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Case Report

Free Functional Muscle Transfer and One Bone Forearm for Upper-Extremity Limb Salvage After High-Energy Ballistic Trauma

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Upper-extremity limb salvage following high-energy trauma poses unique challenges of massive soft tissue injury in the setting of large bone defects, traumatic segmental neurovascular injuries, and functional deficits. These complex injuries require multidisciplinary care to achieve requisite revascularization, bone stabilization, and preservation of remaining options for soft tissue coverage. This case presents a 45-year-old man who sustained a high-velocity gunshot resulting in a dysvascular limb. Through shared decision-making, upper-extremity limb salvage was pursued. Successful initial limb salvage included a reversed great saphenous vein graft from the brachial artery to the radial artery, followed by one bone forearm with nonvascularized graft from the ipsilateral distal ulna, latissimus dorsi free functioning muscle transfer with an end-to-side anastomosis to the brachial artery proximal to the vein graft, and coaptation of the anterior interosseous donor nerve from the proximal median nerve stump to the thoracodorsal recipient nerve.

Management of upper-extremity high-energy trauma and blast injuries has evolved during military conflict; however, the overall pattern of blast injuries in civilian trauma involving upper extremity (30%) is similar in proportion and severity compared with the military population.[1] A contemporary review of high-energy wartime upper-extremity vascular injuries determined that 25% of the injuries were caused by high-velocity gunshots, with 61% and 54% associated with fractures and nerve injuries, respectively, and an acute limb loss rate of 12%.[2] When large bony defects are accompanied by massive soft tissue loss necessitating flap coverage, a one bone forearm reconstruction provides a simple solution to the bone defect without the need for a vascularized bone graft. The two most described techniques for osseous bridging in the one bone forearm include a radioulnar synostosis through articulation of the distal and proximal radioulnar joints and translocation of the distal radius to the proximal ulna, forming one contiguous forearm bone.[3]

We present a rare case of successful creation of a one bone forearm with nonvascularized graft from the ipsilateral distal ulna and latissimus free functional muscle transfer (FFMT) after high-energy trauma due to high-velocity gunshot during a mass casualty shooting.

Case Report

A 45-year-old, right hand–dominant man presented after sustaining a high-velocity gunshot to the left volar forearm during a mass casualty shooting. He sustained large cavitary soft tissue, muscle, and nerve defects to the volar forearm (Fig. 1A, B), with diffuse sensory loss to the hand and dysvascular limb with no dopplerable signal distal to the elbow. Injury films demonstrated comminuted proximal ulna and radius shaft fractures with 8 cm of bone loss (Fig. 1C). He was immediately taken to the operating room for exploration, revascularization, and temporary fracture stabilization. Intraoperatively, segmental transection of the radial and ulnar arteries was found just distal to the

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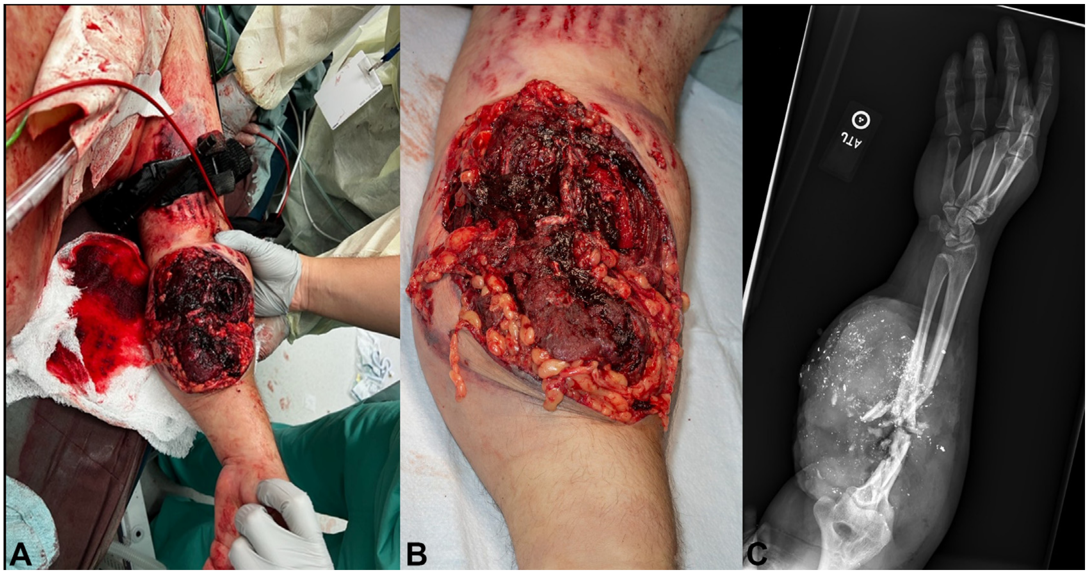

Figure 1. Clinical photographs of left volar forearm after high-velocity gunshot injury on **A** initial evaluation in the emergency department with tourniquet in place and **B** subsequent evaluation after tourniquet letdown in the operating room, along with **C** initial injury anteroposterior radiograph of left forearm, demonstrating proximal radius and ulna shaft fractures with notable comminution and segmental bone loss.

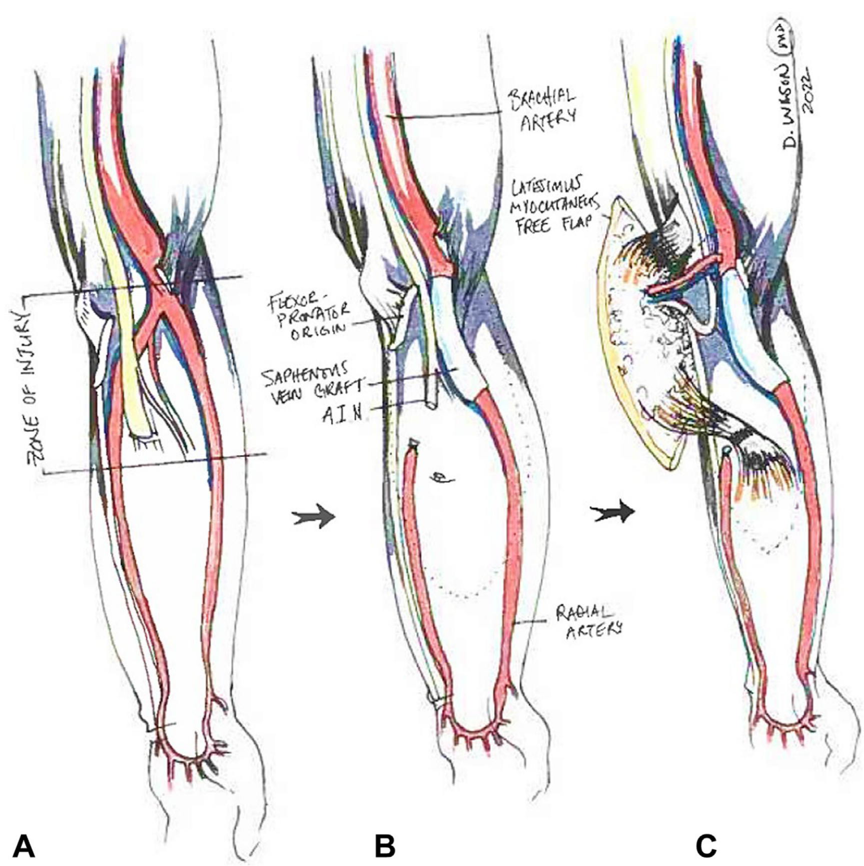

Figure 2. Illustration of the **A** zone of initial high-velocity gunshot injury to the volar forearm, including **B** the RGSV between the brachial artery and radial artery and the level of anterior interosseous nerve injury just distal to its origin from the median nerve and **C** the latissimus FFMT with arterial anastomosis just proximal to the RGSV and neurotization along with side-to-side flexor tendon repair combined into a single tendon insertion of the latissimus with the flexor pronator mass.

bifurcation from the brachial artery at the zone of injury (Fig. 2A). Revascularization was performed from the brachial to radial artery using a reversed great saphenous vein (RGSV) graft (Fig. 2B). There was a 10 cm segmental loss of the median nerve in the forearm, and the ulnar nerve was in continuity with substantial contusion throughout the volar forearm. The superficial and deep

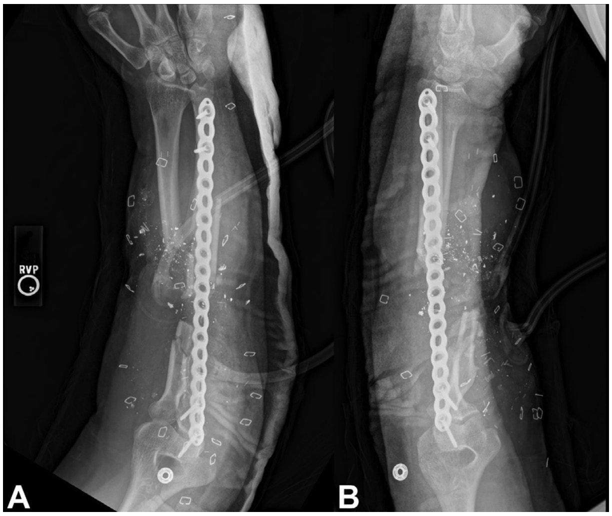

Figure 3. Immediate postoperative **A** anteroposterior and **B** lateral radiographs after acute operative stabilization, demonstrating provisional internal fixation of the ulna using a bridge plate construct.

volar forearm compartment musculature had extensive muscle loss spanning the myotendinous junctions, most of which was debrided at the index operation. After revascularization, he underwent provisional internal fixation of the ulna with a bridge plate construct for bony stabilization and protection of the vascular repair (Fig. 3) and fasciotomies.

After shared decision-making, the patient desired limb salvage with one bone forearm with the understanding that he would lose the ability to pronosupinate after being fixed in forearm pronation. He underwent serial debridements prior to definitive stabilization with a one bone forearm, requiring an 8 cm nonvascularized graft from the ipsilateral distal ulna (Fig. 4). Owing to the prior radial artery revascularization from the brachial artery with RGSV and anticipation for large soft tissue flap coverage requiring anastomosis to the brachial artery, a nonvascularized bone graft was preferred over a vascularized graft because there was not enough real estate to the recipient for an additional vascularized graft. A 15-hole olecranon plate (Acumed LLC) was used for proximal fixation of the distal ulna segmental graft to the proximal ulna, and a 6-hole 3.5 mm straight forearm plate (Acumed LLC) was placed perpendicularly to span the proximal and distal ends of the segmental graft, with the forearm fixed in 50° of pronation, which has been shown to be optimal for activities—such as fine motor, writing, pinch, and grasp—imperative to preserve for the patient's occupation as a teacher.[4]

Subsequently, we chose to proceed with latissimus FFMT for coverage of a 21 × 12 cm defect over the volar forearm (Fig. 5) using shared decision-making owing to a large soft tissue defect of over 20 cm in length along with the need for a long pedicle for anastomosis proximal to the prior RGSV graft and the major functional defects of elbow and finger flexion. The contralateral latissimus was harvested with the patient in the relaxed lateral position while the recipient site was prepared (Fig. 6). The thoracodorsal nerve was preserved for neurotization to the FFMT. Arterial microvascular anastomosis was performed in an end-to-side fashion, from the harvested thoracodorsal artery to the brachial artery (Fig. 7) proximal to the site of the prior RGSV graft. Two venous anastomoses were performed, from the associated venae comitantes, alongside the thoracodorsal artery. The neurotization of the latissimus FFMT was performed with coaptation of the anterior interosseous nerve donor, from the proximal median nerve stump to the thoracodorsal

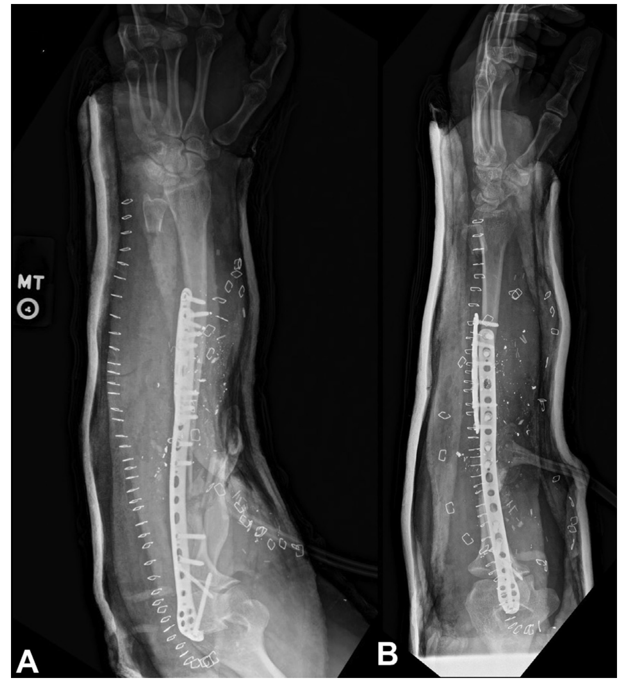

Figure 4. Immediate postoperative **A** anteroposterior and **B** lateral radiographs after definitive bony stabilization with one bone forearm using an 8 cm graft from the distal ulna and perpendicular plating of a 15-hole olecranon plate and 3.5 mm 6-hole straight forearm plate in 50° of pronation.

recipient nerve just proximal to its entry into the latissimus (Fig. 8). The remaining stump of the anterior interosseous nerve (Fig. 2B) was selected for neurotization on the basis of the proximity of the nerve within the zone of injury, requiring coverage as well as the synergy and intuition it provides for the desired function of finger flexion. The median nerve 12 cm segmental defect was reconstructed with a 6 mm diameter nerve allograft (Axogen Corporation). The flexor digitorum profundus of index, middle, ring, and small fingers and flexor pollicis longus tendons were combined into a single tendon insertion by side-to-side repair with the fingers in full extension to ensure symmetric tensioning of the tendon transfer. The FFMT was secured by sewing its musculotendinous insertion into the flexor pronator mass at the medial epicondyle and performing musculotendinous repair distally to the combined flexor tendons with the digits resting in an anatomic cascade of flexion with the wrist in neutral (Fig. 2C). The donor site was closed primarily, and he underwent uncomplicated split thickness skin graft to the exposed muscle of the volar forearm a week later (Fig. 9).

After surgery, the FFMT and skin graft healed without complication (Fig. 10), with evidence of ongoing osseous integration on postoperative films at the 12-month visit (Fig. 11). Eleven months after surgery, he underwent extensor tendon tenolysis and capsulotomy at the metacarpal phalangeal joints for contracture owing to imbalance of flexor and extensor tendons. He had pain-free, full flexion and extension of the elbow from 0–120° arc of motion and preserved active wrist extension to 60° (Video 1). His digit range of motion is documented in Table. There is visible activation of his FFMT to provide thumb interphalangeal joint flexion and index, middle, ring, and small finger flexion against some resistance with grade 4 strength (Video 2). In addition, he had recovery of ulnar nerve function but persistent absent median nerve function, which is unlikely to recover owing to a 10 cm defect, requiring allograft.

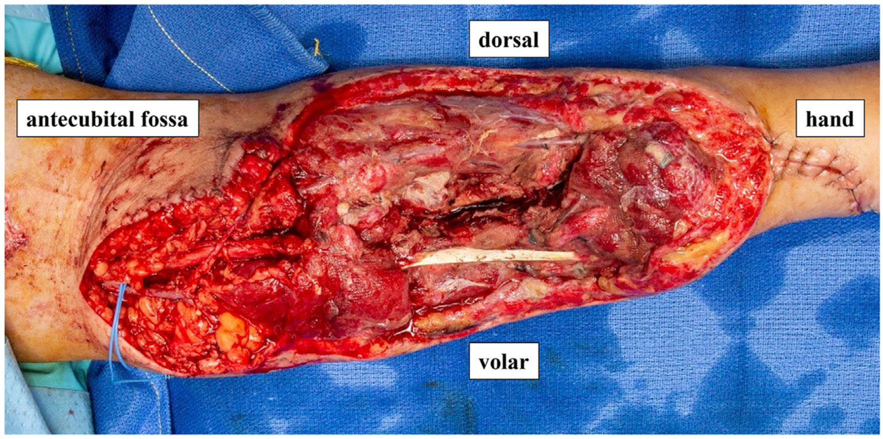

Figure 5. Interim intraoperative photograph prior to final debridement of the soft tissue defect of the volar forearm prior to FFMT in the setting of limb salvage.

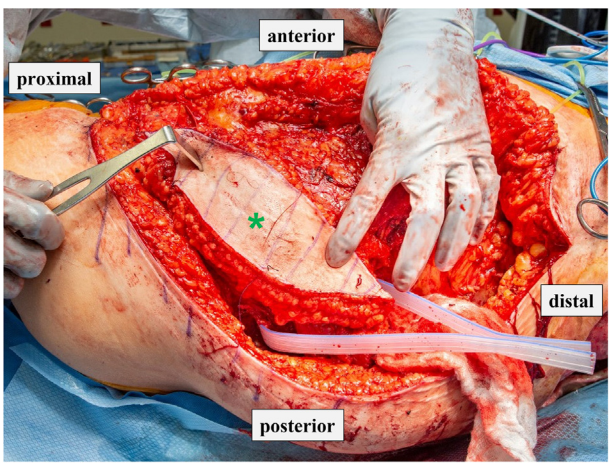

Figure 6. Intraoperative clinical photograph of the contralateral latissimus dorsi donor site harvest in the relaxed lateral decubitus position, illustrating the FFMT skin paddle (green asterisk).

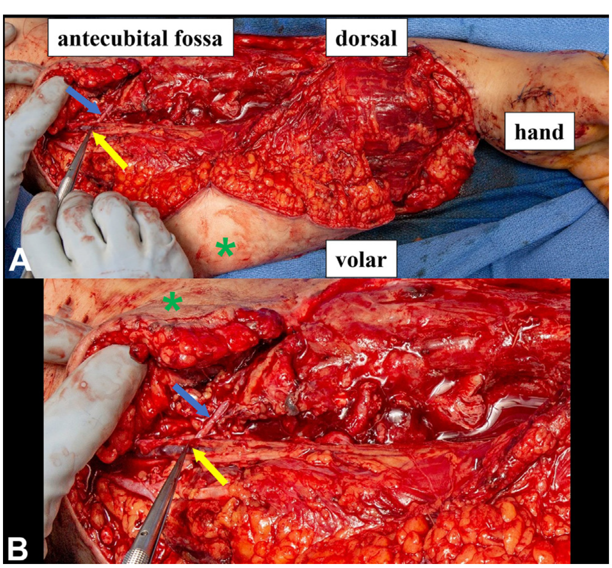

Figure 7. Intraoperative clinical photographs of **A** the FFMT skin paddle (green asterisk) at the recipient site and further identifying **B** the microvascular arterial anastomosis at the site between the thoracodorsal artery (blue arrow) to the brachial artery (yellow arrow) in an end-to-side fashion along with a vena comitantes just proximal to the prior RGSV graft.

Figure 8. Intraoperative clinical photograph of the thoracodorsal nerve (red vessel loop) at the donor site that was preserved for neurotization to the FFMT.

Discussion

We present a rare case highlighting a viable option for upper-extremity limb salvage with one bone forearm and latissimus FFMT after forearm high-energy ballistic trauma with massive volumetric muscle loss. Despite advancements in upper-extremity prosthetics, overall patient satisfaction is higher in patients undergoing limb salvage compared with prosthesis fitting and training after amputation.[5,6] Therefore, limb salvage is aggressively pursued in the upper extremity with the primary goal to preserve or restore elbow flexion, finger flexion, and finger extension.[7]

There are several challenging reconstructive principles in the setting of high-velocity gunshots and blast injuries to the upper extremity. First and foremost, bony stabilization must be achieved prior to soft tissue reconstruction. As illustrated in this case, one bone forearm reconstruction is useful in the acute setting with segmental bone loss and high comminution. Devendra et al[8] reported the largest case series of one bone forearm reconstruction with segmental bone loss due to traumatic injuries, noting immediate stabilization of the proximal ulna to the distal radius as the preferred fixation method. Fourteen of 16 patients achieved osseous union with a mean of 7.3 months to union. In the acute injury cohort, 13 of 16 patients returned to some level of work with near normal sensation and grade 3/4 muscle strength. Second, arterial anastomosis from the FFMT must be performed proximal to the site of injury. In this case, an anastomosis was performed from the brachial artery proximal to the RGSV graft,

Figure 9. Intraoperative clinical photograph after completion of split thickness skin grafting to the remaining volar forearm soft tissue defect after successful FFMT.

Figure 10. Clinical photographs of the volar forearm 8 months after surgery, demonstrating healed **A** latissimus FFMT and **B** split thickness skin graft site.

Figure 11. Six-month postoperative **A** anteroposterior and **B** lateral radiographs after creation of one bone forearm with 8 cm nonvascularized bone graft, demonstrating early osseous integration and no evidence of hardware complication.

which required a lengthy pedicle and an end-to-side anastomosis. This circumstance made for a high-risk anastomosis because a failed arterial anastomosis could not only lead to flap failure but also compromise the vascularity of the entire limb.

In the setting of near-complete loss of the volar forearm muscle mass with a large segmental defect of the median nerve, a latissimus FFMT is the preferred workhorse for large volumetric muscle coverage and restoration of elbow and finger flexion by coaptation of anterior interosseous nerve to the thoracodorsal nerve and also attaching the latissimus to the flexor pronator mass proximally and the flexor tendons distally.[7,9] Kawamura et al[10] found that all patients undergoing latissimus FFMT for elbow function achieved muscle strength of at least resistance to gravity, with the majority of patients achieving a muscle strength grade of 4.

Despite the severity of bone, nerve, muscle, and soft tissue damage in the setting of forearm high-velocity gunshot and blast injuries, this case example demonstrates that reasonable functional outcomes can be obtained after FFMT and nonvascularized bone graft with the creation of a one bone forearm, which offers a viable limb salvage option with enhanced functional ability, appearance, and overall patient satisfaction compared with transhumeral amputation.

Table

Digit Active and Passive Range of Motion 12-Months After One Bone Forearm and Latissimus Free Functional Muscle Transfer for the Treatment of High-Energy Trauma of the Forearm

Digit	MCP joint		PIP joint/IP joint		DIP joint	
	AROM (∘)	PROM (∘)	AROM (∘)	PROM (∘)	AROM (∘)	PROM (∘)
Thumb	10	45	0 (IP joint)	20 (IP joint)	—	—
Index	20	50	30	70	40	50
Middle	25	50	40	70	30	50
Ring	25	40	45	55	30	60
Small	20	45	30	60	40	60

AROM, active range of motion; DIP, distal interphalangeal; IP, interphalangeal; MCP, metacarpophalangeal; PIP, proximal interphalangeal; PROM, passive range of motion.

Statement of Informed Consent

The patient provided informed consent for images and other clinical information related to the case to be used for educational and publication purposes.

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