Experimental investigation of tension-reducing effectiveness of keystone perforator island flap

Timea Helga Virág[1], Maximilian Vlad Muntean[1,2], Attila Zoltán Mihály[3], Alexandru Valentin Georgescu[1,4]

1) Department of Plastic Surgery, Iuliu Hatieganu University of Medicine and Pharmacy, Cluj-Napoca, Romania

2) Department of Plastic Surgery, "Prof. Dr. Ion Chiricuta" Institute of Oncology, Cluj-Napoca, Romania

3) Department of Urology, Clinical Municipal Hospital, Cluj-Napoca, Romania

4) Department of Plastic Surgery, Rehabilitation Clinical Hospital, Cluj-Napoca, Romania

Address for correspondence:
Maximilian Vlad Muntean
drrezidentvth@gmail.com

Abstract

Background and aim. Nowadays, the reconstruction of large and complex defects with keystone perforator island flaps (KPIF) has gained popularity in plastic and reconstructive surgery. The keystone perforator island flap was described as a curvilinear shaped trapezoidal design flap, with two V-Y advancement flaps end-to-side. It is a multiperforator advancement flap, based on multiple fasciocutaneous or musculocutaneous perforators, described by Behan in 2003. These flaps have a simple harvest technique, an easy-to-implement design, and they are time and cost-saving. Their blood supply lends a versatile and robust character, with less complications. Nonetheless, their biomechanical properties and effectiveness are unclear, the wound-closure tension-reducing effect is not well documented in existing literature. The present study aims to investigate the wound closure tension-reducing effect of type I, type IIA, type Sidney Melanoma Unit I (SMU) and type SMU II KPIFs. The main purpose of this study was to clarify the tension-reducing effect of the KPIF technique, which can contribute to the understanding of the biomechanical benefits of the KPIF.

Methods. This is an experimental, in vivo study, based on twelve white race porcine models (PIC-FII-377), as their anatomy and wound healing process is very similar to that of humans. In this study, 42 wounds that could not be closed by primary wound closure, known as 'unclosable' elliptical defects, were created in six different anatomical regions. The criteria used for not achieving primary wound closure were the breaking of 0 nylon suture or the edges of the wound. Each defect was closed with different types of keystone perforator island flap: type I, type IIA, type Sydney Melanoma Unit I and type Sydney Melanoma Unit II. Keystone perforator island flaps were used in 42 cases. Intraoperative tissue tension was measured by an AXIS FB50, 50 N force gauge tensiometer. In all cases a wide elliptical excision was performed for the primary defect. Before reconstruction, tissue tension was measured across the widest point of the elliptical primary defect. Skin incision was performed for the first flap, without division of deep fascia. After preparing first flap, tension was measured at the widest point of the wound. Furthermore, deep fascia for the second flap was divided, tissue tension across the widest point of the primary defect was measured. Finally, tension was measurement across the widest point of the donor-site after closure of the defect-side flap and V–Y closure of either end of keystone perforator island flap.

Results. In this study were included 12 porcine model (PIC-FII-377). A number of 42 keystone perforator island flaps were performed in this study, in six different anatomical regions, ranging between 3.3 x 12 cm and 16 x 30 cm. All elliptical defects were unclosable, with varying sizes ranging between 2 x 4 cm and 8 x 20 cm. The mean tension that was required to close all wounds with primary closure initially was 24.51 N ± 10.73 N. After using a type I KPIF a tension decrease of -7.04 N ± 4.93 N was seen, in the case of type IIA KPIF the tension decreased to -12.43 N± 5.63 N. Furthermore, after reconstruction with type SMU I KPIF the tension decreased to -7.38N ± 5.21N. After using a type SMU II KPIF a tension decrease of -10.52 N± 5.74 N was seen.

Conclusions. The main purpose of this study was to clarify the tension-reducing effect of the KPIF technique, which can contribute to the understanding of the biomechanical benefits of the KPIF. The outcomes of the present study suggest that type I, type IIA, type SMU I, and SMU II of keystone perforator island flaps have a significant tension-reducing effects, especially the technique that involves the division of the deep fascia. The results of this experimental research thoroughly explain the benefits of these flaps. The effectiveness of the flap and doubts on biomechanical properties have not been answered so far. It will encourage more plastic surgeons to use the flap, especially given its proven benefits.

Keywords: reconstructive surgery, keystone perforator island flap, tissue tension, experimental study, plastic surgery

Introduction

Nowadays, the reconstruction of defects with keystone perforator island flaps (KPIF) has gained popularity in plastic and reconstructive surgery. The keystone perforator island flap was described as a curvilinear shaped trapezoidal design flap with two V-Y advancement flaps end-to-side. It is a multiperforator advancement flap based on multiple fasciocutaneous or musculocutaneous perforators, described by Behan in 2003 [1]. Since Behan reported this technique, the KPIF has been used in many cases in plastic surgery to cover defects in all regions of the body, with outstanding results [2-4]. These flaps have a simple harvest technique, an easy-to-implement design, and they are time and cost-saving [1,5]. Their blood supply lends a versatile and robust character, with fewer complications [6]. The V-Y advancement technique reduces longitudinal tension, creating laxity on the central part of the flap, enabling an important mobility of the short axis and minimizing donor-site morbidity [1,5]. Nonetheless, their biomechanical properties and effectiveness are unclear, the wound-closure tension-reducing effect is not well-documented in existing literature.

Despite the usefulness and benefits of KPIFs, as proven in previous studies, there are different opinions regarding their biomechanical efficacy [5-7].

Some authors have investigated the biomechanical properties of KPIFs in cadaveric studies [8]. There are also others who tried to expand the skin paddle of the flap in order to reduce the tension [9,10]. There is no consensus on whether the reconstruction of tissue defects with a keystone perforator island flap reduces tissue tension, nor is there a clearly stated agreement as to whether the keystone perforator island flap can be used in wounds that have failed primary wound closure.

The present study was performed to investigate the wound closure tension-reducing effect of type I, type IIA, type Sidney Melanoma Unit I (SMU) and type SMU II KPIFs. The main purpose of this study was to clarify the tension-reducing effect of the KPIF technique, which can contribute to the understanding of the biomechanical benefits of the KPIF.

Methods

This is an experimental, in vivo study, based on twelve white race porcine models (PIC-FII-377) as their anatomy and wound healing process is very similar to that of humans [11].

This study was approved by the medical ethics committee of the National Sanitary Veterinary and Food Safety Authority of Cluj-Napoca, with approval number: 345/19122022. Statistical analysis was carried out with the SPSS Statistics software package. Data collection was implemented in Microsoft Excel.

In this study, 42 wounds that could not be closed by primary wound closure, known as 'unclosable' elliptical defects, were created in six different anatomical regions (Table I). Tension measurements were performed in 3-5 seconds. The wound edges were allowed to rest between measurements. Flap preparation was 13-15 minutes. The criteria for not achieving primary wound closure were the breaking of 0 nylon suture or the edges of the wound. Defects were closed with four types of keystone perforator island flaps: type I, type IIA, type SMU I and SMU II (Table I). Types that require a skin graft were excluded based on previous studies and clinical experience [5,6]. However, it was interesting to assess the biomechanical properties of the skin bridge in comparison to the classic keystone perforator island flap. Intraoperative tissue tension was measured by an AXIS FB50, 50 N force gauge tensiometer. Based on the type of keystone perforator island flap, the study was divided into two groups: group A and group B. Due to the large number of flaps, they were divided into two groups based on logical criteria in order to facilitate the follow-up. Group A includes type I and type IIA KPIF reconstructions and tissue tension measurements. Group B includes reconstructions with SMU I and SMU II KPIF and tension measurements. All specimens were kept at room temperature for 24 hours.

Table I. Characteristics of the flap: type, dimension, location.

Flap type	Flap size (cm)	Location
I	3.3 x 12	left hip
I	5 x 10	left latissimus dorsi
I	4 x 12	submandibular
I	7 x 14	right hip
I	5 x 14	left shoulder
I	9 x 18	left latissimus dorsi
I	14 x 34	left hip
I	13 x 27	left latissimus dorsi
I	12 x 30	right thoracodorsal
I	12 x 25	right shoulder
IIA	3.3 x 12	right hip
IIA	4 x 10	right latissimus dorsi
IIA	4 x 12	submandibular
IIA	7 x 14	left hip
IIA	5 x 14	right shoulder
IIA	9 x 18	right latissimus dorsi
IIA	14 x 34	right hip
IIA	13 x 27	right latissimus dorsi
IIA	12 x 30	left thoracodorsal
IIA	12 x 25	left shoulder
SMU I	5 x 10	left latissimus dorsi
SMU I	4 x 12	submandibular
SMU I	7 x 14	right hip
SMU I	7 x 14	left hip
SMU I	5 x 14	right shoulder
SMU I	9 x 18	left latissimus dorsi
SMU I	14 x 34	right hip
SMU I	13 x 27	right latissimus dorsi
SMU I	16 x 30	middle right abdominal
SMU I	12 x 30	left thoracodorsal
SMU I	12 x 25	left shoulder
SMU II	5 x 10	left latissimus dorsi
SMU II	4 x 12	submandibular
SMU II	7 x 14	right hip
SMU II	7 x 14	left hip
SMU II	5 x 14	right shoulder
SMU II	9 x 18	left latissimus dorsi
SMU II	14 x 34	right hip
SMU II	13 x 27	right latissimus dorsi
SMU II	16 x 30	middle right abdominal
SMU II	12 x 30	left thoracodorsal
SMU II	12 x 25	left shoulder

Surgical technique

The skin was pinched before excision to determine the approximate wound width required to produce a closed wound. Once primary closure had failed with a single midpoint suture, the wound was declared unclosable. Once a wound was declared unclosable, the defect was reconstructed by keystone perforator island flaps. During the surgical procedure, a wide, elliptical defect was created (Figure 1). The long axis of the defect was oriented parallel to the vascular-nervous structures. The width and length of the flap were determined by the size of the excisional defect,

in the same proportion in all cases. Following excision, an incision at 90 degrees at either end of the defect was created, which meets the greater curvature of the flap (Figure 3). Skin incisions were made all along the flap's margins in the case of type I and type IIA KPIFs. The skin bridge remained intact in the case of type SMU I and SMU II flaps, and the size of the skin bridge was one-third of the length of the greater arc. Deep fascia was divided along the entire length of the greater curvature in type IIA (Figure 3) and SMU II below the skin bridge (Figure 7), with blunt dissection of the surrounding tissue. Around 25-30% of the flaps were undermined in a circular manner, leaving the central part, the hot spot area, intact. The first suture was placed at the widest point of the primary defect, in the middle of the flap-side margin, where maximum tension appears. The limbs of the KPIF were then closed in a V-Y manner, and the greater curvature of the flap was finally approximated. Wound closure was then completed at the donor site too, using a simple interrupted suture (Figure 8). All defects were covered using the same surgical procedure. At the end of the procedure, the wounds were inspected and dressed. The animals were kept alive for two weeks to evaluate wound healing. The bandage was changed every day and photo documentation was created during the follow-up period. The follow-up period was 14 days.

Tissue tension measurements

Tissue tension measurement was performed with two multifilament surgical sutures. USP (United States Pharmacopeia) size 0 were placed through the epidermis and dermis layers across the widest point of the defect (Figure 2, Figure 6), along the longitudinal axis, opposite each other, and 0.5 cm along the wound margin in such a way that the skin would be stretched in a transversal direction, compared to the length of the wound and flap. Each measurement was repeated three times, and an average value was calculated. The sutures were passed through the widest point of both wound edges and mosquito forceps were attached to each suture. Subsequently, the tensiometer was connected to the flap-side forceps and gently pulled it toward the non-flap-side forceps (Figure 4) until the two wound edges were completely approximated. Meanwhile, the non-flap-side forceps were kept centered in the midline of the defect. Tissue tension measurement was performed on the flap-side of each flap.

In group A, a wide elliptical excision of primary defect was performed (Figure 1). Before reconstruction, tissue tension was measured across the widest point of the elliptical primary defect and recorded as position 1 (common defect, N). Skin incision was performed for type I KPIF without division of deep fascia. After preparing type I KPIF, tension was measured at the widest point of the wound (Figure 2), and was recorded as position 2 (type I, N). Tissue tension at the donor site was measured and recorded as position 3 (type I, N). Furthermore, deep fascia was divided

along the entire length of the circumference line of the flap (Figure 3) for type IIA KPIF, tissue tension across the widest point of the primary defect after preparing type IIA KPIF was measured, and position 2 (type IIA, N) was recorded. Finally, tension was measured across the widest point of the donor site (Figure 4) after closure of the defect-side flap and V–Y closure of either end of KPIF (Figure 5) and was recorded as position 3 (type IIA, N).

In group B the elliptical primary defect was closed with type SMU I KPIFs. Tissue tension was measured in three steps: tension measurements across the widest point of the defect before SMU reconstruction, recorded as position 1 (common defect, N); tension measurement across the widest point of the defect after preparing type SMU I KPIF, without division of the deep fascia under the skin bridge (Figure 6), recorded as position 2 (type SMU I, N); and tension measurement across the widest point of the defect after division of deep fascia under the skin bridge of type SMU II KPIF (Figure 7), recorded as position 3 (type SMU II, N).

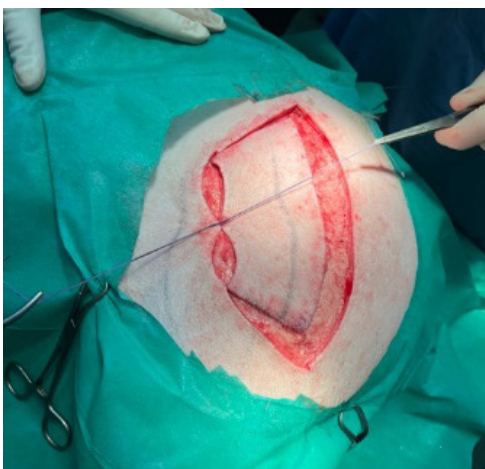**Figure 1.** Preparing the common primary tissue defect in an elliptical shape.

Figure 2. Tension measurement after type I KPIF elevation.

Figure 3. Division of deep fascia during type IIA KPIF elevation.

Figure 4. Tissue tension measurement at the secondary defect, on the donor-site, after preparing a type IIA keystone perforator island flap.

Figure 5. Reconstruction with type IIA keystone perforator island flap.
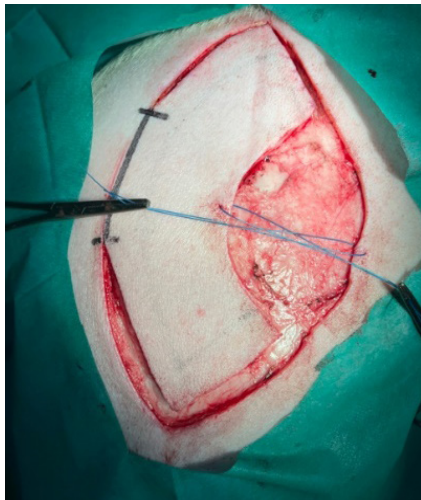
Figure 6. Tension measurement after preparing type SMU I keystone perforator island flap.

Figure 7. Division of deep fascia under the skin bridge of type SMU II keystone perforator island flap.

Figure 8. Reconstruction with type SMU II keystone perforator island flap.

Results

A number of 42 keystone perforator island flaps were performed in this study, in six different anatomical regions, ranging between 3.3 x 12 cm and 16 x 30 cm. All elliptical defects were unclosable, with varying sizes ranging between 2x4 cm and 8x20 cm (Table I). All procedures were performed under general anesthesia. Postoperatively, all wounds were inspected and underwent sterile dressing. Complete flap survival was observed without any flap-related complications in all cases.

Table II shows details related to tissue tension measurements at different positions in group A. The changes in tissue tension when type I and type IIA KPIFs were elevated are shown in detail in table III. The following table (Table III) presents the tension changes in the secondary defect at the donor-site depending on type I and type IIA KPIF.

Tension levels at primary defect sites after type I KPIF harvesting (-7.04 ± 4.93 N) showed a significant decrease in comparison with the initial tissue tension values measured in the primary defect prior to flap elevation (24.51 ± 10.73 N). In case of type IIA KPIF harvesting, a significant reduction in common primary defect was also observed (-12.43 ± 5.63 N).

The mean value of tension changes between reconstruction with type I and type IIA flaps was − 5.39 ± 3.90 N and (P < 0.001). Tension indicators after division of deep fascia were significantly lower compared to prior division indicators in case of type I and type IIA KPIFs. Accordingly, secondary defect tension indicators at the donor sites showed a significant decrease compared with primary defect tension indicators at the defect site (Figure 9, Figure 10) for both types of flaps (type I and type IIA KPIF).
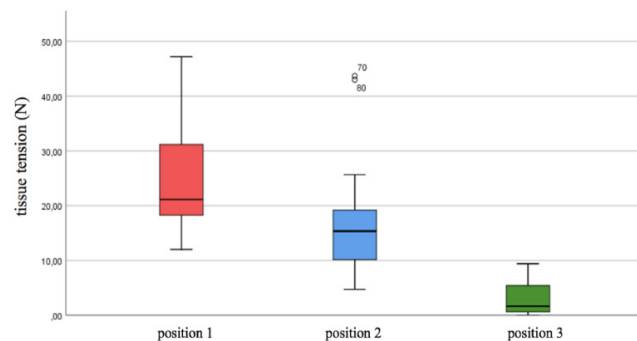

Figure 9. Tension changes at the common defect after type I KPIF reconstruction in Group A. Position 1: common primary defect tension; position 2: tension of the defect after elevation of type I KPIF; position 3: tension of the secondary defect on donor-site.

Table II. Summary of tissue tension measurements of Group A. Position 1(common defect, N): measurements of common primary defect tension; position 2 (type I, N): tension of the defect after flap type I elevation; position 3 (type I, N): tension of the secondary defect on donor-site after flap type I elevation; position 2 (type IIA, N): tension of the defect after flap type IIA elevation; position 3 (type IIA, N): tension of the secondary defect on donor-site after flap type IIA elevation.

Number of defects	Position 1 (common defect, N)	Position 2 (type I, N)	Position 3 (type I, N)	Position 2 (type IIA, N)	Position 3 (type IIA, N)
1	13.37	4.72	7.40	3.20	1.60
2	24.23	19.17	18.10	15.17	9.20
3	22.23	13.83	12.80	12.60	0.20
4	18.23	14.30	14.50	9.73	2.20
5	20.37	16.57	7.93	9.60	1.33
6	12.83	10.30	5.55	4.93	0.73
7	19.13	8.83	4.80	7.83	0.00
8	46.90	43.67	12.70	29.57	6.47
9	31.17	25.67	8.90	16.65	3.17
10	37.30	18.13	12.11	10.97	5.83
11	12.50	5.60	7.70	3.4	1.50
12	24.50	19.20	15.00	16.5	9.40
13	21.90	13.60	6.60	12.6	0.20
14	18.30	14.40	8.20	9.7	1.70
15	19.90	16.30	8.10	9.1	1.30
16	12.00	10.00	7.19	5	0.50
17	19.30	9.00	5.76	8	0.00
18	47.2	43	13.80	29.4	6.4
19	31.2	25.5	9.70	16.5	3.2
20	37.7	17.7	10.90	11.3	5

Table III. Summary of tissue tension changes of Group A. Tension changes at the common defect after type I reconstruction: position 2 (type I) - position 1(common defect); Tension changes at the common defect after type IIA reconstruction: position 2(type IIA) - position 1(common defect); Tension changes between type I and type IIA reconstruction: position 2 (type IIA) - position 2 (type I); Tension changes at the donor site: position 3 (type IIA) - position 3 (type I).

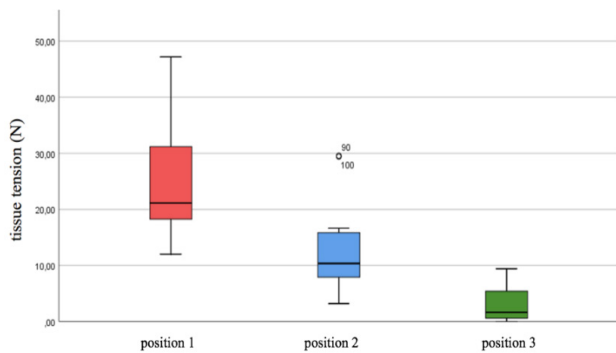| Tension-change at the common defect after type I KPIF (N)	Tension-change at the common defect after type II KPIF (N)	Tension-change between type I and type II KPIF (N)	Tension-change at the donor site (N)
-8.65	-10.17	-1.52	-5.80
-5.07	-9.07	-4.00	-8.90
-8.40	-9.63	-1.23	-12.60
-3.93	-8.50	-4.57	-12.30
-3.80	-10.77	-6.97	-6.60
-2.53	-7.90	-5.37	-4.82
-10.30	-11.30	-1.00	-4.80
-3.23	-17.33	-14.10	-6.23
-5.50	-14.52	-9.02	-5.73
-19.17	-26.33	-7.17	-6.28
-6.90	-9.10	-2.20	-6.20
-5.30	-8.00	-2.70	-5.60
-8.30	-9.30	-1.00	-6.40
-3.90	-8.60	-4.70	-6.50
-3.60	-10.80	-7.20	-6.80
-2.00	-7.00	-5.00	-6.69
-10.30	-11.30	-1.00	-5.76
-4.20	-17.80	-13.60	-7.40
-5.70	-14.70	-9.00	-6.50
-20.00	-26.40	-6.40	-5.90

Figure 10. Tension changes at the defect after type IIA KPIF elevation in Group A. Position 1: common primary defect tension; position 2: tension of the defect after division of deep fascia of type IIA KPIF; position 3: tension of the secondary defect on donor-site.

Table IV shows details related to tissue tension measurements at different positions in group B. The changes in tissue tension when type SMU I and SMU II KPIFs were elevated are shown in detail in table V.

Tension levels at the defect sites in both types of SMU KPIFs showed a significant decrease in comparison with common primary defect tension (Table V).

Table IV. Summary of tissue tension measurements and tension changes of Group B. Position 1: common primary defect tension; position 2: tension of the defect after type SMU I KPIF elevation; position 3: tension of the defect after division of deep fascia of type SMU II KPIF.

Number of defects	Position 1 (common defect, N)	Position 2 (type SMU I, N)	Position 3 (type SMU II, N)
1	22.50	17.23	12.90
2	17.53	12.57	10.80
3	9.07	6.33	5.20
4	4.07	3.40	2.20
5	23.40	23.40	17.00
6	16.50	6.57	4.73
7	27.10	17.10	12.10
8	19.20	6.03	3.23
9	34.13	20.87	25.03
10	32.33	17.90	11.71
11	21.17	12.13	5.30
12	20.3	17.2	12.4
13	17.3	13.2	10.2
14	8.2	6.7	5.4
15	3.7	3.8	1.6
16	23	23	17
17	17	6.5	4.7
18	27	17.1	12.1
19	19.2	6.1	3.4
20	34.3	20.9	25.4
21	32.3	18.3	11.5
22	21.2	11.9	5.2

Table V. Summary of tissue tension changes of Group B. Tension changes at the common defect after type SMU I reconstruction: position 2 (type SMU I) - position 1 (common defect); Tension changes at the common defect after type SMU II reconstruction: position 3 (type SMU II) - position 1 (common defect); Tension changes between type SMU I and type SMU II reconstruction: position 3 (type SMU II) - position 2 (type SMU I).

Tension-change at the common defect after type SMU I KPIF (N)	Tension-change at the common defect after type SMU II KPIF (N)	Tension-change between type SMU I and type SMU II KPIF (N)
-5.27	-9.60	-4.33
-4.97	-6.73	-1.77
-2.73	-3.87	-1.13
-0.67	-1.87	-1.20
0.00	-6.40	-6.40
-9.93	-11.77	-1.83
-10.00	-15.00	-5.00
-13.17	-15.97	-2.80
-13.27	-9.10	4.17
-14.43	-20.63	-6.19
-9.03	-15.87	-6.83
-3.10	-7.90	-4.80
-4.10	-7.10	-3.00
-1.50	-2.80	-1.30
0.10	-2.10	-2.20
0.00	-6.00	-6.00
-10.50	-12.30	-1.80
-9.90	-14.90	-5.00
-13.10	-15.80	-2.70
-13.40	-8.90	4.50
-14.00	-20.80	-6.80
-9.30	-16.00	-6.70

Tension measurements in case of type SMU II KPIF, after division of the deep fascia showed a significant reduction (-3.14 ± 3.15 N) compared to levels before division (Figure 11).
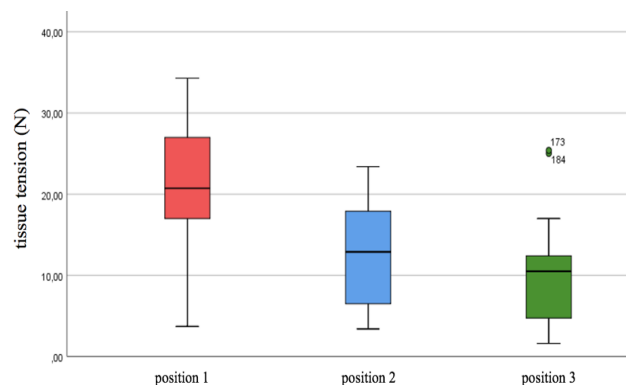

Figure 11. Tension changes at the defect after type SMU KPIF elevation in Group B. Position 1: common primary defect tension; position 2: tension of the defect after type SMU I KPIF elevation; position 3: tension of the defect after division of deep fascia of type SMU II KPIF.

Tension in the common primary defect was reduced with all four flap types, making the primary wound closable using the keystone perforator island flap, but type IIA KPIF reduced tissue defects studied here the most. In both cases (type IIA and SMU II KPIF), the division of the deep fascia contributed significantly to the reduction in tissue tension. No significant data were obtained regarding the beneficial effect of the skin bridge on tension for type SMU I and SMU II KPIFs.

Discussion

There are various surgical solutions to cover large skin defects that cannot be closed primarily, but the biomechanical properties and efficacy of these techniques are disputed, especially as regards the reduction in wound-closing tissue tension.

In addition to flap reconstruction techniques, researchers described some tissue expansion techniques for wound closure, with reduced tissue tension.

Paris et al. used porcine models to investigate the changes in tension during skin stretching in undermined versus not undermined skin. This study clearly showed that when the wound is closed with the skin stretching technique, undermining impairs the viability of skin margins, nonetheless the undermining procedure helps decrease tissue tension [9].

In an experimental study on porcine models, Mackay et al. reported the efficacy of intraoperative tissue expansion in reducing tension during wound closure. The tension required to close the wound was measured and recorded before and after undermining the wound edges and after intraoperative tissue expansion. The study resulted in a significant relief of tissue tension required to close the wounds in the case of undermined wound edges. However, there was no significant tension decrease after intraoperative tissue expansion. Furthermore, the increase in the undermined area significantly reduced wound closure tension. Increasing the extent of the undermining area significantly decreased wound closure stress. Therefore, undermining is superior to intraoperative expansion [10].

Tonseth et al. evaluated the microcirculation and wound-closing tissue tension following undermining on in porcine models using laser Doppler perfusion imaging. In this study, the positive effect on microcirculation by reducing wound-closing tension was weaker than the negative effect of cutting the perforating blood vessels to the skin with a net decrease in blood flow. Undermining the skin resulted in a decrease in wound-closing tissue tension. This is important, because an increased wound tension can affect microcirculation and lead to poor wound healing and other postoperative complications. Undermining is a basic technique to reduce wound-closing tissue tension, facilitate optimal wound healing and produce potential beneficial effects on microcirculation.

In case of undermined skin, perforators are damaged and may negate the effect of tension reduction on blood supply. However, undermining the skin edges in surgical wounds to reduce wound-closing tension could potentially facilitate blood flow of wound edges [12].

One of the key studies was published by Lewis C. Donovan [8]. This experiment was based on fresh frozen cadavers and investigated wound tension changes and the wound-closure ability of three methods, including V–Y advancement flap reconstruction, KPIF-based reconstruction, and primary wound closure. The fresh frozen cadaver study showed that V–Y advancement flaps enabled the closure of unclosable defects and resulted in a significant decrease in wound tension across the primary defect. Keystone perforator island flaps did not close these defects and did not result in tension reduction. During the wound closure, Donovan et al. performed both V–Y closure and donor-side suturing first, followed by defect-site suturing. There is a significantly different principle described by Behan [1,3] for wound closure with the keystone perforator island flap technique. Thus, the order of flap elevation and closure applied by Donovan et al. is opposed to this reconstructive principle, which might have introduced bias and error in their outcomes [8].

Contrary to the study by Donovan et al., other researchers, such as Behan and Shayan et al [13], advocate the usefulness of KPIFs based on the following aspects: the skin is a complex organ with diverse characteristics including non-linear, anisotropic and viscoelastic properties, and it is difficult to interpret the results of in vitro (cadaveric) testing of skin tension because of established differences between in vivo and in vitro settings.

Shayan et al. performed an in vivo study that reflects the real characteristics of the human skin and tissues [13]. Some important steps have been clarified regarding the use of the KPIF to avoid misinterpretations. The primary defect is always closed first. An incremental flap inset technique is also critical to the KPIF method. Initially, interrupted stitches are placed on the central leading edge, at the smaller arch of the flap. After V–Y advancements are performed to close secondary defects at both ends of the flap, hemming sutures are used for optimal dermal apposition [1,3]. However, Behan and Shayan made it clear that soft-tissue cannot be created or destroyed [13], this modest stretch resulting from a combination of the following: redistributed tissue laxity from the longitudinal axis perpendicularly; oblique stay sutures; intraoperative tissue creep and stress relaxation of dermal collagen with tissue expansion. This recruitment of laxity is partially facilitated by V-Y advancement flaps at either end of the KPIF, and tension is redistributed perpendicular to the advancement, that is into the direction of maximum wound tension [1,3,13].

Yoon et al. published a paper in 2019 about the

coverage of back defects using keystone perforator island flaps [14,15]. This study resulted in wound tension decrease using tensiometer measurements. However, this study has some limitations. First of all, the KPIF reconstructions involved the back area alone. Secondly, only type I and type II KPIF techniques were evaluated. It seems important to evaluate the tension-reducing effect of other types of KPIFs. Lastly, wound tension measurements were performed with an analog tensiometer, which might lead to some inaccuracy and errors in measurements compared with digital tension measuring instruments.

Our study evaluated the wound closure tension-reducing effect of KPIFs in six anatomical regions, reconstructed with four different types of KPIFs. The flap preparation technique used for this study is based on the original principles described by Behan [1], following the requirements for flap preparation and positioning, suturing and tension measurements. Our results suggest that all types of KPIFs evaluated in the present study, have tension-reducing effects in all anatomical regions evaluated during the experiment [5-7]. The biomechanical and histological properties of tissues can lead to different results in wound tension change measurements. It is important to emphasize that the study was performed in vivo [14].

Conclusions

The outcomes of the present study suggest that type I, type IIA, type SMU I and SMU II keystone perforator island flaps have significant tension-reducing effects, especially the technique that involves the division of the deep fascia. Furthermore, significant wound-closing tension decrease was observed when using KPIF reconstruction in an in vivo experiment. These outcomes suggest that all these types of keystone perforator island flaps facilitate the wound-closure capacity of KPIFs and offer an opportunity where primary wound closure cannot occur due to increased tissue tension.

The results of this experimental research thoroughly explain the benefits of these flaps. The effectiveness of the flap and doubts on the biomechanical properties that have not been answered so far. It will encourage more plastic surgeons to use the flap, especially given its proven benefits. There are prospects for future studies to confirm the validity of these outcomes and examine other types of KPIFs to clarify the tension-reducing effect of KPIFs in the human body.

References

1. Behan F. The Keystone Design Perforator Island Flap in reconstructive surgery. ANZ J Surg. 2003;73:112–120.

2. Moncrieff M, Bowen F, Thompson JF, Saw RP, Shannon KF, Spillane AJ, 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.

3. Behan F, Sizeland A, Gilmour F, Hui A, Seel M, Lo C. Use of the keystone island flap for advanced head and neck cancer in the elderly--a principle of amelioration. J Plast Reconstr Aesthet Surg. 2010;63:739–745.

4. Huang J, Yu N, Long X, Wang X. A systematic review of the keystone design perforator island flap in lower extremity defects. Medicine (Baltimore). 2017;96:e6842.

5. Virág TH, Muntean MV, Georgescu AV. Minimising donor-site morbidity following limbs' injuries with keystone perforator island flap reconstruction. Wound Repair Regen. 2022;30:357–364.

6. Virág TH, Kadar IA, Matei IR, Georgescu AV. Surgical management of hidradenitis suppurativa with keystone perforator island flap. Injury. 2020;51 Suppl 4:S41–S47.

7. Nedu ME, Matei IR, Georgescu AV. Giant keystone type III perforator flaps for dermatofibrosarcoma protuberans defect reconstruction. Injury. 2019;50 Suppl 5:S21–4.

8. Donovan LC, Douglas C, Van Helden D. Wound tension and 'closability' with keystone flaps, V-Y flaps and primary closure: a study in fresh-frozen cadavers. ANZ J Surg. 2018;88:486–490.

9. Melis P, Noorlander ML, Bos KE. Tension decrease during skin stretching in undermined versus not undermined skin: an experimental study in piglets. Plast Reconstr Surg. 2001;107:1201–1205.

10. Mackay DR, Saggers GC, Kotwal N, Manders EK. Stretching skin: undermining is more important than intraoperative expansion. Plast Reconstr Surg. 1990;86:722-730.

11. Kerrigan CL, Zelt RG, Thomson JG, Diano E. The pig as an experimental animal in plastic surgery research for the study of skin flaps, myocutaneous flaps and fasciocutaneous flaps. Lab Anim Sci. 1986;36:408-412.

12. Tønseth KA, Hokland BM. Evaluation of microcirculation and wound-closing tension after undermining the skin. A study in a porcine model using laser Doppler perfusion imaging. Eur J Plast Surg. 2004;27(6):295–7.

13. Shayan R, Behan F. Re: the 'keystone concept': time for some science. ANZ J Surg. 2013;83:499–500.

14. Yoon CS, Kong YT, Lim SY, Kim J, Shin HW, Kim KN. A comparative study for tension-reducing effect of Type I and Type II keystone perforator island flap in the human back. Sci Rep. 2021;11:16699.

15. Gómez O, Barón OI, Peñarredonda ML. Keystone Flap: Overcoming Paradigms. Plast Reconstr Surg Glob Open. 2019;7:e2126.