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# Management of Complex Upper Extremity Trauma with Associated Vascular Injury

Ravi K. Mahajan[1] Krishnan Srinivasan[1] Adish Jain[1] Abhishek Bhamre[1] Udit Narayan[1] Manish Sharma[1]

[1] Department of Plastic and Reconstructive Surgery, Amandeep Hospital, Amritsar, Punjab, India

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**Address for correspondence** Krishnan Srinivasan, DNB, Consultant Plastic Surgeon, Amandeep Hospital and Clinics, GT Road, Model Town, Amritsar, Punjab, 143001, India (e-mail: s.drkrish@gmail.com).

## Abstract

**Introduction** Combined soft tissue and vascular injuries of the upper extremity pose several challenges at once to the plastic surgeon. Many decisions have to be taken urgently that will influence the salvage or amputation of the affected extremity. The aim of this article was to provide an evidence-based outline for the management of such injuries. Learning objectives of this article are as follows: (1) approach to a patient with upper extremity composite tissue and vascular injury presenting to the emergency, (2) decision-making as to when to salvage and when to go for amputation of the traumatized upper extremity, (3) role of imaging in emergency situation, (4) role of fasciotomy, (5) intraoperative sequencing of steps, and (6) options for vascular reconstruction and the flaps used for coverage. After reading this article, the reader should have a clear understanding of the management of vascular injury in a patient with composite defects of upper extremity.

**Keywords**
- upper extremity trauma
- vascular injury
- flow-through flap
- free flap
- complex upper extremity trauma

## Introduction

Complex upper extremity trauma with vascular injury can be managed either with two-stage surgery involving initial vascular repair followed by soft tissue cover or simultaneous soft tissue and vascular repair. This article intends to provide the reader with a comprehensive management plan for patients presenting to the emergency with extensive soft tissue and vascular injury of the upper extremity.

## Emergency Management

Advanced trauma life support protocol needs to be followed for every trauma patient presenting to the emergency.[1]

A quick history focusing on the time since injury, mode of injury, and comorbidities has to be taken.

Any active bleeding should be controlled with direct pressure.[2] If direct pressure is not possible, a tourniquet can be used.[3] If that is not possible due to the location of injury, a vascular clamp should be used. Only when all the above fail, the vessel should be ligated. Radiological investigations to look for fractures of the involved limb one joint above and below the injury are performed.[4]

## Local Examination

Examination of the involved extremity includes examination of the condition of exposed muscles and identification of cut structures, if possible and assessment of distal vascularity, sensation, and movement. The distal part should be examined for the development of compartment syndrome. Assessment of vascularity of hand[5] is done by feeling the pulses, checking for oxygen saturation in the fingers,[6,7] and checking for bleeding on pinprick. On pinprick, bleed should be brisk and bright red. Skin vascularity may be preserved through collaterals even if the underlying muscles are ischemic.

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**Table 1** Clinical signs for the prediction of an arterial extremity injury

| *"Hard signs"* | *"Soft signs"* |
|---|---|
| Active or pulsatile hemorrhage | Asymmetric extremity blood pressures |
| Pulsatile or expanding hematoma | Stable and non-pulsatile hematoma |
| Clinical signs of limb ischemia | Proximity of wound to a major vessel |
| Diminished or absent pulses | Peripheral neurological deficit |
| Bruit or thrill, suggesting arterio-venous-fistula | Presence of shock/hypotension |

Audible impulse on handheld Doppler does not rule out major vascular injury.[5] Hence, in cases of known vascular injury with the absent palpable distal pulse, it is best to explore the patient immediately.

## Role of Imaging

In situations where hard signs[8] of vascular injury are present (►**Table 1**) and the location of vascular injury is known, there is no role for computerized tomography (CT) angiography.[8–10] In multi-level injury when the site of vascular injury cannot be discerned clinically, CT angiography can be done.[11,12]

## Contraindications for Revascularization[13]

- Concomitant life-threatening injuries—head injury, intra-abdominal, or chest injuries needing urgent care.
- Patient is in a state of hemorrhagic shock and needs inotropic support.
- Extensive structural damage to the hand in the form of crushing.

### Surgical Management

In the past 10 years, there were 317 patients who presented with complex upper extremity injury out of which 71 underwent primary amputation due to the severity of injury and prolonged ischemia time. Remaining 246 patients underwent reconstruction with free flap among which vascular compromise was seen in 41 patients. Two of these patients underwent flow-through radial artery flap, and the remaining were managed with vein grafting followed by free flaps/pedicled latissimus dorsi (LD) flap. Five of them underwent pedicled LD flap. Among the free flaps, seven LD + serratus anterior (SA) flaps were used, and remaining were anterolateral thigh (ALT) free flaps. Transient intravascular shunts (TIVS) were used in 60% of these patients. Secondary amputation was required in one patient in whom pedicled LD was used due to secondary infection and resultant blow out of the repaired brachial artery. One patient who had ALT free flap reconstruction died due to cardiac event. Partial flap loss was seen in 5% of the patients, which was managed with initial vacuum-assisted closure therapy followed by regional flaps. Eighteen percent of the patients had long-term cold intolerance. Seventy-three percent of the patients needed the change of occupation following the successful reconstruction as they were manual laborers.

In the management of such patients, broad-spectrum antibiotics have to be started at the earliest.[14,15]

### Anesthesia

It is preferable to perform these surgeries under regional anesthesia as far as possible. It has the advantages of postoperative analgesia, good muscle relaxation during surgery, decreased opioid requirements, greater hemodynamic stability, and less nausea postoperatively.[16] It also has the added advantage of providing vasodilatation that could be useful in vascular reconstructions.[17] It requires well-trained anesthetists in regional blocks.

In case vein graft needs to be harvested, it can be done under local anesthesia or, if need be, spinal anesthesia.

►**Fig. 1** summarizes the approach to a vascular injury to upper extremity.

## Fasciotomy and Use of TIVS

It is the author's practice to do distal fasciotomy in all major vascular injury cases as the first step, irrespective of the presence or absence of compartment syndrome at presentation. This helps in assessing the condition of the muscles before and after revascularization and acts as prophylaxis against compartment syndrome developing after revascularization.[18] The problems that can happen with missed compartment syndrome are much worse than that of a negative fasciotomy.[10,13,19]

Ischemia time may be less than the conventionally thought 6 hours.[20–22] In cases where the time since injury is 3 to 6 hours and direct repair of the artery is not possible, a TIVS (vascular conduit) is first placed and the condition of muscles is assessed.[8,12,23] If the muscle continues to remain dusky after placing conduit, there is a high chance of the patient going in for reperfusion syndrome. In such cases, a primary amputation is done.

After placing the shunt, if the condition of muscles improves and systemic signs remain stable, then the limb is perfused for half hour, and then, under tourniquet control, debridement and repair of other structures and bone fixation are done. Following this, a definite vascular repair using vein graft is done.

TIVS is not kept for more than 6 hours[19] as the chance of blockage is high. Although its use up to 24 hours without thrombosis has been reported,[24]it should be limited to absolute minimum duration required.

### Author's Method of Placing the Shunt

After performing a proximal and distal embolectomy using a Fogarty catheter, an appropriately sized infant feeding tube is selected and passed into the cut ends of the vessel (►**Fig. 2**). It has to be passed approximately 1 to 1.5 cm into the vessel and secured in place using 3/0 silk sutures tied around. There should be no kink in the conduit. Conduit is flushed with heparinized solution (the author uses a high-

 

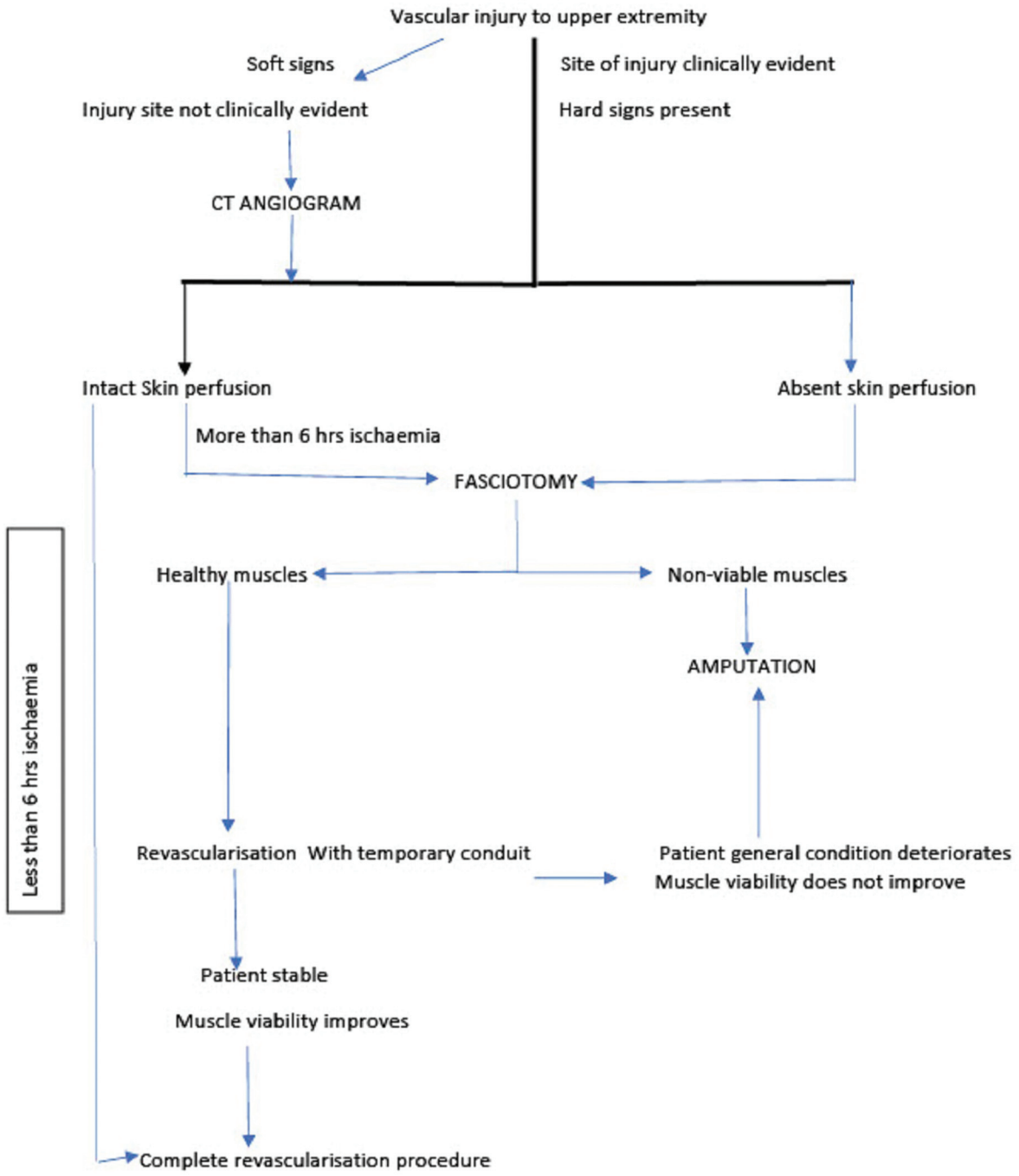


**Fig. 1** Algorithm for emergency management of vascular injuries of upper extremity.

concentration solution of 100 units/mL of unfractionated heparin).

### Advantages

The use of TIVs has the following two advantages.

- It helps in assessing patient response to revascularization and can help in making a decision of limb salvage versus amputation.
- It reduces ischemia time and, hence, improves the chance of limb salvage. Various recent studies have proven the value of shunts in reducing amputation rates by reducing the ischemia time.[25–29]

### Problems with Shunt

### There are two problems with shunts.

- Need for the extra length of vein graft—it is preferable to excise the portion of the vessel till which the shunt had been passed. This increases the length of vein graft needed.

 

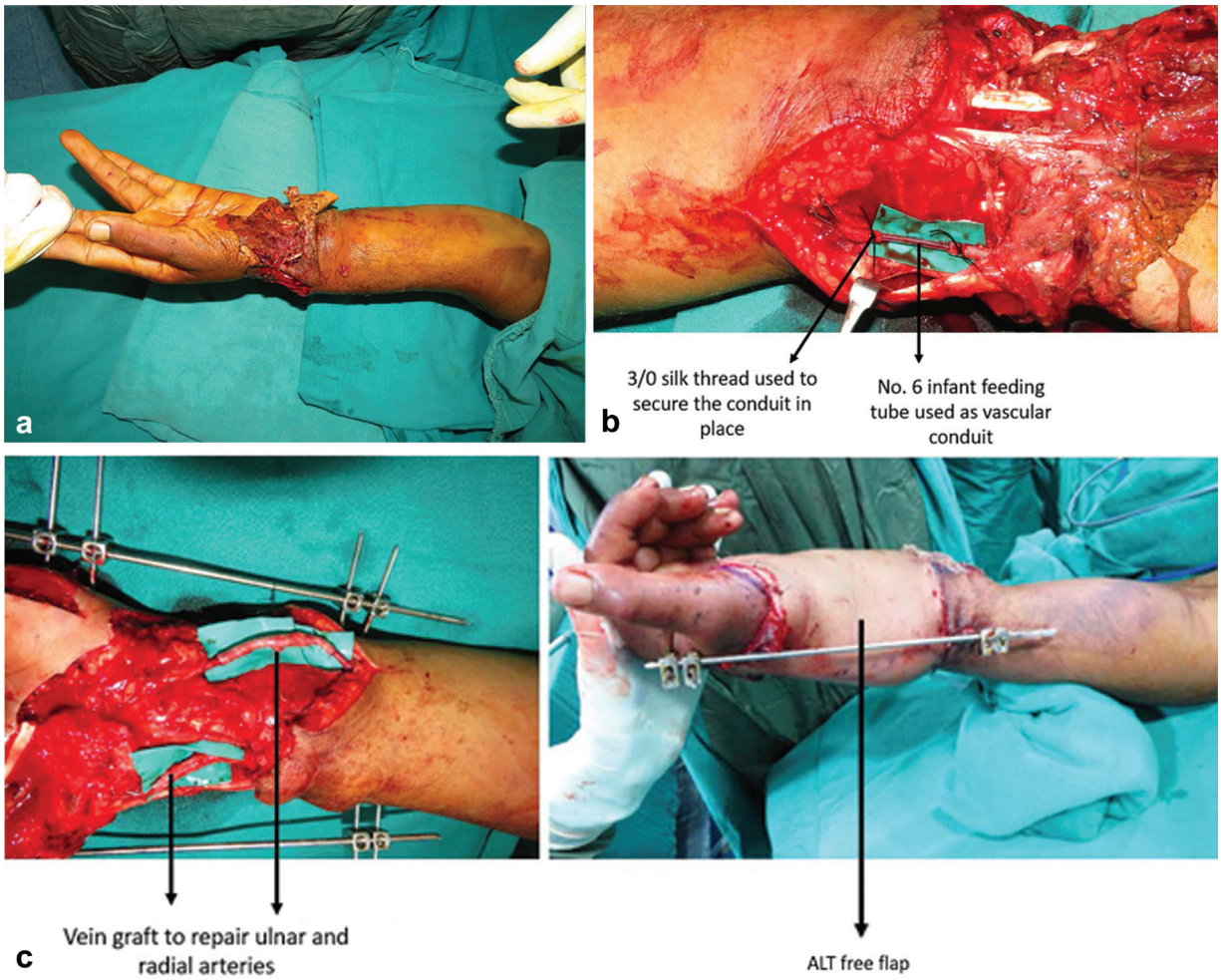


**Fig. 2** Placement of vascular conduit. (**a**) Crushed contaminated hand at presentation with radial and ulnar artery injuries. (**b**) Placement of vascular conduit (no. 6 infant feeding tube) into the ulnar artery. The conduit has to be measured to go not beyond 1.5 to 2 cm inside the vessel ends. There is no kinking of the conduit and it has been secured with 3/0 silk ties on both ends. (**c**) (*Left*) Vein graft has been used to repair ulnar and radial arteries and was covered with collagen dressing and (*Right*) ALT free flap done to cover the defect 12 hours after revascularization.

- Shunt slippage—shunt can slip out of the vessel and cause primary hemorrhage.

## Debridement

Debridement of the wound is the most crucial step to ensure primary wound healing and bony union after any sort of reconstructive procedure.[30] Inadequately debrided wounds often result in infection, thrombosis of the grafted, or repaired artery and also life-threatening blowouts of the vessels.

A sterile tourniquet is then applied as high up in the arm as possible and inflated. Debridement is performed under tourniquet control to minimize further bleeding and to clearly see the devitalized structures.[5,31,32] In cases of avulsion injury, the distal muscles do not survive and have to be debrided leaving behind only the tendons.[32] A special case has to be made of biceps brachii. The arterial supply is maximal in the middle of the upper arm just distal to the greater tubercle.[33] Hence, even in case of sharp injuries, the distal biceps may not survive and is best debrided leaving behind only the tendon.

Once debridement is completed, tourniquet is deflated and the arterial conduit is reopened. Hemostasis is achieved and bone fixation is then done by the orthopaedic team. It is the author's practice to do bone fixation prior to definitive arterial repair, as there is the risk of the anastomosis being disrupted during bone fixation. During the time bone is fixed, the conduit maintains perfusion to the tissues. Vein graft, if required, can be harvested simultaneously. Alternately, some authors have recommended doing the arterial repair first followed by bone fixation.[34,35]

## Osteosynthesis

In contaminated wounds, high-grade soft tissue injury, and unstable patients, it is best to go for external fixation for bone stabilization.[12,15,36,37] Definitive fixation can be performed when the flap cover is settled. This is generally achieved in 2 to 3 months' time. The fixator is removed and orthosis is applied for 2 weeks. Then, definitive fixation is done.[18,38]

In non-contaminated wounds with less severe soft tissue injury and relatively more stable patients, it's the author's practice to go for definitive fixation in the form of nailing or plating.[12,37] Nailing has the advantage of not having to strip the periosteum of the already-traumatized bone, in contrast

 

to plating. Plating is done only in cases where immediate flap cover can be provided.[4]

Prior to fixation, adequate bone shortening must be done to ensure healthy soft tissue covers the wound and also to facilitate the primary repair of vessels and nerves.[5] Bone shortening of up to 5 cm in humerus and 4 cm in forearm can be done.[5,39]

Definitive types of wound cover are:

- Flow-through flaps
- Vein graft with flap cover

### Surgical Options for Bone Loss

- primary free fibula osteo-cutaneous flow-through flap using peroneal vessels and
- vein graft and flap cover followed after few months by free fibula flap or distraction osteogenesis.

### Flow-Through Flaps[40–42]

Commonly used flaps for this purpose are ALT flap, anteromedial thigh flap, radial artery forearm flap, and LD muscle flap (►**Fig. 3**).[43–45] The free fibula can also be used as flow-through flap using the distal part of peroneal artery as a flow-through segment.

Flow-through flaps can only be used if two teams of experienced plastic surgeons are available, and patient's general condition permits prolonged surgery.

### Vein Graft with Flap Cover

This is the author's preferred method of reconstruction in soft tissue injury of upper extremity with vascular compromise. The reasons are given as follows.

- There is freedom to bridge any length of the arterial gap.
- Multiple vein grafts to reconstruct multiple vessels may be used.
- Appropriate size-matched graft harvest is possible.
- It provides faster revascularization than a flow-through flap and has lesser blood loss.
- Two teams are not required.

In most cases, debridement of the wound followed by vein graft is done. It is best to do a definitive flap cover immediately. If that is not possible, the vein graft may be covered temporarily by a collagen sheet or split skin graft. It is best not to delay flap coverage in such cases for more than 12 hours.

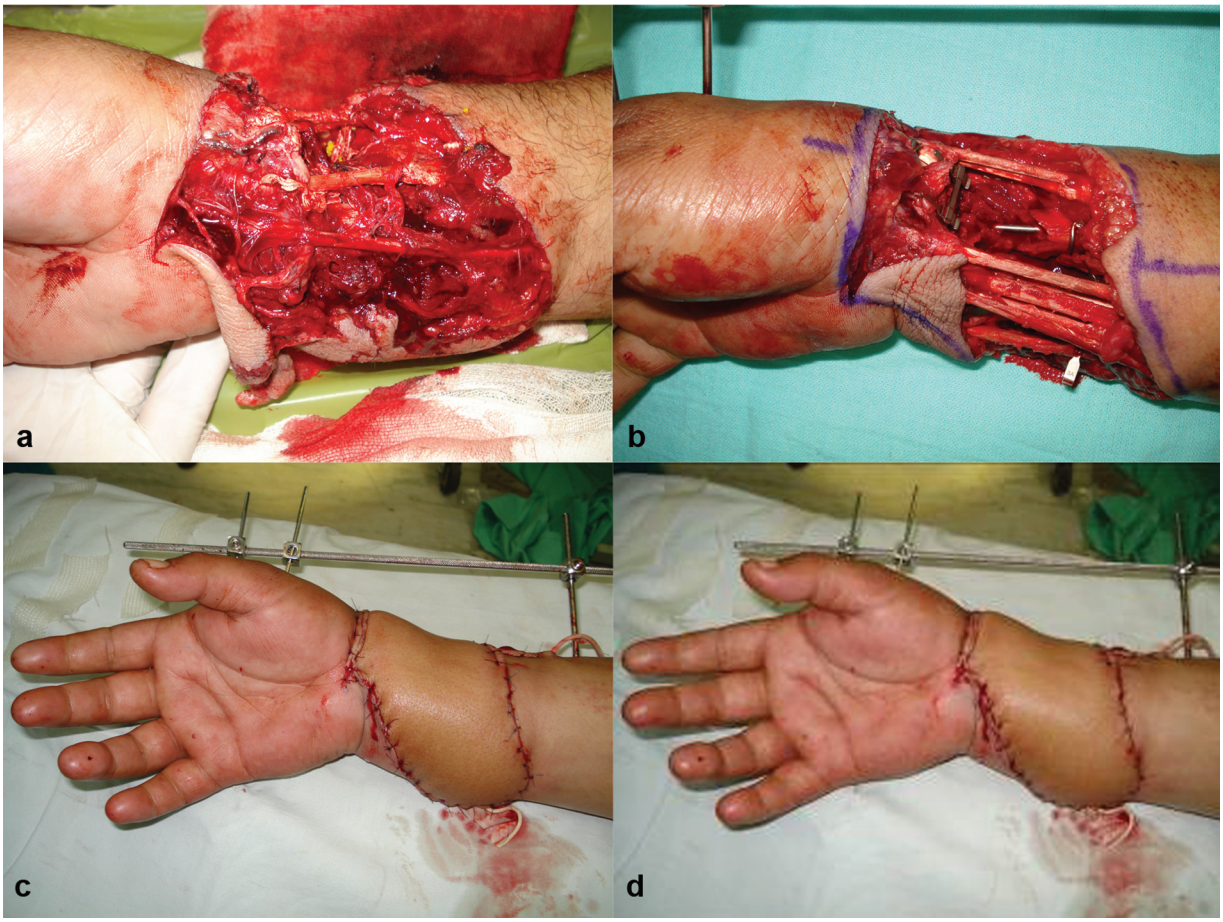


**Fig. 3** Radial artery forearm flow-through flap for lower forearm vascular injury. (**a**) Wound at presentation to the emergency cut radial and ulnar arteries. (**b**) Wound after debridement. (**c**) Radial artery forearm flap harvested with flow through segment. (**d**) RAFF flow through done to radial artery. (This patient had vein graft for ulnar artery reconstruction, tendon graft for FCR using fascia lata, graft for distal radius reconstruction, and nerve graft for median nerve reconstruction, illustrating the all-in-one stage surgery).

 

The use of acellular dermal matrix has also been described to provide temporary cover and prevent wound desiccation,[46] but cost is the major limitation for this in the Indian scenario.

Most commonly used graft is the great saphenous vein. Important points when using vein grafts are as follows:

- Wound bed should be healthy.
- Length of vein graft does not have a significant impact on the patency as long as the wound bed is absolutely healthy.[47] Only in cases where the length exceeds 40 cm, some impedance in outflow causing late graft failure has been observed.[48,49]
- The vein graft tends to dilate and expand once the flow is restored. Hence, it is important to anastomose the graft in a mild stretch.[47] Other way is to do the proximal anastomosis first and let the vein dilate by restoring flow and then doing the distal anastomosis.

In cases where the wound is chronic or the bed consists of bone/fascial structures, a "sandwich" technique of placing vein/nerve grafts can be done. When using the ALT flap, part of vastus can be taken like a chimeric flap and placed to cover the deep defect. The vein graft is positioned to run on the vastus flap and on the top of the graft the fascio-cutaneous part of ALT placed (►**Fig. 4**).

In forearm injuries, both the arteries may be repaired with a vein graft. Repair of major veins helps by reducing post-operative edema and helps maintain the arterial repair patency.[35,50]

**Table 2** Intra-operative sequencing

| |
|---|
| 1. Vascular conduit placement (for 15–30 min) |
| 2. Apply and inflate sterile tourniquet |
| 3. Radical debridement |
| 4. Appropriate bone shortening and skeletal fixation |
| 5. Tendon/muscle repair (if deeper to the vessels) |
| 6. Release tourniquet (maximum tourniquet time in one stretch—90 min, to be followed by 15 min period of release before re-inflating, if needed) |
| 7. Definitive vascular repair (vein graft) |
| 8. Temporary cover (split skin graft or collagen) |
| 9. Flap cover within 12 h |

►**Table 2** gives the intraoperative sequence followed by the author options for soft tissue cover.

## Flap Choice

The choice of flap depends on the location of defect, size of defect, the structures involved, the presence or absence of wound cavity, and also on the surgeon's preference.

- Forearm defect
  - Free ALT
  - Free LD
  - Medial sural artery perforator (MSAP) and superficial circumflex iliac artery perforator (SCIP) flaps

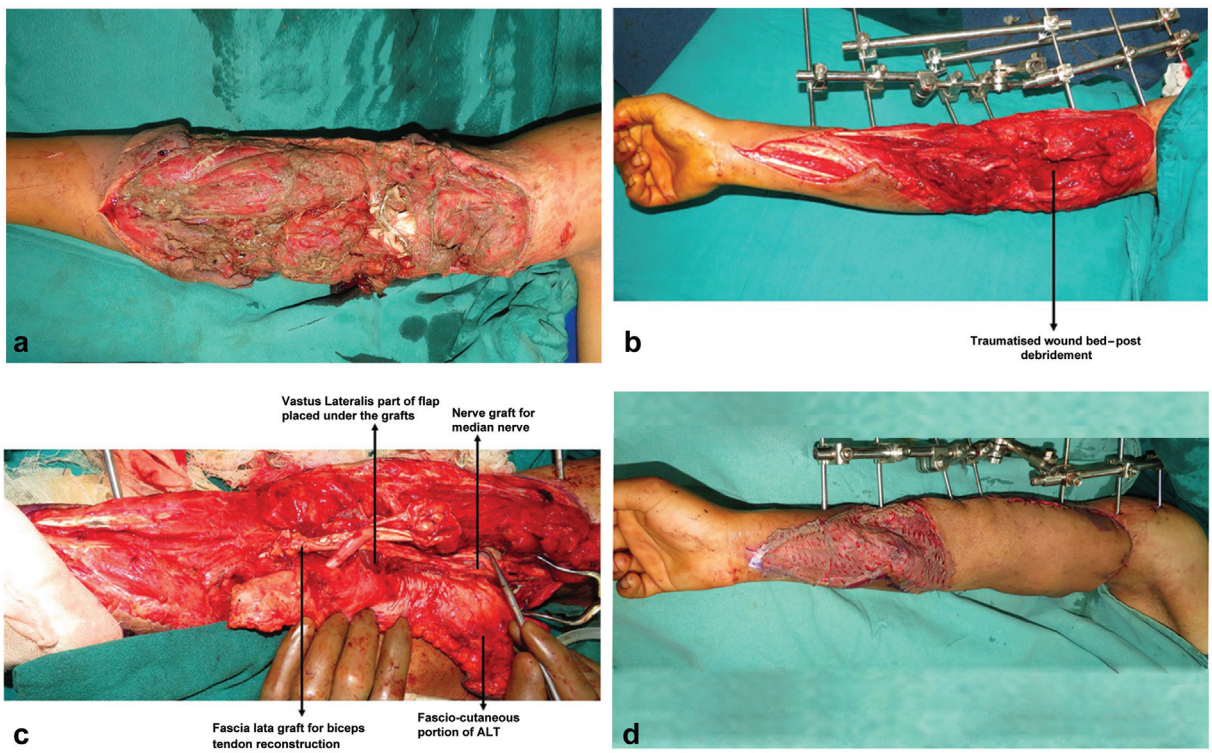


**Fig. 4** Anterolateral thigh chimeric musculocutaneous flap as "sandwich" flap. (**a**) Wound in the arm at presentation with thrombosed segment of brachial artery and divided median nerve. (**b**) Wound post-debridement. (**c**) Flap inset with the vastus filling the wound cavity and forming the bed for the nerve, tendon, and vein grafts. The vein and nerve grafts placed between the muscle and fasciocutaneous segments. (**d**) Flap inset and skin graft done distally.

 

  - Abdominal flap
- Arm defects and defects around elbow
  - Pedicled LD
  - Free flaps—LD and ALT
- Abdominal/Thoracoabdominal flap.[51,52] The advantage of this flap is the ease of elevation, speed of surgery, and there is no requirement for microsurgical expertise. Disadvantages are that part of the wound will still remain exposed under the flap in the region of skin bridge where there is a chance of exposure of vessels or other vital structures and re-exploration is difficult. The donor area needs skin grafting and can be very unsightly. Providing adequate hand elevation and comfortable positioning is also not possible. It is reserved for situations where a free flap is impossible or too risky due to the general condition of the patient.
- Pedicled LD flap[52] (►**Fig. 5**). This is a very useful flap providing comprehensive coverage of large wounds and also filling up cavities in wounds of the arm till medial elbow region.[52] In certain exceptional cases where the patient has a long torso and short arms, the flap may even reach beyond the elbow. It can also be used as a functional transfer for elbow flexion in cases where the elbow flexors are injured beyond repair. This is the author's flap of choice in defects of the arm and medial elbow region. It generally does not reach the lateral elbow region. It cannot be used for forearm wounds. In proximal vascular injuries, involving the subclavian vessels, CT angiogram must be done and the patency of thoracodorsal vessels confirmed before harvesting the flap.
- Free flaps. Free flaps are the flaps of choice in the author's unit for defects involving forearm, lateral elbow region, lateral arm, and wounds of the arms where pedicled LD cannot be used.

The advantages of free flap are as follows.

- The flap can be tailored as per the requirement of the wound.
- Donor area is away from the injured recipient site.
- Positioning of the limb is more comfortable and can be done as needed unlike the pedicled distant flaps. Hence, any re-exploration of the repaired vessel, if needed, can be done easily.

Disadvantages are as follows.

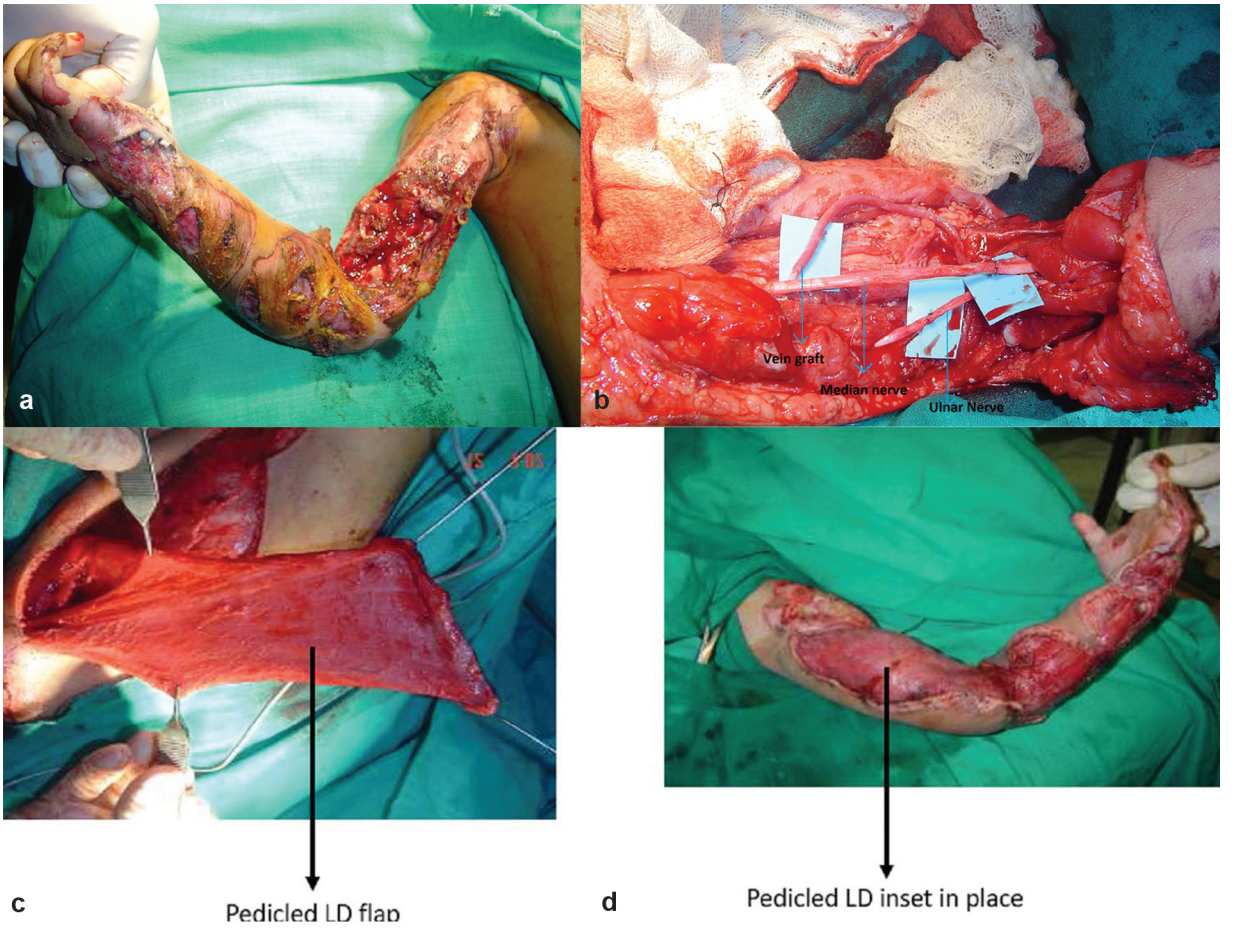


**Fig. 5** Pedicled LD flap for arm defect extending up to medial elbow in a child. (**a**) Wound at presentation with defect in the medial arm and elbow. (**b**) Wound after debridement and vein graft reconstruction of brachial artery and nerve repair median nerve. (**c**) (*left*) Pedicled LD flap harvested and (*right*) inset into the defect. (**d**) Long-term result showing good wound healing. LD, latissimus dorsi.

 

**Table 3** Flap options depending on the location of defect and the need for secondary surgery

| Location of defect | Need for secondary surgery | Flap cover |
|---|---|---|
| Arm till medial elbow | If secondary free fibula or functioning free muscle transfer is needed | Pedicled LD (if thoracodorsal artery is uninjured) |
| | If non-microsurgical secondary surgery is required | ALT free flap |
| Surface defect involving any area of forearm/arm | Yes<br>No | ALT fasciocutaneous free flap<br>1. ALT free flap<br>2. LD free flap |
| Defects with wound cavity. Wound bed not ideal for vein/nerve graft | Yes<br>No | ALT musculocutaneous sandwich flap<br>1. ALT musculocutaneous sandwich flap<br>2. LD + SA sandwich flap |
| Circumferential defects with wound cavity | Yes/no | LD / LD+ SA free flap |

Abbreviations: ALT, anterolateral thigh; LD, latissimus dorsi; SA, serratus anterior.

- There is a need for expertise in microsurgical skill.
- There is a paucity of recipient vessels later on if a functioning muscle transfer is required.

In most of the cases, anastomosis has to be done proximal to the site of vascular repair and in an end to side fashion.

The most common free flaps for upper extremity reconstruction are the ALT flap, LD muscle flap and LD, and SA chimeric flap for bigger and deeper defects. ►**Table 3** summarizes the flap options as preferred by the author.

**ALT Flap (or Other Fascio-Cutaneous Flaps)**

In upper extremity wounds, it is preferable to do fasciocutaneous flap cover as it is easier for later re-elevation in cases where secondary surgeries are required.[53,54] ALT has the advantage of providing large skin cover with long good-sized vascular pedicle. It is a very versatile flap and can be used as a chimeric flap along with part of vastus lateralis, if needed.

In obese patients, it has to be elevated in the supra-fascial plane as "super-thin ALT.".[55] This requires good preoperative imaging in the form of CT angiogram and color duplex imaging to know the exact location, course, and size of perforators.[56] Author's practice is to raise the flap suprafascially as described by Hong et al.[57] Suprafascial elevation of the flap is done between deep and superficial fat globules till approximately 3 cm around the perforator, following which dissection is deepened subfascially.

## LD Free Flap (or Other Muscle Flaps)

LD and LD + SA (►**Fig. 6**) flaps can also be used to provide coverage for upper extremity defects. Muscle flaps have the advantage of covering large area, obliterating dead space, having a long vascular pedicle, and are also easier to elevate.[53] They also lead to atrophy with time reducing the overall bulk. For circumferential defects, LD + SA free flap is especially used flap. SA when taken along with LD can be used to fill cavities, to cover an adjacent defect, and in broad proximal defects.[58] Muscle flaps have the disadvantage of difficulty in re-elevation for secondary surgeries.[53,54] Flap has to be elevated from the inset margin, and incisions in the middle of the flap are to be avoided.

Gracilis flap is useful as a functioning muscle transfer as well as to cover small defects where secondary surgery is not anticipated.

Other flaps like SCIP flap and MSAP flaps can also be used.

### Tendon and Nerve Reconstruction

In non-contaminated wounds, tendon and nerve reconstruction is best done in the same stage (►**Fig. 3**). If nerve or tendon grafts are to be used, immediate flap cover is needed. If that is not possible, then grafting should be done at the time of providing flap cover, which usually happens within 12 hours of vascular repair.

In conditions where the wound is contaminated or there is extensive crushing, it is better to do the nerve and tendon reconstruction at a later date. In such a situation, the distal and proximal ends have to be tagged with sutures and dissected away from the zone of anastomosis. Good documentation as to the location of nerve ends and tendon ends needs to be made to make secondary reconstruction easier.

## Summary

anagement of complex upper extremity trauma with associated vascular injury requires multidisciplinary approach with good planning and quick decision-making from the outset. The decision to salvage or amputate has to be made on an individual case basis and emphasis laid on early radical wound debridement. Flap cover in the form of flow-through flap or vein graft along with a pedicled or flee flap can be done based on individual case and surgeon preferences. Planning of the stages of reconstruction and rehabilitation to the endpoint of painless functional limb ideally has to be visualized right at the moment patient is seen in the emergency and taken up for first surgery.

 

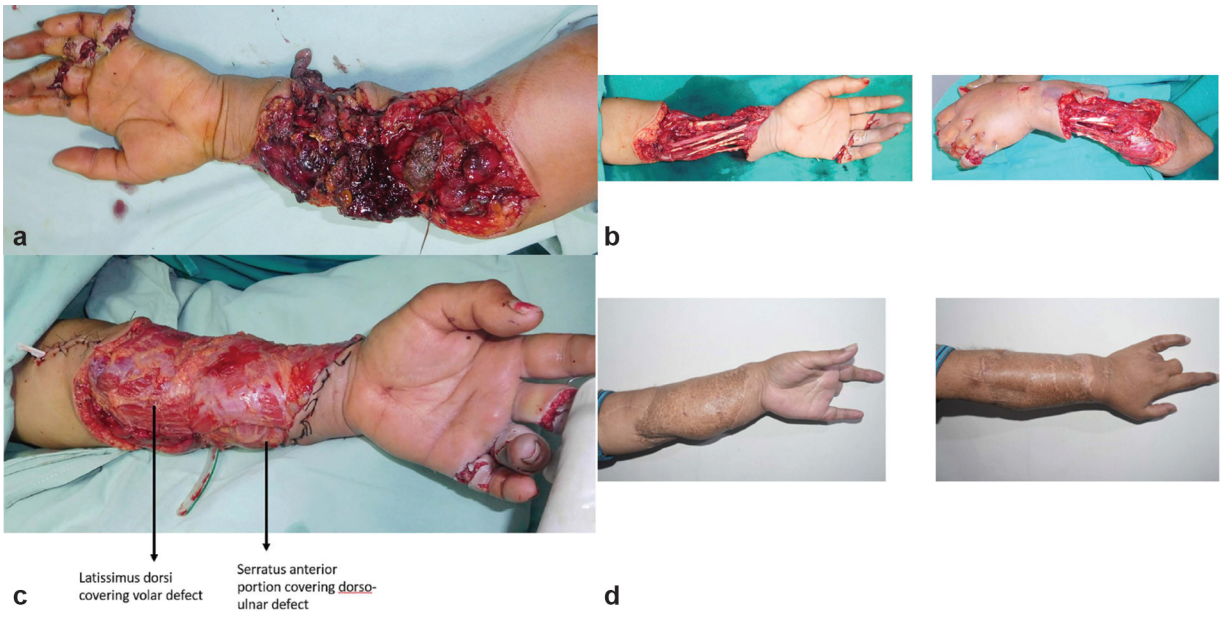


**Fig. 6** Latissimus dorsi (LD) + Serratus anterior (SA) free flap. (**a**) Circumferential defect involving distal forearm with exposed tendons and both arteries injured. (**b**) Wound post-debridement. (**c**) Vein graft for both arteries done and LD + SA flap inset. LD covering the volo, radial and SA covering the dorso, ulnar portion of the wound. (**d**) Long-term follow-up showing completely healed wounds. Two fingers were gangrenous and had to be amputated.

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Conflicts of Interest
None declared.

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