THE DISTALLY BASED, VENOUS SUPERCHARGED ANTEROLATERAL THIGH FLAP

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The distally-based anterolateral thigh flap is an attractive option for proximal leg and knee coverage but venous congestion is common. Restoration of antegrade venous drainage via great saphenous vein supercharge to the proximal flap vein is proposed. The purpose of this study was to evaluate and compare outcomes of 18 large, distally-based anterolateral thigh flaps with and without venous augmentation on the basis of flap size, venous congestion, and clinical course. The average age of 12 men and 6 women was 35.9-year old (range, 16–50 years old). Wounds resulting from trauma, burn sequela, sarcoma, and infection were localized to the knee, proximal leg, knee stump and popliteal fossa. The mean defect was 17.6×9.4 cm^2 (range, 6×7 cm^2 to 22×20 cm^2). The mean flap size was 21.4×8.8 cm^2 (range, 12×6 to 27×12 cm^2). There were 14 cases in the venous supercharged group and 4 cases in the group without supercharge. The mean size of flaps in the venous supercharged group was significantly larger than that in the group without supercharge ($22.6 \pm 3.8 \times 9.1 \pm 1.7$ cm vs. $17.5 \pm 4.4 \times 7.8 \pm 1.7$ cm, $P = 0.03$). Venous congestion occurred in all four flaps without supercharge that lasted 3–7 days and partial flap loss occurred in two cases. There was no early venous congestion and partial flap loss in supercharged flaps but venous congestion secondary to anastomotic occlusion developed in two cases. Early exploration with vein grafting resolved venous congestion in one case. Late exploration in the other resulted in flap loss. Preventive venous supercharge is suggested for the large, distally-based anterolateral thigh flap. © 2015 Wiley Periodicals, Inc. Microsurgery 36:20–28, 2016.

Complex lower extremity wounds are a challenge for reconstructive surgeons because of poor wound healing, unreliability of local cutaneous flaps, complex recovery protocols, and contour abnormality after free tissue transfer.[1–4] In the modern era, refinements in flap choice and technique enable them to do more than cover a wound. Aesthetic concerns and minimized donor site morbidity have become critical considerations in reconstruction. Perforator flaps address these challenges, and may be more reliable and versatile than local cutaneous flaps.[5] Numerous lower extremity perforator flaps are described in the literature.[5–8] Although feasible free tissue options exist,[9] candidate tissue and vessels may be involved in the zone of injury, deeming them unreliable or nonexistent.

Since its introduction by Song et al in 1984, the anterolateral thigh (ALT) flap has become a widely popular and versatile workhorse.[10] The ALT flap can provide ample soft tissue, including a large skin paddle, vascularized fascia lata, and vastus lateralis muscle. Pliable fasciocutaneous designs will adapt to irregular soft tissue defects. The proximally-based pedicled ALT is an institutional favorite for coverage of lower trunk and pelvic defects. It promises a hearty blood supply, and cosmetic and functional donor site morbidity is well tolerated.[11–18]

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If the thigh is not involved with the zone of injury, aforementioned benefits of the ALT can be exploited for wounds involving the knee and proximal-third of the leg. Zhang et al.[19] described a distally-based ALT (dbALT) flap in 1990 that is based on retrograde flow from the lateral superior geniculate artery, profunda femoris artery, or both.[20] Advantages of the dbALT flap, compared to a free flap from a different site, include reduced operative time and obviation of position change. Using perforator technique, muscle is spared and the dbALT will impart minimal functional deficit at the donor site and a good aesthetic result.

The dbALT has not gained widespread acceptance. Just as the reverse soleus,[21] reverse sural,[22–28] and reverse upper extremity flaps[29–35] are condemned for their tendency toward venous congestion and soft tissue loss, dbALT flap edema and compromise has been reported.[36,37] Because arteries function bidirectionally and veins rely on small interconnections to bypass functional valves,[38] outflow in reverse-flow flaps is inherently compromised. An ideal reverse-flow flap, therefore, should rely on antegrade outflow. This can be accomplished with "venous supercharging."

A simple modification of dbALT harvest technique that provides antegrade venous outflow to the great saphenous vein (GSV) is expected to improve flap reliability.[39] The purpose of this retrospective case-control study was to evaluate outcomes after venous augmentation of large flaps associated with venous congestion and complications,[20,37,40,41] and compare outcomes of venous-supercharged (VdbALT) and nonsupercharged distally-based ALT flaps.

PATIENTS AND METHODS

Between June 2005 and January 2014, 18 patients with complex lower extremity defects were treated with distally-based ALT flaps at Chang Gung Memorial

Table 1. Patients' Information in the Group with dbALT Flap

Age/sex	Cause of defect	Wound location	Defect size (cm)	Pedicle (cm)	Flap size (cm)	Type of flap	LCFA branch	Vein graft	Venous congestion	Complications
19/M	MVA	lateral knee	10 × 6	15	12 × 6	1 perforator plus arterial supercharge	descending	N/A	Noted immediately Resolved after 3 days	None
40/M	Burn	knee	6 × 7	12	16 × 7	1 perforator	descending	N/A	Noted immediately Resolved after 3 days	None
46/M	Necrotizing fasciitis	lateral knee	22 × 20	14	22 × 8	1 perforator	descending	N/A	Noted immediately Resolved after 7 days	2/3 flap necrosis wound infection
29/M	MVA	patella	10 × 10	16	20 × 10	2 perforators	descending	N/A	Noted immediately Resolved after 5 days	1/3 flap necrosis hematoma

Hospital. The average age of all patients was 35.9 years (range, 16–50 years). There were twelve men and six women. Thirteen wounds were the result of trauma, two resulted from burn injury and postburn sequela, two resulted from wide excision of sarcoma, and one resulted from necrotizing fasciitis debridement. Eleven patients had wounds localized to the knee, two had combined knee and proximal leg defects, two had proximal leg defects, two had below-knee amputation stump wounds and one had a popliteal defect. The mean defect was 17.6×9.4 cm^2 (range, 6×7 cm^2 to 22×20 cm^2). Associated injuries included patellar tendon loss in three patients, ligament disruption in two cases, and an exposed joint in two cases. Time from wounding to reconstruction averaged 26.3 days (range, 0–117 days). Four patients were treated with dbALT flaps by senior reconstructive trauma surgeons at this institution (Table 1). Fourteen were treated with VdbALT flaps by two authors of this study (C.H.L., C.C.H.) using the technique of Lin et al, when large flaps were needed (Table 2).[39]

Surgical Technique

Cutaneous perforators were identified by Doppler and marked. Flaps were designed over the distal perforator. The medial incision was made and perforators were identified in the subfascial plane and traced to the souce vessel. In the majority of cases, the predominant ALT blood supply arose from perforators of the descending or oblique branch of the LCFA.[42] If the perforator(s) arose from the transverse branch special care was taken to ensure distal communication with the geniculate system. After vessels were identified, the lateral incision was made and an Acland clamp was applied to the proximal descending branch to confirm perfusion.

The descending branch was dissected distally until an adequate pivot point was reached to allow tension-free flap transposition into the recipient site. The great saphenous vein was then identified, isolated, and transposed anteriorly by open incision or subcutaneous tunnel. The proximal flap pedicle was positioned to allow the dominant pedicle vein to be anastomosed to the GSV (Fig. 1). Following anastomosis, antegrade venous drainage was confirmed.

Outcomes and Comparisons

Patient data collected from chart review included age, gender, etiology, time to reconstruction, wound location and associated injury, donor-site management, defect size, flap size, pedicle length, pivot point distance to patella, flap characteristics (source vessel, perforator number), and outcomes including the need for revision surgery. Our procedures were in accord with the Helsinki Declaration of 1975. The sizes of defects and flaps between groups were compared using Student's t test. Venous congestion in both groups was compared; it was defined as inherent partial or complete flap compromise despite adequate arterial inflow and no obvious mechanical obstruction. Statistical comparisons of the two groups were performed using a two-sided Fisher's test. All data were evaluated using SPSS software (SPSS, Chicago, IL. Version 17.0). Statistically significant results were obtained for values of $P < 0.05$.

RESULTS

There were no important differences in demographics in each group (Table 3). The mean size of all of flaps was 21.4 ± 4.4 cm $\times$ 8.8 ± 1.8 cm. The mean size of flaps in the VdbALT group ($22.6 \pm 3.8 \times 9.1 \pm 1.7$ cm) was larger than that in the dbALT group ($17.5 \pm 4.4 \times 7.8 \pm 1.7$ cm) ($P = 0.03$). Twelve flaps relied on a single perforator and six flaps relied on two perforators. One flap in the dbALT group was supercharged with an additional artery (no vein). Average pedicle length was 16.9 ± 3.3 cm (range, 8–29 cm) with a pivot point 8.6 ± 3.3 cm above the patella (range, 5–15 cm). The

Table 2. Patients' Information in the Group with VdbALT Flap

Age/sex	Cause of defect	Wound location	Defect size (cm)	Pedicle (cm)	Flap size (cm)	Type of flap	LCFA branch	Vein graft	Venous congestion	Complications
26/M	MVA	knee	12 × 7	15	16 × 7	2 perfs with fascia lata for tendon repair	descending	no	None	None
46/M	Burn	popliteal fossa	20 × 7	20	20 × 7	1 perforator	descending	no	None	None
46/F	Sarcoma	knee	8 × 8	17	18 × 8	2 perforators	descending	no	None	None
16/F	MVA	proximal leg	19 × 8	26	19 × 8	1 perforator	oblique	no	Developed postop day 2 Did not resolve	Vein occlusion Flap demise
46/F	Sarcoma	proximal leg	15 × 7	16	20 × 9	2 perforators	descending	no	None	None
46/M	MVA	lateral knee proximal leg	23 × 8	17	23 × 8	1 perforator	descending	no	None	Wound infection
47/F	MVA	knee	24 × 9	14	24 × 9	2 perforators	descending	no	None	None
31/F	MVA	knee	14 × 6	13	25 × 9	1 perforator	descending	no	None	None
44/M	MVA	BKA stump	25 × 9	21	25 × 9	1 perforator	transverse	yes 12 cm	None	None
33/M	MVA	knee proximal leg	29 × 8	15	29 × 8	1 perforator	descending	no	None	None
50/M	MVA	knee	14 × 12	18	20 × 12	2 perfs with fascia lata for tendon repair	descending	no	None	None
31/F	Crush	knee stump wound	27 × 10	17	27 × 10	1 perforator	descending	yes 8 cm	Developed postop day 2 Resolved with revision	Venous occlusion
34/M	MVA	knee	23 × 12	20	23 × 12	1 perf with fascia lata for tendon repair	descending	yes 7 cm	None	None
16/M	MVA	knee	15 × 15	18	27 × 12	1 perforator	oblique	no	None	None

dominant source vessel in continuity with the distal system was the descending branch of the lateral circumflex femoral artery in 15 flaps (83%), the oblique branch in two (11%), and the transverse branch in one (6%). Interposition vein graft was used in three VdbALT flaps (average length, 9 ± 2.6 cm; range, 7–12 cm). The donor site was closed primarily in 13 patients, four required shoelace repair (progressive closure) and one required split-thickness skin grafting.

Intraoperative laser Doppler studies demonstrated improved blood flow after venous anastomosis (Fig. 2). Following restoration of antegrade flow, none of the VdbALT flaps were congested in theater or the recovery unit. In contrast, all dbALT flaps were noted to exhibit clinical signs of venous congestion intraoperatively, including turgor, dark bleeding at the edges, and hue changes in the skin paddle.

After the patients were discharged from the recovery unit, venous congestion was observed in six flaps, including all four dbALT flaps (100%), and two of 14 VdbALT flaps (14%). The rate of venous congestion was significantly greater in the dbALT flap group ($P < 0.05$). Venous congestion developed at 18 hours in one case and 2 days in the other in the VdbALT group; one was vein grafted in the initial operation and one was not. In the dbALT group, venous congestion resolved after 4.5 days (range, 3–7 days) but there was resultant partial flap necrosis in two cases (50%) and an unsightly widened scar in one. In one flap with 1/3 partial necrosis, there was a perioperative hematoma that was evacuated soon after discovery and negative pressure therapy was initiated to the resultant wound. In the other flap with 2/3 necrosis, a resultant infection occurred that was managed promptly with antibiotics.

There was no partial flap loss in the VdbALT flap group; both occurrences of delayed venous congestion resulted from occlusion at the venous anastomosis. Early re-exploration in one case with revision vein grafting resolved venous congestion and the flap survived with no subsequent loss. In the second case, late re-exploration revealed occlusion at the venous anastomosis and the venous congestion did not resolve, leading to total flap loss. The wound was managed initially with local tissue rearrangement, negative pressure therapy, and a full-thickness skin graft. Ultimately, all flaps without venous congestion went on to survive completely. One flap, however, developed a localized infection that cleared with conservative management and oral antibiotics. Representative dbALT and VdbALT flap outcomes are shown in Figures 3 and 4.

DISCUSSION

The dbALT flap is an attractive option for proximal leg and knee coverage. Despite its versatility, this flap

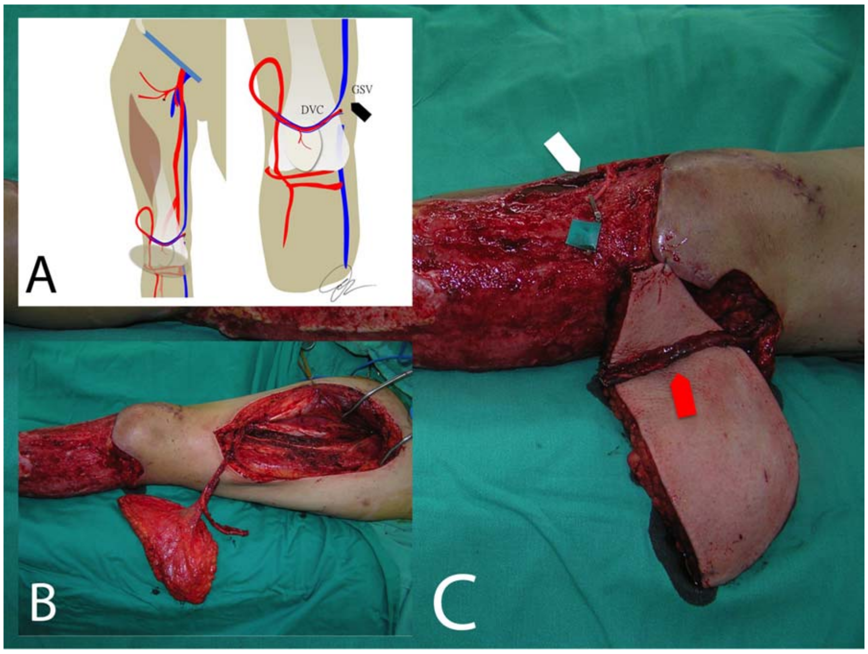

Figure 1. After confirming distal perfusion, the LCFA branch was divided and dissected distally until an adequate pivot point was reached. The flap was inset and great saphenous vein (GSV) transposed. The dominant vena comitante (DVC) was anastomosed to the great saphenous vein (inset, black arrow). ***B****. Flap excursion on pedicle.* ***C****. The long proximal pedicle was draped over the flap (*red arrow*) and easily reached the saphenous vein (*white arrow*).*

receives little accolade in the literature, and the volume of reported cases is limited.[19,20,36,37] As with any reverse-flow flap, venous drainage relies heavily on anatomic bypasses or shunts to circumvent valves. The ALT flap is larger than other reverse flow flaps, so inadequate venous drainage may be less forgiving. Fortunately, antegrade drainage is achievable with venous supercharging to the GSV.

Long retrograde pedicles (i.e., distal to the perforator) allow for better flap mobilization and reach but may imply additional valves to bypass and a foreshortened proximal venous leash. The pros and cons of each must be considered; Shieh type II and IV flaps (oblique branch dominant, or descending branch perforator arising proximally)[43] are controversial for distally-based transfer because of their longer retrograde venous course,[20] and yet their proximal (antegrade) venous leash is shortest. In those flaps, the distally-based pedicle length was increased by proximal ligation of the descending branch after it was "jackknifed" open (Fig. 5). In our series, a 12-cm vein graft was required in the only flap supplied predominantly by the transverse branch. When a type II or IV flap is encountered and there is inadequate proximal pedicle length, the GSV can be exploited to account for the discrepant length. As the GSV runs from the foot to the thigh, it can be ligated distally and transposed to the anterior knee. However, this may not always be possible, especially in cases where there is injury to the medial leg or vein itself. In our series, the GSV was transposed in two cases where the oblique branch was dominant, obviating the need for vein grafting.

In this series we raised flaps exceeding 20 cm × 10 cm. Larger dbALT flaps demonstrated venous congestion universally; this was not the case for VdbALT flaps. We did not observe arterial insufficiency in any case. Pan et al. presented three dbALT flaps, the largest of which was 16 cm × 7 cm, and there was no partial or total flap loss in that series.[20] In our series, the largest two (20 × 10 cm^2 and 22 × 8 cm^2) of four dbALT flaps developed flap necrosis following prolonged venous congestion. In one flap, partial necrosis may have been exacerbated by a perioperative hematoma. However, given urgent correction of the issue, we do not believe this was a significant contributor. In the second case, necrosis may have been exacerbated by a brewing soft tissue infection, but we expect that necrotic tissue was the cause, not the effect, of an infection that was promptly managed.

We do not know whether a size threshold exists that indicates venous supercharging. Just as in Pan's series,[20] every dbALT flap 16 × 7 cm^2 or smaller had an acceptable outcome in this series. In Demirseren's series, the largest dbALT flap without issue was 9 × 13 cm^2,[40] and in Wang's it was 9 × 11 cm^2.[41] Although greater numbers will provide more definitive answers, aforementioned data suggest dbALT flaps exceeding a length ×

Table 3. Comparisons and Outcomes

	dbALT (4 flaps)	VdbALT (14 flaps)	*P* value
Age	33.5 ± 12 years	36.6 ± 11.6 years	NS
Gender	4M: 0F	8M: 6F	–
Time to reconstruction	30.8 ± 28.7 days	25 ± 29.7 days	–
Defect size	12 ± 6.9 cm × 10.8 ± 6.4 cm	19.1 ± 6.3 cm × 9 ± 2.5 cm	NS
Flap size	17.5 ± 4.4 cm × 7.8 ± 1.7 cm	22.5 ± 3.8 cm × 9.1 ± 1.7 cm	0.03
Pedicle length	14.2 ± 1.7 cm	17.6 ± 3.3 cm	–
Perforators	3 single, 1 double	9 single, 5 double	–
Early venous congestion	4 (100%)	0 (0%)	<0.001
Delayed post-op congestion	0 (0%)	2 (14%)	–
Partial flap necrosis	2 (50%)	0 (0%)	0.039
Total flap loss	0 (0%)	1 (7%)	NS

NS = not significant, - = not compared.

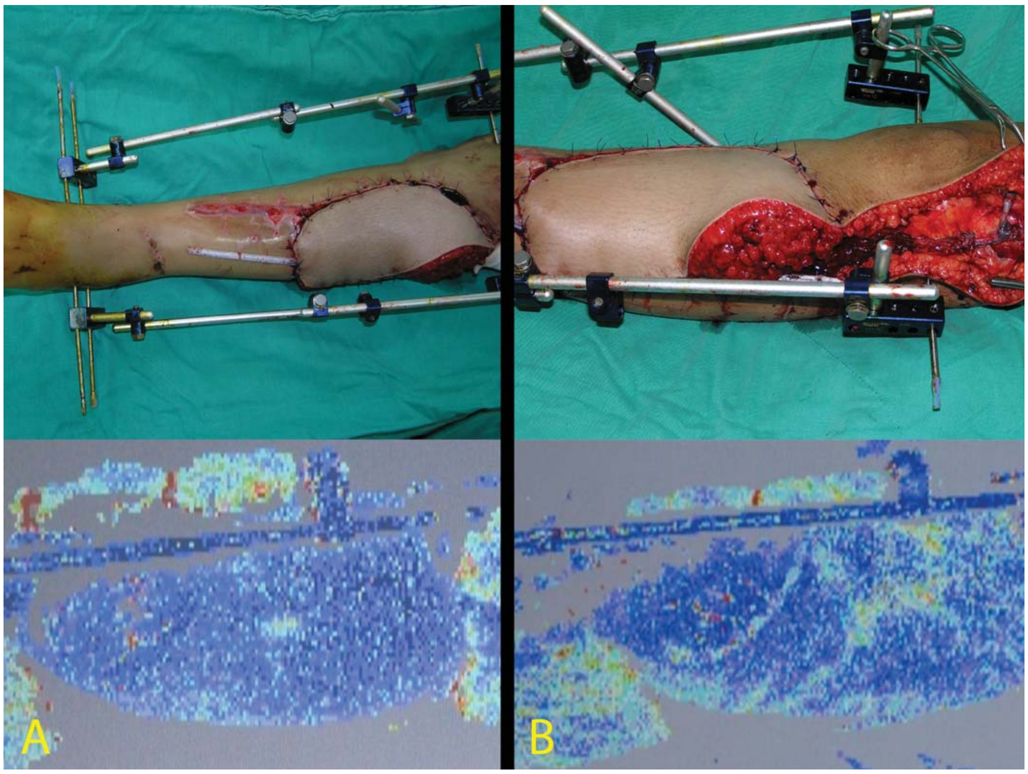

*Figure 2. **A**. Elevation of the reverse flow ALT flap showed venous congestion of the flap and laser Doppler showed minimal blood flow* (dark blue tone, below*), dusky color, and dark bleeding from the flap edges. **B**. Antegrade drainage of the proximal stump of the descending branch to a tunneled greater saphenous vein immediately relieved venous congestion with an improved laser Doppler signal (*light blue tone, below*) and assuring clinical signs.*

width product of 100 cm^2 might benefit from venous supercharging. Of course, other factors such as pedicle diameter, thickness, length, vascular anatomy, intraoperative findings, blood pressure, and surgeon instinct play a critical role. It seems unlikely that a set threshold exists but the topic warrants further study.

Many creative methods of improving outflow in reverse-flow flaps are described in the literature, including expansion of a subcutaneous tunnel,[23] flap delay,[26] and insertion of a venous catheter to intermittently relieve venous engorgement.[44] Venous supercharging physiologically addresses the arteriovenous imbalance inherent to reverse-flow flaps. We relied on this concept with other reverse-flow flaps with success,[45] and venous augmentation has proven itself elsewhere.[34,46,47] Our study has several built-in controls that illustrate the benefit of antegrade venous flow. First, one VdbALT flap developed venous congestion that was reversed with

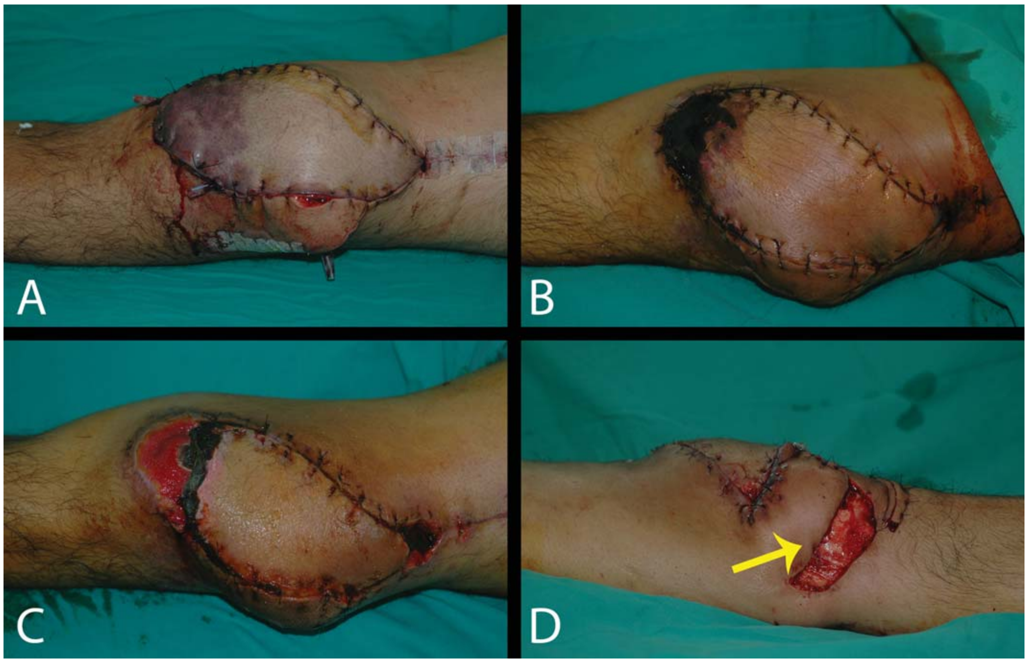

*Figure 3. Distally-based ALT (dbALT) flap. **A**. A 29-year-old male involved in a motor vehicle accident had a 10 cm long × 10 cm wide wound exposing his patella. A 20 cm long × 10 cm wide distally-based 2-perforator ALT flap was used to cover the defect without venous supercharge. Venous congestion was noted right away. By 5 days surrounding congestion resolved, but the distal tip was necrotic. **B**. The appearance at 1 week. **C**. The result at 2 weeks. **D**. The wound was treated with V-Y advancement of the flap, a rhomboid flap and a full thickness skin graft (not shown) of the resulting defect (*yellow arrow*).*

antegrade venous revision. Second, resolution of venous congestion was visualized intraoperatively after the venous anastomosis was performed.

There was one flap loss secondary to irreversible venous congestion in the VdbALT flap group. Late re-exploration revealed occlusion at the venous anastomosis and revision grafting was not attempted. The unfortunate incident supports the importance of venous supercharging. Venous anastomotic occlusion functionally converted a 19 × 8 cm^2 oblique branch-supplied VdbALT flap to a dbALT flap. In that case, the dbALT flap had insufficient intrinsic outflow. Augmentation with antegrade drainage rectified the outflow problem until an event 18 hours postoperatively led to occlusion of the venous anastomosis. Early re-exploration may have prevented irreversible damage and eventual flap loss.

This illustrates another important point. These flaps are fundamentally pedicled, but should be treated like free flaps after antegrade venous drainage is restored. No inherent venous congestion should be expected with VdbALT flaps. Any indication of venous congestion must be taken seriously with a low threshold to release sutures or return to the operating room for exploration. Other disadvantages of this flap include donor site morbidity of the ALT flap and saphenous vein. The functional and cosmetic morbidity of muscle-sparing ALT flap harvest is limited and generally well tolerated.[12,16,17] Moreover, saphenous veins are routinely harvested in cardiothoracic surgery and plastic surgery with infrequent morbidity, and they are routinely ligated in varicose vein treatment. Although infection and noninfectious wound healing complications[48] should be considered, the authors do not consider saphenous vein sacrifice a morbid procedure.

This is the first series to investigate the impact of venous supercharging on postoperative venous congestion and flap outcome. Although the data support our expectations, limitations must be considered. The number of patients is this series is small, especially in the dbALT flap group. Second, the study design was imperfect; data was not collected prospectively and patients were not matched for age, etiology, flap size or other parameters. Another limitation is the challenge of defining flap size. ALT flaps were raised as an ellipse, not a rectangle; the product of length and width would overestimate the true area. For the sake of comparison, we estimated area as the product of $\pi \times \frac{1}{2}$ length $\times \frac{1}{2}$ width assuming the flaps were true ellipses, although they were probably not; the variability of free hand design compromised standardization of data but provided a fair estimate. We also did not account for the flap thickness, a parameter that invariably influences physiology and metabolic demand.

Our experience supports antegrade venous drainage for relieving venous congestion in large flaps and any

Figure 4. *Distally-based ALT flap with venous supercharge (VdbALT).* ***A***. *A 31-year-old female involved in a motor vehicle accident had a 14 cm long × 6 cm wide wound over her knee. A 25 cm long × 9 cm wide distally-based single-perforator ALT flap was used to cover the defect. After proximal ligation the flap demonstrated venous congestion. Because of flap size and appearance, the proximal ALT flap vein was anastomosed to the GSV* (yellow arrow, *Acland clamp).* ***B***. *There was immediate venous decongestion after supercharge. The flap survived completely and without incident.* ***C***. *Outcome at 6 months, lateral view.* ***D***. *Anterior view.* ***E***. *Knee flexion was not limited and there was no functional impairment.*

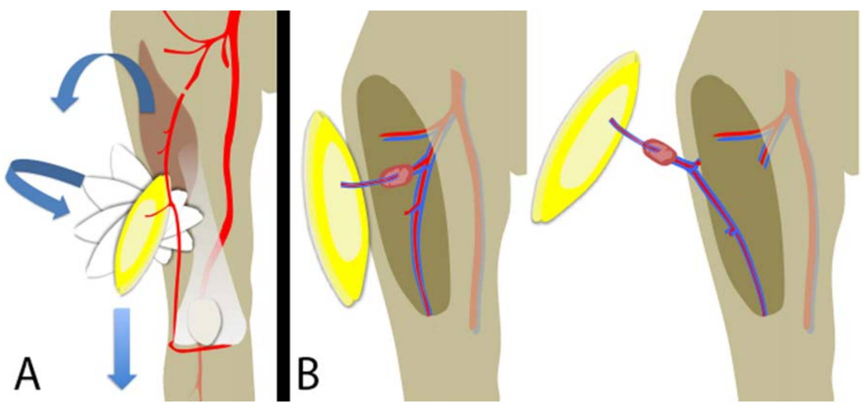

Figure 5. *Pearls.* ***A***. *When the distal perforator was used alone, the flap acted as a "propeller" flap with a shorter retrograde arterial pedicle and long proximal leash.* ***B***. *Alternatively, when the oblique branch and descending branch of the LCFA shared a common origin, and the oblique branch was the dominant supply to the flap, pedicle length was markedly increased with "jackknifing" of the oblique branch. Pedicle lengths of >20 cm from the pivot point were achieved.*

flap that demonstrates intraoperative venous congestion of the knee and proximal leg. With skilled hands venous supercharging adds 30 min of operative time.[39] We did not rely on preoperative angiography, but it must be noted when predominant supply arises from the ascending or transverse branch of the lateral circumflex femoral artery,[42] distal communication may not be achievable or existent. In those cases, conversion to a free flap is recommended.[8,39,49] When there is concern, preoperative imaging studies may identify such cases beforehand.[50,51]

CONCLUSION

Venous augmentation may improve the reliability of the distally-based ALT flap. Preventive venous supercharge is suggested for the large, distally-based anterolateral thigh flap.

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