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Original Article

Customized reconstruction of a complex soft-tissue defect around the knee with a free perforator flap

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Abstract: Reconstruction of a complex defect around the knee, particularly involving a large soft-tissue defect or disruption of the extensor mechanism, is always a challenging problem. The purpose of this study was to introduce the use of a customized free perforator flap for complex soft-tissue reconstruction around the knee. Between June 2010 and March 2017, 16 patients underwent this procedure. The choice of flap design is based on the location of the wound, the required pedicle length, the missing tissue components and their volumes, and the risk of donor-site morbidity. The reconstruction was performed using anterolateral thigh perforator (ALTP) flaps in five cases, modified ALTP flaps in two cases, chimeric ALTP flaps in four cases, dual-skin paddle ALTP flaps in two cases, and chimeric thoracodorsal artery perforator flaps in two cases. Multiple perforator flaps and vascularized fascia lata were used in one case. All flaps survived postoperatively. No vascular congestion was observed, and partial necrosis was observed in only one case. Primary closure of the donor site was performed for all patients. At a mean follow-up time of 16.5 months, most cases showed satisfactory flap contours and acceptable functional outcomes. A free perforator flap is a reliable option for repairing complex soft-tissue defects in the knee region, especially when local and pedicled flaps are unavailable. Various flap designs allow for more individualized treatment approaches and can achieve better results.

Keywords: Perforator flap, knee, soft-tissue defect, reconstruction

Introduction

One-stage reconstruction of complex defects in the knee region, particularly involving a large soft-tissue defect or disruption of the extensor mechanism, is a challenging problem for reconstructive surgeons [1, 2]. Previous strategies have been described in the literature for reconstruction involving local flaps, pedicle flaps, muscle flaps with skin grafting, or musculocutaneous flaps [3-7]. However, local and pedicled flaps are unsuitable for the reconstruction of complex soft-tissue defects because of their limited soft-tissue volume and less flexible shapes [8]. Some authors have reported that complex soft-tissue defects around the knee can be resurfaced using muscle flaps with skin grafting; however, the use of this approach often results in a bulky appearance, unsatisfactory color match, and an unstable surface [9]. While musculocutaneous flaps have also been widely used for the reconstruction of complex tissue defects in the extremities, donor-site morbidity and flap bulkiness are limitations.

In the current era of advances in microsurgical and perforator flap technologies, free perforator flaps have become the primary choice for the treatment of large wounds in the lower extremities in cases where local flaps are unavailable. The use of a free perforator flap is popular because of its large cutaneous area, low donor-site morbidity, appearance, adjustable donor sites, long vascular pedicle, and customizable design involving adjacent structures [10]. However, there are few reports of the reconstruction of complex soft-tissue defects of the knee using a free perforator flap in the literature.

Extensive trauma and soft-tissue tumor excision often cause complex extremity defects; thus, individualized reconstruction of complex

tissue defects in the knee region is essential to salvage the extremity and restore its function. However, the traditional use of free perforator flaps in such reconstructions does not result in a precise or efficient repair. An ideal reconstructive procedure should not only cover the soft-tissue defect but also restore the function of the knee using a single procedure and reduce the donor-site morbidity as well. Therefore, in this study, we present a case series of complex soft-tissue defect reconstructions around the knee using various flap designs that allow for more customized treatment approaches. To our knowledge, the concept and practice of using customized free perforator flaps for the reconstruction of complex soft-tissue defects in the knee region have not been described in the literature previously.

Materials and methods

From June 2010 to March 2017, 16 patients (3 females and 13 males) underwent the reconstruction of complex soft-tissue defects in the knee region using free perforator flaps. Patient ages ranged from 5 to 65 years (mean, 36.1 years). Of the 16 cases, one had a chronic ulcer, one had skin contracture after a burn, two had skin necroses after total knee arthroplasty, and 12 had post-traumatic injuries. Patients' characteristics and outcomes are provided in **Table 1**. The study followed the ethical guidelines of the Hospital Ethical Committee of Xiangya Hospital. Protocols were performed in accordance with the ethical standards of the Helsinki Declaration of 1975 and all subsequent revisions.

Surgical technique

A hand-held Doppler probe was routinely used to preoperatively map the perforators at the donor site. A pinch test was performed on the donor site to evaluate the available width of the flap. After radical debridement, a paper template was prepared according to the shape of the soft-tissue defect. The surgical team preoperatively assessed and classified the soft-tissue defects to provide all patients with a specific customized reconstruction. Various flap designs were considered for the reconstructions. Flap choice was based on the location of wound, the required pedicle length, the missing tissue components and their volumes, and the risk of donor-site morbidity.

For the reconstructions, a conventional free ALTP flap was a good choice. However, when the extensor mechanism or joint capsule of the knee was damaged, a modified design was considered for the defect reconstruction that involved preserving a part of the fascia lata of the flap, which allowed the resurfacing of the superficial skin defect and the simultaneous restoration of the extensor mechanism or joint capsule (**Figure 1**, Supplementary Materials Video). This procedure involved harvesting the ALTP flap with a specific size of the fascia lata based on the characteristics of the soft-tissue defect, which preserved the remaining tissue and minimized donor-site morbidity. When required, a free perforator flap and vascularized fascia lata could be used for a more extensive reconstruction procedure (**Figure 2**).

To repair very large soft-tissue defects, and also achieve primary closure of the donor site, dual-skin paddle perforator flaps were used (**Figure 3**). A single unified narrow flap was harvested and then split into two skin paddles between the perforator vessels. The dual-skin paddles were stacked alongside each other to effectively enlarge the width of the flap. This approach enabled greater coverage of the defect and direct, tensionless closure of the donor site. When the dual-skin paddle perforator flap was used, the conversion of the flap length into the desired shape was performed. A part of the fascia lata of this flap was also preserved to repair the joint capsule or restore the extensor function of the knee.

For the repair of larger, deeper wounds, a chimeric perforator flap could be designed to achieve a three-dimensional reconstruction. Using this approach, the skin paddle was used to cover the surface of the soft-tissue defect, and the muscle paddle was used to obliterate the dead space (**Figure 4**). Each component was precisely inserted to repair the wound with greater movement. Most importantly, the muscle paddle was also used to restore the extensor mechanism of the knee and cover the knee joint simultaneously (**Figure 5**).

Results

A total of 17 perforator flaps were successfully harvested in this series of cases. Five cases were repaired using ALTP flaps, two cases were repaired using modified ALTP flaps, four cases

Table 1. Patients' characteristics and outcomes

Patients	Age (y)/ Sex	Cause of injury	Type of flap	Size of flap (cm)	Restoration of knee function or repair of the joint capsule	Recipient vessel (s)	Complication (s)	Follow-up (mos.)
1	25M	Traffic injury	Dual-skin paddle ALTP and part of the FL	15×7 and 15×7	FL for repair of the joint capsule	MGA	None	18
2	40F	Traffic injury	Dual-skin paddle ALTP	16×10 and 13×8	None	ATV	None	14
3	52M	Ulcer with knee infection	Chimeric ALTP	21×9 for skin paddle and 12×5 for muscle paddle	None	ATV	None	18
4	59M	Traffic injury	Chimeric ALTP	24×8.5 for skin paddle and 10×5 for muscle paddle	None	PTV	None	9
5	31M	Traffic injury	ALTP	20×10	None	ATV	None	15
6	27M	Traffic injury	ALTP and part of the FL	29×10	FL for repair of the joint capsule	ATV	None	24
7	64M	Skin necrosis after TKA	ALTP	12×6	None	MSA	None	6
8	26F	Traffic injury	ALTP	14.9×9	None	ATV	None	10
9	65M	Skin necrosis after TKA	Chimeric ALTP	15×7 for skin paddle and 6×5 for muscle paddle	None	MGA	None	12
10	7M	Traffic injury	ALTP and part of the FL	16×7	FL for repair of the joint capsule	MSA	None	18
11	5M	Scar contracture after a burn	ALTP	14×6.5	None	MSA	None	24
12	25F	Traffic injury	Chimeric TDAP	25×10 for skin paddle and 17×4 for muscle paddle	Restoration of function using a muscle paddle	MSA	None	24
13	39M	Traffic injury	Chimeric TDAP	15×9 for skin paddle and 6×12 for muscle paddle	None	LCFV	None	8
14	36M	Traffic injury	Chimeric ALTP	25×9	Restoration of function using the FL	MGA	None	12
15	45M	Traffic injury	Dual-skin paddle ALTP flap, SLGA flap, and vascular FL	18×9 and 9×20 for dual-skin ALTP, 23×7 for SLGA flap, and 18×7 for vascular FL	Restoration of function using vascularized FL	MSA	Partial necrosis	35
16	32M	Traffic injury	ALTP	24×8	None	ATV	None	18

F: Female; M: Male; TKA: total knee arthroplasty; ALTP: anterolateral thigh perforator flap; TDAP: thoracodorsal artery perforator flap; SLGA: superior lateral genicular perforator flap; MGA: medial genicular artery; MSA: medial sural vessel; ATV: anterior tibial vessel; PTV: posterior tibial vessel; LCFV: lateral circumflex femoral vessel; FL: fascia lata.

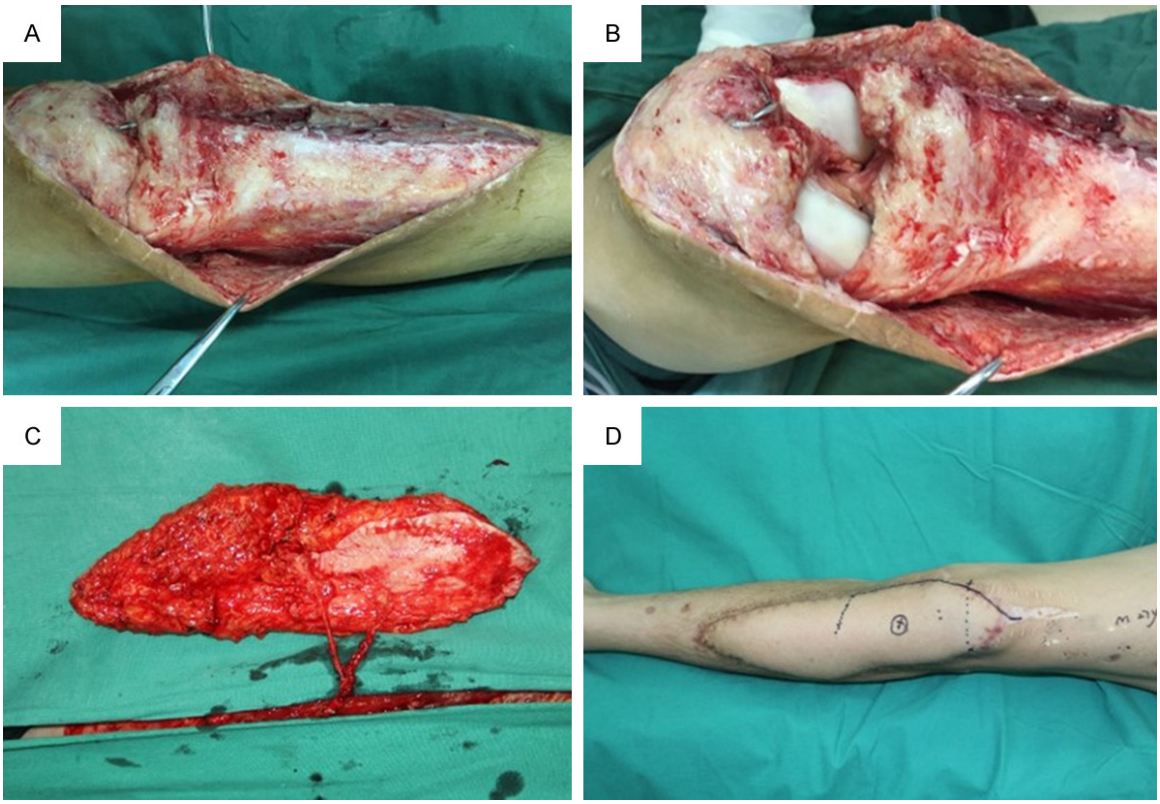

Figure 1. (A and B) A 27-year-old male shown with a large soft-tissue defect (A), exposure of the knee joint (B), and disturbance in the extensor mechanism of the knee. (C) An ALTP flap and part of the fascia lata were raised to reconstruct the soft-tissue defect and restore the extensor mechanism of the knee. (D) At the 12-month follow-up, the appearance of the recipient site contour was acceptable. The patient experienced good recovery and functional outcomes.

were repaired using chimeric ALTP flaps, two cases were repaired using dual-skin paddle ALTP flaps, and the remaining two cases were repaired using chimeric thoracodorsal artery perforator (TDAP) flaps. In addition, multiple perforator flaps and vascularized fascia lata were used in one case. The size of the soft-tissue defects ranged from 72 cm^2 to 503 cm^2 (mean, 196.8 cm^2).

The use of recipient vessels varied widely based on the location of the knee defect and the available vascular supply. Specifically, seven (43.75%) arterial anastomoses were performed distal to the knee [posterior tibia artery (PTA) and anterior tibia artery (ATA)], whereas eight (50%) were performed around the knee [the superior medial genicular artery (SMGA) and medial sural artery (MSA)], and one (6.25%) was performed proximal to the knee [descending branch of the lateral circumflex femoral artery (LCFA)].

All flaps survived postoperatively. No vascular congestion was observed, and partial necrosis was observed in only one case (case 15). Necrotic tissues were debrided, and the resulting defects were repaired using split-thickness skin grafting. Primary closure of donor sites was successfully achieved for all patients. At a mean follow-up time of 16.5 months (range, 8-35 months), most cases exhibited satisfactory contours with no excessive bulkiness. Those patients could walk normally without any assistance. The knee range of motion was available for 15 (94%) patients except for one case in whom a knee fusion procedure was performed. The mean active range of motion was 110.4 degrees (range, 60-130 degrees).

Discussion

A complex soft-tissue defect in the knee region can be caused by a previous surgery, extensive trauma, and soft-tissue tumor excision. Defects of the bone, skin, and extensor mechanism

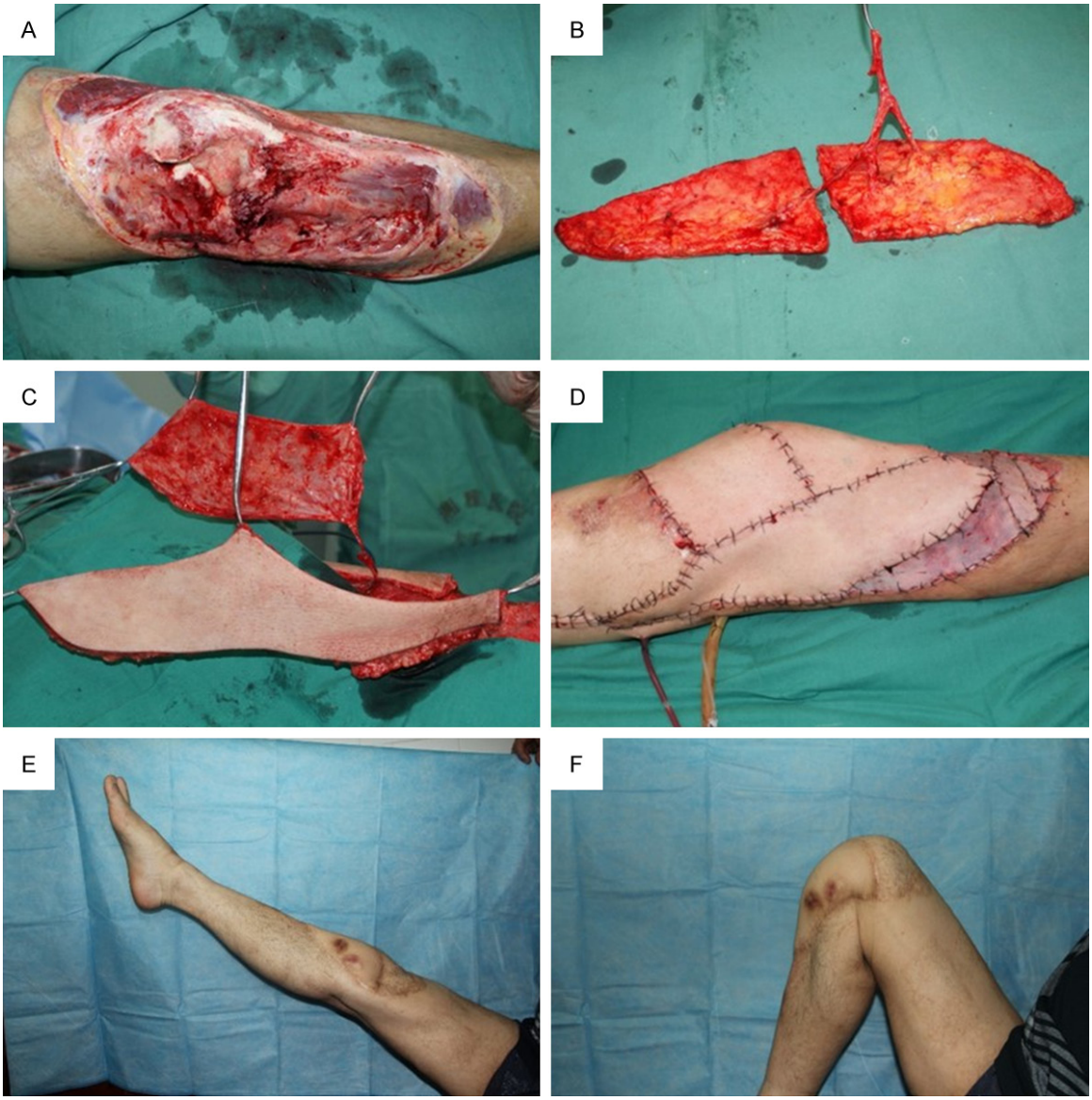

Figure 2. A: A 45-year-old male shown with a very large soft-tissue defect, disruption of the extensor apparatus, and partial exposure of the joint capsule of the knee from a traffic accident. B: A free double-skin paddle ALTP flap was harvested from the contralateral thigh. C: The SLGA flap and vascularized fascia lata were harvested from the bilateral thigh. D: Postoperative view of the recipient site. E and F: The appearance of the knee contour was acceptable at the 35-month follow-up. The patient could stand and walk without any assistance.

may also be observed in such cases. Soft-tissue reconstruction in the knee region requires a thin, flexible, large cutaneous flap. A local or pedicled flap has long been considered the optimal choice in such procedures [11]. Recently, Ling et al. [12] recommended the MSA perforator (MSAP) flap as the best choice for soft-tissue defect reconstruction around the knee. However, local and pedicled flaps were often the only choice for repairing small to medium-size defects due to the limited volume of soft tissue available. While the descending branch of the ALTP is also considered a good reconstructive solution for soft-tissue defects of the knee [13], it has never gained popularity among reconstructive surgeons because of venous congestion and difficult flap dissection in the presence of the vascular pedicle [14]. In addition, its limited arc of rotation and extension are major disadvantages. Thus, there was a need to identify an alternative surgical solution.

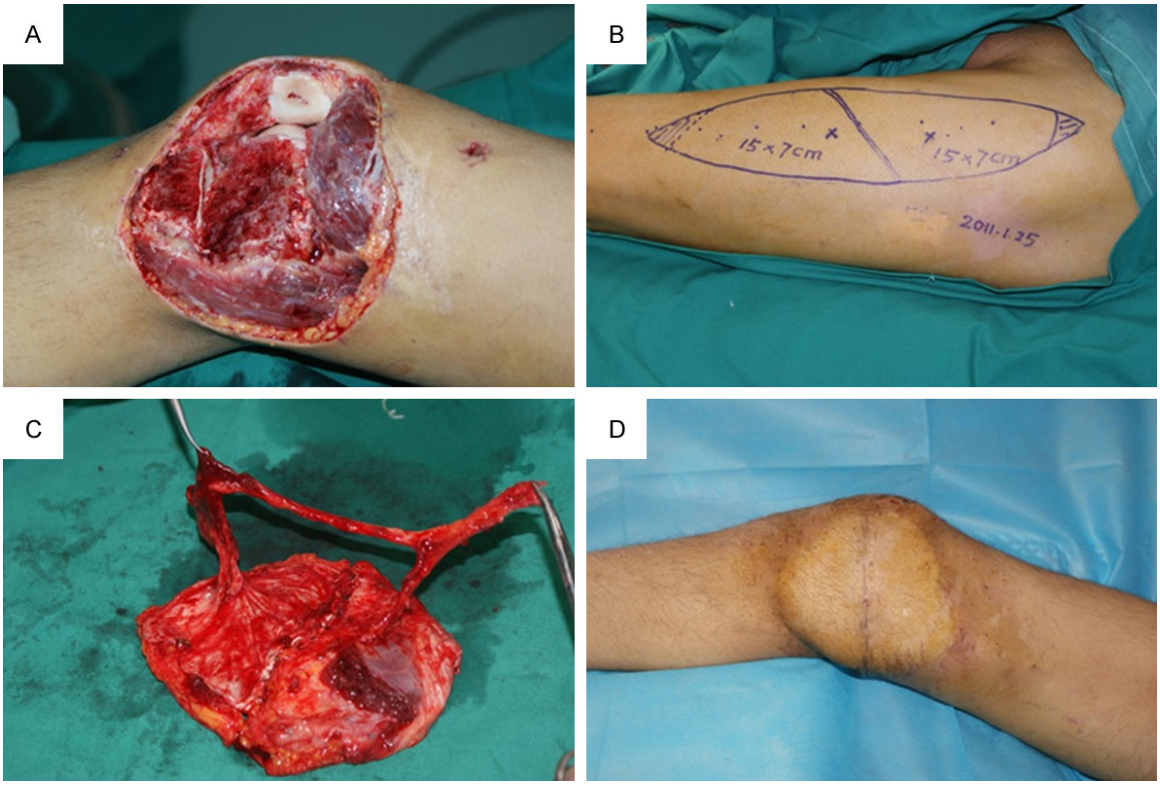

Figure 3. A dual-skin paddle ALTP flap was used for the reconstruction of a very large soft-tissue defect in the knee region. A: A 25-year-old male sustained a very large soft-tissue defect with exposure of the knee joint. B: A dual-skin paddle ALTP flap and part of the fascia lata were raided to reconstruct the soft-tissue defect and restore the extensor joint capsule of the knee. C: Intraoperative view of the dual-skin paddle ALTP flap. The two skin paddles were placed side by side to enlarge the width of the flap. D: The appearance of the recipient site contour was acceptable at the follow-up.

A previous study showed that a free flap could be an ideal choice when local tissue options were unavailable or inadequate, especially when the vascular web around the knee had been damaged. Free muscle flaps, such as latissimus dorsi and gracilis muscle flaps, are considered reliable alterative options for the reconstruction of the complex tissue defects in the knee region because of their rich blood supply and large cutaneous area [15, 16]. These advantages are particularly indicated in defects with joint and/or prosthesis exposure. However, donor-site morbidity and flap bulkiness are persistent problems. In this study, we present a series of soft-tissue defect repairs using various flap designs, including free ALTP flaps, ALTP flaps with a portion of the fascia lata, chimeric ALTP flaps, dual-skin paddle ALTP flaps, chimeric TDAP flaps, and multiple perforator flaps with vascularized fascia lata. To our knowledge, this is the largest series to date reporting the microvascular reconstruction of such defects using free perforator flaps. Our report focuses on a customized flap design for the reconstruction to minimize donor-site morbidity and recover acceptable knee function, issues that have rarely been addressed previously.

Due to limited tissue resources, the flap donor site has attracted the attention of reconstructive surgeons [17]. One of the most important goals of modern reconstructive microsurgery is to minimize donor-site morbidity. Reconstructive surgeons have shifted their focus from the repair of only the soft-tissue defect to include the function and aesthetic appearance of the donor site as well. In this context, harvesting a free perforator flap using traditional approaches may not be suitable for the repair of very large defects because of the limited amount of soft tissue available from a nonaesthetic donor-site skin graft [8]. Recently, dual-skin paddle perforator flaps were introduced as an ideal approach for the reconstruction of very large

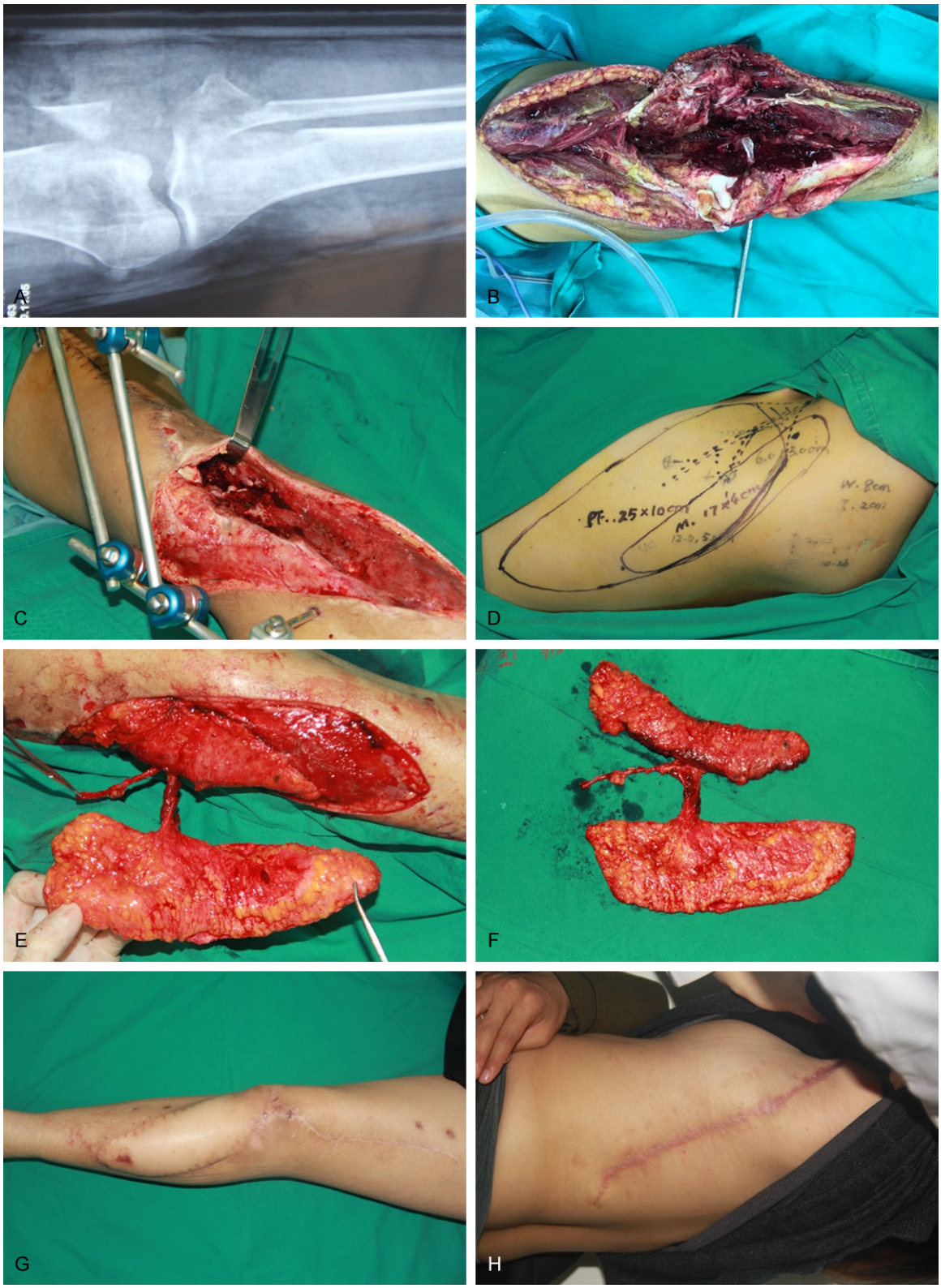

Figure 4. A 25-year-old female suffered a huge soft-tissue defect, fracture of the lateral femoral condyle, and exposure of the knee joint. A chimeric TDAP flap was designed to obliterate the dead space, restore the extensor mechanism, and repair the soft-tissue defect during a single procedure. (A-C) Radical debridement left a large soft-tissue defect with a dead space, and the lateral extensor mechanism of the knee was deficient. (D) Design of the chimeric TDAP flap. (E) Intraoperative view of the flap. (F) The muscle paddle was inserted into the dead space and used to restore the extensor mechanism. (G and H) Postoperative view of the recipient (G) and donor (H) sites. The patient could walk normally without any assistance.

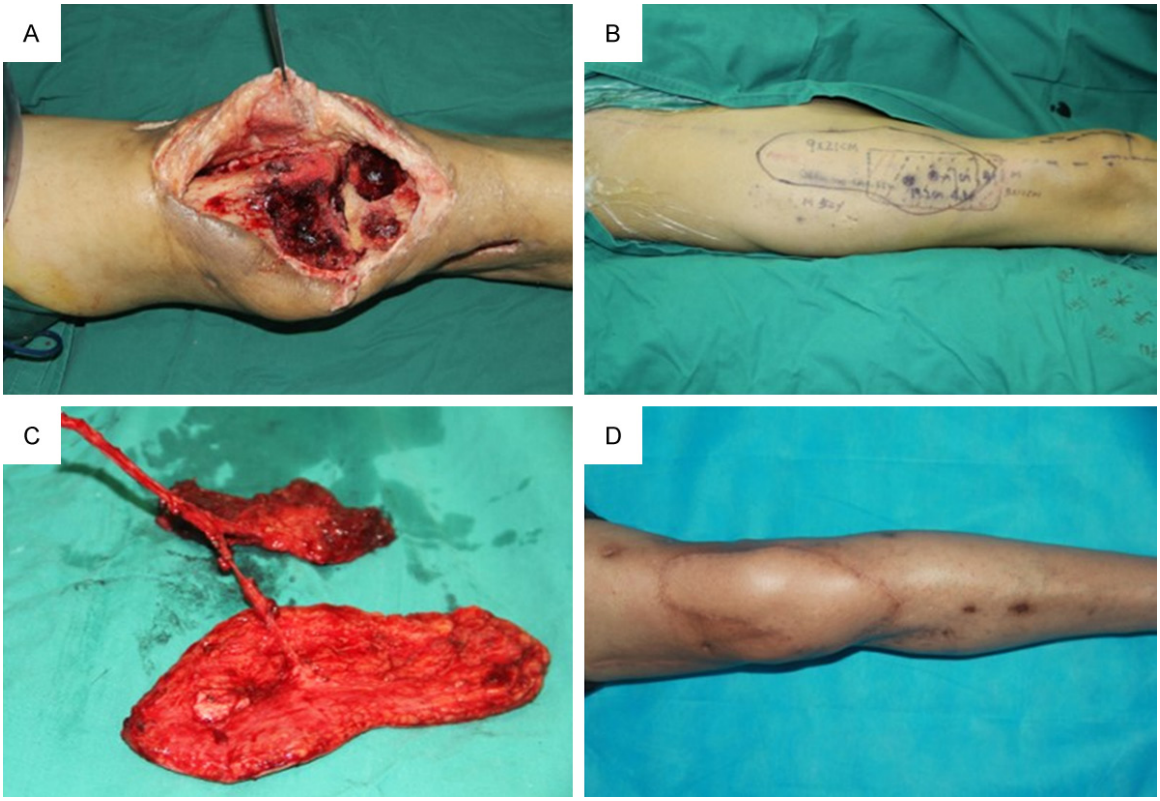

Figure 5. A: A 52-year-old male with a chronic ulcer in the knee region. Radical debridement left a large soft-tissue defect and a dead space. B: A chimeric ALTP flap was used to reconstruct the defect. C: Intraoperative view of the flap. D: Postoperative view of the recipient site.

soft-tissue defects and for the primary closure of the donor site [18, 19]. Zhang et al. [17] reported that dual-skin paddle perforator flaps allow dual-skin paddles to be placed side by side, effectively doubling the width of the flap using the kiss technique. Our previous study also demonstrated that dual-skin paddle ALTP flaps were an alternative option for the repair of extensive soft-tissue defects of the foot and ankle [20]. However, to our knowledge, no previous studies have described the use of dual-skin paddle perforator flaps for the repair of complex tissue defects in the knee region. In two cases presented here, double-skin paddle ALTP flaps were successfully used to cover very large soft-tissue defects and close the donor sites.

Extensive trauma and soft-tissue tumor excision often cause complex three-dimensional defects in the extremities, which can be accompanied by large surface soft-tissue defects, dead spaces, and disruptions of the joint capsule and/or extensor apparatus of the knee; such injuries are also challenging to repair precisely and efficiently. One-stage reconstruction of soft-tissue defects and repair of the extensor mechanism in the knee region do not often result in functional outcomes [21]. In the present series, six patients exhibited disruptions of the joint capsule or extensor mechanism of the knee. Repair using ALTP flaps with part of the fascia lata was performed for two cases to simultaneously restore the joint capsule of the knee and repair the soft-tissue defect. However, it was difficult to use this approach for the repair of very large soft-tissue defects because the fascia lata was not completely separated from the skin paddle, preventing its precise placement. To overcome these disadvantages, a free perforator flap and vascularized fascia lata were used to cover the large soft-tissue defect, restore the extensor apparatus of the knee, and achieve primary closure of the donor site. In this case, a contralateral double-skin paddle ALTP flap and bilateral superior lateral genicular artery perforator flap were obtained to cover the soft-tissue defect. Vascularized

fascia lata was harvested and used to repair the patellar tendon. This method provided sufficient soft and double-layered vascularized tissue for the reconstruction of the large surface soft-tissue defect and restoration of the extensor mechanism of the knee during a single procedure.

Several extensor reconstruction procedures have been previously reported in the literature, such as a gastrocnemius transposition flap [22], quadriceps advancement [23, 24] and tendon graft [25]. However, multiple procedures were required for those methods. Recently, the use of a chimeric flap has become one of the most popular procedures for the reconstruction of three-dimensional defects because of its increased degree of freedom and flexible design [17, 26-28]. Chimeric MSAP flaps have been reported as excellent options for the reconstruction of composite and three-dimensional knee defects [29]. However, donor-site morbidity and the inability to repair very large defects during a single procedure are significant limitations [30]. According to our experience, chimeric TDAP and ALTP flaps are reliable options for the reconstruction of complex tissue defects in the knee region, as those flaps provide a large skin area and sufficient muscle volume [28].

The selection of appropriate recipient vessels is essential for successful free flap transfer in the knee region. The size, shape, location, and depth of the soft-tissue defect affect the normal anatomy of the knee and influence the choice of surgical options according to the quality of the vessels available. Park et al. [31] recommended the MGA as an excellent option because of its proximity to the knee and its consistent, versatile, and suitable caliber. Hong and Koshima [32] presented a reliable approach using perforator vessels as recipients for free flaps in the knee region, but the perforators are not always reliable in terms of their caliber and location. According to our experience, the vasculature near the knee should be considered first in selecting which flap to use. If vessels near the recipient site are damaged and microsurgical anastomosis must be performed outside the zone of injury, the LCFA, PTA, or ATA may be suitable choices. In this present case series, 43.75% of arterial anastomoses were performed distal to the knee (using the PTA or ATA), 50% were performed around the knee (using the SMGA or MSA), and 6.25% were performed proximal to the knee (using the LCFA).

Conclusion

The use of free perforator flaps plays an important role in the reconstruction of complex soft-tissue defects in the knee region in cases where local or pedicled flaps are unavailable. The choice of flap design is based on the location of the wound, the required pedicle length, the wound characteristics, the missing tissue components and their volumes, the quality of the donor site, and the risk of donor-site morbidity and provides a more customized treatment approach. Most previous studies focused on local and pedicled flaps, instead of free perforator flaps, for the reconstruction of soft-tissue defects of the knee; however, during this time of microsurgical and perforator flap advances, the use of free perforator flaps should not be relegated as a second choice.

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Disclosure of conflict of interest

None.

Abbreviations

ALTP, anteriolateral thigh perforator; TDAP, thoracodorsal artery perforator; MSAP, medial sural artery perforator; SLGAP, superior lateral genicular artery perforator; LCFA, lateral circumflex femoral artery; PTA, posterior tibial artery; ATA, anterior tibial artery; SMGA, superior medial genicular artery; MSA, medial sural artery.

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Supplementary Materials Video. The patient recovered good function in the knee.