Orthplastic Extremity Trauma

E Battaloglu, F Page, K Wallis, P Fenton, D Bose
Department of Clinical Traumatology, University Hospital Birmingham, United Kingdom
Correspondence: Mr Emir Battaloglu Email: emir.battaloglu@nhs.net
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Abstract

Many challenges exist in the management of severe open fractures, which have historically tested surgeons’ ability and resourcefulness. Complications are difficult to avoid and can be serious, frequently life changing for the patient. Co-ordinated inter-specialty care provided by experienced Orthopaedic and Plastic surgeons, can improve patients’ likelihood of a successful outcome. A key factor for achieving organized care is timely and effective communication between teams to evaluate reconstructive options and generate the most appropriate definitive surgical plan. A number of key decision-making steps must be made during the patient’s initial or primary operative intervention, therefore a comprehensive understanding of the issues facing each specialty is vital. Prompt, versatile clinical considerations must be made, especially when faced with the polytrauma patient, requiring intensive care support. Ill-conceived early management decisions can significantly impact upon the definitive surgical options available. This article will aim to outline key principles in the surgical management of severe open fractures and provide guidance to facilitate combined care.

Keywords: Reconstruction, Wound Management, Open Fractures, Trauma Surgery, Plastic Surgery.

Introduction

Open fractures and traumatic wounds of the extremities represent a spectrum of injury and pose numerous clinical challenges. For patients suffering such injuries, there is the risk of deep tissue infection, poor functional status, amputation and even death. These challenges must be tackled through a multidisciplinary approach to overcome the burden of the injury, minimize mortality and morbidity and optimize functional outcome. The term “open fracture”, also referred to historically as “compound”, describes a multitude of traumatic injuries. These injuries extend from minor wounds overlying fracture of a subcutaneous bones to extensive soft tissue damage with highly complex fracture patterns.

Clinical care in the United Kingdom has recently undergone a paradigm shift following the introduction of the British Orthopaedic Association (BOA) and British Association of Plastic and Reconstructive Surgery (BAPRAS) standards for the management of lower limb open fractures. These prescriptive measures detail a comprehensive and targeted approach to dealing with the clinical and administrative dilemmas. Yet, the nationwide acceptance and adherence remains elusive, with many organizational and structural obstacles limiting compliance.

Classification

Wound classification is of principle importance for treatment planning, prognosis and research. Multiple wound classification systems have been developed, however one in particular has been widely adopted. The classification put forward by Gustilo and colleagues, described in Table 1, offers advantages of simplicity, reproducibility and effectively guiding management. Of crucial importance is the application of this classification to open fractures following the thorough debridement of the wound, for below seemingly small wounds can lie major soft tissue injury.
Yet, in trade off for these aspects, the categories are inherently broad and limit comparative analysis. The range of severity encompassed by type 3B & 3C injuries allows wide heterogeneity. Therefore, large scale analysis is difficult. OTA Open Fracture Classification Version 2 applies a greater degree of structural injury description, defining injury severity for bone, skin & soft tissues, vessels, as well as patient factors. Therefore, these are favoured for research, but are more difficult to implement on a practical level.

**Epidemiology**

Within the United Kingdom, the national burden from open fractures and severe extremity injuries is not accurately known. The recent developments in national structure for major trauma care has seen a heightened diligence in record keeping and research. The work of the Trauma Audit and Research Network (TARN) has made major advances in the understanding of the epidemiology of trauma across the nation. Yet, certain limitations exist within such an all-encompassing registry making it difficult to accurately determine features for a particular subset of patients or injuries.

Historical studies estimate the annual incidence of long bone open fractures at 11.5/100’000 population [3]. Tibial/fibular fractures comprise approximately 50% of open fractures, followed by upper limb fractures at 35% and femoral fractures at 15% [4]. Open fractures carry a range of complications associated with such injuries, including; infection, mal-union / non-union, neurovascular deficiency, functional limitation, chronic pain and amputation. The likelihood of complication increases with severity or grade of injury, as shown in Table 2 [4].

Attention is mostly directed towards leg injuries since these occur more frequently, and defects involving the tibia frequently require advanced surgical / free flap reconstruction. This is because the leg, in particular the lower third, is an area which has relatively poor soft tissue healing and is less amenable to local reconstructive options.

**Phases of Management**

**Emergency Phase**

The most vital aspect of management of the trauma patient is to diagnose and treat life-threatening injuries. When all life-threatening injuries have been treated, attention can be directed towards identification of limb threatening injuries and focused management initiated.

Aspects for open fracture management in sequence are: (1) Clinical examination to determine vascular (and neurological) status of the limb, this is of paramount importance. If vascular compromise is identified, the emergent treatment should be to obtain restoration of anatomical alignment and reassessment, followed if necessary by further investigation. (2) Removal of gross contamination is advised, but routine irrigation of wounds in not recommended [5]. (3) Clinical photography has advantages for aiding communication. (4) Wounds dressing with saline soaked gauze; the use of topical antimicrobial agents should be avoided during the emergency or surgical stabilization phases [6], in particular the use of iodine-based agents. Fibroblast growth was progressively retarded at concentrations of 0.01% and 0.025%, and totally inhibited by 0.1% and 1% povidone-iodine solutions [7]. Thus, even dilute solutions of povidone-iodine are toxic to human fibroblasts and placement of povidone-iodine in to open wounds, or prolonged contact with viable uncontaminated tissue, should be avoided [8]. (5) Application of a suitable dressing, ideally an adhesive film, to seal the wound from the environment is required, followed by limb splintage. (6) Administration of prophylactic antibiotics and anti-tetanus prophylaxis is recommended [9].

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>I</td>
<td>An open fracture with a wound &lt;1cm long and clean.</td>
</tr>
<tr>
<td>II</td>
<td>An open fracture with a laceration &gt;1cm long without extensive soft-tissue damage, flaps, or avulsions.</td>
</tr>
<tr>
<td>III</td>
<td>A Adequate soft-tissue coverage of a fractured bone despite extensive soft-tissue laceration or flaps, or high-energy trauma irrespective of the size of the wound. B Extensive soft-tissue injury loss with periosteal stripping and bone exposure. This is usually associated with massive contamination. C Open fracture associated with arterial injury requiring repair.</td>
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Table 1: Open Fracture Classifications [1,2]
Early administration of antibiotics, within 1 hour of injury, has been shown to be an independent predictor for reduction in infection risk [10]. (7) Regular assessment should be performed to exclude the presence of an evolving compartment syndrome. (8) Organization of adequate radiographic imaging, plain films or cross-sectional imaging, is crucial to planning surgical stabilization. (9) Transfer; given the resource required to manage patients with such injuries they should be transferred to the regionally designated major trauma center or facility capable of providing definitive care.

Surgical Stabilization

Primary debridement should be undertaken within 24 hours from the time of injury, unless the patient’s clinical status precludes this [5]. Delay to debridement in high grade open fractures has been associated with increased deep tissue infection at a rate of 3% per hour delay [11,12]. However, systematic review of the “six-hour rule” has not been shown to decrease infection rates following all open fractures [13] and further studies failed to demonstrate reduction of infection rates following early debridement [4,14].

There is an imperative to undertake the index procedure with a considered approach and this is to ensure that subsequent reconstructive options are not compromised. Thorough debridement should result in the excision of all devitalized tissue [5]. Saline lavage, with 3-9 litres without pressure, has been shown to be the optimal method of irrigation [15]. Exploration of wounds should be made by extending incisions to and then along fasciotomy lines. The principles of debridement should be applied to all structures, including the bone. Devitalized bone can be a prime and persistent source of contamination, therefore meticulous attention is required to ensure adequate debridement is performed.

External fixation is primarily used to provide skeletal stabilization in the presence of high-grade soft tissue injury and fixation should be established outside the zone of injury, when possible. Internal fixation should be used where adequate soft tissue coverage is immediately achievable. Therefore, fixation method is dictated by the condition of the soft tissues, not vice versa.

Immediate closure in low energy or grade III-A open fractures can be performed and is associated with a decreased rate of deep tissue infection, however careful wound selection is required to achieve successful treatment [12]. Frequently immediate closure is not achievable and the severity of the injury will require a staged approach. Negative Pressure Wound Therapy (NPWT) would be applied as the primary method for temporary wound cover. NPWT should not be used for prolonged wound management and failure to achieve definitive wound closure, or reconstruction, after longer than seven days is associated with increased deep infection [16]. If deemed appropriate, initial skeletal stabilization may form part of the definitive reconstruction.

Limb Salvage versus Amputation

Although many complications are recognized following such devastating injuries, the most frequently encountered include: mal-union, non-union, multiple surgical procedures, graft or flap failure, chronic pain and non-functional limbs [2]. Infection is potentially the most significant complication and its prevention is paramount. Chronic osteomyelitis is associated with significant morbidity and major disability [17]. The chief objective for implementing improved standards of multi-specialty care is to minimize the risk of long-term bone infection and optimize functional outcome.

Factors to be considered when determining the selection of primary amputation include; multiple myofascial compartment involvement, multiple vessel injury, failed vascular reconstruction, severe muscle loss or crush injury, multilevel neurological or vascular injury, warm ischaemia time > 4 hours, and patient choice.

Outcomes following amputation or limb salvage have been demonstrated to be functionally equal [18,19,20]. Limb salvage is associated with increased length of hospital stay, surgical procedures and complication rates [21]. For severe injuries to the hindfoot or ankle, requiring free flap reconstruction
and/or ankle fusion, outcomes from limb salvage have been seen to be poorer than from primary amputation [22].

**Reconstruction**

A myriad of reconstructive options exists, to date there is no evidence to support or refute any choice. However, reconstruction should be bespoke depending upon patient characteristics, injury factors and surgical expertise. A broad overview of reconstructive options for bone is outlined in table (3) and for soft tissue in table (4).

The mode of fracture fixation is an important consideration and requires multi-specialty discussion in order to determine the optimal management plan. Particular orthopaedic options may limit or be limited by reconstructive options. Each injury requires an individual approach for a successful outcome. Fracture fixation should be harmonious with soft tissue reconstruction. Cast immobilization is of limited use in the management of open fractures, due to difficulties in wound care and controlling unstable fractures.

Definitive fixation is thus usually performed with the use of external or internal fixation. External fixation is categorized into two broad types; pin & rod constructs or fine-wire frames, although hybrid frames can also be used. Both advantageous for their versatility, as well as minimizing the amount of retained metal implants at the site of injury, fine wire frames have the ability to provide long term deformity correction (often through distraction osteogenesis). The frames can be cumbersome for patients and hamper rehabilitation, physically and psychologically. Pin site infection can be minimized with appropriate wound care; however, it is a common complication for those treated with external fixation as a definitive option.

Internal fixation often represents the optimal fracture fixation method. Intramedullary nails are associated with increased rates of limb salvage [23], when compared to alternative fixation techniques. However, it can only be used for fractures in the metaphyseal or diaphyseal regions of long bones. Internal fixation with plates and/or screws can provide stability for most fracture configurations, in particular intra-articular, comminuted, or those with bone loss. Internal fixation with plates can increase the complexity of soft tissue coverage required.

The primary consideration when selecting the most appropriate reconstructive option is the post-debridement wound bed composition. Other considerations will include the extent of the zone of injury, injury energy, and defect size. When possible, direct closure would be preferable, but with high energy injuries this is frequently unachievable. Wound defects must therefore be managed by techniques upon the reconstructive ladder.

Successful ‘take’ of skin grafts is reliant on their application onto a vascularized wound bed. The graft requires neovascularization to enable its survival. Thus, skin grafts will not survive on bare cartilage, tendon, bone or metal implants. Full thickness skin grafts are rarely indicated due to the limitations in their size, the donor defect and the increased risk of graft loss when compared to split thickness grafts. For larger wounds, or those with exposed vital structures, the use of a skin graft is not appropriate and the defect requires a more robust coverage option.

Soft tissue flaps can provide for such requirements and can be applied in a variety of fashions to meet the reconstructive need. A flap is a unit of tissue transferred from its donor to a recipient site whilst maintaining its own blood supply [24]. Flaps can be classified in a number of different ways, this may be based on the circulation, tissue composition, method of tissue transfer and locality of the flap to the defect (contiguity). Flaps classified by contiguity are broken down into: local flaps, when using tissue adjacent to the wound; regional flaps, when using tissue from the same region of the body; or distant flaps, when using tissue from a distant area of the body. Distant flaps can be pedicled where they remain attached to their blood supply or free flaps where they are completely detached from their blood supply and anastomosed to vessels closer to the defect.

In low energy injuries, the use of local flaps may accomplish coverage of the defect because there is preservation of the vascular integrity. Local flaps can be based on random pattern vasculature or on an axial supply from a known vessel. The advantages of local flaps are their low donor site morbidity, locality relative to the injury, aesthetic outcome and lower complexity.

Free tissue transfer may be required if there is significant damage to surrounding tissues or vascular
structures negating local reconstructive options. High energy injuries or those in which the zone of injury precludes local options, require tissue to be mobilized either based upon a vascular pedicle or as a free flap. The advantages of pedicled or free flaps are their ability to cover large areas of soft tissue deficit, cover non-graftable wounds (exposed metalwork, bone, tendon) or vital structures. Free flaps are reliant upon anastomosis to local vasculature for survival. It is important to highlight ideally the need to ensure the anastomosis of vessels should be performed outside the zone of injury, to maximize likelihood of success. Free or pedicled flaps are also advantageous for their ability to conform to the dimensional requirements of the wound site. The muscle component of a flap will contribute greater vascularity to a defect when compared to fasciocutaneous tissue, thus improving the potential for fracture healing [25]. Free muscle flaps have been shown to have similar flap survival rates, infection / osteomyelitis rate and bone non-union rate when compared to fasciocutaneous flaps [26]. Figure 1 illustrates the common flap coverage options based on an anatomical map.

**Radial Forearm**

The radial forearm flap is a fasciocutaneous flap, supplied by perforators based on the radial artery. It is a good source of thin pliable skin with a long, reliable pedicle. A short segment of the radius can be harvested as vascularized bone alongside the flap and enables great versatility. However, limitations for use include; relative small size, difficulty in direct closure of donor site, and potential compromise to the vascular supply of the hand.

**Scapular/Para-Scapular**

The scapular, or parascapular flap, is based on the circumflex scapular arterial system. The lateral boarder of the scapula may also be harvested, if bone is required. The donor sites are often closed primarily. The ability to provide a wide reconstruction for large soft tissue defects make it an option where extensive coverage is required.

**Latissimus Dorsi**

A commonly used, versatile option is the latissimus dorsi flap. It can be harvested as a pedicled (for proximal upper limb defects) or a free flap. It can be taken as solely a muscle flap or a myocutaneous flap. It has a long pedicle based on the thoracodorsal artery, a branch of the subscapular artery. The muscle is broad and flat and can be used to cover large defects. A muscle only flap may be used and then skin grafted to reduce the bulk of the flap and donor site morbidity. The commonest recognized complication of latissimus dorsi flap is donor site seroma [27].

**Gracilis**

The gracilis is a muscle flap, which can also be harvested with a skin paddle (TUG) and as a functional muscle flap. It is based on the medial circumflex femoral vessels and the pedicle length is relatively short. It has wide reconstructive applicability, as a local option for perineal wounds or as a free flap for lengthy defects and limb salvage. The donor site usually closes directly [24]. Advantages for muscle transfer include, minimal functional and donor site morbidity, ease of surgical access and high conformability of this thin and flatly shaped muscle [28]. However, this can be inadequate for larger wounds.

**Antero-Lateral Thigh Flap**

The anterolateral thigh, or ALT, is a fasciocutaneous flap, based on the lateral circumflex femoral vessels and has a relatively long pedicle. It can cover a relatively large defect and still achieve direct closure at the donor site with relatively little donor site morbidity. ALT is highly effective for lower limb reconstruction, with flap success rates reaching 91-92%, even in ipsilateral trauma [29]. Therefore, preservation of this anatomical region from direct orthopaedic intervention is paramount – the perforators for this flap arise at the midpoint of a line drawn between the anterior superior iliac spine and the lateral border of the patella – this zone should be avoided when applying external fixator pins.

**Gastrocnemius**

Suitable for local rotational options, which have minimal functional morbidity. Choice of the medial or lateral head is dependent upon the defect site. The harvest incision for access can be through a posterior midline, but if pre-planned upon the medial or lateral head then usually a postero-medial or postero-lateral approach can be used accordingly [30]. Risk of injury to the common peroneal nerve & sural nerve exists, thus care should be taken to preserve these structures. Despite minimal functional morbidity the resultant contour depression can be unsightly. *Gastrocnemius medial head;* single proximal neurovascular pedicle, broad belly, longer. Primary blood supply, medial sural artery. *Gastrocnemius lateral head;* smaller muscle belly in comparison to the medial head, harvesting risk to common peroneal nerve. Primary blood supply, lateral sural artery.
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<table>
<thead>
<tr>
<th>Option Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Contra-indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Fixation</td>
<td>Minimizes local soft tissue disruption.</td>
<td>Pin site infection, psychological burden</td>
<td></td>
</tr>
<tr>
<td>Internal Fixation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plates, Wires &amp; Screws</td>
<td>Preserves endosteal blood supply.</td>
<td>Requires local soft tissue disruption and adequate coverage.</td>
<td>Articular or juxta-articular fracture patterns.</td>
</tr>
<tr>
<td>Intramedullary Nails</td>
<td>Minimizes local soft tissue disruption.</td>
<td>Disrupts endosteal blood supply.</td>
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</table>

Table 3. Bone Reconstruction.

<table>
<thead>
<tr>
<th>Option Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Contra-indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Intention</td>
<td>Minimal intervention.</td>
<td>Slow, poor cosmesis &amp; scar contracture.</td>
<td>Exposed bone, tendon or metalwork</td>
</tr>
<tr>
<td>Direct Closure</td>
<td>Good cosmesis. No donor site morbidity</td>
<td>Limited role if soft tissue loss or oedema</td>
<td>Excessive wound tension</td>
</tr>
<tr>
<td>Skin Grafts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Split Thickness</td>
<td>Versatile, expansive, multiple donor sites.</td>
<td>Poor cosmesis, fragility, scar contracture.</td>
<td>Exposed bone, tendon or metalwork</td>
</tr>
<tr>
<td>Full Thickness</td>
<td>Good cosmesis</td>
<td>Limited size, donor deficit, poorer take rates.</td>
<td>Exposed bone, tendon or metalwork</td>
</tr>
<tr>
<td>Flaps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>Donor and recipient site adjacent.</td>
<td>Limited size.</td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>Suitable for medium sized defects.</td>
<td>Limited availability within/ near zone of injury</td>
<td></td>
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<tr>
<td>Free Tissue</td>
<td>Versatility with multiple soft tissue composite variations.</td>
<td>Anatomical and coverage size limitations.</td>
<td>Donor site morbidity.</td>
</tr>
<tr>
<td></td>
<td>Large area coverage.</td>
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Table 4. Soft Tissue Reconstruction.

Complications

Within the treatment options for this severe category of injury, complications exist in abundance. The commonest complication for all patients remains wound infection, affecting 25 – 37% [31,32]. Osteomyelitis (10%) and non-union (30%) present significant risks post reconstruction, wound healing problems and dehiscence occurs in 15% of cases for primary amputations [31]. Smoking history increases the risk for infection and non-union, when compared to non-smokers [33].

Type of flap reconstruction has not been well demonstrated to impact upon flap failure rates, nor rates of wound infection, late amputation or non-union [34].

Chronic pain is another frequent complication for those sustaining severe extremity injuries, in particular the prevalence of phantom pains following amputation [35]. The impact of patients’ psychological status and their levels of anxiety or depression on perceptions of acute and chronic pain have been shown to be correlated [36].

Rehabilitation

Facilitated multidisciplinary physical and cognitive rehabilitation phase of care is a crucial stage in the recovery of patients with open fractures or severe extremity injuries. Short and long-term rehabilitation
Figure 1 illustrates the common flap coverage options based on an anatomical map.

needs of patients, which may include the need for repeat or revision surgery, must be carefully coordinated through the healthcare network. Access to medical records and rehabilitation prescriptions are vitally important for continuity of care, patient support and compliance. Patient morale throughout the arduous process of recovery must also be addressed and clinical psychological support should form part of comprehensive rehabilitation. Additionally, donor site rehabilitation should not be overlooked in case when limb salvage has been achieved by autologous tissue transfer from another limb.

Conclusion

Understanding the difficulties and challenges associated with the management of open fractures is crucial to improving clinical outcomes. Examining the key aspects of emergency management and surgical stabilization highlights the importance of coordinated, specialist input needs to be coupled with precise, timely basic interventions, including early antibiotics and logical debridement.

Ortho-plastic management provides the optimal knowledge base to avoid clinical decisions which may
compromise surgical options. Awareness and communication between specialists, between hospitals and between clinicians and their patients is vital for elevating clinical outcomes. The variety of surgical options, both from an orthopaedic and plastic surgery perspective, provide great scope for strategies tailored to be patient specific and achieve optimal outcome. The relative advantages and disadvantages for osseous and soft tissue reconstruction have been outlined to highlight aspects which must be considered during surgical planning. However, technical, anatomical choices must also be influenced by multiple factors ranging from patient expectations, desires and functional requirements, to rehabilitation.

References


