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SOFT TISSUE COVERAGE FOR ELBOW TRAUMA

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Background

Elbow trauma may result in soft tissue injury or loss. Reconstruction of subsequent defects can be complicated. Inadequate reconstruction of elbow soft tissue defects can severely limit functional outcomes by restricting motion and impairing upper extremity function. Ideal tissues for reconstruction are soft, thin, pliable, and durable with repetitive motion. Appropriate debridement is critical and the surgeon must balance removal of all nonviable tissue with preservation of critical structures. Timing of the reconstruction is important for preserving function and avoiding infection.

Principles of Reconstruction

Trauma is a common cause of soft tissue defects of the elbow. Traumatic wounds are often complicated by exposure of or injury to bone, nerve, tendon, and vasculature. Reconstruction of each of these structures coverage that is supple and durable. Classically, the “reconstructive ladder” was used to suggest a course of action. However, a more complicated reconstruction may be the better option if it grants improved motion or a more durable construct. This escalation in complexity is known as the “reconstructive elevator.”

Patient health and the mechanism of injury change the surgical management of traumatic wounds. High-energy traumatic wounds are more complicated than those from low-energy. High-energy wounds can have occult injuries that declare over time. These wounds need serial debridement and repeat examination prior to definitive coverage. Patient comorbidities

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or systemic injury may dramatically affect overall care. Smokers may have a predilection for peripheral arterial disease and vasoconstriction. Other causes for healing impairment should be considered prior to reconstruction, including diabetes, irradiation, immunosuppression, or autoimmune disease. These conditions should be optimized at the earliest feasible point in care.

Wound Location

Reconstruction of the posterior elbow poses different challenges than the anterior antecubital elbow. In general, the total area of the skin envelop on the posterior elbow is greater than the anterior elbow because the posterior elbow is tight when flexed. The elbow is capable of greater than 130° of motion and coverage must be stable in both flexion and extension.¹ The skin overlying the olecranon and posterior elbow is thin and is at high risk for pressure injury. Therefore, protective sensation on the posterior elbow is useful to prevent further injury after reconstruction. The anterior and posterior antebrachial cutaneous nerves provide sensory innervation to the elbow. Primary closure, nerve repair, or innervated flap reconstruction may restore protective sensation to this area.

Reconstruction should not be delayed after the wound is clean and can tolerate coverage. A suggested reconstruction algorithm is provided (Fig. 1). Ideally, an isolated traumatic elbow wound should undergo immediate reconstruction. However, if the wound is grossly contaminated or tissue viability is questionable, continue with serial debridement. For a complicated wound, the first priority is fracture fixation and vascular repair. In general, fracture fixation should precede other procedures to guard against injury to nerve or vessel repairs. In contaminated wounds, external fixation is preferred as this preserves wound care options while not exposing the permanent fixation hardware to additional infection risk. In cases of concomitant life threatening injuries, amputation or delayed management should be considered. Early coverage of wounds, within the first 24-72 hours, decreases edema, lowers wound infection rates, improves scar healing, and improves limb function.^{2,3}

Primary, Delayed Primary, or Secondary Closure

Primary closure is the simplest option for clean, easily approximated, tension-free wounds. The presence of hardware or graft material should prompt the surgeon to consider other options. Nerve and vascular graft failure can result from erosion, infection, or pressure on the closure. Undermining skin edges is a common technique to aid in wound closure, but should be done judiciously in early traumatic wounds. For contaminated wounds, primary closure may be an option if a delay is possible and local tissues are sufficient. Serial debridement and local wound care should be performed prior to definitive closure. If delayed primary closure is considered, there should be minimal tension on the repair and underlying vital anatomic structures should be well protected. Healing by secondary intention is reserved for small, structurally-intact wounds. Secondary healing is also an option in patients whose wounds cannot be addressed due to other systemic issues. Tissue expanders have been used historically. Expanders require multiple procedures and are at risk for pressure injury, tissue thinning, infection, and extrusion.⁴

Skin Grafting

Skin grafts are suitable reconstructive options in selective elbow injuries. Ideal wounds for skin grafting are those without exposed critical structures and an adequate vascular bed (Fig. 2). Grafts can be placed over intact fascia, paratenon, or periosteum with adequate revascularization, but may result in unstable scarring. Over the olecranon, skin grafting may not be adequate to provide long-term durable coverage.

Local Random Pattern Flaps

Local flap reconstruction of the elbow provides more durable coverage than skin grafting and can be attempted in small wounds too large for primary repair. Use of local flaps at the elbow is limited because of a paucity of soft tissue laxity. Local random flaps depend on dermal and subdermal blood supply and healing is less consistent than axial flaps. Examples of local tissue rearrangements include advancement flaps, Z-plasty, rhomboid flaps, or rotational flaps.⁵⁻⁷ Secondary donor site defects may require skin grafting. A 1:1 ratio of flap length to width is typically recommended. Narrow flaps are more prone to flap edge necrosis and delayed wound healing.⁸

Axial Pattern Fasciocutaneous Flaps

Axial pattern flaps are commonly used for upper extremity reconstruction. These flaps have well-defined blood supplies and can be designed as peninsular, island, or microvascular free flaps. The most common examples of axial pattern fasciocutaneous flaps in the upper extremity are the radial forearm, lateral arm, ulnar artery, antecubital fasciocutaneous, and posterior interosseous flap.⁹⁻¹⁹ Care must be taken to ensure patent vascular arcades at the wrist and palm to allow for retrograde flow to the flap or to ensure vessel patency to distal tissues. An Allen test should be documented preoperatively. If necessary, donor arteries can be repaired with vein grafting.

Radial Forearm Flap

<i>Dominant Arterial Supply:</i>	Radial artery
<i>Sensory Innervation:</i>	Lateral antebrachial cutaneous n (volar radial forearm); Medial antebrachial cutaneous n (volar ulnar forearm)
<i>Skin (Length × Width):</i>	Length 3 – 40 cm (up to 3cm) × Width 2 – 15 cm (up to 2cm)

The radial forearm flap is a classic upper extremity workhorse flap.²⁰⁻²³ The flap can be raised with sensory innervation and can be used as a composite flap with incorporation of distal radius bone. A patent palmar arch is mandatory to maintain hand perfusion and this should be confirmed by Allen test.²⁴ If necessary, the radial artery can be reconstructed with saphenous vein graft. Thumb ischemia has been described in cases of an incomplete palmar arch after radial artery harvest.^{25,26}

Donor site morbidity is relatively high with the radial forearm flap and the appearance of the donor forearm can be a major concern for patients. The forearm typically requires secondary

reconstruction with skin grafting as the skin laxity of the distal forearm is not amenable to primary repair. Furthermore, up to 13% of patients may develop exposed tendons, 19% have delayed donor site wound healing, and 32% have decreased sensation in the radial nerve distribution.²⁷ Bone harvest increases risk for radius fracture. Finally, cold intolerance, aching at the wrist, tendinous adhesions, and neuroma are also common donor site complications.²¹ A suprafascial harvest has been described that may limit donor site morbidity.^{22,28-30} However, subfascial dissection allows for ease of dissection, protection of subdermal vessels, and protection from shearing.

Lateral Arm Flap

<i>Dominant Arterial Supply:</i>	Posterior radial collateral artery
<i>Sensory Innervation:</i>	Lateral brachial cutaneous n (distal: posterior antebrachial cutaneous nerve)
<i>Skin (Length × Width):</i>	Length 5 – 20 cm × Width 3 – 12 cm (up to 6cm)

The lateral arm flap is another common upper extremity workhorse flap (Fig. 3).³¹ The lateral arm can be used as a free, pedicled, or contralateral cross arm flap.^{13,32-34} Composite flaps with sensation, muscle, or bone have been described.³⁵ The length can be extended up to 15cm past the lateral epicondyle.³⁶

Pedicle Muscle or Myocutaneous Flaps

Muscle flaps are preferred over fasciocutaneous flaps in the setting of significant empty space or infection.^{37,38} Neurotized muscle flaps can be used for restoration of motion. Local muscle flaps include the anconeus, brachioradialis, extensor carpi radialis longus, and flexor carpi ulnaris.³⁹⁻⁴⁸ The most common distant pedicled muscle flap is the latissimus dorsi muscle. Local flaps may be limited by involvement in the zone of injury, whereas, latissimus dorsi is often spared from localized trauma. Other than the latissimus, distant muscle flaps are rarely used as they require a secondary operation, have high donor site morbidity, may induce joint stiffness, and free tissue transfer alternatives exist.⁴⁹

Anconeus Muscle

<i>Dominant Arterial Supply:</i>	Recurrent posterior interosseous & medial collateral artery ²⁴
<i>Motor Innervation:</i>	Radial nerve
<i>Muscle Length:</i>	2.5 × 7cm (up to 10.6cm) ^{24,50}
<i>Pedicle Length:</i>	3.1 cm (range 2.4 – 3.8cm)
<i>Mathes & Nahai Class:</i>	Type I versus Type III ^{24,51}

The anconeus muscle is useful for coverage of small posterior elbow defects and loss of anconeus function results in minimal patient morbidity.⁶ It is particularly useful for injuries overlying the radiocapitellar joint, distal triceps tendon, or olecranon.⁴⁷ However, the anconeus is not dependable to cover defects greater than 5 – 7cm² in area and the short arc of rotation makes it a poor choice for anterior or medial defects.

Brachioradialis Muscle

<i>Dominant Arterial Supply:</i>	Radial recurrent artery and/or radial artery ^{45,52}
<i>Motor Innervation:</i>	Radial nerve
<i>Muscle Dimensions:</i>	Range 8 × 15 cm (tapers distally)
<i>Pedicle Length:</i>	3 cm from radial artery; located 7-10cm distal to muscle origin
<i>Mathes & Nahai Class:</i>	Type II

The brachioradialis muscle is used to cover small defects on the distal $\frac{1}{3}$ to $\frac{1}{2}$ of the arm or proximal forearm (Fig. 4). For the upper arm, it is best suited for anterolateral or posterolateral defects. The only relative contraindication to harvest is absence of dominant elbow flexors, due to its functions as a weak elbow flexor.

Flexor Carpi Ulnaris (FCU) Muscle

<i>Dominant Arterial Supply:</i>	Ulnar or recurrent ulnar arteries
<i>Motor Innervation:</i>	Ulnar nerve
<i>Muscle Dimensions:</i>	Range 5 × 20 cm (tapers distally)
<i>Pedicle Location:</i>	5.7cm from medial epicondyle (range 3 – 10cm) ⁵³
<i>Mathes & Nahai Class:</i>	Type II

The flexor carpi ulnaris muscle flap is useful for defects on the anterior, posterior, or medial elbow. Relative contraindications include a lack of other wrist flexors or lower morbidity alternatives for reconstruction.⁵⁴ Ulnar artery absence or ulnar hand dominance may also limit use of the flap. Loss of flexor carpi ulnaris results in weakened wrist flexion and ulnar deviation.

Latissimus Dorsi Muscle

<i>Dominant Arterial Supply:</i>	Thoracodorsal artery
<i>Motor Innervation:</i>	Thoracodorsal nerve
<i>Muscle (Length × Width):</i>	Length 35cm (Range 21 – 42cm) × Width 20cm (Range 14 – 26cm)
<i>Skin (Length × Width):</i>	Length 18cm (up to 35cm) × Width 7 cm (up to 8 – 9cm primarily)
<i>Pedicle Length:</i>	8.5cm (range: 6.5 – 12cm)
<i>Mathes & Nahai Class:</i>	Type V

The latissimus dorsi muscle is a robust flap used in both pedicle-based and free flap reconstruction. The flap can be designed to include a skin paddle or scapula. Furthermore, the muscle can remain innervated for functional innervated transfer to restore biceps or triceps function.⁵⁵⁻⁵⁹ For elbow reconstruction, the pedicle flap can reach up to 6 – 8cm distal to the olecranon.^{60,61} The flap is particularly useful for large defects over the posterior upper arm or with a large zone of injury precluding local flap use.

Sacrifice of latissimus dorsi may result in shoulder weakness. Use may be contraindicated in paraplegics or patients requiring a life-long wheelchair or crutch use. Likewise, the latissimus dorsi should be used judiciously in patients at increased risk for breast cancer, as it is a common option for breast reconstruction. Preoperative vascular imaging should be considered if the patient has a history of axillary surgery. The most common complication is donor site seroma, but partial flap necrosis can occur at a high rate (> 35%) when inset beyond the olecranon.⁶²

Two-Stage Axial Fasciocutaneous Flaps

Distant axial fasciocutaneous flaps are a reliable option in hand and upper extremity reconstruction.⁶³⁻⁶⁵ Thoracoabdominal flaps were first described in the 1940s and options have expanded with the advent of perforator free tissue transfer.⁶⁶⁻⁶⁸ Like distant muscle flaps, distant axial flaps often require a secondary procedure for flap inset and pedicle division. These flaps have been described for defects up to 22cm in length.⁶³ The ideal use for these flaps is in the setting of a large defect, with the zone of injury eliminating local and regional reconstructive options. Two-stage flaps are a useful alternative when microsurgical techniques are unavailable. The main limitation for use is the need for prolonged immobilization and donor site morbidity. Perforator based thoracoabdominal flaps include branches of the superior epigastric, inferior epigastric, deep circumflex iliac, intercostal (Fig. 5), and subcostal arteries.⁶⁸ However, thoracoabdominal angiosomes can be variable and large perforator-based fasciocutaneous flaps rely on a random pattern of perfusion near the flap edges.⁶⁹

Free Tissue Transfer

Microsurgical free tissue transfer is the most robust reconstructive option for customized soft-tissue coverage at the elbow. Options for elbow coverage include muscle-only, myocutaneous, fasciocutaneous, omentum, vascularized bone, or composite flaps. The first indication for free tissue transfer is a large defect that exceeds the capability for local or regional flap coverage. Other indications include the need for multiple tissue types, specific flap orientation, and injury to local flap options. Free tissue transfer is also an alternative to multi-stage procedures. The only absolute contraindication to free tissue transfer is a vascular injury involving potential recipient vessels. Common free flaps used for elbow reconstruction include the anterolateral thigh (ALT), groin, scapular, parascapular, gracilis muscle, latissimus dorsi muscle, or fibular osteocutaneous flaps.⁷⁰⁻⁷⁷ Free fasciocutaneous flaps can be harvested from the contralateral upper extremity, including the lateral arm and radial forearm flaps.

Donor site selection is a key benefit of free tissue transfer. Flaps can be chosen that have minimal donor site morbidity. For example, the anterolateral thigh and the gracilis muscle are both common flaps used from the lower extremity that can be closed primarily and result in minimal functional deficit. These tissues can also be neurotized for sensory or motor function. Reported risk of total flap loss in an experienced microsurgical center is less than 3%.⁷⁸ Risks for flap loss include elevated BMI, technical difficulty, smoking, tamoxifen, or anastomosis in the zone of injury.^{79,80}

Anterolateral Thigh Flap (ALT)

<i>Dominant Arterial Supply:</i>	Descending branch of the lateral circumflex femoral artery
<i>Skin Sensory Innervation:</i>	Lateral femoral cutaneous nerve
<i>Motor Innervation:</i>	Branch to vastus lateralis from femoral nerve
<i>Skin (Length × Width):</i>	Length 16cm (Range 4 – 35cm) × Width 8 cm (up to 8cm primarily)
<i>Pedicle Length/Diameter:</i>	12cm (range: 8 – 16cm); 2.1mm diameter
<i>Muscle component:</i>	range: 2 – 20cm of vastus lateralis muscle

The anterolateral thigh flap is a fasciocutaneous flap that can include muscle and results in minimal donor site morbidity.⁸¹ Typically, the donor site can be closed primarily. The perforator is found either septocutaneous or musculocutaneous, but the flap is noted to be highly reliable despite this variability.⁷⁷

Gracilis Muscle

<i>Dominant Arterial Supply:</i>	Medial femoral circumflex or branch of the profunda femoral artery
<i>Motor Innervation:</i>	Anterior branch of the obturator nerve
<i>Muscle (Length × Width):</i>	Length $\frac{2}{3}$ length of medial thigh × Width 5 – 8cm
<i>Skin Sensory Innervation:</i>	Medial cutaneous nerve of the thigh
<i>Skin (Length × Width):</i>	Length $\frac{2}{3}$ of muscle length × Width up to 4 – 6cm primarily
<i>Pedicle Length/Diameter:</i>	7cm (range: 6 – 8cm); 1.5mm (range: 0.5 – 2.0mm)

Summary

Wounds of the elbow present unique anatomic and functional challenges for the reconstructive surgeon. The ultimate success of reconstruction relies on durable wound coverage and early motion of adjacent joints, muscles, and tendons. Therefore, management requires a thorough understanding of the advantages and limitations of coverage options. The choice of technique may change greatly with variation in patient comorbidities, wound size, or wound quality. Using the techniques discussed, reconstruction of the elbow can be accomplished in a directed, patient-specific manner.

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Synopsis

The elbow is particularly prone to trauma and soft tissue reconstruction can be challenging given the inherent motion, pressure, and lack of local tissue laxity. Small wounds and those without exposure of vital structures may be amenable to primary repair, but larger wounds and those requiring more substantial structural or anatomic repair may require complex, flap-based reconstruction. A comprehensive review of soft tissue reconstruction of the elbow is provided to offer surgeons alternative options in complicated upper extremity wounds.

Key Points

- 1) Durability, early-motion, and ease of patient recovery are important considerations for elbow wound coverage.
- 2) After debridement, small elbow wounds without exposure of vital structures may be closed primarily.
- 3) Local or regional flap options are often available and may be adequate to accomplish wound closure. However, local flaps may be involved in the zone of injury.
- 4) Fasciocutaneous flaps are preferable for coverage of tendons to provide a gliding surface. Muscle flaps are useful when filling empty space or if infection is a concern.
- 5) When recipient vessels are intact, free tissue transfer may be an alternative if local or regional flaps are unavailable.

Fig. 1.

Traumatic elbow wound reconstruction algorithm, suggested by the authors.

Fig. 2. Negative pressure wound care and skin grafting. (A) Ulnar-sided forearm / elbow wound without vital structure exposure. (B) Wound granulation following negative pressure therapy. (C) & (D) Early and long-term outcomes after skin grafting

Fig. 3. Lateral arm pedicled perforator flap. (A) Chronic post-traumatic contracture and unstable elbow scarring. (B) Wound size following scar release; ulnar neuroma resection. (C) Preoperative marking for extended lateral arm flap. (D) & (E) Flap elevation with identification of the vascular pedicle; demonstration of flap mobility. (F) Flap inset.

Fig. 4. Pedicled brachioradialis muscle flap. (A) & (B) Chronic traumatic wound overlying olecranon process, flexion and extension. (C) & (D) Brachioradialis harvest with demonstration of dissected vascular pedicle. (E) & (F) Long-term reconstructive result.

Fig. 5. Intercostal artery pedicled perforator flap. (A) Elbow flexion and forearm scar contractures. (B) Elbow and forearm wound after debridement and Z-plasty. (C) Flap design and elevation. (D) Flap inset. (E) Long-term result.

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