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Original Article

Cross-leg flaps: Case series, review, and proposed classification

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ABSTRACT

Background: Cross-leg (CL) flap procedures have a long history in reconstructive surgery, having been described for the first time in 1854. The application of these flaps can potentially solve many reconstructive issues with satisfactory outcomes.
Patients and methods: During our research into the history and development of CL flaps, we identified a variety of flaps for which a classification system can be proposed based on blood supply and flap modifications. In this study, 10 patients with different complaints were managed using posterior tibial artery (PTA) perforator CL flap and superiorly based sural CL flap with satisfactory outcomes.
Results: All flaps survived and healed smoothly; consequently, the flaps provided stable coverage, and the donor sites were reconstructed using skin grafts, which provided satisfactory results to the patients and/or their guardians.
Conclusion: To our knowledge, this is the first study to propose a simple classification and group different types of flaps mentioned in the literature under one category. CL flaps are a common reconstructive option for patients with injuries that limit their mobility.

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Introduction

In 1854, Frank H. Hamilton, an American surgeon, described the cross-leg (CL) flap for the first time, which eventually became one of the cornerstones upon which the modern era of plastic surgery was built. Hamilton named the procedure helcoplasty, which refers to the process of treating ulcer-induced lesions.[1] Owing to the irresponsible use of the direct pedicle flap, flap delay was implemented to decrease morbidity. In 1950, Stark[2] summarized the technique and reported its advantages in the reconstruction of the lower limb.

In 1983, Ponten[3] introduced the concept of fasciocutaneous flap and described the role of deep fascia in flap surgery. Prior to the introduction of Ponten's concept, the CL flap was harvested as random skin flaps. The deep fascia was not included, which limited the length: breadth ratio to 1:1. Therefore, flap delay was required to increase the flap length, which resulted in extended hospital stay and increased number of surgical procedures. Following the introduction of Ponten's concept, the CL flaps were operated safely at width: length ratios of 1:3 and 1:3.5. In the late 1980s, with the advent of the anatomical description of angiosomes and perforasomes, flaps nourished by these perforators were designed using nontraditional measures of ratios higher than 1:3.[4]

Since then, many types of CL flaps have been described. In modern reconstructive surgery, CL flaps have several identities and descriptions (see Table 1), which can be classified as:

Skin flaps: **Conventional random** pattern CL flaps were raised in 1:1 width: length ratio, and in an **axial pattern**, CL flap dimensions were increased to 1:3 width: length ratio.[5]

Table 1
Proposed classification of cross-leg flaps, (Sabry's etal classification of cross-leg flaps).

No	Type	Subtypes		Varieties
1	**Skin**	Random[5]		
		Delayed[4,10]		
2	**Fasciocutaneous**	Axial	PTA	Distally based[6–9]
				Superiorly based[5]
				Modified triangular[10]
				Whole leg[11]
			Peroneal[12,13]	
			Sural	Distally based[16–19]
				Supercharged reversed[20]
				Medial sural artery[21]
				Superiorly based superficial sural[22]
			Saphenous	Longitudinal[14]
				Distally based[15]
			Medial planter	Cross-foot flap[23–25]
			Popliteal	Posterior descending subfascial cutaneous branch[26,27]
				Geniculate artery reverse-flow anterolateral thigh[28]
3	**Muscle**	Musculocutaneous	Gastrocnemius[29,30]	
			Gracilis[31]	
		Muscle and STSG	Soleus[32]	
4	**Free**	Traditional free[5]		
		Free cable[5]		
		Venous repair[33]		
		Free style puzzle[34]		
		Flow through[35]		
5	**Modified**	Pre-laminated[37–39]		
		Fillet[40,41]		
		Crane principle[43]		
		Staged division[44]		
		With distal fascial extension[45]		

Fasciocutaneous *(axial)* flaps: Posterior tibial artery (PTA) perforator CL flap has been described in the literature in many forms, such as the distally based flap,[6–9] superiorly based flap,[5] modified CL flap for triangular soft-tissue loss of the lower extremity based on the PTA perforators located in the middle one-third of the leg,[10] and whole leg CL flap based on the septocutaneous perforators of the PTA emerging between the soleus and flexor digitorum longus muscles.[11]

Peroneal artery septocutaneous perforator CL flap.[12,13]

Saphenous artery based: flaps based on saphenous artery, nerve, and vein were first described as longitudinal fasciocutaneous CL flap[14] and distally based saphenous neuro-fasciocutaneous and musculo-fasciocutaneous CL flaps.[15]

Sural artery based: flaps also have numerous descriptions in the literature, such as a distally based sural artery island fasciocutaneous flap,[16–19] supercharged reversed sural artery CL flap, contralateral reversed sural artery flap that covers the raw area and an anastomosis designed between the deep perforating and long saphenous veins of the recipient extremity,[20] medial sural artery CL flap,[21] and posterior calf fasciocutaneous pedicle CL flap centered on superiorly based superficial sural artery.[22]

Medial planter artery cross foot flap.[23–25]

Popliteal artery based: a CL flap nourished by a branch of the popliteal artery named posterior descending subfascial cutaneous artery[26,27] and geniculate artery reverse-flow anterolateral thigh island CL flap[28]

Muscle and Musculocutaneous CL flaps such as musculocutaneous CL flap that uses the medial head of the gastrocnemius muscle[29,30] or gracilis muscle[31] and soleus muscle as a CL muscle flap covered by split-thickness skin graft (STSG).[32]

Free CL flaps: such as the traditional free CL flap and free cable bridge (FCB) CL flap.[5] CL venous repair involves free flap reconstruction when the arterial anastomosis between the artery of the flap and recipient artery of the ipsilateral leg is operated, and the venous anastomosis is designed between the vein of the flap and long saphenous vein of the contralateral leg.[33] Freestyle puzzle CL flap involves the reconstruction of defects on both lower limbs with exposed joints and free latissimus dorsi musculocutaneous flap is used to reconstruct the right leg. Then, a musculocutaneous CL flap is harvested from the previous redundant flap to reconstruct the contralateral knee[34] and cross flow through free CL flap in which both the distal and proximal ends of the pedicle are anastomosed, thereby providing blood flow to distal circulation.[35]

Modified CL flaps such as pre-laminated CL flap; pre-lamination is a procedure in which extra tissues are added to the existing flap without interfering with its blood supply, so that it can be used in a multilayered reconstruction.[36] Pre-laminated CL flaps[37–39] where the pseudo-synovial osteogenic membrane induced by a cement spacer in the Masquelet technique.[37] CL fillet flap[40,41] applies the concept of harvesting tissue from amputated extremities or "spare parts." These are axial flaps that can be used for composite-tissue reconstructions if sufficient tissues are available.[42] Crane principle[43] involves the coverage of defect using a CL flap. Two weeks later, the attached flap is split horizontally in the subcutaneous layer to create a skin-subcutaneous fat flap (repositioned to the donor's leg) and a subcutaneous fat-fascia flap that is covered with STSG. Staged division[44] of the broad pedicle increases the flap's contact with the bed, and CL flaps with distal fascial extension[45] being placed beyond the defect in the subcutaneous plane.

Methods of cross-leg fixation

The flap's viability depends on fixation of the two limbs. The external fixator has significant advantages over plaster casts, including optimal CL position, easy nursing, and satisfactory relief for the patient. Furthermore, tension-free repair can be achieved via fine adjustments to the external fixator,[46] two Kirschner wires crossing through both tibiae in CL position,[47] and Steinmann pins that are then connected using steel rods held by universal clamps,[48] preoperative application of plaster casts to both legs, transfer of the pedicle through windows in the casts,[49] the Hoffman transfixation equipment,[50] Resur®-Splint,[51] an adjustable device made of steel to obtain rigid immobilization of plaster of Paris,[52] and Cross-Ilizarov external fixator.[53]

Complications of the cross-leg flap operation

Preventable complications such as flap necrosis, the position of any CL flap must have a gentle extension between both legs, and hematomas beneath the flap due to improper hemostasis. Infection can be decreased by providing a well-debrided bed prior to CL flap application. Pressure areas such as the heels, Achilles tendon, and both malleoli must be protected using appropriate padding. Pressure may cause damage to nerves such as the lateral popliteal nerve, and the posterior tibial nerve.[54] Genitourinary tract infections, joint stiffness, and deep vein thrombosis may occur, but proper hygiene and pumping exercises can virtually eliminate these risks.[55]

Pedicled CL flaps vs. free CL flaps

Advantages of pedicled CL flaps:

Pedicled CL flap is an easy-to-perform procedure that does not require advanced equipment or microsurgical experience.[45] Additionally, microsurgery is relatively time-consuming[56] and requires advanced postoperative monitoring.[57]

With regard to the time of flap division, Landra[30] documented dividing a CL flap on the 15th day, and Tauxe et al.[58] reported Technetium isotope usage as a possible guide for deciding the time for flap division. Other researchers suggested time for flap division to be between the 12th and 16th days postoperatively.[15] Most patients were unable to walk prior to flap division due to significant or associated trauma.[59] In a free CL flap, a major artery of the limb is used for end-to-end anastomosis, and the distal circulation is decreased, although it can be managed via additional interventions which may induce more complications.[60]

Pedicled CL flaps are highly dependable for reconstructing difficult tissue loss of the lower extremities. Moreover, the flaps present a great platform for reconstructing most of the lower limbs, especially with exposed vital structures such as bones, tendons, nerves, and vessels.[61]

Disadvantages of pedicled CL flaps: include superiority of free CL flap in some conditions such as bilateral trauma,[34,59] chimeric flap (when the osseous element is needed for a large bone defect, but it can be managed using traditional CL and Masquelet[37] technique), and/or bone transport procedures using Ilizarov fixator. When muscle flap is needed, a recent study found no significant variance between application of muscle and fasciocutaneous flaps on patients with chronic post-traumatic sequelae of the lower extremities.[62] Additionally, CL pedicled muscle or musculocutaneous flaps can be used.[29–32]

Indications for CL flaps

CL flaps are used for reconstruction of tissue losses due to trauma (as a result of road traffic accidents, gunshots, bullets, crush injuries, degloving injuries, land mines, and explosions), burns (electric), malignancies, leprosy, and congenital (club foot).[63]

Case series

Materials and methods

Since 2019, the PTA perforator CL flap and superiorly based sural CL flap procedure have been used to reconstruct soft-tissue defects of the lower leg and foot in 10 patients admitted to Minia University Hospital with various complaints. The data was collected retrospectively (Table 2). The mean age of the patients was 24.6 ± 19.3 years (range, 2–60 years) with 10 (100 %) males.

The operations were carried out under spinal block; general anesthesia and tourniquet were used. A template of the defect was designed and applied to the donor's leg. The flaps were operated at the same size as the target defects. Before setting the flap, the tourniquet was released, and bleeding was controlled. At the time of flap separation, the STSG harvested from the thigh region was used to reconstruct the secondary defects of the flap.

Table 2
Data of the patients who were managed using cross-leg flaps.

No	Age (years)	Sex	Operation time (minutes)	Hospital stay (weeks)	Follow up period (months)	Type of flap	Type of fixation	Complications	Defect location	Disability	Time of pedicle separation (days)	Secondary procedures
1	29	m	30	6	36	PTA	External fix	Partial loss	Lower 1/3	Segmental loss	21	Masquelet and Ilizarov
2	50	m	30	8	12	PTA	External fix	Infection	Knee upper 1/3	Fracture necrotizing fasciitis	21	Ilizarov
3	11	m	40	4	6	Sural	Plaster of Paris	Stich sinus	Lower 1/3	Achilles tendon cut	21	Stitch sinus removal
4	2	m	25	4	2	PTA	Plaster of Paris	–	Lower 1/3	contracture	21	–
5	33	m	25	4	6	PTA	External fix	Infection	Middle 1/3	Fracture infection	21	Ilizarov
6	12	m	30	4	2 4	PTA	Plaster of Paris	–	Dorsum of foot	PT Raw area	21	–
7	6	m	25	4	6	Sural	Plaster of Paris	Infection	Lower 1/3	Short tendon Achilles	21	–
8	13	m	40	6	6	PTA	Plaster of Paris	Partial loss	Dorsum of foot	Fracture metatarsals	21	–
9	60	m	40	4	2	Sural	Plaster of Paris	Partial loss	Heel	Heel ulcer	21	–
10	30	m	35	4	3	PTA	Plaster of Paris	–	Dorsum of foot	Metacarpal fractures	21	–

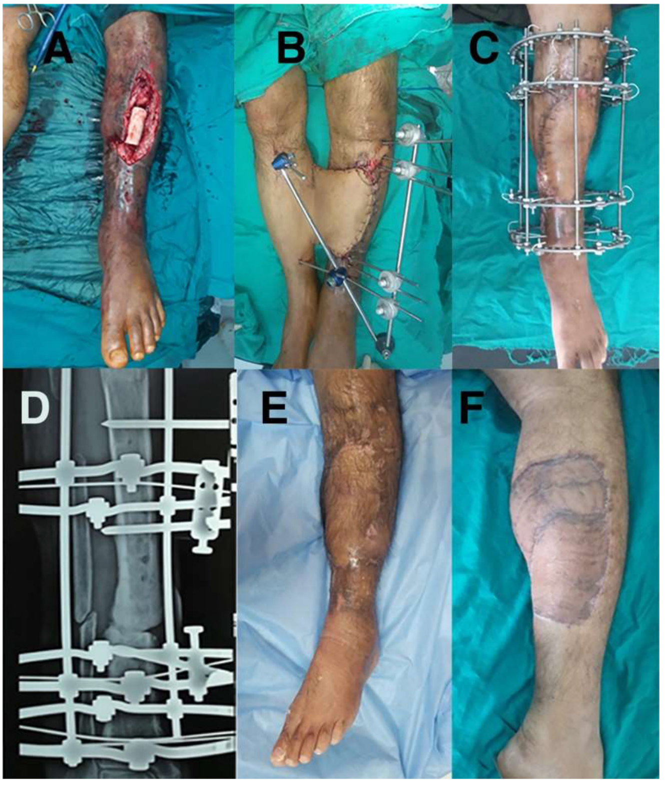

Figure 1. Infected bone graft and plate of a 33-year-old patient (A) infection removal and application of cement spacer at the middle 1/3rd of tibia, (B) coverage using PTA perforator CL flap, (C) application of Ilizarov, (D) X-ray, (E) end result of the procedure with stable flap coverage, and (F) satisfactory results of STSG at the donor site.

In this case series, all patients underwent two or more operations for debridement, flap harvest and inset, management of complications, flap separation, and application of skin grafts to the secondary defects. All 10 flaps were fasciocutaneous flaps. All flaps were divided 21 days from the time of flap inset. We immobilized both lower limbs using plaster of Paris (figure of 8) in 7 (70 %) cases and external fixators in 3 (30 %) cases (Table 2).

Surgical procedure

Seven primary defects were reconstructed using PTA perforator CL flap (Figure 1), based on 2 to 3 neighboring perforators located 1–2 cm from the medial border of the middle third of the tibia. Preoperatively, the perforators were recognized using a hand-held Doppler. No attempts were made to isolate or skeletonize the perforators.

All the flaps were harvested as fasciocutaneous flaps involving the posterolateral and the anterior compartmental tissue. The secondary defect of the calf skin was reduced as much as possible. Then, the donor site was reconstructed using a STSG at the time of flap division. The cross-legged position was maintained by using external fixators or plaster of Paris (figure of 8), and the flaps were divided after 21 days.

After determining the recipient site dimensions for superiorly based sural CL flaps (in three cases), the pivot point and pedicle length were lined, and dimensions of the flap were designed. Following the course of the small saphenous vein, the median sural artery and sural nerve, and the fasciocutaneous flaps were placed on an imaginary line on the posterior leg skin (Figures 2 and 3).

Figure 2. Heel of a 60-year-old patient (A) recurrent heel ulcer, (B) after excision of the ulcer and old skin graft, (C) coverage using a superiorly based sural CL flap, (D) end result of the procedure with stable flap coverage, and (E) satisfactory results of STSG at the flap's donor site.

At the midpoint of the lower leg, the sural nerve pierces the deep fascia and passes between the medial and lateral heads of the gastrocnemius muscle. At this point, the neurovascular bundle may adhere to the nearby structures, necessitating careful dissection.

In a sub-fascial plane, we dissected the posterior calf fasciocutaneous flap in a superiorly based pattern. The proximal end of the Achilles tendon marks the distal end of the flap. The sural nerve, median sural artery, and small saphenous vein were ligated and centered in the flap.

The subsequent steps were then completed following the procedures mentioned in the previous operations.

Adequate space was left between the two limbs, allowing free air circulation to keep the area dry. The sutures were after removed two weeks.

Physical therapy was initiated on the second day following flap separation.

Figure 3. Case of a 11-year-old patient (A) post traumatic raw area at the lower 1/3rd of the leg with previously operated tendon Achillis, (B) after debridement, (C) coverage using superiorly based sural CL flap, (D) coverage of the donor site of the flap by STSG and (E) end result of the procedure with stable flap coverage.

Results

For most patients, the postoperative course was uneventful (Table 2). The patients who underwent external fixation, except for one patient, complied well with their restricted postoperative position better than the patients who were restricted using plaster of Paris. All flaps survived and were then divided after 21 days. The three patients who received CL flaps on the dorsum of their feet could wear normal shoes and were capable of performing their daily activities. Three flaps showed partial necrosis; debridement and coverage were carried out using STSG. In addition, three patients developed an infection and were managed conservatively.

The total hospitalization period averaged 4 weeks; there was a significant relation between the total hospital stay and associated patient disability ($p = .035$). The follow-up period averaged 34 months, ranging between 2 and 36 months. In most cases, the CL flaps and donor sites were considered cosmetically acceptable by patients, relatives, and surgeons. Nine patients did not suffer from either knee or ankle stiffness owing to the restricted mobilization prior to the separation of the CL flaps. Only one patient who suffered from extensive necrotizing fasciitis secondary to knee trauma had a CL flap applied to the proximal leg and knee; he suffered from subsequent ankylosis of the knee joint. One patient had a heel ulcer, which was reconstructed using proximally based sural CL flap and no hyperkeratosis or ulceration of the flap occurred, and the patient could walk on his flap. Secondary procedures were performed on four patients. One of the procedures involved the removal of stitch sinuses, and three procedures involved the Masquelet technique and Ilizarov bone transport that required bone grafts. There was no significant relation between CL fixation type and postoperative complications ($p = .380$)

Discussion

By researching and tracing the history of the CL flap, we found that several descriptions and forms are available for a single flap, which changed with the advancements in the understanding of the lower leg vasculature, particularly with the development of the concept of angiosomes and the anatomical description of each flap depending on which branch or perforator enabled us to identify and classify these flaps (Table 1). To our knowledge, we compiled the documented indications, complications, methods of prevention, procedures for CL fixations, and versatile characteristics of both the pedicled and free CL flaps. The current study findings add to the existing literature to help practitioners determine the most suitable tool for the reconstruction of complex lower leg and foot defects, in addition to limiting complications and overcoming challenges.

Complex lower extremity trauma is always associated with exposed vital structures, such as tendons, vessels, and bones, and may result in amputation and/or shortening of the traumatized limb.[64] Lack of suitable local flaps in these regions makes it difficult for plastic and reconstructive surgeons to cover lower leg defects.[16,19]

In this study, we overcame these challenges by utilizing the PTA and superiorly based sural CL flap, which resulted in satisfactory outcomes.

Free tissue transfer is believed to be a cornerstone for the reconstruction of the distal lower leg tissue loss as it allows three-dimensional reconstruction in a single operation. However, these flaps have some limitations,[45] such as major vessel sacrifice, extended time of operation,[45] and morbidities of the donor sites. In addition, free flaps need specialized surgical skills, sophisticated equipment, more than one team of surgeons,[45] and advanced postoperative monitoring.[57] Moreover, the patients and/or their guardians who had to undergo this surgery refused free tissue transfer because of the associated hazards and risks.

Pedicled CL flap procedure is a highly reliable technique, with a relatively short operation time, simple technique suitable for junior plastic surgeons, and highly valuable method for reconstructing complex wounds in the lower extremities. It presents a flap with large dimensions to reconstruct nearly all the challenging defects of the lower leg.[61]

Wang et al.[65] illustrated that the CL neuro-fasciocutaneous flap is a conventional method of covering soft-tissue defects of large dimensions on the lower limbs. This procedure has the advantages of reliable end results, depending on simple technology and relatively short operation time. Additionally, Ahn et al.[22] operated on six superior-based posterior calf CL flaps and one distal-based CL flap transfer to treat deep foot ulcers in patients with leprosy. They obtained satisfactory results in six patients and partial necrosis in the patient managed using distally based CL flap, which corresponds to the outcomes of our patients treated with a superiorly based usual CL flap.

Morris et al. achieved 94 % success rate using the conventional CL flap. When they incorporated the deep fascia in the flap, they achieved approximately 100 % success rate,[66] and Kamath et al.[10] reconstructed three defects on the lower leg and ankle using modified triangular fasciocutaneous flaps nourished by the PTA perforators in the middle one-third of the tibia and gained 100 % success rate. In addition, these results align with our results from patients managed using PTA perforator CL flap.

The CL external fixator can increase the versatility of CL flaps.[67] During this series, we used external fixator and plaster of paris methods and determined that each patient's condition, availability of resources, and consultation with the orthopedic team enabled us to determine the appropriate method to be performed for each patient. Furthermore, the nursing team indicated that external fixation, when used for limb immobilization, resulted in better postoperative nursing care, contrary to the recommendation by Lu et al.,[55] who did not favor this method as they mentioned that the CL external fixator might inflict additional harm to the patients. Their experiment hypothesized that the conventional plaster of Paris was adequate.

If partial flap necrosis occurs, a STSG could be used for wound coverage during flap division. No complete flap loss was documented in our study.

Children with trauma, such as fractures, that need time to heal have limited activities and are carried by their parents and this encourages us to perform CL flaps, which also applies to patients with lower limb fractures or associated disabilities.

Every case should be managed as an individual case by a team of specialists, as the team concept always has better outcomes in all fields of medicine.

Conclusion

We proposed a classification of CL flaps based on the history of flaps' evolution, anatomy of the flaps' feeding vessels, and modifications made to them based on the review of the relevant literature. In patients with injuries that limit their mobility, CL flaps are a popular reconstructive option. In treating complex foot and lower leg deformities, CL flaps are known to resolve numerous problematic issues.

Conflict of interests

All Authors declare that they have no conflict of interests.

Patients consent

Informed consent was obtained from the patients and or their guardians.

Ethical approval

This study was approved by the local Ethics Committee, Faculty of Medicine, Minia University REC no (462:10/2022). This work was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

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