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EXPERIMENTAL

Percutaneous Fasciotomies versus Traditional Keystone Flap: Evaluating Tension in Complex Wound Closure

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Background : The keystone flap is a popular reconstructive option for closure of cutaneous defects. Traditionally, this is a perforator-based fasciocutaneous advancement flap that uses both skin incision and fascial release. We propose a limited skin incision technique that utilizes percutaneous fasciotomies to accomplish wound closure.
Methods: Fresh cadavers were used to compare closure techniques in traditional keystone flaps versus percutaneous fasciotomy technique. Each cadaver served as its own control; traditional keystone flaps were performed on the right side, experimental fasciotomy technique on the left. Bilateral large wound defects were created in 6 anatomical locations: anterior leg, lateral thigh, buttocks, lower back, upper back, and brachium. These defects could not be closed primarily, as defined by tension >25 Newtons or rupture of a 2-0 nylon suture. Twenty-four flaps were created. Keystone flaps were designed on the right side using a 1:1 ratio of defect size to flap width, incorporating both skin and fascial incisions. On the left, percutaneous fasciotomies were drawn using a mirror template and performed through two small access incisions. If wound closure could not be achieved by fasciotomy alone, additional incisional release was performed incrementally until closure was obtained. The tension of closure was measured using a PESOLA (10 N, 25 N) tensiometer (Chandelle, Switzerland), and the average of three recordings was used. Tension was measured at various stages of flap development including: keystone flap (posterior fascia, lateral fascia, V-Y skin closure) versus percutaneous fasciotomy (posterior fascia, lateral fascia, posterior skin). Statistical analysis was completed using Wilcoxon Signed Rank test to compare the two techniques.
Results: Lower tension closures were achieved through release of the posterior fascia in the traditional keystone flap compared to the percutaneous fasciotomy technique. These differences in tension were statistically significant ($P < 0.001$). Release of the lateral fascia in the keystone flap resulted in a similar decrease in tension ($P < 0.01$). The percentage drop in tension before and after each particular intervention was measured. No significant difference was found between these 2 groups.
Conclusions: When compared with the traditional keystone flap, the percutaneous fasciotomy technique displayed higher tensions in closure. However, this technique showed the ability to close defects in certain locations of the body without excessive tension and should be considered as an option in soft-tissue reconstruction. *(Plast Reconstr Surg Glob Open 2019;7:e2444; doi: 10.1097/GOX.0000000000002444; Published online 29 October 2019.)*

BACKGROUND

A perforator-based fasciocutaneous advancement island flap, the keystone flap was popularized due to its versatility in complex wound reconstruction. Originally described by Behan,[1] this curvilinear-shaped trapezoid design maintains a 1:1 defect/flap width and uses both fascia and skin release. Posterior tissue laxity is recruited and opposing ends are advanced in V-Y fashion. The V-Y

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advancement is thought to reduce longitudinal tension and create mid-flap laxity, allowing horizontal movement along the short axis.[1,2] Additional mobilization is gained from incision of the underlying deep fascia.[1]

Located within dermatomal segments, the keystone maintains a rich blood supply by incorporating known and random fasciocutaneous and musculocutaneous perforators.[1] Developments in perforasome theory have improved our knowledge of vascular "hot spots" and areas of increased perforator density.[3] Connected to an axial vascular system, fascial-based flaps have become a reliable means of wound closure.[4] Linking vessels are generally oriented axially in the extremities and perpendicular to the midline in the trunk.[3]

The keystone is a locoregional option which can be used as a primary flap or an adjunct to other flaps used in reconstruction. Complications include delayed healing, infection, dehiscence, and partial or total flap loss.[1,2,5–8] Modifications of the keystone flap's design have been described. Variations include skin only incisions, progressive division of the deep fascia, subfascial undermining of up to 50%, double opposing keystones, and backgrafting to secondary defects.[2] Moncrieff et al[5] previously described preservation of a small skin bridge and a limited incision approach.

A clear understanding of the biomechanical properties of the keystone flap is not well documented in the current literature, whereas the benefits of fascial release are better described (eg, galeal scoring and abdominal component separation). The successful use of fasciotomies as an adjunct in soft-tissue extremity reconstruction to close defects not amenable to primary closure was noted by Dumanian et al.[9] We propose a limited skin incision technique that predominantly relies on underlying fasciotomies for wound closure. This study investigates the percutaneous limited incision keystone (PLIK) for wound closure by measuring skin tension and comparing it to the traditional keystone flap.

METHODS

This study was performed on fresh cadavers. Institutional Review Board was waived as per institutional policy on the study of nonliving subjects, and adheres to the Declaration of Helsinki conducting biomedical research. Twenty-four flaps were performed using 2 fresh cadavers (1 male, 1 female, mean age 62 at death). Each side of the cadaver (hemi-body) served as its own control. Keystone flaps were performed on the right side and PLIK flaps performed on the left, mirroring the defects created on the contralateral side of the body. To recreate complex wounds, circular incisions were made at the following locations: anterior leg, thigh, buttocks, lower flank, upper back, and brachium. These defects could not be closed primarily. Defect size varied with anatomical location (anterior leg = 7 cm, lateral thigh = 8 cm, buttocks = 9 cm, lower flank = 6 cm, upper back = 6 cm, and brachium = 6 cm]. The criteria used for not achieving primary closure were empiric, three or more recordings > 25 Newtons (upper limit of the tensiometer) or the successive break of a 2-0 monofilament Nylon suture (J&J Ethicon, Somerville, N.J.) (surrogates for high tension closure). Skin tension measurements were made using a hand-held PESOLA [10 N, 25 N] Tensiometer (Schindellegi, Switzerland) at 75% of the transverse defect. The average of three independent recordings was obtained and entered into our tables (see appendix, Supplemental Digital Content 1, which displays keystone study addendum protocol. http://links.lww.com/PRSGO/B274) Statistical analysis was performed using Wilcoxon Signed Rank test to compare results between the traditional keystone and PLIK. All statistical analysis was performed in SAS 9.4 (SAS Institute Inc., Cary, N.C.).

Operative Technique

After unclosable defects were cut, flaps were created. Keystone flaps were designed on the right side of the body using a defect/flap ratio of 1:1. Progressive amounts of skin and fascia were released and wound tensions were measured using the tensiometer. Measurements were recorded after the posterior fascia was released, the side fascia was released, and after V-Y closure. PLIK flaps were then designed on the left. Small 1.5-cm access points were created with a #15 blade on the junction of the posterior and lateral limb. The deep fascia was identified and a fascial window made with blade. A Vanderbilt forceps was then used to create tunnels above and below the fascia. Under direct visualization, fasciotomies were performed by sharply releasing the deep fascia with Metzenbaum scissors. Measurements were recorded after the posterior fascia was released and side fascia was released. If closure could not be achieved, a releasing incision was made along the posterior border of the flap at the level of the skin and subcutaneous tissue (Figs. 1–2). To decrease interobserver variability, operative technique was performed by the same investigator for each flap (keystone-NRU, PLIK-JG). All defect measurements were performed by the same investigator (N.R.U.).

RESULTS

Closure tension varied with anatomical location. The lower flank [1.9 N, 3 N] in general had lower tension on closure in both the traditional keystone and PLIK. In contrast, the brachium [23 N, 25 N] and anterior leg [19.7 N, 25 N] were found to have higher tension on closure in the keystone and PLIK, respectively.

In all locations, when the posterior fascia was released, the keystone flap had lower tension than the PLIK flap. This difference was statistically significant ($P < 0.001$). Similarly, the release of the side fascia in the keystone yielded lower tension than the PLIK ($P < 0.01$). The difference in tension between the V-Y advancement of the traditional keystone and the posterior skin releasing incision of the PLIK was not statistically different ($P = 0.054$) (Table 1).

There was a drop in tension in the traditional keystone (25 ± 13%) after the posterior and side fascia were released (Table 2). There was an additional drop in

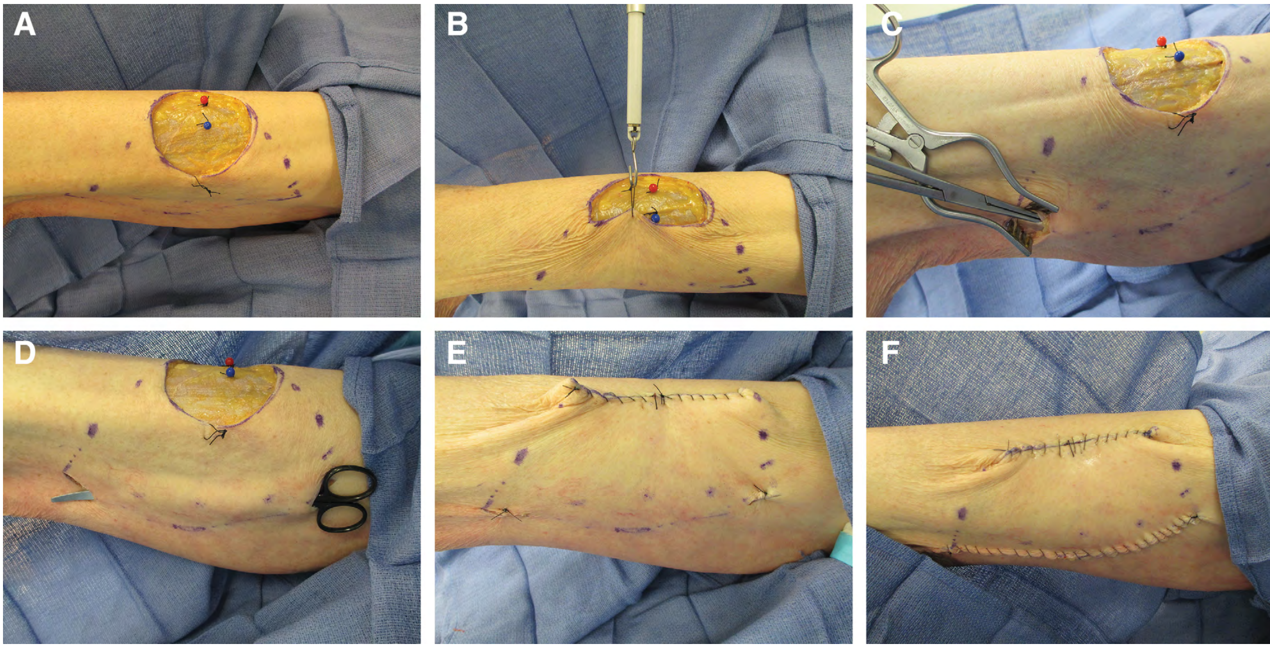

Fig. 1. PLIK surgical steps. A, Circular defect on the thigh, red and blue pin at 50% and 75% of defect, respectively, with regular Keystone markings. B, Tensiometer pulling tension measuring the skin advancement. C, Through small access incisions, the fascia is identified and supra and subfascial tunnels are created with Vanderbilt clamp. D, A metzenbaum is used to incise the fascia, now showing the posterior fascia released. E, A percutaneous approach was used and the wound was closed, please note the access incision closure. (Only defect needed to be closed.) F, A posterior skin release approach is portrayed, in addition to the defect closure the posterior skin was closed as well.

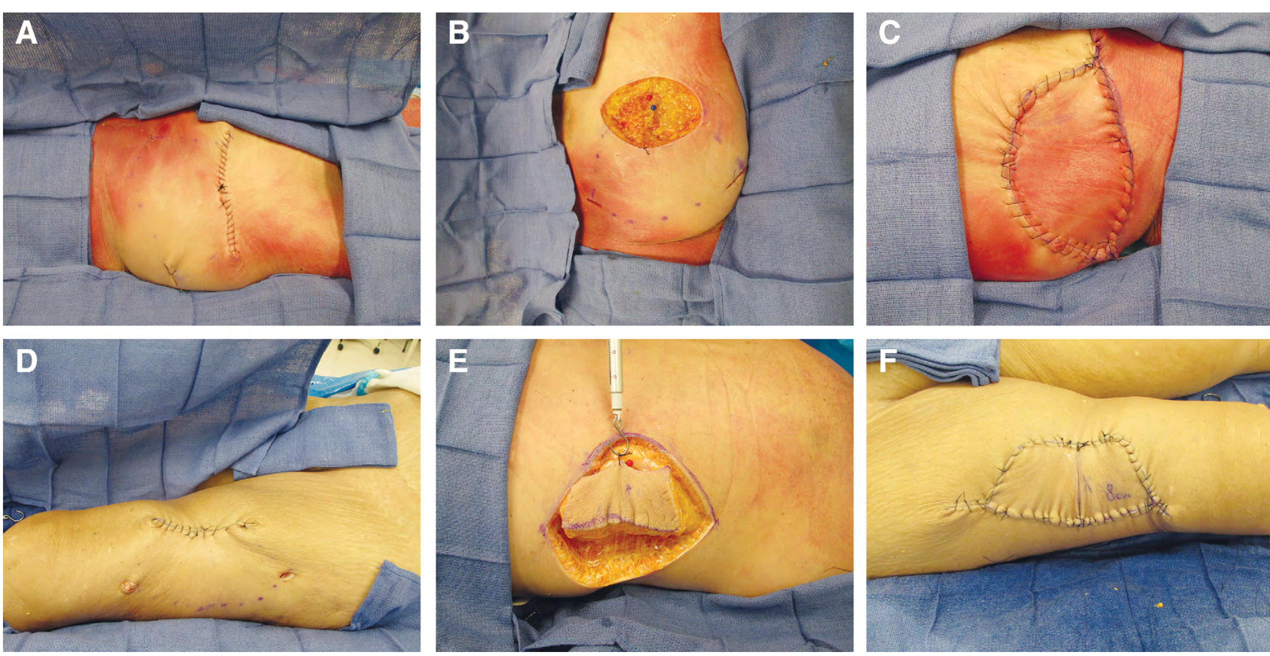

Fig. 2. PLIK vs. traditional keystone. A, Defect in the buttocks closed with PLIK. B, Nine centimeter defect in the buttocks. C, Defect in the buttocks closed with keystone flap. D, Defect in the thigh closed with PLIK. E, Eight centimeter defect in the thigh. F, Defect in the thigh closed with keystone flap.

tension (29 ± 24%) when the V-Y closure was performed. However, this drop was not statistically different between these groups.

Median tension values were generally lower in the traditional keystone (4.5 N) compared with the PLIK (23.3 N). There was a drop in tension observed in the PLIK after the posterior fascia and side fascia were released (20 ± 17%). There was a further decrease when the posterior skin was released (42 ± 27%). These changes were not statistically significant (Table 2).

Table 1. Keytsone versus PLIK Release

	Keystone Posterior Fascial Release, Newtons (N)*	Keystone Side Fascial Release, Newtons (N)†	Keystone V-Y Advancement, Newtons (N)‡	PLIK Posterior Fascial release, Newtons (N)*	PLIK Side Fascial Release, Newtons (N)†	PLIK Posterior Relaxing Incision, Newtons (N)‡
Body A upper back	4.66	4	2.83	25	21.66	5.33
Body A lower back	2.66	2	1.16	25	25	13.33
Body A buttock	3.16	2.33	1	9.83	5.66	4.33
Body A thigh	9.66	8.66	4.33	25	20.33	8.66
Body A brachium	23	19.66	19	25	14.66	15.33
Body A anterior leg	19.66	16.33	8.66	25	24.66	20.33
Body B upper back	5.83	4.66	4	4.66	3.93	2.5
Body B lower back	1.93	0.93	1	3	1.5	1.16
Body B buttock	3.33	2.33	1.66	21.67	19.33	5.33
Body B thigh	11.66	5.66	4	25	19.66	13.66
Body B brachium	3.33	2.5	0.8	7.5	4.66	1
Body B anterior leg	4.33	3.16	3.23	10.33	6.33	2

Different in tension at closure for keystone versus PLIK.
*Higher tension closures for PLIK when compared with Keystone posterior fascial release $P < 0.001$.
†Lower tension in side fascial release $P < 0.01$.
‡For V-Y advancement, it was not statistically significant $P = 0.054$.

Table 2. Percentage Drop after Each Surgical Step

	Percentile 25	Median	Percentile 75	Percentage Drop in Tension Median (±SD)
Keystone posterior fascial release, Newtons (N)	3.25	4.5	10.66	0.25 (0.13)
Keystone side fascial release, Newtons (N)	2.33	3.58	7.16	0.29 (0.24)
Keystone V-Y advancement, Newtons (N)	1.08	3.03	4.17	
PLIK posterior fascial release, Newtons (N)	8.67	23.34	25	0.20 (0.17)
PLIK side fascial release, Newtons (N)	5.16	17.00	21	0.42 (0.27)
PLIK posterior relaxing incision, Newtons (N)	2.25	5.33	13.50	

When compared as percentage in drop between Keystone flap and PLIK, there are not differences in percentiles.

DISCUSSION

Primary closure remains the simplest and most straightforward method of achieving wound closure. However, larger wounds cannot be closed primarily without significant tension, leading to local tissue ischemia and healing complications.[10–12]

Our cadaveric experience with the PLIK flap demonstrated it to be a viable option for reconstruction of soft-tissue defects. Although closure tensions were higher than the traditional keystone flap, tensions were not excessive and wound closure could be achieved with 90% less skin incision (Fig. 2) We experimentally proved that wounds in multiple anatomical locations not amenable to primary closure could in fact be closed using percutaneous fasciotomies as an adjunct. PLIK was most effective in the thigh and buttocks areas that possessed robust underlying muscle belly and abundant donor tissue laxity. It was least effective in the arm and leg areas that lacked muscle and adjacent skin laxity. In areas where closure was more difficult, an additional posterior skin relaxing incision can be made to facilitate closure.

This study provided a better understanding of the biomechanical properties of the keystone flap and its application. It is generally accepted that the V-Y advancement of the keystone plays a key role in facilitating wound closure.[1,2,13] The decrease in longitudinal tension is thought to cause a substantial drop in short-axis tension which promotes flap mobility. Other studies have questioned the importance of this contribution. Measurements performed by Douglas et al[14] found the transverse skin stretch gained from longitudinal skin release to be minimal.[14] In similar fashion, our study did not find the V-Y advancement of the traditional keystone to cause a significant decrease in wound tension. By comparison, the release of the posterior fascia along the greater arc of the keystone provided the largest drop in tension. In contrast to Donovan et al[15] who found no biomechanical benefit of the keystone flap and were unable to close "unclosable wounds," we found the keystone to be able to facilitate closure of wounds that could not be closed primarily. Our results support the benefit of the keystone in accomplishing wound closure (Fig. 3).

A skin-sparing approach to reconstruction is an intriguing concept with potential benefits. This technique would decrease scar burden, preserve cutaneous sensation and lymphatics, and avoid injury to vascular perforators. Decreasing the amount of skin incision minimizes donor site morbidity and reduces risk of wound healing complications. This is particularly advantageous in high-risk patients or those with multiple comorbidities (smokers, diabetics, malnourished, and immunocompromised). If a more complex reconstruction can be avoided, future reconstructive options are preserved. Operative time is likely to be decreased and reasonable aesthetic outcomes achieved.

The percutaneous limited incision technique follows similar reconstructive principles shared by a traditional keystone flap. The size and location of the defect should be evaluated. The longitudinal axis of the flap should be based on tension vectors and maximize vascularity (longitudinal to extremities, perpendicular to trunk). The size of the flap should be increased as needed to improve

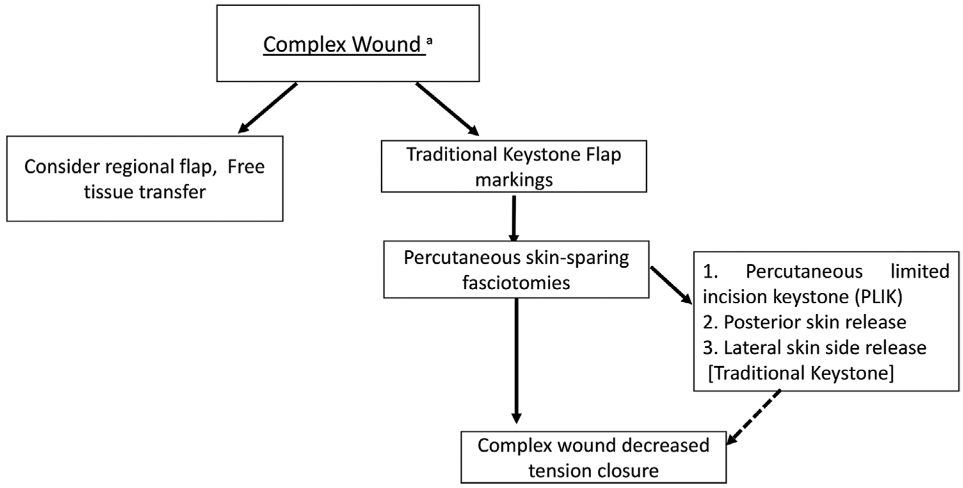

Fig. 3. Wound closure algorithm. Percutaneous fasciotomies preserve the traditional keystone markings. Complex wound: defined as not being amenable to primary closure, rupture of 2-0 nylon or >25 Newtons on the Tensionmeter.

mobility. Adjacent donor site tissue laxity must be adequate to allow for advancement. This technique should be avoided in the scalp/foot areas with minimal tissue laxity. Considerations pertinent to a skin-sparing technique include potential standing cone deformity, blind fasciotomies causing increased bleeding, and a lack of tissue bulk for dead space obliteration. Future studies evaluating the percutaneous technique may involve increasing flap size (exceeding traditional 1:1 ratio), more extensive undermining, including endoscopic approaches for fascial release.

Limitations of this study include its small sample size and use of nonliving patients. Soft-tissue mechanics in fresh–frozen cadavers have inherent variability compared with living patients. However, evidence from small animal models suggests the effects of freezing on tension are not significant.[16] Our technique for measuring wound tension using a tensiometer has been well described.[17,18] Potential inaccuracy of readings was combatted by taking the average of three recordings. The impact of creep and stress relaxation on tissue elasticity was mitigated with delicate handling of tissues.

For a given defect that could be closed by both methods, we would encourage you to consider the PLIK as a reconstructive option. Surgeons should implement a systematic approach to defect closure, progressing from simple to more complex. By adjusting the amount of skin incision required incrementally, wound closure can potentially be achieved in simpler fashion with less inherent risk.

CONCLUSIONS

When compared with the traditional keystone flap, the percutaneous fasciotomy technique displayed higher tensions in closure. However, this technique showed the ability to close defects in certain locations of the body without excessive tension and shows promise as a reconstructive option.

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