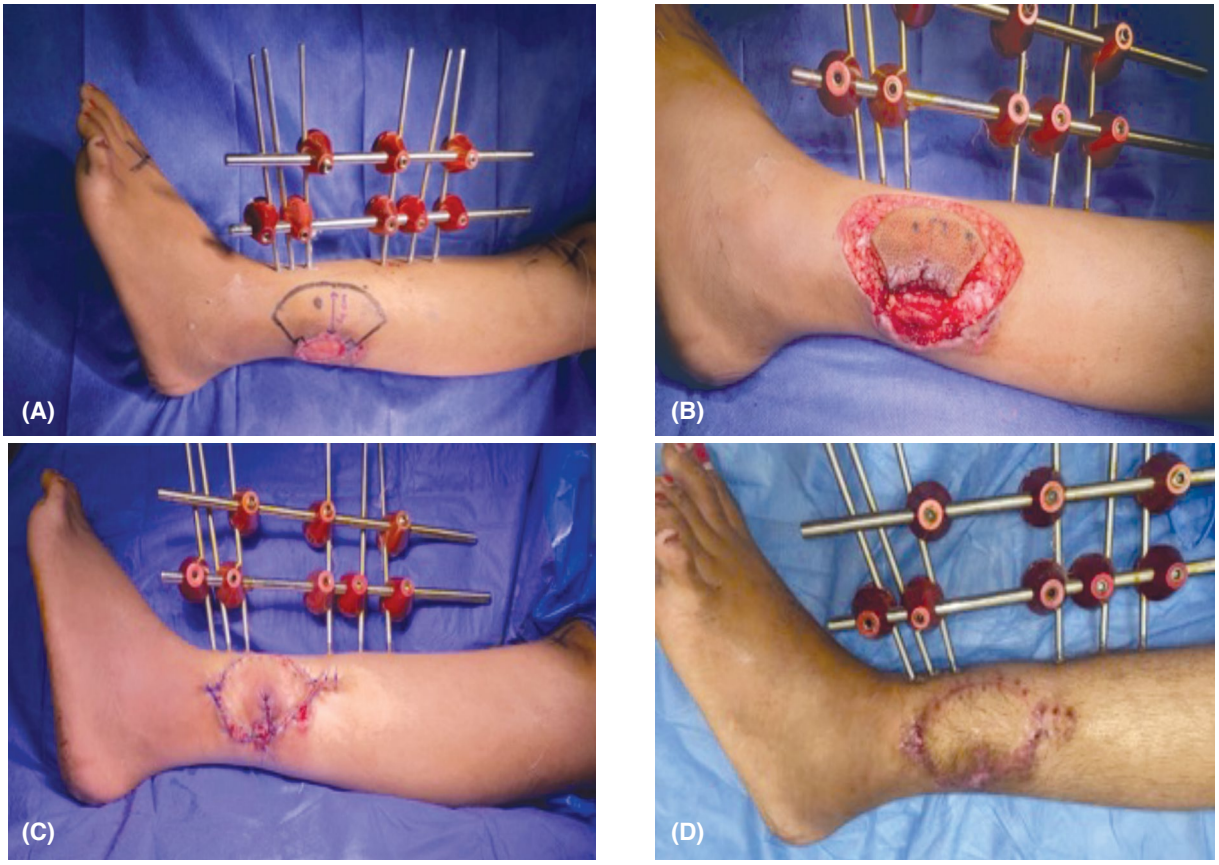

Fig. (4): (A) Left lateral leg defect with keystone flap design. (B) Flap dissection. (C) Flap in setting and primary closure of donor site. (D) Three weeks post-operative.

Case (4): 64-year-old male patient, medically free, presented with a pigmented macular lesion of 2*3cm in dimensions, occupying the lower 1/3 of the right leg over the lateral malleolus.

On presentation the lesion had 5 years duration with recent increase in size and itching of 1 month duration.

- Punch biopsy was done pre-operative and revealed: Bowen's disease.
- Arterio-venous duplex was done for the right leg: patent arterio-venous vasculature with marking of 2 perforators with 1.8 mm diameter & 25 cm/sec PSV.
- Operative excision of the lesion was done with 0.5cm safety margin all around, resulting in a defect of 3.5*4 cm in dimension.
- Type IIA keystone flap was designed to cover the defect.
- The flap size was determined to be 4*6 cm, including 2 perforators confirmed by hand doppler
- The donor site was primarily closed.

(A)

(B)

(C)

(D)

Fig. (5): (A) Intra operative excision marking and flap planning. (B) Right distal leg defect immediate post excision. (C) Flap in setting and primary closure of donor site. (D) Three months post operative.

Case (5): 15-year-old female patient, medically free, presented with pigmented lesions with average of 4*2.5cm, affecting the distal two thirds of the right leg. The lesions were noticed at the age of 5 years old as pigmented lesions, that underwent recent slowly progressive course of 3 years duration and irregular transformation of its surface.

- Punch biopsy was done pre-operative and revealed: verrucous hemangioma which was clinically diagnosed by dermatology team.
- Arterio-venous duplex was done for the right leg: patent arterio-venous vasculature with marking of 1 perforator with 2mm in diameter & 31cm/sec PSV.
- The upper three lesions were excised en bloc resulting in a defect of 4.5*9cm with exposed tibia.
- Type III keystone flap was designed to cover the defect.
- The flap size was determined to be 12*4.5cm for each half, including 5 perforators as a total in both sides confirmed by hand doppler & the donor site was primarily closed.
- The rest of the lesions were excised with no exposed structures and STSG coverage was done.

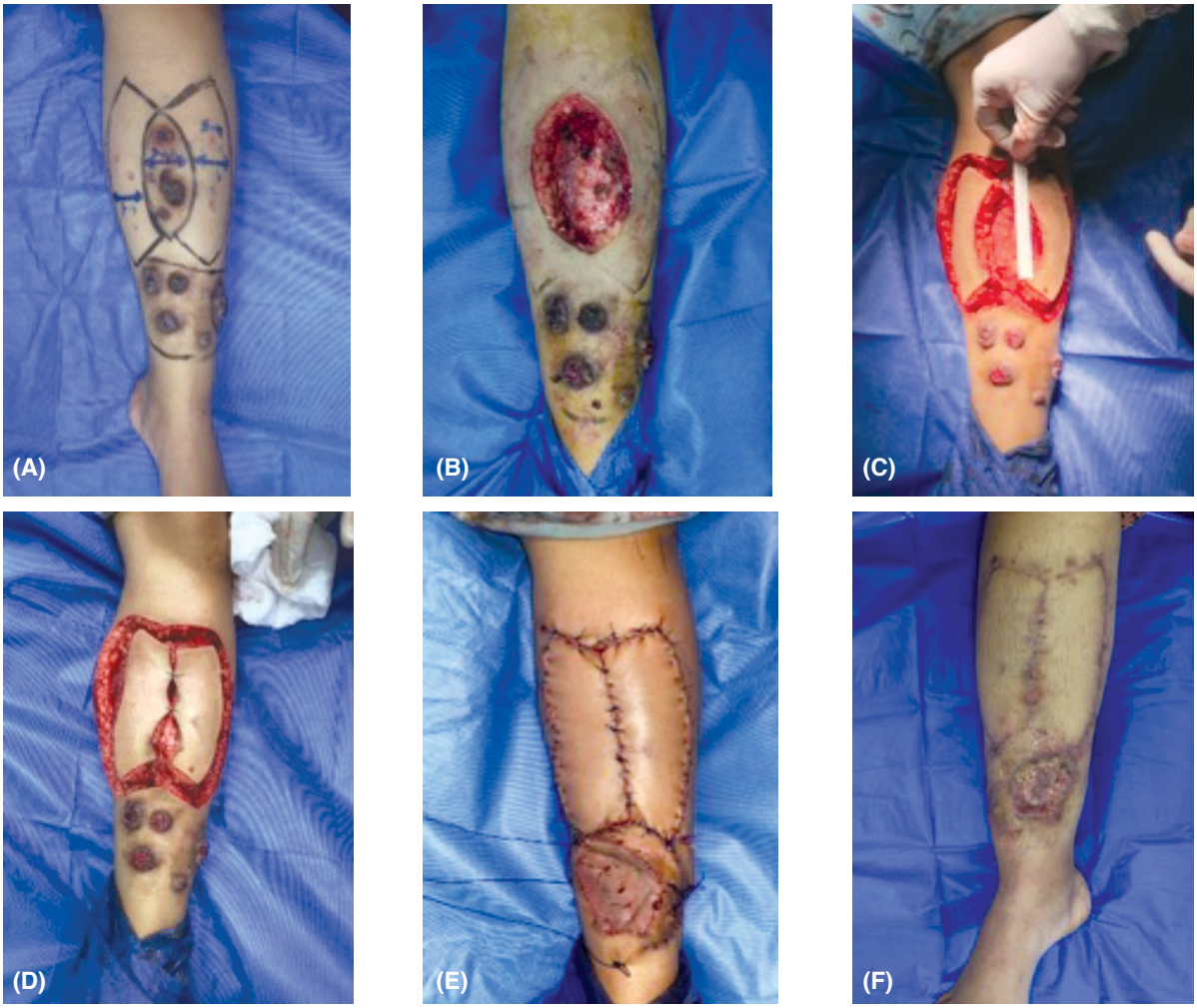

Fig. (6): (A) Lesions excision markings and type III keystone flap design. (B) Intraoperative picture showing leg defect after excision of the upper lesions of verucous hemangioma. (C,D&E) Flap dissection, in setting and 1ry closure of the donor site. (F) One months postoperative.

Discussion

The keystone flap has many modifications mentioned in the literature like The UQ flap modification described by Hassani et al. in 2022 on 10 patients, which is very helpful for areas with low skin laxity **[5]**.

The literature has examples of many uses of keystone flaps for coverage of defects in different areas throughout the body **[6,7]**. Ophthalmologiests utilize eyelid reconstruction techniques **[8]**, maxillofacial surgeons cover parotid defects **[6]**, periauricular defects are treated **[9]**, general and gynecological surgeons focus on perineal and vulvar defects, as well as neurosurgeons deal with defects in the dorsolumbar and lumbosacral area **[10,11]**.

Srivastav S et al., conducted a prospective investigation published in The Journal of Orthopedic and Trauma in 2020. A total of fifty cases participated in the trial, with thirty of them undergoing keystone flap surgery for type I and II lower limb reconstruction. The investigation indicated that the approach is related to reduced surgical times, a single operative field, and a shorter hospital stay. Unquestionably, it surpasses the limitations of microsurgical reconstruction. Advanced equipment such as a microscope is unnecessary, and the learning process is shorter **[12]**.

In this study, 20 keystone flaps were performed for 20 patients with lower limb defects; 9 patients underwent type IIA (45%), 6 patients underwent type I (30%), type III and type IV were both used in 2 patients each (10%), while type IIB was used in only one case (5%).

Preoperative arteriovenous duplex for the affected limb was done for all cases with perforator

mapping, skin marking of their sites, and commenting on their diameter and PSV. The sites of the perforators were confirmed immediately preoperatively by using a hand doppler.

In general, the keystone flap complications rate is usually low [12].

In their 2008 investigation published in The Annals of Surgical Oncology, Moncrieff et al., found that out of 176 cases who had lower limb keystone flap repair following melanoma excision, there was one occurrence (0.6 percent) of partial flap necrosis and one occurrence (0.6 percent) of whole flap necrosis [13].

Upon the initiation of this study, we had one case of flap failure. This suboptimality was attributed to faulty dissection, over-skeletonization of perforators, and, with a better understanding of the anatomy, blood supply of the flap, and tedious dissection, none of the future flaps had this suffering.

The rate of complications was noticed to be higher with distal tibial defects, as shown in the results, with 3 cases out of 5 (60%) of the total complications occurring in flaps done for coverage of distal tibial defects, varying from wound dehiscence to a single case of total flap loss. The higher complications in distal tibial defects may be related to the less skin laxity in the distal leg making flap advancement more difficult, which led us to further dissection and perforator skeletonizing, which threatens the flap vascularity through the risk of perforator injury during dissection vasospasm, kinking of the blood supply during flap advancement, and inset or compression of the vessels which became no longer supported by soft tissue by postoperative edema. Moreover, relative tension closure of the flap associated with lower skin laxity can add to the flap burden, leading to the emergence of wound dehiscence, which was encountered in 2 of our cases. Wound dehiscence may also be related to the vascular insult, including ischemia or congestion of the periphery (distal part) of the flap leading to wound dehiscence.

In this study, the mean surface area of the 20 flaps was 56.13±37.29cm^2, with a median surface area of 45.00cm^2 (interquartile range: 28.00-72.00 cm^2). As shown in the results, cases with complications had a significantly lower mean number of perforators (1.20±0.45) compared to those without complications (2.13±0.99), with a significant *p*-value of 0.033*. Additionally, patients with complications had a significantly smaller average perforator diameter (0.88±0.04mm) compared to those without complications (1.45±0.36mm), with a significant *p*-value of 0.002*. Moreover, the mean average perforator PSV was significantly lower in patients with complications (20.60±1.95cm/sec) than in those without complications (28.67±6.77cm/sec), with a significant *p*-value of 0.001*.

The number of perforators, average diameter, and average PSV of perforators in the proposed flap were the only variables found to be of great significance in relation to the complications; however, the mean defect-nearest perforator distance was found to be of no statistical significance in relation to the complications (p=0.933), as the keystone flap being an island flap with the periphery of the island all-around is considered distal and the central part is considered proximal.

In order to minimize the complications beside the routine proper preoperative assessment and selection of the patients, avoid smoking, proper perioperative control of medical co-morbidities, and adequate postoperative monitoring and follow-up.

This study recommends the consideration of preoperative duplex for perforator mapping in addition to the measurement of perforator diameter and PSV in the area surrounding the defect to be taken as a guide during flap planning and design.

Intraoperatively, avoid over dissection and perforator skeletonization to avoid the risk of injury, vasospasm, kink, and compression when the vessels lose the surrounding soft tissue support, which results in vascular complications such as flap congestion or ischemia. Whenever needed, deep fascia should be incised to achieve further flap mobility and advancement and reduce tension, as discussed before.

Conclusion:

The keystone flap provides a stable, reproducible, and versatile solution for lower limb defects, with a simple, timesaving, single-stage procedure that minimizes complications compared to more sophisticated flaps, thanks to pre-operative duplex and perforator mapping.

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