Alternative Flap Options for Upper Extremity Reconstruction

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- **Article Title:** Alternative flap options for upper extremity reconstruction
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- **Key Words**
  - Upper extremity, flap reconstruction, DIEP flap, SCIP flap, Microsurgical reconstruction

- **Key Points** (3-5 bulleted sentences indicating the main takeaways/defining elements of the article)
  - Various flap techniques exist for the reconstruction of major upper limb defects, with positive outcomes in success rate, function, and aesthetics
  - Alternative free flap options exist other than the widely used ALT; these include the bi-pedicled DIEP flap for extensive defects, and the SCIP flap which represents a newer alternative with promising results
  - While fasciocutaneous flaps are ideal, their complexity requires case-by-case assessment, and muscle flaps remain a viable alternative

- **Synopsis** (100 words or less)

For major upper limb defects, a wide range of established pedicled and free flap options can be utilized. These include the latissimus dorsi/TDAP, lateral arm, PIA, rectus abdominis, gracilis, ALT. Technical proficiency is essential, and favorable success rates in terms of functional and aesthetic outcomes can be achieved. Herein, alternative flap options (both pedicled and free) are introduced and discussed through a few illustrative case examples.

INTRODUCTION

The reconstructive approach towards major defects of the upper limb has evolved over time. Muscle flaps have progressively been replaced by fasciocutaneous flaps that show similar or better outcomes with lower morbidity (e.g. less tendon adhesions)[1-3]. With improvements in surgical techniques and anatomical knowledge, available fasciocutaneous options have evolved even further. They can be used in a variety of configurations, such as free or pedicled and even propeller flaps[4,5].

When available, pedicled flaps are a reliable solution for defects of the upper extremity[6]. McGregor first described two-stage pedicled groin flaps[7-9] using neo-vascularization (or autonomization) principles[10, 11]. While this traditional technique is less commonly used nowadays[12, 13], it has inspired several solutions, such as the superficial inferior epigastric artery (SIEA)[14], lateral inter-costal artery perforator (LICAP)[15], and paraumbilical flaps[16]. In one-stage reconstruction, the pedicled thoracodorsal artery perforator (TDAP) flap can be used to cover proximal defects from the axillary fold to the elbow[17, 18]. Its pedicle length can be up to 25cm allowing elbow reconstruction with little to no tension[19]. Other established pedicled options include the lateral arm flap[20, 21] and the posterior interosseous artery flap[22, 23], depending on the defect location.

Current free flap options are led by the anterolateral thigh (ALT) flap, which has established itself as the workhorse for the modern reconstruction of major upper limb defects[24-26]. Refinements in recent years have led to improvement of the initial technique with super-thin dissection planes[27], double skin paddles[28], and turbocharging[29], thereby improving safety and functional and cosmetic outcomes. This perforator-based approach has been supplemented by similar options, such as the free TDAP[30-32] and, more recently, superficial circumflex iliac artery perforator (SCIP) flaps[33-35].

Finally, the development of the profunda artery perforator (PAP) flap in breast reconstruction has led to alternative, novel use in the upper limb[36]. Further refinements of the PAP flap, with thin and super-thin dissection planes, allow the attainment of excellent outcomes and are now used as the procedure of choice in some centers[37]. Such modern perforator flaps require meticulous dissection, and improvements in pre-operative planning through computed tomography angiography and color duplex ultrasonography have emerged[37,38].

All these microsurgical solutions demand a high level of technical ability and stringent postoperative monitoring protocols but can be limited by the operative time and the patient's overall condition. It is thus critical for the hand surgeon to master several reconstructive techniques. Therefore, the objective of this work is to discuss alternative flap options for major upper limb defect reconstruction through the use of some illustrative case examples.

ALTERNATIVE FLAP OPTIONS

We have selected four different flap techniques performed at our centers for patients with major soft tissue defects of the upper limb that required flap surgery (free or pedicled). Table 1 illustrates the variety of indications and contexts.

Case 1. Free bi-pedicled deep inferior epigastric artery perforator (DIEP) flap

The first case describes a 64-year-old female with type 2 diabetes who suffered a comminuted open fracture of the left humerus and a degloving injury to her left upper limb in a road traffic accident. The patient was intubated in the emergency department at another institution, where a trauma computed tomography (CT) and CT angiography were performed. The CT showed a minor

pulmonary embolism, but no other injuries were found. The patient was then transferred to our center, where she underwent an exploration of the left brachial artery, followed by thrombectomy and a bovine pericardial patch repair performed by the vascular surgeons. An open reduction and internal fixation (ORIF) was then performed on the left radius, with external fixation of the humerus. The external fixation was considered the definitive management due to the already compromised soft tissues in a case complicated by COVID-19 positivity and underlying diabetes, which increased the risks of infection and delayed healing.

In order to cover the resulting soft tissue defect that was near circumferential (Fig 1A), a free bi-pedicled DIEP was performed to resurface the left upper limb. An intra-flap anastomosis (end-to-end) was performed between the "opposite" DIEP pedicle to a branch of the main DIEP pedicle, followed by an extra-flap anastomosis between the DIEA and DIEV to the brachial artery (end-to-side) and the cephalic vein (end-to-end), respectively (Fig 1B). The extended DIEP-based flap allowed for tension-free closure and full coverage of the soft tissue defect (Fig 1C). The donor site was also closed easily as per a standard DIEP procedure (Fig 1D). The patient's postoperative course was otherwise unremarkable, and primary healing was obtained, with a satisfactory aesthetic and functional outcome at one year of follow-up (Fig 1E). This case illustrates the benefit of the bi-pedicled technique based on the same principles as supercharging[39-31] and turbocharging[29, 40], improving blood flow through multiple anastomoses to achieve the survival of an extended flap beyond the angiosome of a single perforator. Therefore, the bi-pedicled DIEP flap can be an option in patients with a moderate-to-high body mass index who have sustained major degloving injuries[42].

Case 2. Pedicled latissimus dorsi flap

Our second patient was a 27-year-old man with ciliary dyskinesia and who was an active smoker. He was the victim of an assault with a firearm (pellet gun) resulting in major trauma of the left arm with extended loss of skin from the mid-arm to the elbow. No significant bone damage was found. Emergent surgical exploration revealed the absence of the radial pulse, preservation of the ulnar pulse, hypoesthesia of the hand, and subtotal loss of prehension in terms of neurological signs. Decompression of the radial artery by evacuating a hematoma allowed for flow restoration. No nerve discontinuity was observed in the radial, ulnar, and median nerves. The elbow joint was preserved. After soft tissue debridement, the defect was extensive (Fig 2A).

In view of the potential for partial vascular damage (given the initial loss of radial artery flow), a free flap was considered risky by our team. A pedicled solution was decided upon, and since the defect size was major, a musculocutaneous latissimus dorsal (LD) flap was preferred to a TDAP, with the best benefit-risk ratio (short surgery time, safety, robustness of the flap). The flap was harvested with the patient in an intermediate supine/lateral decubitus position. A vertical skin paddle was drawn to allow for optimal flap inset after 45 degrees of rotation (Fig 2B). The distal tendon of the LD flap was used to reconstruct the distal biceps. Video A (Supplementary Digital Content) shows the resulting contraction, eventually allowing restoring flexion of the elbow. A strip of muscle in the left arm was left exposed to avoid compression of the pedicle (Fig 2C) with the placement of a split-thickness skin graft two weeks later. Complete wound healing was achieved, and the patient could start physiotherapy after six weeks, with a satisfactory functional outcome at four months follow-up (Fig 2D). This case illustrates that while fasciocutaneous free flaps are in vogue for modern upper extremity defect reconstruction, it is still important to consider

the robustness of pedicled musculocutaneous flaps[43]. While a vascularized skin paddle should be preferred for the fold and joint areas to avoid motion range limitation, major defects in the context of emergency can be managed adequately with muscle coverage and delayed skin grafting[44].

Case 3. Pedicled brachioradialis muscle flap

The third case was that of a 19-year-old man with no past medical history who was involved in a mountain biking accident. He sustained trauma to the right upper limb resulting in an open trans-olecranon fracture dislocation associated with a closed comminuted distal radius fracture. His initial surgery was performed at a local facility where he had sustained the injury, using an external fixator. The patient then presented to our center at POD 15 with a wound infection and was taken to the OR. After debridement, an open reduction and osteosynthesis of the olecranon was performed using a screwed plate (Variax, Stryker, Michigan, USA) (Figure 3A). A brachioradialis muscle flap (Figure 3B) associated with a local rotation skin flap was then used for hardware coverage. Additional acellular dermal matrix (ADM) (Duragen, Integra Lifescience, Princeton, NJ) was applied and affixed with staples (Figure 3C) The distal radial fracture was reduced and fixed with a volar locking plate (Aptus, Medartis, Bale, Switzerland). The joint surface was reduced under arthroscopic control and fixed with K-wires. A split-thickness skin graft was performed 3 weeks after application of the ADM, and full wound healing was obtained after 4 weeks. No complication was reported, and the patient achieved a satisfactory range of motion (flexion 130°, extension -20°, Pronation 80°, Supination 80°) (Figure 3D). This case emphasizes the usefulness of local muscle flaps that represent an efficient solution in such difficult situations by obtaining well-vascularized tissue for coverage and providing an optimal wound bed for skin grafting[45]. The brachioradialis flap has been described as an alternative for posterior elbow

wounds[46]. In addition, to improve the quality of the healed tissue, ADM has proven to be a valuable tool in the upper extremity[47,48].

Case 4. Free SCIP flap

Finally, the last patient was a 58-year-old female who was treated four months previously for a right forearm sarcoma with surgery and post-operative adjuvant radiotherapy who then presented with radiodermatitis and consequent exposure of the underlying radius (Fig. 4A). Unfortunately, the patient was still actively smoking. After a multidisciplinary team discussion, wide soft tissue resection with bone trimming was decided upon, followed by one-stage soft tissue coverage. Given the location of the defect, a free SCIP flap raised along the superficial fat layer above the superficial fascia, in erthin fashion, was chosen (Fig. 4B). The flap was harvested on the superficial branch of the SCIA only, and the vessels were anastomosed end-to-side to the radial artery and accompanying venae comitantes (Fig. 4C and 4D). No postoperative complication occurred, and the patient's wound had fully healed after four weeks. The result was found to be excellent, with minimal contour deformity of the flap in the forearm after one year (Fig. 4E). The flap's thinness also allowed the patient to resume her usual activities. The donor site healed without complication. The SCIP flap shows high adaptability through the variable thickness, adjustable pedicle length, and flap dimensions[33, 34].

DISCUSSION

These selected cases demonstrate the effectiveness of various modern reconstructive techniques for major defects of the upper limbs resulting from various etiologies, with high technical success, satisfactory functional and aesthetic results, and a low rate of complications. Therefore, the modern

hand and reconstructive microsurgeon should keep in mind that alternative solutions, both pedicled and free, do exist besides well-established approaches such as the ALT and TDAP flaps.

LIMITATIONS

One critical parameter missing in our case series and poorly described in the literature is assessing the quality of life following upper limb reconstruction. It could be highly informative to assess function and quality of life using validated questionnaires, such as the Upper Extremity Function Test or the Sollerman hand function test, to better objectively assess the outcomes of all different alternatives. That, however, is beyond the scope of the current manuscript.

SUMMARY

In conclusion, the discussion around this series of patient cases demonstrates the efficacy of various flap reconstruction techniques for major upper limb defects, with favorable outcomes regarding success rate and functional and aesthetic results. Bi-pedicled DIEP flaps can be used for selected patients with extensive defects. Various refinements can improve ALT flaps to reach even better outcomes, while SCIP flaps represent an attractive newer alternative providing high-quality results. Reconstructive surgeons have a range of solutions at their disposal, among which fasciocutaneous flaps are generally considered the most optimal given the functional requirements of the hand. However, technical sophistication and complexity of these options require a case-by-case assessment. Simpler solutions, such as pedicled musculocutaneous flaps combined with skin grafts, should also be part of our armamentarium to ensure that patient outcomes are not compromised regardless of the circumstances.

Clinics Care Points – ***Bulleted list of evidence-based pearls and pitfalls relevant to the point of care :***

- *Alternative flap options for reconstruction of major defects of the upper limb can be used successfully*
- *Bipedicled DIEP flaps can be an adequate solution for extensive and deep defects in patients with soft tissue excess at the donor site*
- *Pedicled myocutaneous/ muscle flaps such as the latissimus dorsi and brachioradialis flaps are invaluable options in cases where microsurgery may not be suitable*
- *Newer techniques, such as free SCIP flaps, are challenging but can provide superior results in selected patients*

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Figure Legends

Figure 1. Case of a 64-year-old female with a comminuted open fracture of the left humerus and degloving injury. A free bi-pedicled DIEP flap was performed to cover the defect and the material. Consented pictures kindly provided by Mr. Marios Nicolaou (Salisbury District Hospital).
(A) Preoperative presentation with a massive soft tissue defect. The brachial artery and cephalic vein (white asterisk) and the extensor digitorum communis tendons (yellow asterisk)
(B) Intra-flap anastomosis between the two deep inferior epigastric arteries (yellow arrow). Anastomosis on the brachial artery (white arrow).
(C) Tension-free closure and full coverage of the soft tissue defect allowed by the extended flap paddle.
(D) Direct closure of the donor site.
(E) Final result. Primary healing, with a satisfactory aesthetic and functional outcome at one year of follow-up.

Figure 2. Case of a 27-year-old male who was the victim of a pellet gun trauma resulting in a major defect of the left arm. A low-risk solution was chosen, and a pedicled musculocutaneous latissimus dorsi (LD) flap was performed.
(A) Preoperative presentation with an evident soft tissue defect.
(B) A vertical skin paddle (yellow arrow) allowed for optimal flap inset after 45 degrees of rotation with low tension on the pedicle (white arrow). No injuries of the vascular axes (brachial artery, white asterisk) or nerves were found. The biceps brachii was partially preserved (yellow asterisk).
(C) A strip of the LD muscle was left exposed (black asterisk) in the medial arm to avoid compression of the pedicle.
(D) Final result. Complete wound healing, with a satisfactory aesthetic and functional outcome at four months follow-up.

Figure 3. Case of a 19-year-old man with an open transolecranon fracture initially treated with an external fixator. A wound infection led to debridement, screwed-plate-based osteosynthesis, and the resulting defect was covered by a combination of a pedicled brachioradialis flap and an acellular dermal matrix prior to skin grafting.
(A) Open reduction and osteosynthesis of the olecranon with a screwed plate (Variax, Stryker, Michigan, USA) (yellow arrow) performed after debridement.
(B) Brachioradialis muscle flap (white arrow) associated with a local rotation skin flap.
(C) Acellular dermal matrix (ADM) (Duragen, Integra Lifescience, Princeton, NJ) was applied to enhance healing and was affixed with staples.
(D) Final result. Full healing, with a satisfactory aesthetic and functional outcome at four weeks follow-up.

Figure 4. Case of a 58-year-old woman presenting with radiodermatitis and bone exposure following radiotherapy. A wide soft tissue resection with bone trimming was performed, and the defect was covered using a free thin SCIP flap, resulting in optimal coverage. Consented pictures kindly provided by Dr. Paul Girard and Pr. Nicolas Bertheuil (CHU de Rennes).
(A) Radiodermatitis and exposure of the radius after surgery and postoperative adjuvant radiotherapy.
(B) Free SCIP flap raised in the thin plane.

(C) Harvesting of the flap on the superficial branch of the Superficial Circumflex Iliac Artery (SCIA, white asterisk).
(D) Final positioning of the flap with the vessels (SCIA) anastomosed end-to-side to the radial artery and accompanying venae commitantes.
(E) Final result. Full healing, with an excellent aesthetic outcome at four weeks of follow-up.

Table 1.

Case	Sex	Age (years)	Comorbidities	Etiology	Flap	Outcome
Patient 1	F	64	T2DM	Comminuted open fracture of the left humerus	Free bi-pedicled DIEP	Fully healed at 1 year follow-up, able to play piano
Patient 2	M	27	Ciliary dyskinesia, active smoking status	Major trauma of the left arm with extended soft tissue defect from mid-arm to elbow	Pedicled musculocutaneous latissimus dorsi flap	Full healing, physiotherapy after 6 weeks, satisfactory functional outcome after 4 months
Patient 3	M	19	None	Loss of substance after mountain biking accident	Pedicled brachioradialis muscle flap	Full healing after 4 weeks (skin graft at week 3)
Patient 4	F	58	Previous sarcoma of the right forearm, active smoking status	Sarcoma of the right forearm treated with surgery and adjuvant radiotherapy	Free SCIP flap	Full healing after 4 weeks

Figures:

- Figure Legends

Figure 1. Case of a 64-year-old female with a comminuted open fracture of the left humerus and degloving injury. A free bi-pedicled DIEP flap was performed to cover the defect and the material. Consented pictures kindly provided by Mr. Marios Nicolaou (Salisbury District Hospital).
(A) Preoperative presentation with a massive soft tissue defect. The brachialis artery and cephalic vein (white asterisk) and the extensor digitorum communis tendons (yellow asterisk)

(B) Intra flap anastomosis between the two deep inferior epigastric arteries (yellow arrow). Anastomose on the brachial artery (white arrow).
(C) Tension-free closure and full coverage of the soft tissue defect allowed by the extended flap paddle.
(D) Direct closure of the donor site.
(E) Final result. Primary healing, with a satisfactory aesthetic and functional outcome at one year of follow-up.

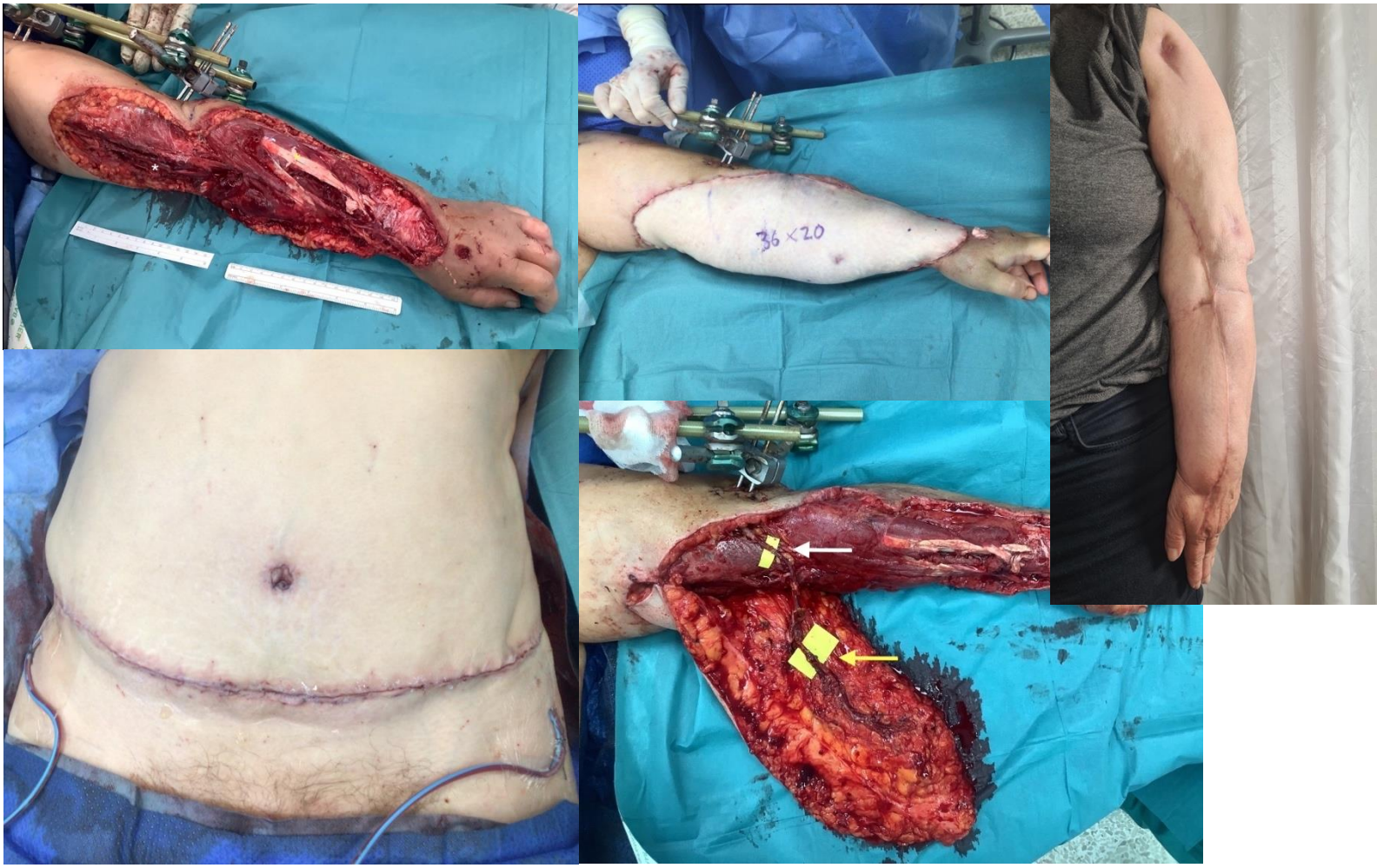

Figure 2. Case of a 27-year-old male who was the victim of a pellet gun trauma resulting in a major defect of the left arm. A low-risk solution was chosen, and a pedicled musculocutaneous latissimus dorsi (LD) flap was performed.
(A) Preoperative presentation with an evident soft tissue defect.
(B) A vertical skin paddle (yellow arrow) allowed for optimal flap inset after 45 degrees of rotation with low tension on the pedicle (white arrow). No injuries of the vascular axes (humeral artery, white asterisk) or nerves were found. The biceps brachii was partially preserved (yellow asterisk).
(C) Left exposure of a strip of the LD muscle (black asterisk) in the left to avoid compression of the pedicle.

(D) Final result. Complete wound healing, with a satisfactory aesthetic and functional outcome at four months follow-up.

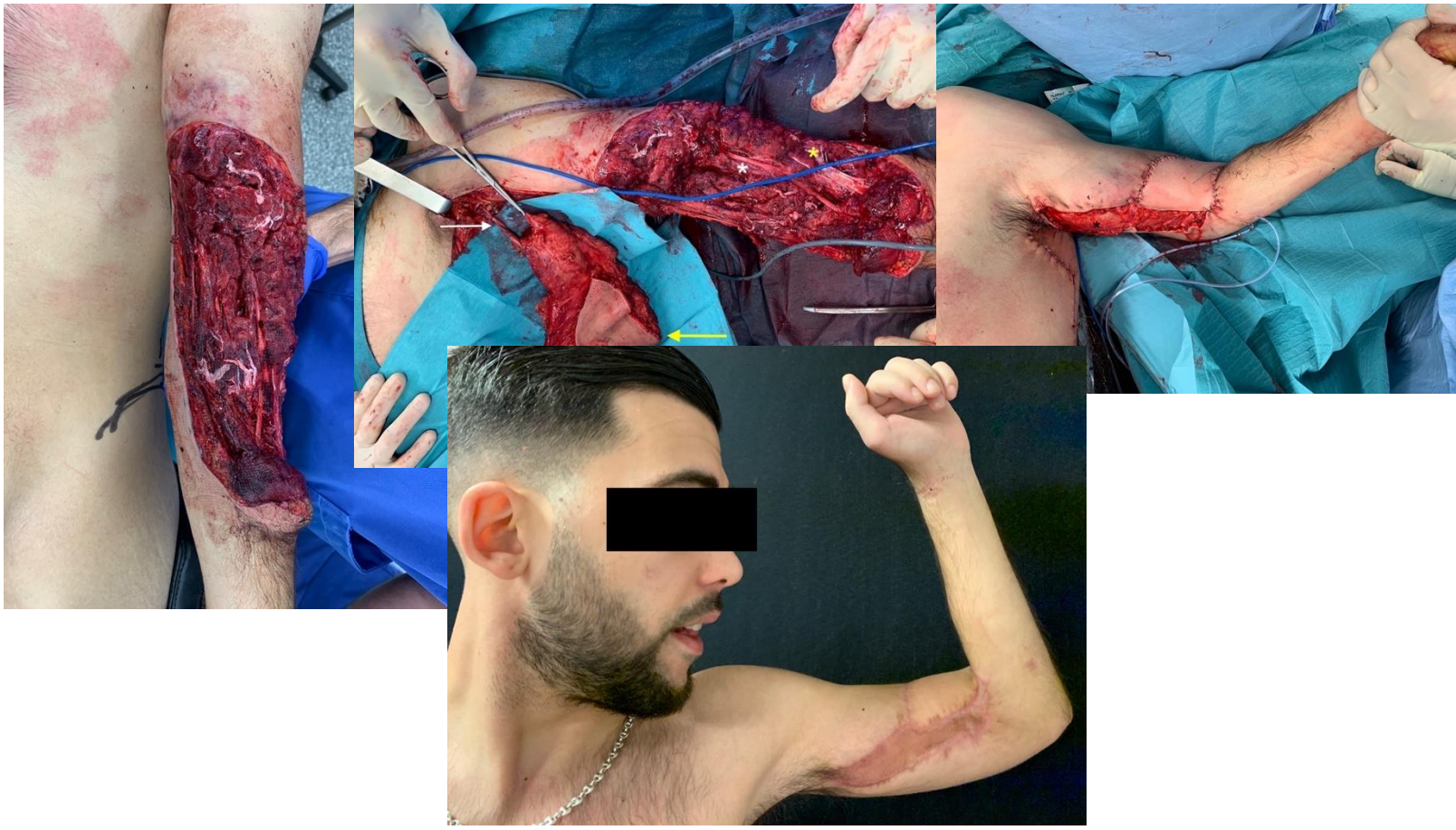

Figure 3. Case of a 19-year-old man with an open transolecranon fracture initially treated with an external fixator. A wound infection led to debridement, screwed-plate-based osteosynthesis, and the resulting defect was covered by a combination of a pedicled brachioradialis flap and an acellular dermal matrix prior to skin grafting.
(A) Open reduction and osteosynthesis of the olecranon with a screwed plate (Variax, Stryker, Michigan, USA) (yellow arrow) performed after debridement.
(B) Brachioradialis muscle flap (white arrow) associated with a local rotation skin flap.
(C) An acellular dermal matrix (ADM) (Duragen, Integra Lifescience, Princeton, NJ) was applied to enhance healing and was affixed with staples.
(D) Final result. Full healing, with a satisfactory aesthetic and functional outcome at four weeks follow-up.

Figure 4. Case of a 58-year-old woman presenting with radiodermatitis and bone exposure following radiotherapy. A wide soft tissue resection with bone trimming was performed, and the defect was covered using a free ultrathin SCIP flap, resulting in optimal coverage. Consented pictures kindly provided by Dr. Paul Girard and Pr. Nicolas Bertheuil (CHU de Rennes).
(A) Radiodermatitis and exposure of the radius after surgery and postoperative adjuvant radiotherapy.
(B) Free SCIP flap raised in supra-thin fashion.

(C) Harvesting of the flap on the superficial branch of the Superficial Circumflex Iliac Artery (SCIA).
(D) Final positioning of the flap with the vessels (SCIA, white asterisk) anastomosed end-to-side to the radial artery and accompanying venae comitantes.
(E) Final result. Full healing, with an excellent aesthetic outcome at four weeks of follow-up.