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ORIGINAL PAPER

Cross-leg free flaps and cross-leg vascular cable bridge flaps for lower limb salvage: experience before and after COVID-19

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Abstract

Background Previous reports have evidenced the disruptive effect of the COVID-19 in microsurgical and reconstructive departments. We report our experience with cross-leg free flaps and (CLFF) and cross-leg vascular cable bridge flaps (CLVCBF) for lower limb salvage, technical consideration to decrease morbidity, and some structural modifications to our protocols for standard of care adapted to the COVID-19.

Methods We retrospectively included consecutive patients undergoing reconstruction with CLFFs and CLVCBFs for lower limb salvage from January 2003 to May 2022. We extracted data on baseline demographic characteristics, mechanism of trauma, and surgical outcomes.

Results Twenty-four patients were included, 11 (45.8%) underwent reconstruction with CLFF while 13 had CLVCBFs (54.2%). Fifteen patients (62.5%) underwent lower limb reconstruction under general anesthesia while 9 (37.5%) had combined spinal-epidural anesthesia. During COVID-19 pandemic, six CLFF cases were performed under S-E (25%). The average time for pedicle transection of muscle CLFFs and muscle CLVCBFs was comparable between groups (60 days versus 62 days, $p = 0.864$). A significantly shorter average time was evidenced for pedicle division of fasciocutaneous flaps in the CLFF group when compared to CLVCBFs (45 days versus 59 days, $p = 0.002$).

Conclusions In selected patients, CLFFs and CLVCBFs offer an optimal alternative for lower limb salvage using recipient vessels out of the zone of injury from the contralateral limb. Modification in the surgical protocols can decrease improve resource allocation in the setting of severely ill patients during COVID-19.

Level of evidence: Level III, Therapeutic.

Keywords Soft tissue injuries · Free tissue flaps · Leg injuries · Lower extremity · Limb salvage · Reconstructive surgical procedures · Surgical flaps

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Introduction

Current evidence on validated scoring systems that assist surgeons to determine whether limb salvage should or should not be attempted for complex wounds of lower extremities is still inconsistent and reproducibility is limited [1–3]. Some studies have even shown equivalent results comparing amputation versus lower limb reconstruction in severely compromised limbs [4, 5]. Patients undergoing amputations often present depression, posttraumatic stress disorder, or phantom pain [6], and can represent an increased economic burden when compared to patients undergoing limb salvage [7]. In order to avoid amputation, it is important to evaluate all reconstructive alternatives and approaches to improve surgical results and enhance patient-reported outcomes according to proper patient selection [8].

Ideal surgical outcomes following free tissue transfer depend in great part on the quality of recipient vessels. For lower limb reconstruction, free flaps cannot be transferred if there are extensive traumatic injuries with axial vessel damage, severe peripheral arterial disease, vascular thrombosis, or patients with suboptimal baseline characteristics [9]. Additionally, relative contraindications for microvascular reconstruction include previous radiotherapy, electrical injury, and single-vessel runoff. In these circumstances, the risk of free flap loss or necrosis increases, and cross-leg free flaps (CLFF) or cross-leg vascular cable bridge flaps (CLVCBF) may offer an appropriate reconstructive alternative [9].

The coronavirus disease 19 (COVID-19) pandemic has generated massive pressure on healthcare systems around the globe [10]. During this period, medical centers have increased the total inpatient capacity, redeployed medical staff from their usual roles, and created COVID-19 wards in response to the increased demand for healthcare. Furthermore, microsurgical units providing complex reconstructive services added further pressure to centers managing the large influx of critically ill patients with COVID-19, generating an increased competition for radiologic services, access to operating rooms, use of available ventilators, and vacant inpatient rooms [10]. Also, as non-urgent surgeries were postponed, including the cases of lower limb microvascular reconstruction, increased risk of pain, complication rates, and mortality alongside limited recovery, function, and quality of life have been hypothesized to result from delaying surgical management [11].

Reconstruction of lower limb defects can be problematic due to the lack of local soft tissue for transposition. Preserving the morphology and biomechanics adds complexity to the procedures and management [12]. Previous reports have evidenced the disruptive effect of COVID-19 in microsurgical and reconstructive departments [13]. Most studies on this subject have evidenced the necessity to diverge from standard clinical practices towards new protocols and different surgical management methods to provide more comprehensive care for patients that require lower limb reconstruction [13].

In response to COVID-19, we promoted alternative anesthesia modalities favoring neuraxial techniques to decrease post-anesthesia care unit (PACU) admissions, reduce the use of ventilators, and ease the transition of patients to the floor; we favored the use of loupe magnification to expedite the initiation and finalization of cases in a resource-constrained setting, and we implemented several workhorse flaps to optimize postoperative care in a pandemic setting. Herein, we reported our experience with CLFF and CLVCBF for lower limb salvage, technical consideration to decrease morbidity, and some structural modifications to our protocols for the standard of care adapted to COVID-19.

Patients and methods

Study protocol

This study was conducted in accordance with the World Medical Association Declaration of Helsinki. After institutional review board approval, a retrospective review of data was conducted including all consecutive patients undergoing reconstruction with free flap for lower limb salvage from January 2018 to June 2022. We included patients undergoing CLFFs and CLVCBFs for lower limb salvage. We excluded patients who underwent pedicled cross-leg flaps, reconstructions with flow-through flaps perfused from the ipsilateral limb, and patients with incomplete data.

Variables

Our demographic and baseline characteristics included the number of patients; age; sex (male/female); smoking status; past medical history of diabetes, peripheral vascular disease, congestive heart failure, hypertension, chronic kidney disease, or liver dysfunction; preoperative American Society of Anesthesiologists (ASA) physical status; and etiology of the defect or indication for reconstruction.

Surgical variables included the type of anesthesia, duration of surgery, location of defects, number of flaps, type of flap, type of magnification for anastomosis (microscope versus magnification loupes), recipient vessels of contralateral limb, and type of donor site closure (primary/skin graft-assisted closure). We extracted data for postoperative outcomes as follows: length of the stay in the intensive care unit (ICU), time for excision of the pedicle, donor site complications, and recipient site complications.

Surgical management

All patients were thoroughly assessed during physical examination and using computed tomography angiograms to evaluate the current status of vascular structures of the lower extremity and to detect potential recipient vessels [8]. The surgical technique has been reported in previous studies [8, 14]. Briefly, CLFFs were used for extensive injuries comprising the leg when a pedicled cross-leg flap was deemed inappropriate, while CLVCBFs were used if coverage of larger areas and increased reach was required. For CLVCBFs, a vascular bridge was designed with radial forearm free flaps as a flow-through free flap [8, 15]. The latissimus dorsi (LD) [16], medial sural artery perforator (MSAP) [17], profunda artery perforator (PAP) [18], fibula osteocutaneous [15], or anterolateral thigh (ALT) free flap were anastomosed to the distal segment of the flow-through cable bridge RFAFF for CLVCBF (Fig. 1) [8, 14]. For

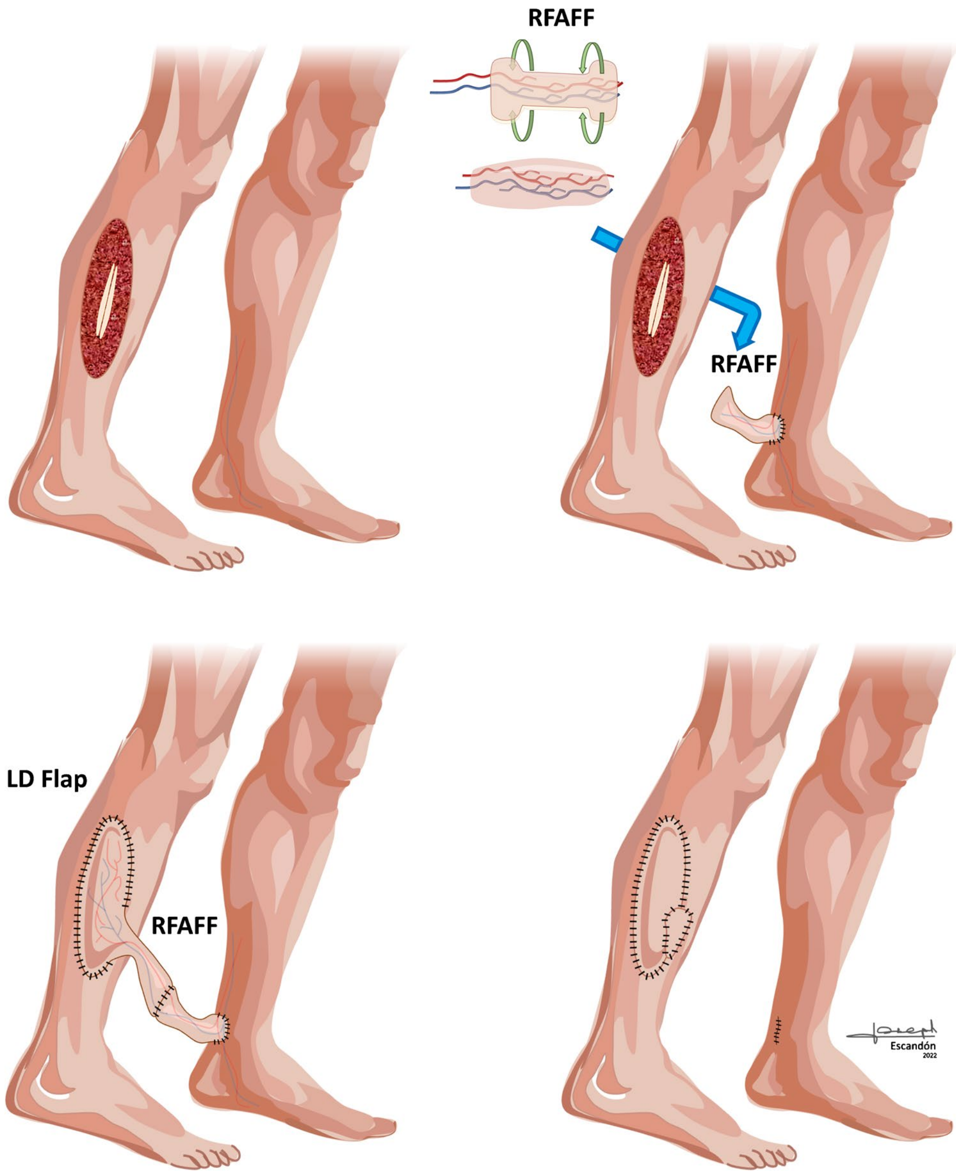

Fig. 1 Cross-leg vascular cable bridge flaps. Defect in right lateral leg (upper left), radial forearm free flap anastomosed to contralateral posterior tibial vessels as a vascular bridge (upper right), free latissimus dorsi flap inset into right lower extremity defect and anastomosed to contralateral leg pedicle of radial forearm free flap (lower left), and division of pedicle 1–2 months after surgery and rotation of the radial forearm flap (lower right)

CLFFs, the aforementioned free flaps were directly anastomosed to the contralateral leg (Fig. 2) [8, 14].

When combined spinal-epidural anesthesia was implemented, ALT flaps, PAP flaps, or MSAP flaps were used. General anesthesia was preferred in patients who had lower limb reconstruction with LD flaps. Flap checks were performed with handheld Doppler every hour the first 2 days after surgery, every 4 h on postoperative day three, and every 6 h during postoperative day four through seven.

Fig. 2 Free cross-leg flap. Free latissimus dorsi flap shaped and inset to cover a right lower extremity defect. Anastomosis is based on contralateral posterior tibial vessels

After 5 to 6 weeks, ischemic preconditioning was implemented to stress the flap and promote angiogenesis. During the week prior to division, pedicles of flaps were clamped every day for several minutes. Once optimal revascularization was determined, the vascular bridge or the pedicle of the cross-leg flap was divided and used as a rotation flap to cover any exposed area. External fixation at the time of reconstruction was necessary to stabilize the legs and avoid the avulsion of the pedicle of the CLFF or vascular bridge with an orthopedic external fixator or a custom-made orthopedic plaster cast. To preserve the muscle mass and enhance venous return, physical therapy using static contracture was started as soon as possible with the patient still in the room bed.

Statistical analysis

R statistical software, version 4.0.0 (R Core Team, 2020), was used for statistical analysis [19]. The Mann-Whitney test or *t*-test was used to analyze continuous data. Categorical variables of paired data were compared using the chi-square test. The outcomes of cable bridge vascular RFAFFs were also reported and included in the analysis in patient who had CLVCBFs.

Results

Twenty-four patients were included, eleven (45.8%) underwent reconstruction with CLFF while 13 had CLVCBFs (54.2%). Nineteen patients (79.2%) were males and five were females (20.8%) (p = 0.833). The average age of patients was 37.2 years (range, 27–50 years). Five patients were active smokers at the time of reconstruction (20.8%), three had past medical history of diabetes (12.5%), and five had hypertension (20.8%). The most common indication for reconstruction was trauma (50%) followed by burns (16.6%), osteomyelitis (16.6%), and diabetic ulcers (16.6%) (Table 1).

Fifteen patients (62.5%) underwent lower limb reconstruction under general anesthesia while nine (37.5%) had combined spinal-epidural anesthesia (Table 2). The overall surgical time (10.5 h versus 8.2 h, p <.001) and

Table 1 Baseline demographic characteristics

Variables	Cross-leg free flap	Free cable bridge flap	*p*-value
Number of patients (No.)	11 (45.8%)	13 (54.2%)	
Sex			0.833
Male (%)	8 (72.7%)	11 (84.6%)	
Female (%)	3 (27.3%)	2 (15.4%)	
Age (years)	39.09 (range, 29–50)	35.61 (range, 27–44)	0.214
Smoking (%)	3 (27.3%)	2 (15.4%)	0.833
Comorbidities			
Diabetes (%)	1 (9.1%)	2 (15.4%)	0.877
Peripheral vascular disease (%)	0 (0%)	0 (0%)	-
Congestive heart failure (%)	0 (0%)	0 (0%)	-
Hypertension (%)	2 (18.2%)	3 (23.1%)	0.834
Chronic kidney disease (%)	0 (0%)	0 (0%)	-
Liver disease (%)	0 (0%)	0 (0%)	-
ASA			0.556
Class I (%)	10 (90.9%)	10 (76.9%)	
Class II (%)	1 (9.1%)	2 (15.4%)	
Class III (%)	0 (0%)	1 (7.7%)	
Etiology of the defect			0.182
Trauma (%)	3 (27.3%)	9 (69.2%)	
Burn (%)	2 (18.2%)	2 (15.4%)	
AVM excision (%)	0 (0%)	0 (0%)	
Diabetic ulcer (%)	3 (27.3%)	1 (7.7%)	
Osteomyelitis (%)	3 (27.3%)	1 (7.7%)	
Osteoradionecrosis (%)	0 (0%)	0 (0%)	

ASA American Society of Anesthesiologists Physical Status Classification System, *AVM* arteriovenous malformation, *BMI* body mass index

Table 2 Surgical outcomes

Variables	Cross-leg free flap	Free cable bridge flap	*P*-value
Number of patients (No.)	11 (100%)	13 (100%)	
Type of anesthesia			< .001
General anesthesia (%)	2 (18.2%)	13 (100%)	
Epidural (%)	0 (0%)	0 (0%)	
Combined spinal-epidural (%)	9 (81.8%)	0 (0 %)	
Duration of the surgery (hours)	8.2	10.5	< .001
Defect size of defects (cm^2)	370	510	< .001
Location of defects			0.757
Knee (%)	0 (0%)	0 (0%)	
Upper third of the leg (%)	1 (9.1%)	3 (23.1%)	
Middle third of the leg (%)	4 (36.4%)	4 (30.8%)	
Lower third of the leg (%)	3 (27.3%)	4 (30.8%)	
Foot and ankle (%)	3 (27.3%)	2 (15.4%)	
Total number of flaps	11 (100%)	26 (100%)	
Flap for reconstruction			0.431 **Ω**
Anterolateral thigh free flap (%)	6 (54.5%)	4 (30.8%)	
Latissimus dorsi free flap (%)	2 (18.2%)	5 (38.5%)	
Free fibula osteocutaneous flap (%)	0 (0%)	2 (15.4%)	
MSAP flap/PAP flap (%)	3 (27.3%)	2 (15.4%)	
Radial forearm free flap†	N/A	13 (50%)	
Anastomosis			0.851
Microscope (%)	8 (72.7%)	9 (69.2%)	
Loupes (%)	3 (27.3%)	4 (30.8%)	
Recipient vessels			0.503
Posterior tibial A. and V. (%)	9 (81.8%)	11 (84.6%)	
Medial sural A. and greater saphenous V. (%)	1 (9.1%)	0 (0%)	
Dorsalis pedis A. and V. (%)	1 (9.1%)	2 (15.4%)	
Donor site closure			0.016
Primary closure (%)	9 (81.8%)	10 (38.5%)	
Skin graft (%)	2 (18.2%)	16 (61.5%)	

†Cable bridge flap

A artery, *MSAP* medial sural artery perforator flap, *PAP* profunda artery perforator, *V* vein

ΩExcluded the Radial Forearm Free Flaps from analysis

average size of defects (510 cm^2 versus 370 cm^2, $p < .001$) were significantly higher in the CLVCBF group when compared to the CLFF group. Overall, thirty-seven free flaps were transferred for reconstruction of lower limbs (100%). Of the total number of CLFFs ($n = 11$), six ALT flaps (54.5%), two LD free flaps (18.2%), and three PAP flaps (27.3%) were used for reconstruction (Figs. 3 and 4). Of the total number of patients who underwent reconstruction with CLVCBFs, four patients had ALT flaps (30.8%), five patients had LD flaps (38.5%), two had MSAP or PAP flaps (15.4%), and two had free fibula osteocutaneous flaps (15.4%, $p = 0.431$). Thirteen RFAFFs were used as a vascular bridge (Fig. 5).

Eighteen cases were performed before the COVID-19 pandemic (Table 3). Two CLFF cases were performed under general anesthesia (11.1%) and three under combined spinal-epidural anesthesia (16.6%). Thirteen CLVCBF cases were performed under general anesthesia (72.2%). During COVID-19 pandemic, six CLFF cases were performed under combined spinal-epidural anesthesia (100%). The proportion of cases performed with microscope magnification (70.8%, $n = 17$) or loupe magnification (29.2%, $n = 7$) for the micro-anastomosis were comparable between groups ($p = 0.851$). A higher proportion of reconstructions during COVID-19 were performed with loupe magnification.

The recipient vessels were the contralateral posterior tibial artery and vein in 20 reconstructions (83.3%), medial sural artery and greater saphenous vein in one patient (4.2%), and dorsalis pedis artery and vein in three

Fig. 3 Cross-leg anterolateral thigh free flap inset to cover left distal lower extremity defect. The recipient vessels were the contralateral posterior tibial vessels

Fig. 4 Cross-leg latissimus dorsi free flap inset to cover right lower extremity defect. The recipient vessels were the contralateral posterior tibial vessels

patients (12.5%). No difference was found between groups regarding the recipient vessels (p = 0.503). Following flap transfer for reconstruction with CLFFs, primary closure of the donor site was possible in nine patients (81.8%) and split-thickness skin grafts (STSGs) were required in 2 patients (18.2%). Following flap transfer for reconstruction with CLVCBFs, 16 donor sites required STSG (61.5%) for closure while 10 (38.5%) were closed primarily (p = 0.016) (Table 2).

Postoperative outcomes

ICU admission was reported in two patients (18.2%) who underwent reconstruction with CLFFs and 12 (92.3%) with CLVCBFs (p <.001). None of the patients who had combined spinal-epidural anesthesia was admitted to the ICU (100%). The average time for pedicle transection of muscle CLFFs and muscle CLVCBFs was comparable between groups (60 days versus 62 days, p = 0.864). A significantly shorter average time was evidenced for pedicle division of fasciocutaneous flaps in the CLFF group when compared to CLVCBFs (45 days versus 59 days, p = 0.002). The average time for pedicle division of osteo-fasciocutaneous flaps was 68 days.

Donor site morbidity in patients who underwent CLFFs included partial STSG loss in one patient (50%) and partial skin necrosis in one patient (9.1%). Donor site morbidity in patients who had CLVCBFs included partial STSG loss in four patients (14.3%), partial skin necrosis in one patient (3.8%), and donor site infection in one patient (3.8%). No significant difference was found between groups for donor site morbidity (Table 4).

Two total flap loss (7.7%) and three partial flap loss (11.5%) were reported following reconstruction with CLVCBFs. Also, three anastomosis revisions were required due to venous thrombosis (11.5%) and four patients reported prolonged pain of the recipient site (15.4%). None of the patients who underwent reconstruction with CLFFs experienced total flap loss (0%), but two experienced partial flap loss (18.2%). Two patient required

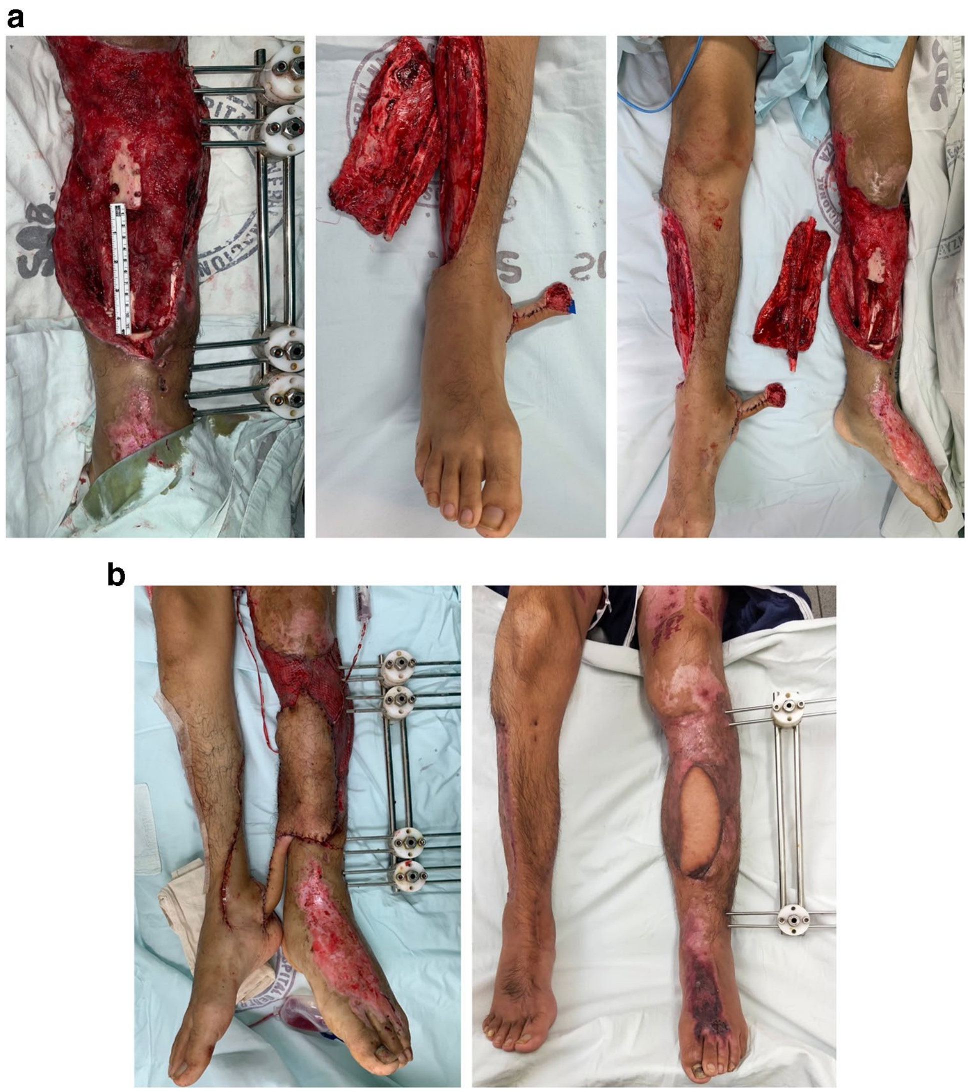

Fig. 5 **A** Intraoperative findings of reconstruction of lower and middle third of the leg with fibula osteocutaneous free flap using radial forearm free flap as cross-leg vascular cable bridge flap. **B** Immediate and late postoperative photos after reconstruction with cross-leg vascular cable bridge flap

Table 3 Type of procedure and type of anesthesia over different periods of time

Period	Type of reconstruction				Magnification		Total
	CLFF GA	CLFF S-E	CLVCBF GA	CLVCBF S-E	Microscope	Loupes	
Total	2 (8.3%)	9 (37.5%)	13 (54.2%)	0 (0%)	17 (70.8%)	7 (29.2%)	24 (100%)
2018–2019	2 (11.1%)	3 (16.6%)	13 (72.3%)	0 (0%)	16 (88.9%)	2 (11.1%)	18 (75%)
2020–2022	0 (0%)	6 (100%)	0 (0%)	0 (0%)	1 (16.6%)	5 (83.4%)	6 (25%)

CLFF cross-leg free flap, *CLVCBF* cross-leg vascular cable bridge flap, *GA* general anesthesia, *S-E* spinal-epidural

revision of the anastomosis due to venous congestion in one case (9.1%) and arterial obstruction in another case (9.1%). One patient experienced recipient site infection (9.1%), and two presented prolonged recipient site pain (18.2%). The rates of recipient site complications were comparable between groups.

Discussion

Due to the high contamination rate and active transmissibility of the coronavirus, countries around the globe have experienced several global health challenges since the beginning of the COVID-19 pandemic [20]. The

Table 4 Postoperative outcomes

Variables	Cross-leg free flap	Free cable bridge flap	*P*-value
Number of patients (No.)	11 (100%)	13 (100%)	
Number of flaps (No.)	11 (100%)	26 (100%)	
Admission to ICU (%)	2 (18.2%)	12 (92.3%)	< .001
Time for pedicle division (days)			
Muscle flaps (days)	60	62	0.864
Fasciocutaneous flap (days)	45	59	0.002
Osteo-fasciocutaneous (days)	N/A	68	-
Donor site complications (%)			
Partial skin graft loss (%)	1 (50%)	4 (14.3%)	0.743
Partial skin necrosis (%)	1 (9.1%)	1 (3.8%)	0.519
Infection (%)	0 (0%)	1 (3.8%)	0.510
Recipient site complications (%)			
Total flap loss (%)	0 (0%)	2 (7.7%)	0.344
Partial flap loss (%)	2 (18.2%)	3 (11.5%)	0.589
Revision of anastomosis (%)	2 (18.2%)	3 (11.5%)	0.589
- Arterial thrombosis (%)	1 (9.1%)	0 (0%)	0.119
- Venous thrombosis (%)	1 (9.1%)	3 (11.5%)	0.827
Surgical site infection (%)	1 (9.1%)	0 (0%)	0.119
- Superficial incisional (%)	1 (9.1%)	0 (0%)	0.119
- Deep incisional (%)	0 (0%)	0 (0%)	-
Hematoma (%)	0 (0%)	0 (0%)	-
Deep venous thrombosis (%)	0 (0%)	0 (0%)	-
Prolonged pain (%)	2 (18.2%)	4 (15.4%)	0.833

ICU intensive care unit, *LOSS* length of stay

impact of this situation has been so meaningful, some reports have suggested the need to take a step down on the reconstructive ladder to provide optimal health care management [20]. On the other hand, the implication of severe acute respiratory syndrome 2 (SARS-2) in the current microsurgical management of patients could be taken as an opportunity to improve perioperative protocols for microvascular reconstruction, especially in countries with limited health care access and delayed vaccination [21, 22]. For instance, proof of this concept was evidenced in this current report with the incorporation of different anesthesia protocols alongside the reduction of ventilators, minimization of the use of microscopes, and reduction of patient admission to ICU for postoperative flap monitoring during complex microvascular lower limb reconstruction.

With contemporary developments and the introduction of cutting-edge technology, microvascular free tissue transfer has become an optimal alternative for lower limb salvage, even in patients with substandard wound healing status, calcified vessels, or peripheral vascular disease [23, 24]. Free flaps provide well-vascularized tissue for long-lasting coverage of important structures (e.g., vessels, cartilage, nerves) and enhance distal lower limb perfusion [25]. The effect of healthy transplanted autologous tissue in limb salvage is so prominent, that it has been shown to improve 5-year survival rates and maintain functional outcomes [26].

In some cases, a single recipient vessel or no recipient vessel can be identified during preoperative evaluation or intraoperative assessment [8]. These patients represent the most intricated reconstructions for microvascular free tissue transfer and a more complex approach is required [8]. Although previous reports have evidenced the feasibility of using a single-vessel runoff as recipient vessel, the risk of injuring the only vessel perfusing the lower limb is exceedingly high for some surgeons to contemplate this alternative [27]. Certainly, if an end-to-side anastomosis is attempted in a single-vessel extremity, partial or complete flap loss and limb necrosis distal to the anastomosis site can occur as possible aftermath of the procedure [8, 28]. Alternatively, a super-microvascular approach has been suggested for these patients. With this technique, the vascular quality of major vessels in the lower extremity is of less apprehension and there is no need for deep dissections of major vessels as anastomoses are performed with cutaneous perforators [29]. Nonetheless, this approach may not be possible in certain cases due to discrepancies in vessel caliber or unsuitable dimensions of perforator flaps to fill or cover the whole extension of defects [24, 29].

In case no recipient vessel is available, long arteriovenous fistulas or vein grafts have been reported [30]. Likewise, ipsilateral pedicle flaps or propeller flaps can be also considered; nonetheless, these flaps are fixed to their pedicle and usually do not reach the distal segment of defects due to their limited length [12, 30] Similarly, comparable length restrictions have been encountered using ipsilateral flow-through flaps. But again, the additional requirement of the presence of at least one healthy main vessel perfusing the limb limits their use in single-vessel runoff extremities [8, 31]. In some cases, the reverse ALT pedicled flap has been reported to be versatile for coverage of the leg's proximal third [32]. However, even after supercharging, it may not fulfill the reconstructive requirements for large defects, exposure of osteosynthesis material and bone, or defects in the lower third of the leg [32–35].

As shown in our series, CLFFs and CLVCBFs are resourceful alternatives and should be considered in a surgeon's armamentarium for distal lower extremity salvage in patients with single-vessel runoff or with no recipient vessels [8]. This approach is advantageous as the recipient vessels are usually located outside the zone of injury with the additional benefit of avoiding further incisions and dissections in an already compromised or affected limb [8]. Postoperative assessment with ICG-angiography to evaluate revascularization can decrease the time for pedicle division, especially if there is past surgical history of oncologic ablative procedures and preoperative radiation of the recipient wound bed [8, 36]. With ICG-angiography, surgeons can objectively evaluate if the flap has integrated and if division of the pedicle can be accomplished without complications secondary to lack of perfusion [8, 37]. In fact, the prolonged time for pedicle division in our series may be explained by the lack of fluorescein imaging to evaluate the revascularization of flaps.

For the selection of recipient vessels, the preoperative assessment should guide the decision-making but we prioritize the use of the posterior tibialis artery and vein of the contralateral leg as seen from our series. In most cases, we try to implement end-to-side anastomoses to the recipient vessels to avoid disrupting perfusion distal to the anastomosis site in a healthy lower limb and to reduce the incidence of vasospasm. Once the flap is inset, another important aspect to decrease morbidity is to cover the pedicle, as exposure can lead to the dissection of any of these vessels. For instance, in most of the cases, a precise dissection was carried out of local flaps surrounding the recipient vessels on the contralateral leg. By elevating these flaps, local tissue of the contralateral leg/foot can be maximized to cover the anastomosis site and part of the flap's pedicle. Likewise, if local tissue rearrangement of the contralateral leg is deemed inappropriate to cove the pedicle, the design of the skin paddle of the free flap was tailored so that a distal fasciocutaneous segment was specifically used to be wrapped around the pedicle at the time of inset.

Despite their advantages, crossed-leg flaps remain a technically challenging operation and should be only considered when all limb salvage alternatives have failed or are not feasible. Careful consideration should be given to donor site morbidity and patient comorbidities prior to surgical intervention with this approach. Adequate postoperative management, such as DVT prophylaxis, specialized beds, and in-bed physical therapy can reduce the possibility of complications. Furthermore, physical therapy is of paramount importance following the removal of the external fixator to re-establish quick ambulation, prevent contraction or atrophy of the legs, and avoid other potential risks such as DVT. A dangling protocol is used to accustom the flaps to gravity and motion as soon as the patient starts walking.

Besides the fact that this is a complex procedure and involves a careful preoperative assessment, requires multiple anastomosis, has several steps, and an experienced microsurgeon is required, patient selection is another key factor to achieving successful reproducible outcomes [8]. As seen from our results, limb salvage with CLFs is best suited for highly motivated young patients, with optimal health baseline status, able to tolerate complex surgical interventions with long intraoperative times, extended periods of inpatient care, and patients who are compliant with prompt physiotherapeutic regimens [8, 38]. Certainly, multiple long surgical procedures and limited mobility during the early postoperative period in unfitted patients with several comorbidities increase the risk of complications and these subjects are not good candidates for complex non-lifesaving interventions [8].

Healthcare systems and institutions have acknowledged the imperative role of proper patient admission to the ICU after the COVID-19 pandemic. Critical care management should be reserved for seriously sick and de-compensated patients; otherwise, it unnecessarily increases healthcare-related costs [39, 40]. Contemporary reports have shown comparable outcomes in patients admitted to the ICU versus the floor immediately after free flap reconstruction of lower limbs [41]. Likewise, despite the patients presented in our series having complex procedures, with the incorporation of combined spinal-epidural neuraxial anesthesia, we were able to transfer patients directly to our plastic surgery floor unit. In this setting, and especially for patients who underwent CLVCBFs which had two free flaps, we were able to better monitor the postoperative status of free flaps and had better control of the physiotherapeutic regimen [42]. None of the patients required mechanical ventilation or presented with postoperative hemodynamic compromise when using this type of anesthesia, decreasing the rate of ICU admission and increasing the availability of these resources for severely ill patients. In accordance with previous statements by Evans et al., most centers admit patients to ICU for frequent flap monitoring as opposed to medical necessity [41]. In this reports with a multidisciplinary approach including the nurses and physiotherapists, we were able to transfer patients directly to the floor using neuraxial anesthesia replicating outcomes on flap survival from previous articles [41].

Finally, with the implementation of neuraxial anesthesia, several authors have suggested that the peripheral vasocontraction secondary to pain, hypovolemia, and hypothermia is reduced [43]. In the context of microvascular reconstructive surgery for lower limb salvage, the chemical sympathectomy-like effect achieved with regional anesthesia has been shown to improve the rate of arterial and venous spasm, and improve flow velocity in the immediate postoperative period, promoting flap survival [44–47]. These variables might have played a role in the success rate of some surgical cases presented in this series.

Limitations

This current report is a single-center study implementing a retrospective review of data. Therefore, temporal associations are often difficult to assess, some variables were not evaluated, causality cannot be determined, and there is an inherent risk of bias and possible inaccuracy of data related to our methodology. Despite this is the largest report using CLVCBFs, the limited sample size may decrease the significance of some associations. The assessment of outcomes could be improved with standardized patient-based questionnaires for quality of life and limb function.

Conclusion

In selected patients, CLFFs and CLVCBFs offer an optimal alternative for lower limb salvage using recipient vessels out of the zone of injury from the contralateral limb. These reconstructive methods avoid the requirements of amputation in patients with single-vessel runoff or severe peripheral vascular disease, where using the only patent vessel can further increase the risk of amputation. Furthermore, the implementation of combined spinal-epidural anesthesia can decrease the requirements of PACU admission and ventilators to improve resource allocation.

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Authors' contributions (i) conceptualization: Ciudad P; (ii) data curation: Ciudad P; (iii) formal analysis: Ciudad P; (iv) funding acquisition: all authors; (v) investigation: Ciudad P; (vi) methodology: Ciudad P; (vii) project administration: all authors; (viii) resources: Ciudad P; (ix) software: Escandón JM; (x) supervision: Ciudad P, (xi) validation: all authors; (xii): visualization: all authors; (xiii) writing—original draft: all authors; (xiv) writing—review and editing: all authors.

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Declarations

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of interest Horacio F. Mayer is the Editor-in-Chief of the European Journal of Plastic Surgery.
Pedro Ciudad, Joseph M. Escandón, Oscar J. Manrique, Lilyan Llanca, César Reynaga declare no conflict of interest.

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