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REVIEW ARTICLE
Reconstructive

Best Local Flaps for Lower Extremity Reconstruction

Faris M. AlMugaren, MD, SB
Changsik John Pak, MD, PhD
Hyunsuk Peter Suh, MD, PhD
Joon Pio Hong, MD, PhD, MMM

Summary: The ideal reconstruction of lower limb defects should replace like with like and minimize morbidity to the donor site, achieving the best possible esthetic and functional outcome. The goal is to obtain stable healing and to resume daily life in an efficient manner. Although the classical local flaps such as gastrocnemius, soleus muscle flap, and the reverse sural flap have allowed to achieve those goals, perforator flaps are now added on to the armamentarium in lower extremity reconstruction using local flaps. A perforator-based local flap, such as a propeller or keystone flap, has made reconstruction efficient while further reducing donor-site morbidity. This article aims to provide a useful review of the best available local flaps for lower limb defects. *(Plast Reconstr Surg Glob Open 2020;8:e2774; doi: 10.1097/GOX.0000000000002774; Published online 30 April 2020.)*

INTRODUCTION

Lower limb defects are frequently the result of trauma, tumors, or chronic illness.[1] They continue to be a common and challenging field of reconstructive surgery.[2,3] Due to their thin, non-expandable soft tissue, small defects can become problematic, especially in the lower limb. Traditional reconstructive tools for the lower limb defects suggest local muscle flaps for defects in the thigh and proximal and middle third of the leg, whereas microvascular flaps are most useful for the distal third of the leg and foot. Although muscle flaps serve the purpose of reconstruction, attempts to reduce donor-site morbidity led to the use of fasciocutaneous flap followed by perforator flaps. These flaps preserve muscle function and reduce donor-site morbidity, which led to a new trend of reconstruction. The same can be said for local flaps. Perforator-based local flaps such as propeller flaps introduced by Hyakusoku et al[4–8] have expanded the option to approach lower limb reconstruction. Keystone flap is another form of perforator-based flap where a large bilateral V-Y advancement is used to close large defects with relative ease. This recent evolution of using perforator flaps requires to change the thought process in approaching the lower extremity defects.

As the title asks, what makes a local flap better than the other? What is the "best" local flap? The answer can be based on one's experience, education, resources, and whatever may lead to the best result in the given situation. As plastic surgeons, we continue to innovate, evolve, and accumulate knowledge. Just 20 years ago, no one would have imagined how much perforator flaps would impact our daily reconstruction practice. It is in that context that one should know what options are available and how one can apply these new techniques to individual practice.

Based on our experience and the literature review, we defined the best local flap as follows: it should be technically simple, a single-stage procedure, replacing like with like, minimizing donor-site morbidity, and resulting in functional with esthetic outcome.[6,9–12] We should keep in mind that the simplest is not always the best and that reconstructive surgery should entail parallel, creative thoughts rather than sequential processing.[13] However, if we can achieve the aim although being simple, it would be the best. The propeller and keystone flaps allow to achieve goals in such a way as we mentioned above with many advantages and are leading a new trend for reconstruction. Nevertheless, classical approaches such as gastrocnemius, soleus muscle flaps, and reverse sural flaps provide distinctive advantages that one needs to use for various defects.

This review aims to help the plastic surgeon on when to consider local flap for lower limb defects introduces new trends while advocating the classical local flap options, which may be the best local flap to approach lower extremity reconstruction.

ALGORITHM FOR LOWER LIMB DEFECTS

The actual selection process can be guided according to the zone of injury.[14,15] The lower limb can be divided into 5 zones to facilitate choosing the best method for coverage: thigh, knee, middle leg, lower leg, and foot and

From the Department of Plastic Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Republic of Korea.

Received for publication September 29, 2019; accepted February 24, 2020.

DOI: 10.1097/GOX.0000000000002774

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

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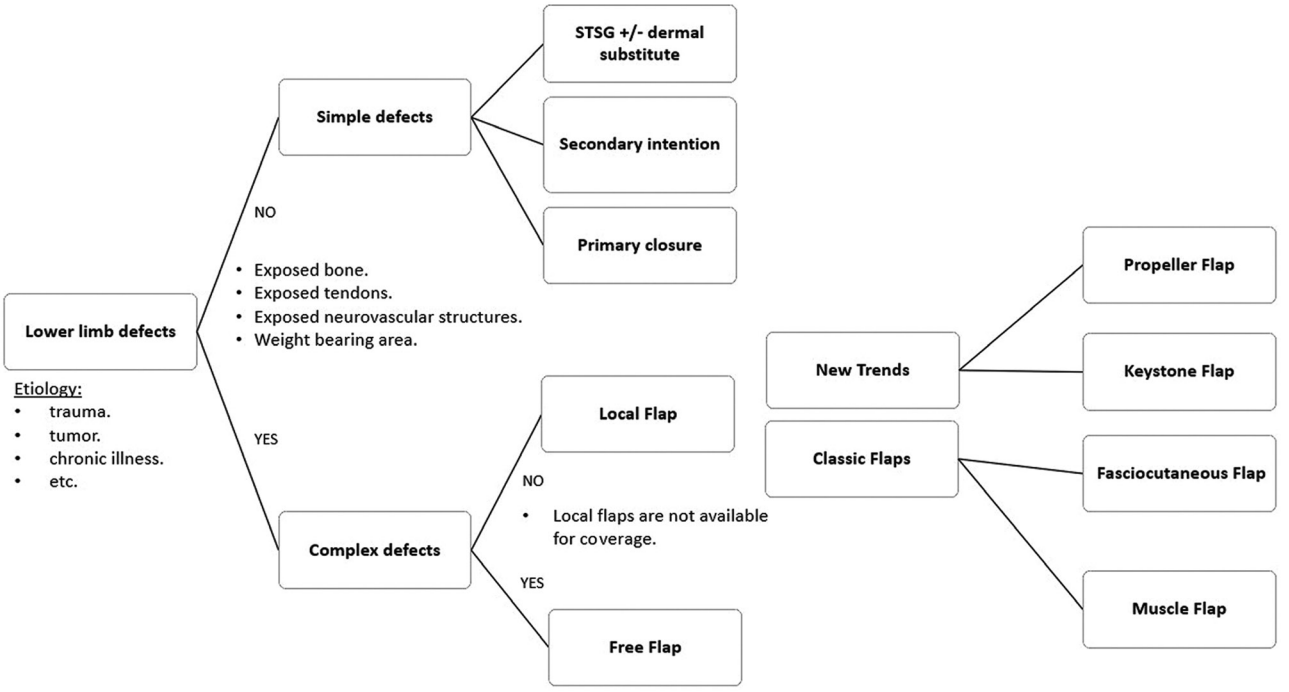


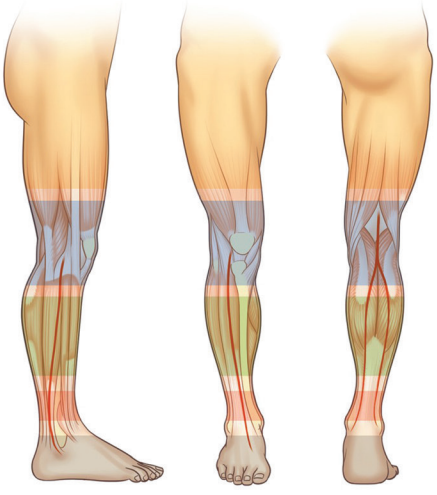
Fig. 1. Algorithm to approach the lower extremity defect and to select appropriate flaps for reconstruction. STSG, split thickness skin graft.

ankle. Classic reconstructive armamentarium suggests the use of local muscle flap for the upper two-third of the leg and free tissue transfers for the distal leg and foot.[16] However, with the application of the propeller and keystone flaps for leg reconstruction, the classic approach can be altered, and with many advantages, these flaps can lead to better and simpler results (Figs. 1–3).

NEW TRENDING FLAPS

Propeller Flaps for Lower Limb Defects

The lower extremity is the largest donor site in the body for a perforator flap harvest. And this is why there is a very high possibility to use this option. Anatomic studies by Morris et al[17] showed 93 perforators from the lower limb from 21 territories. There are relatively constant perforators from the 3 major vessels on the lower extremity allowing design of the propeller flaps predictable (Fig. 4).[18] The skin perforator flaps usually contour well because the surrounding tissue has similar thickness. It can be de-epithelialized to obliterate dead spaces; the skin laxity allows secondary procedures with ease and can have esthetically better results.[19] Most of all, anchoring on a perforator and modifying the design (free style) that allows the best possible result, the simplicity and reliability of approach make this flap intriguing to use.[3,20–24] When 1 propeller is not enough, one can use >1 propeller flaps to reconstruct the defect.[25]



Region	Traditional Flap	Preferred Flap
Thigh	Local Muscle Flap	Propeller Flap. Keystone Flap.
Knee	Gastrocnemius Flap	Propeller Flap. Gastrocnemius.
Middle leg	Soleus Flap	Propeller Flap. Soleus Flap.
Lower leg	Free Flap	Propeller Flap. Free Flap.
Foot & Ankle	Free Flap	Reverse Sural Flap. Free Flap.

Fig. 2. Flap selection by the zones of the leg.

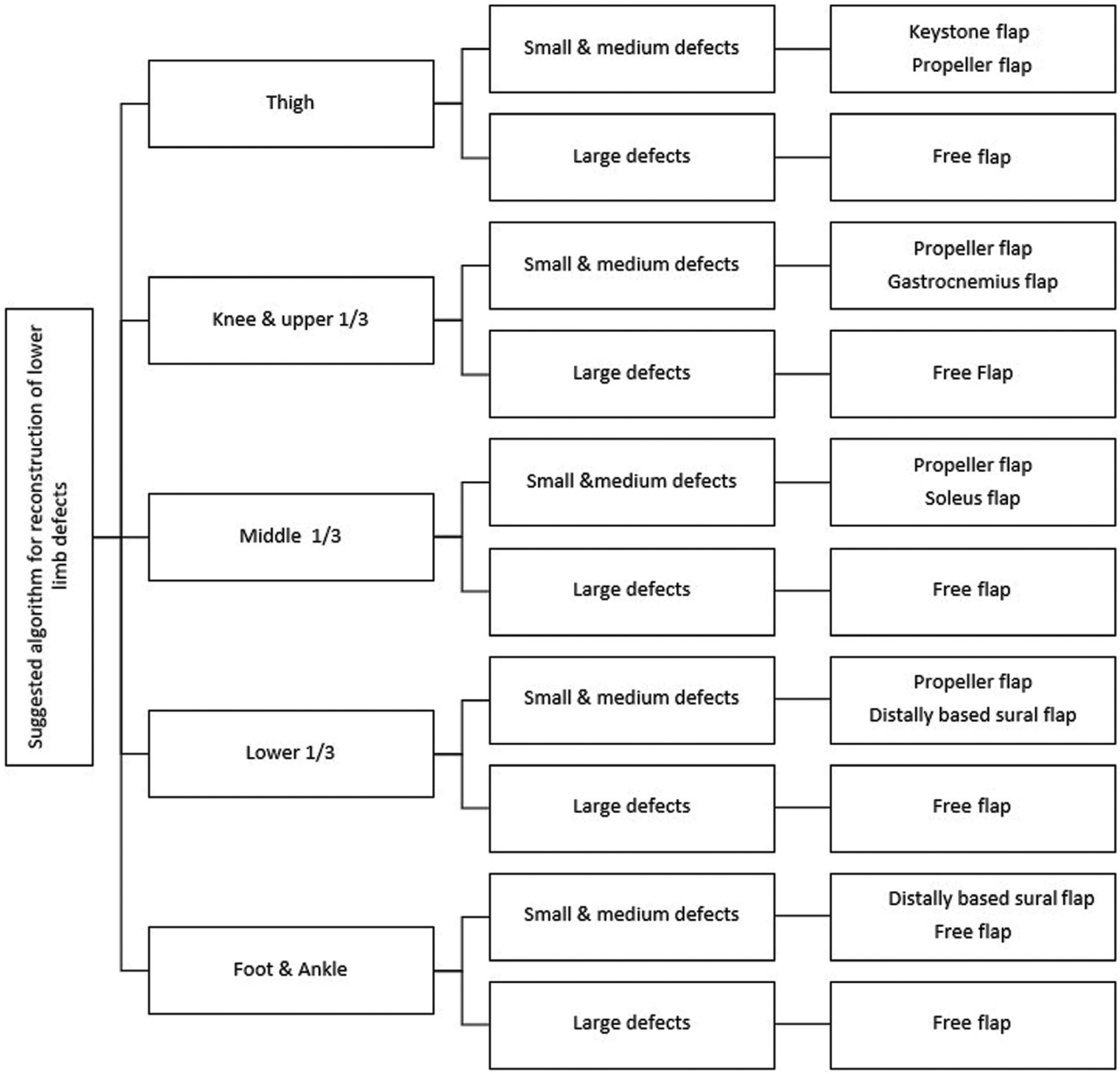


Fig. 3. Reconstruction algorithm of approach and to select appropriate flaps for each zone of the leg.

Goals of the Procedure

The goal is to achieve reliable reconstruction of lower limb based on a local perforator flap near the defects while obliterating the dead space if needed.[26]

Description of the Procedure

A handheld Doppler is used to confirm a good perforator signal. However, recent article suggests that using duplex ultrasound may be superior to handheld Doppler because it is able to determine the perforator with the best flow volume and velocity.[27] Based on these findings, the most dominant perforator within the optimal pivot point is selected. The perforator closest to the defect should be chosen to allow economical approach. The final decision, however, is made only after direct observation and assessment of the perforator's dimension, location, and pulse.[12,28] With the perforator as the pivot point, the typical design of a propeller flap is longitudinally oriented and proximal to the defect.[23,29] First, the distance between the perforator and the proximal edge of the defect is measured and is called the minor paddle. The major paddle is the area proximal to the pivot point, and it equals the minor paddle plus the length of the defect, adding a 1 cm (to anticipate for tissue contraction and to avoid tension when insetting the flap). Next, the width of the flap needed equals the width of the defect plus 0.5 cm.[6] Flap is dissected under loupe magnification. Plane of dissection can be sub- or suprafascial. One must free the perforating vessels from all the muscular branches and fibrous adhesions while achieving reasonable length of the pedicle to minimize any kinking.[22] (**See Video**

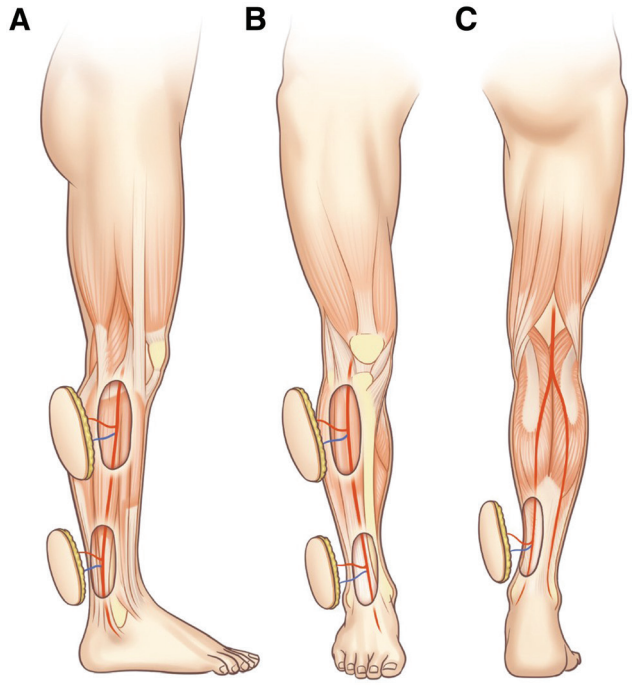


Fig. 4. Commonly found perforator flaps from all 3 major vessels on the lower extremity. Illustration of the lower leg revealing the location of reliable perforators from the peroneal artery (A), anterior tibial artery (B), and posterior tibial artery (C).

1 [online], which displays a surgical approach to propeller flap.)

For thigh defects, perforators from superficial femoral artery, descending genicular artery, and saphenous artery branches can be used.[30–33] For knee defects, perforators from the genicular system can be used (Figs. 5).[34–36] For leg defects, perforators from any of the three major vessels can be used (Fig. 6).[24]

Pearls and Pitfalls

1. Do an exploratory incision to confirm perforator location.
2. Dissect the perforator from all attachments and branches.
3. Dissect the perforator long enough below the fascia to avoid kinking.
4. Design the flap 1-cm longer and 0.5-cm wider.

Keystone Flaps for Lower Limb Defects

Goals of the Procedure

The goal is to cover elliptical defects over the thigh and leg, with low complexity and short operative time.[37]

Description of the Procedure

The keystone flaps should be designed on the defect's edge of greater cutaneous laxity. Classical marking draws the line at the ends of the primary defect with average angles of 90 degrees, reaching a 1:1 ratio with the amplitude of the initial defect and ending with a curvilinear line that joins these 2 lines at the outer edge of the keystone flap.[38–41] Centering the flap over dominant perforators allows more aggressive undermining away from these sites when required. The longitudinal axis of the flap should be oriented to the principal axiality of flow of the dominant perforators to include dominant linking vessels between perforators.[29] The circumferential incision of the deep fascia will increase the amplitude of rotation and advancement.[42] Flap-to-defect ratio is 1:1, and larger flap-to-defect ratios of 2:1 up to 5:1 may be required, which is dependent on regional tissue laxity (Fig. 7). (**See Video 2 [online],** which displays a surgical approach to a modified keystone.)[28,38] Modifications of this original design are summarized in Supplemental Digital Content 1 (**see table, Supplemental Digital Content 1,** which displays modification of keystone flaps, http://links.lww.com/PRSGO/B388).[28]

Pearls and Pitfalls

1. Try to locate and center >1 perforator to allow for more aggressive undermining.
2. If there is insufficient local tissue laxity for tissue advancement, the keystone flap cannot be applied for reconstruction.

CLASSIC FLAPS

The reconstruction that demands the use of gastrocnemius, soleus muscle flaps, and reverse sural flaps is usually very complex and challenging. Unlike the propeller flap, the muscle flap can provide enough bulk to obliterate dead space, minimizing the risk for potential infection. The reverse sural flap is an important option to cover the heel defect when microsurgery is not feasible.

Distally Based Sural Artery Flap for Lower Limb Defect

Goals of the Procedure

The goal is for reconstruction of simple and complex defects in the lower third of the leg, foot, and ankle.

Description of the Procedure

The classically described arterial supply is through septocutaneous perforators (3–6 perforators are usually present) between the peroneal artery and the superficial sural artery. The most distal perforator is located 4–7 cm proximal to the lateral malleolus. The distal pivot point of the flap should be at least 5 cm proximal to the lateral malleolus.[43–45] Doppler ultrasonography helps locate the most distal perforating vessel of the peroneal artery. The course of the flap pedicle is marked on the posterior midline of the leg along a line that extends from behind the lateral malleolus to the junction of the 2 heads of the gastrocnemius muscle to the midpoint of the popliteal fossa. The flap is designed 2–3 cm wider than the defect to compensate for the skin retraction. The procedure may be done under tourniquet control with the patient in the prone or lateral decubitus position. Flap can be harvested as a fasciocutaneous, adipofascial, and fasciomusculocutaneous flaps.[46–48] Adding the deep fascia and part of the gastrocnemius muscle may enhance flow and reduce venous congestion.[43]

Fig. 5. A large defect on the lower lateral thigh and upper region of the knee is noted (A). Using a handheld Doppler, potential perforators are marked and initial design is based on the perforator most likely from the geniculate system (B). One side of the flap is first approached to identify the perforator and then the design is modified accordingly based on the final finding of the perforator. After elevation of the flap, status of the flaps is checked to see if there is any compromise and then insetting is performed (C). The patient at 12 months shows good functional and esthetic results (D).

Pearls and Pitfalls

1. Include the lesser saphenous vein, to augment venous drainage.
2. Design the adipofascial pedicle wide enough.
3. Patients with venous insufficiency had 9 times higher risk of complications.[49]

Local Muscle Flaps for Lower Limb Defects

Goals of the Procedure

Gastrocnemius muscle flap is widely used as a workhorse for reconstruction of knee and upper third leg defect while soleus muscle flap is reliable for covering middle and lower leg defects.

Gastrocnemius Muscle Flap

Description of the Procedure

The gastrocnemius muscle flap with skin graft is a reliable method of reconstruction for the knee.[50] Although the gastrocnemius can carry a skin paddle, the donor-site defect created is undesirable. Each head has direct blood supply from the sural branches.[1] The medial head is generally larger and is shown to have a large arc of rotation all the way to the distal anterior aspect of the thigh.[51] It can be harvested through a medial or posterior incision and should avoid crossing the knee joint to prevent cicatricial contracture. The median raphe is split to allow for unilateral muscle harvest and rotation. The distal tendinous portion is divided.[4] The arc of rotation can be increased by detaching the muscle's origin from the femur, carefully dissecting the pedicle, and either scoring or removing the muscle fascia.[51] When harvesting lateral head, particular attention must be given to the common peroneal nerve

Fig. 6. An unstable wound is noted after multiple repair and dehiscence (A). Anticipating a propeller flap will be needed after debridement, multiple perforators are identified using a handheld Doppler. After complete debridement including the necrotic tissue underneath the skin, a propeller flap is designed based on a perforator near the defect and most likely from the peroneal artery (B). During the final design, pinch test on the donor site was performed to allow primary closure. The flap is elevated, rotated, and the donor site is closed primarily (C). The patient at 12 months shows good functional and esthetic results (D).

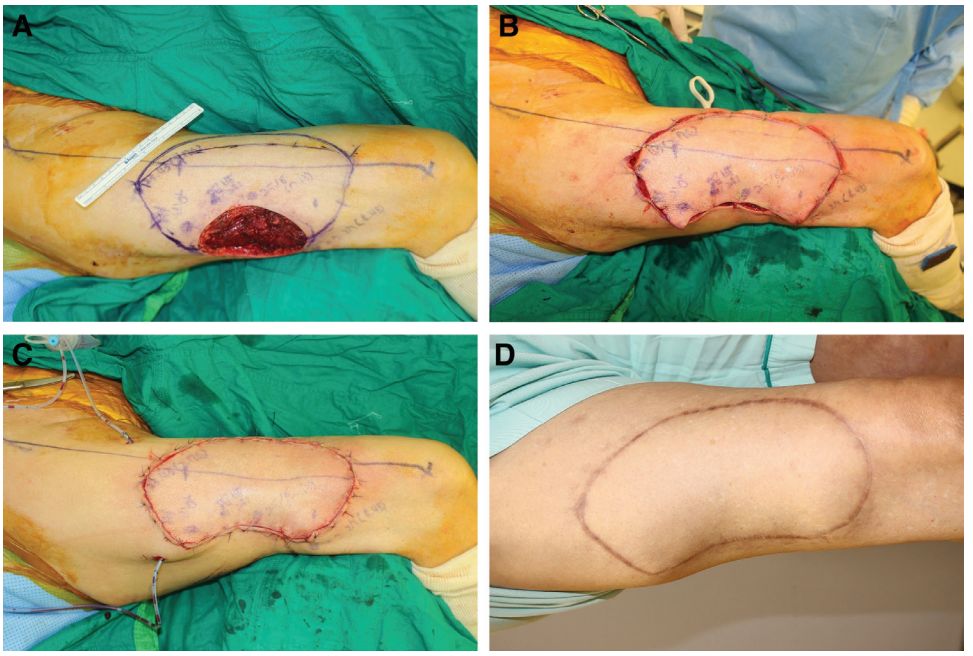


Fig.7. An elliptical defect on the lateral mid-thigh is noted (A). A keystone flap is designed to close the defect (B). Incision was made all the way to the deep fascia allowing the flap to advance without tension. Because of the laxity of the thigh, the flap did not need to be closed with a V-Y but rather just an advancement and a tensionless reposition of the flap (C). The thigh at postoperative 6 months shows good functional and esthetic results (D).

as it wraps around the fibular head, and patients should be informed of the 5% incidence of postoperative nerve palsies.[52]

Soleus Muscle Flap

Description of the Procedure

The soleus muscle flap can be elevated and transposed into wounds of the proximal, middle thirds, and even distal part of the leg.[53,54] The dominant vascular pedicles of the soleus are branches of the popliteal artery, branches of the posterior tibial artery (medial belly), and branches of the peroneal artery (lateral belly).[14,55]

The soleus muscle is often accessed through a preexisting wound if located along the medial aspect of the calf. If an overlying wound does not exist, an incision is made on the calf medial and just posterior to the medial gastrocnemius muscle. The soleus is identified through that incision. After separating the soleus from the Achilles tendon, perforators from the posterior tibial artery and peroneal artery can be identified as they enter the muscle. The perforators are ligated as needed to allow rotation of the muscle into the adjacent traumatic wound. The soleus muscle can be split longitudinally and used as a hemisoleus flap.[56]

Pearls and Pitfalls

1. Preserve as many as minor pedicles as possible while allowing adequate arc of rotation.
2. When using hemisoleus muscle flap, proximally based flaps are quite reliable, whereas distally based flaps are reliable in healthy patients, but tip necrosis may develop.[57]

CONCLUSIONS

Propeller and keystones flaps have gained popularity in the last decade due to the better understanding of anatomy and minimal complications involved. These flaps can indeed fulfill the criteria of "best local flaps in lower limb defect." Nevertheless, there will always be situation where muscle flaps will be crucial to serve the ultimate goal of reconstruction. The classical local flaps do have value in the approach, still deserving the title "best" along with the new trends. However, one must also consider what is best for them based on experience, comfort, resource, and personal decision-making processes.

Joon Pio Hong, MD, PhD, MMM
Department of Plastic Surgery
Asan Medical Center
University of Ulsan Collage of Medicine
88 Olympic-ro, 43-gil, Songpa-gu
Seoul 05505, Korea
E-mail: joonphong@amc.seoul.kr

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