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The Ortho-Plastic Approach to Soft Tissue Management in Trauma

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Abstract: Fractures with associated soft tissue injuries, or those termed 'open,' are not uncommon. There has been much discussion regarding there management, with the guidance from the combined British Orthopaedic Association and British Association and Aesthetic Surgeons teams widely accepted as the gold level of therapy. We aim to discuss the current evidence about the initial management of this group of injuries, taking a journey from arrival in the accident and emergency department through to the point of definitive closure. Other modes of therapy are also reviewed.

Keywords: Debridement; open fracture; soft-tissue.

1. INTRODUCTION

Fractures are a commonly seen injury in the accident and emergency department. Open and closed fractures differentiate themselves due to the amount of damage to the soft tissues enveloping the bone. Any injury to the bone will damage the surrounding soft tissues to a degree, but where there is a communication to the outside, through a wound, the injury is termed as an open, or compound, fracture. Closed (simple) fractures are those where the bone fracture is not linked to the outside environment.

The communication with the environment can be formed in several ways. High trauma injuries often result in an inside to outside injury where the bone tears through the soft tissues. In comparison, a high velocity penetrating injury, such as in a gun shot wound, will cause injury to the soft tissue and then the underlying bone, dragging material from the environment into the wound. The latter is also seen in blast injuries of war and animal bites, and can often be associated with a greater soft tissue to bone ratio injury. The main concern regarding open fractures is that they permit contamination by the outside world, increasing the morbidity and outcome associated with the bony injury.

The main morbidity results from deep infection, non-union of the fracture, osteomyelitis and amputation [2], with fracture healing being dependant, to a significant extent, on the soft tissue envelope quality surrounding the injured bone, and its blood supply [3].

2. EPIDEMIOLOGY

Open fractures studies have often been studied in regional rather than national terms, and its epidemiology varies depending on war and peace situations. It is thought overall incidence of open fractures is 3.2% of all fractures or 11.5 per 100,000 people. Anatomically it is thought around 3.3% of upper limb, 3.7% lower limb and 0.3% of limb girdle, fractures are open. Up to 21% of tibial fractures are open, mainly due to the thinner surrounding soft tissue envelope as compared to other bones [4].

Open fractures have been seen to affect the population in a bimodal form. Often a younger group, generally male, caused by high energy injuries [mainly relating to sport and road traffic accidents] and an elderly peak, involving low energy injuries [often the osteoporotic female] caused by for instance a fall from standing [4].

Open fractures, despite improved management strategies, continues to involve late infection rate ranging up to 25% [5, 6]. Worldwide agreement on mandatory management follows along intravenous antibiotic use, emergency wound debridement and copious irrigation [6-13]. although the timing and choice of these treatments is less conclusive.

The desired outcome in the management of open injuries is not merely salvage in more extreme injuries, but a limb which is functional, painless and aesthetically pleasing and this should be remembered at all stages of management.

3. THE MANAGEMENT OF OPEN FRACTURES

3.1. Initial Management

Open fractures can present in many scenarios, varying from isolated injuries to multiple traumatic injuries to the patient [4].

Although the more minor open fractures, for example of the upper limb digits may appear to be inconsequential, a quick and safe approach to examining the patient must be adhered to so as to not miss more serious problems. In respect to this, the more traumatic open fractures often act as a distraction to the treating physician masking a more

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immediate threat to both the unconscious and conscious patient. For this reason, the internationally recognised Advanced Trauma Life Support (ATLS) protocols [14] are best adhered to [1].

The first aspect of the ATLS principles is to stabilise the cervical spine and assess the airway. The unconfused patient that walks in with an open injury to the arm usually allows these areas to be considered without formal need, as well as hinting to an adequate breathing and circulatory state. In more severe or multiple trauma cases these areas must be assessed in order and treated appropriately. Radiological scans at this time should be undertaken and include any joints above and below any queried bony injuries [1].

Preliminary assessment of open fracture/s may be commenced once life threatening injuries have been managed appropriately. Initial splinting of the fracture will help with both haemorrhage and pain relief, but prior to this the wound should be examined and the limb status documented [1]. The wound should be examined in a careful and systematic approach, noting size, approximate depth and any active bleeding. This includes a circumferential assessment of the limbs as the soft tissue injury may be initially hidden from sight. Concerns at this time regarding distal vascularity should be addressed early in the therapy. Sensation and motor function should also be grossly examined as to confirm injury pre or post therapy, but often nerves are highly tolerant of stretching injuries and there viability is often unaltered [15, 16].

Direct pressure, and as a last resort, application of a tourniquet usually resolves gross bleeding, but its use is currently only indicated in lethal haemorrhage [17].

At this stage, guidance suggests only gross contamination should be removed and if able to, photography of the wound for records [1]. Finally dressing of the wound ought to take place. Photography of the wound allows easy review of the wound without causing further distress to the patient with repeated dressing changes.

There is currently debate regarding the optimum dressing to cover the wound, with the main debate involving the addition of a povidone-iodine or antibacterial dressing or a simple saline soaked gauze alternative. The former, although with the aim of reducing any present and potential bacterial load [18], has been stated as being a potential source of further soft tissue and cell damage due to the cytotoxic properties of the soak [19]. Rogers *et al*. [20] showed no statistical difference in infection rate between saline and povidone-iodine based dressings, and so at present saline is suggested in guidelines by the BOA/BAPRAS [1].

After gross contamination is removed from the wound, provisional cleaning of the wound with both exploration and irrigation should not be undertaken unless done so by the orthopaedic or plastic teams involved [1]. Antibiotic administration should start as early as possible with appropriate tetanus prophylaxis administered. In the next part, we aim to discuss the current evidence for the above guidance as well as the key steps in the initial debridement process.

Once the patient is stable, and the open fracture is stabilised with appropriate splinting helping to ease both haemorrhage and pain, the management of the wound can take priority. As stated the current guidance is that the next stage of management is early wound debridement and this needs to be preferably undertaken at a specialist centre if in respect to soft tissues, there is any query regarding tension free closure of the wound, muscular or vascular injury and degloving-type injuries [1].

4. WOUND MANAGEMENT

The key parts of wound management involve firstly grading or attempting to classify the wound to assess the degree of surgical input, and by what teams is required. End morbidity studies have shown that the key factors in wound management involve antibiotics and surgical debridement, the latter involving timing, irrigation of the wound and actual surgical technique. These areas will now be discussed.

4.1. Wound Assessment and Classification

Open fractures are common injuries, and often will present to a hospital where the definitive management is unable to be performed. For this reason, classification of the injury is needed for a concise, reproducible and comparable description of the wound that can be explained to the specialist unit most often over the phone. This classification should also be simple to perform, accurate as well as helping both the initial and specialist unit decide a management plan, based on predictive outcomes related to the injury's score. There are multiple classification systems in use for open fractures but since 1976 one system [13] has been felt to be the most simple and reproducible system available. The Gustilo and Anderson classification also suitably predicts prognostic outcome of the injury, taking into account the bone and soft tissue injuries as well as contamination of the wound. The system was based on diaphyseal long bone injuries and so is less functional for metaphyseal, intra-articular, as well as small bone injuries. The Gustilo and Anderson grading system unfortunately has been questioned as to whether it gives poor inter-observer reliability but as stated is the current mainstay of classification [1, 21, 22]. Gustilo modified his scale further in 1984 to take into account the bone exposure and consequent soft tissue coverage as well as vascular injury of the more severe grade III injuries and the scale is shown in Table **1** [6].

The Gustilo classification system must be used with adjuncts of information given. These include the mechanism and force involved in the injury, and other concomitant injuries or co-morbidities [23].

As well as the Gustilo and Anderson classification, many other indexes have been designed to firstly categorize the injury, and also predict whether or not salvage of the limb is feasible.

Other systems in use for the grading of an injury include the Tscherne Classification, which later evolved to form the Hannover Fracture Scale. Likewise the AO classification is used to describe the degree of bony and soft tissue injury and may be more useful for audit and data collection as it is a more comprehensive scale [1, 24].

The Byrd -Spicer classification is another les used scale [25]. It has a large degree of inter-observer variance, but scores include the force of energy and any presence of

Table 1. Gustilo-Anderson classification of open fracture injuries.

Gustilo Type	Definition
I	Open simple fracture, Clean wound, Wound <1cm in length
II	Open simple fracture, Wound >1cm in length without extensive tissue damage including flaps or avulsion type injury
III	High energy injuries resulting in Open segmental/multi-fragmental fracture or bone loss associated with extensive soft tissue laceration, damage or loss. This includes severely contaminated wounds, including farmyard related, any vascular involvement, severe crush injuries and fractures that have been open for over 8 hours pre-treatment
IIIA	As above with adequate periosteal coverage of the fractured bone despite soft tissue damage/loss
IIIB	As above with extensive tissue loss and periosteal stripping. Associated with massive contamination
IIIC	As above associated with an arterial injury requiring repair irrespective of degree of soft tissue injury

devitalised tissue, although it is more vascular injury weighted.

Salvage of more serious injuries, avoiding amputation both early and late, has caused several classifications to be suggested. The majority of these are based on battlefield injuries. Unfortunately each has their own positives and flaws ranging from complexity, reproducibility and predictive outcome [23].

Regarding the need for early or late amputation of the limb, several scores have been designed to assess the benefit of limb salvage *versus* amputation and include the MESI, MESS, PSI, LSI and NISSSA indexes (Table **2**).

Bosse *et al.* [26] examined the usefulness of the above scores as well as the Hanover fracture scale and found all lack sensitivity, with the MESS appearing to have a reasonable specificity in limb salvage. They found lower

Table 2. Open fracture injury scores.

Score	Unabbreviated	Main Indices for Scoring	Predictive Outcome [26]
MESI	Mangled Extremity Syndrome Index [27]	• Injury Severity Score (ISS) • Tegmentum Injury • Vascular Injury • Fracture Type • Bone Loss • Wait Time • Age • Pre-existent Disease	>20 = amputation
MESS	Mangled Extremity Severity Score [28]	• Type injury • Limb ischemia • Presence of shock • Age • Score is doubled for Ischaemia > 6 hours	>7 amputation [29]
PSI	Predictive Salvage Index [30]	• Level of arterial injury • Degree of bone injury • Degree of muscle injury • Interval from injury until arrival in operation room	>8 amputation
LSI	Limb Salvage Index [31]	• Artery injury • Nerve Injury • Bone Injury • Skin Injury • Muscle Injury • Deep Vein Injury • Warm Ischaemia Time	>6 likely amputation
NISSSA	See Indices [initialled] [32]	• Nerve injury • Ischemia • Soft tissue contamination • Skeletal injury • Shock • Age	<7 salvage and > 11 amputate

numbers correlated well with salvage, but that higher numbers should not equal amputation. These scores do allow the categorisation of injuries, as no two are identical, and should be used in aiding clinical judgement rather than being a set decision making tool. Ultimately, the patient must be assessed in terms of an individual with personal, psychological and social circumstances as well as their critical physical needs being considered.

There is also some debate whether the classification of an open wound should be done post debridement, [33] and also whether the amount of tissue contamination should be taken into account, especially as this and the size of the wound do not always correlate. These debates are the reason for the numerous attempts to classify all wounds into groups, and these should really only be used for guidance rather than the rule. BOA/BAPRAS guidance states post debridement assessment for wound grading [1].

In this paper injuries will be talked about in terms of Gustilo's classification unless stated.

4.2. Antibiotic Use

The choice of antibiotic has been under debate since studies into open fractures began.

Debate ranges from choice of antibiotic, the way it is administered and even to whether or not antibiotics are even indicated in the first instance.

It is however, well established that antibiotic use is a requirement in the open fracture [1, 6, 13, 34].

Initially the antibiotic regime was given as prophylaxis as injury to the soft tissue envelope of the bone pre-disposes to both wound infection as well as late osteomyelitis, although the higher rates of infection seen in these injuries without antibiotics means it is now thought of as therapeutic [34]. Excision of non viable bone and soft tissues allows any source of bacteria to be removed and aided by the high vascularity of bone allows systemic administration to reach the area and thus be a suitable choice. It is generally accepted that a combination of debridement and antibiotics, as opposed to either one course on its own reduces the risk of future complications. Both these therapies also appear to be only of benefit while there is still non-viable tissue and until the normal fracture healing process has begun, and so serial debridement may be required.

It has been shown that open fractures managed only by debridement may result in infection rates as high as 13.9%, while the addition of antibiotics reduces this rate to 2.3% [34].

A Cochrane study suggested the role of prophylactic antibiotics in reducing infection rates by 59% [35].

The wound can be contaminated at the time of injury, particularly in outside to inside injuries, as well as whilst in the hospital, with Cooney *et al.* showing close ties with the bacterial cultures taken from both the patients nose or skin as well as that from the air surrounding the wound [36, 37]. Despite this, pre-debridement cultures do not appear to correlate with either later infections of the wound or systemic sepsis [5] and this association only mildly improves with post debridement cultures [38]. The general consensus is that if a wound appears infected, then at this point there is a higher prediction of link to quantitative positive culture results [39, 40]. It has been seen that there is no correlation between the time elapsed between injury and debridement and quantitative bacterial counts [39, 41, 42].

Studies have shown benefits of antibiotic therapy in open fractures, when compared to administration of a normal saline placebo [43]. Gustilo [44] also pointed to a mixture of gram positive, gram negative and mixed bacterial growths from these injuries on arrival of the patient to hospital.

The cephalosporin family has long been the source of antibiotics in the treatment of open fractures due to their good broad spectrum activity against both gram positive and negative organisms. Bischoff *et al.* [45] showed that Cefuroxime was secreted into open fracture wounds increasing the antibacterial activity of the wound secretion, and that this reached a highest peak 4 hours after intravenous administration. This, alongside the paper by Gustilo [44] showing cephalosporin's administered within 3 hours reduced morbidity, points towards the use of antibiotics early in the management of these injuries.

In addition to this the use of a local, or topical, antibiotic therapy has been researched. Neomycin, Bacitracin and Polymyxin have all been assessed with varying benefits suggested, and often only in animal studies [46-49].

An 'antibiotic bead pouch' appears to aid reduction of the bacterial load of the wound, as well as reducing consequent infection rates and osteomyelitis [50-53].

Aminoglycoside impregnated Polymethylmethacrylate (PMMA) beads appear to be the most researched in this field. The benefits of the beads include stopping the re-growth of soft tissue interposing the bone ends as well as creating a space in the healing envelope for later bone grafting/management. As well as this it reduces any systemic toxicity, and reduces secondary wound contamination [54]. And these are now recognised as a useful adjunct in the open fracture therapy, especially in higher grade injuries where bone loss is significant [1].

Studies have equally shown that Type I and II injuries require one pre and two post surgery doses of antibiotic (in this case Cephalosporins again) due to mainly gram positive infection, whilst grade III benefit from a longer course, 48-72 hours post definitive soft tissue coverage, due to an increased incidence of gram negative organisms [55]. The addition of Penicillin G as a third antimicrobial agent is highly recommended for open fractures which have been exposed to soil or a farm environment and in injuries with a considerable crush component or vascular compromise] [56, 57].

Several doses of Teicoplanin has also been shown to help reduce the incidence of infection following open fractures, although results seem to be mainly beneficial in soft tissue injuries with Type II fractures, and the study did not include grade III injuries [58].

Longer courses of antibiotics have not been shown to aid benefit, and especially once definitive coverage of the injury has taken place [13, 56, 59-62].

More recent studies have shown that in grade IIIB infections, the benefit of a one off dose of Teicoplanin and

Gentamycin at the time of definitive soft tissue closure would help reduce the risk of future deep surgical site infection. The reason behind this being the increase of nosocomial organisms present at wound closure as opposed to skin flora, present at time of injury, which are covered by the more broad-spectrum antibiotics [63].

The amount of soft tissue injury does appear to correlate with the infection rates of the wound, and so higher graded injuries appear to require more extensive debridement and antibiotic duration. Infection rates for grade I injuries appear to be up to 2%, rising to 2-7% in grade II injuries. Grade III injuries appear to have an overall incidence of 10-25% of infection rates, with this sitting at 7% for grade IIIA, 10-50% in grade IIIB and 25-50% in grade IIIC [2, 5, 6, 13, 62].

This low rate in grade I fractures is the area which questions whether there is any additional benefit of antibiotics to the thoroughly cleaned wound [64].

The current BOA/BAPRAS guidance takes many of the above points [1]. It states antibiotics should be started as soon as achievable, preferably before 3 hours have elapsed since injury. Co-amoxiclav (1.2 g 8 hourly) is now first choice as is has a similar spectrum of therapy to the cephalosporins (Cefuroxime 1.5 g 8 hourly) but is currently less associated with complications such as Clostridium Difficile related Colitis. Clindamycin is a non penicillin related alternative for patients with history of allergic reactions (600 mg 6 hourly).

This should be continued for a maximum of 72 hours, or until soft tissue coverage is achieved, with a dose of whichever antibiotic as well as Gentamycin (1.5 mg/kg) being administered at time of induction of the first debridement.

A further dose of Gentamycin should be given, with either a single dose of Teicoplanin (800 mg) or Vancomycin (1g), at the time of skeletal fixation.

Regarding tetanus, Rhee *et al.* suggested after reviewing the literature that tetanus vaccine should be administered in traumatic wounds in the form of tetanus toxoid if the last booster was given more than 10 years prior or if history is not reliable or available, and as tetanus immunoglobulin in patients with incomplete primary immunization or to patients for whom it has been longer than 10 years since their last booster dose [65].

4.3. Surgical Management

It has been suggested that in high energy tissue injuries, surgical debridement is the most important prophylactic measure in reducing infection risk [66] and the first procedure may well determine the long term outcome of the injury and patient [67]. This has been evident in the opinion that inadequate debridement may in fact cause an iatrogenic injury and raise later morbidity rates and long term outcome [68, 69].

This theory has been challenged, as for the need of antibiotics, in low energy injuries [70], where it has been considered grade I injuries could be treated as closed injuries, although currently this should be the exception rather than the rule, at least until further evidence is shown. Grade II and above type injuries are often unstable or involve displacement and will almost definitely need some aspect of surgical therapy.

Debridement is one of the key stages of open fracture management; its basics running through the fact that nonviable tissues and foreign material in the wound both hinder the host defence mechanisms and enhance bacterial growth [71]. Failure to excise the devitalised tissue often causes increased morbidity, as the amount of devitalised tissue contributes to the amount of present bacteria and is often linked to the degree of energy released into the tissues by the injury. Hence why the larger injuries appear to have higher infection rates and require more radical debridement.

4.3.1. Vascular Injury

Vascular injury occurs in 1-4% of open fractures that present in non-war situations, and often requires rapid management, often with the use of shunts or vein interposition especially with the risk of infection in these injuries [72]. These are best analysed in the suspicion of a vascular injury using a Doppler probe, with signs of ischaemia, absent pulses and neurological signs, or a bony injury known to have high arterial damage association [73].

Angiography can be used to confirm, particularly upper limb ischaemia, as this may define limb salvage *versus* amputation [73], although it can delay therapy, and clinical judgement in light of findings and the level and configuration of the fracture can strongly guide in decision making [1]. Vascular compromise should be recognised immediately [loss of distal pulses]. Restoration of circulation should take place under six hours, although muscle death has been seen to occur as soon as 3 hours post injury [1].

4.3.2. Time to Debridement

Thorough the literature there is described a 6 hour rule in which time surgical debridement should take place. However, there does not seem to be any agreed study or text where this rule arose from although numerous studies report the potential benefits, the majority experimental [74-76].

Early debridement has been seen to significantly reduce later infection rates in war related open fractures [77, 78] as well as within civilian populations [79]. Kindsfater [80] showed increased risk in debridement after 5 hours post-injury. This study in not as conclusive as other studies as several variables were not taken into account and numerous dissimilarities between the treatment groups was seen.

Naique *et al.* [81] found that there was no significant difference in deep infections between pre 6 and post 6 debridement but that there was a higher percentage of infections in the second group.

Likewise, a number of studies have questioned the 6 hour rule, with delayed debridement [often within 24 hours] showing no significant outcome difference when compared to pre-6 hour post injury debridement [62, 82-84].

Webb [85] and Harley [86] showed no difference between the time of debridement and end clinical or functional outcome in type 3 fractures specifically, whilst a delay from injury to presentation, such as in more remote regions has been shown to have good outcomes as long as the main principles of satisfactory debridement, fracture stabilisation and soft tissue management [87].

Some studies have shown that the specific timing of debridement relates no correlation to quantitative bacterial counts [42, 88] whilst studies in children have shown no benefit in urgent debridement of the wound under 6 hours post injury, as long as intravenous antibiotics have been started [89]. In this study procedures occurring after the 7th hour had similar long term complications to those operated on earlier, and the complication risk being more dependent on the grade of injury.

This is reflected in the suggestion that all open wounds should be explored in normal working hours, but within 24 hours of injury [1].

Immediate exploration is indicated in wounds grossly contaminated, devascularised distally, or those with evidence of compartment syndrome. The multiply injured patient should also be considered in this group [1].

4.3.3. Irrigation

Irrigation is used as an adjunct to aid the reduction in any bacterial load of a wound. Again an area of debate, many surgeons have shown benefit of using free flowing solutions and high pressure pulsatile lavage in cleaning the wound [90]. However, it also been suggested that high pressure pulsatile lavage can damage the viable soft tissues of the wound, including the healing bone [91], as well as driving foreign materials further into the wound [92, 93].

High pressure pulsatile lavage may be useful in removing large particulate debris and foreign matter. However, it may lead to a illogical rebound in the bacterial count of the wound, possibly due to the above factors [94].

Guidance by Crowley [90], based on literature available, suggested the use of normal saline without adjunctive solutions through low pressure irrigation methods, and is matched with current guideline from the BOA/BAPRAS [1].

Soap has been used as an adjunct, similar to povidone-iodine to help reduce any bacterial load of the wound. Conroy [47] and Anglen [48] showed no great benefit when comparing soap *vs* antibiotic and antiseptic solutions, and its use is not widespread due to concerns regarding potential cytotoxic properties. Likewise the use of additives, such as bacitracin, castile soap, and benzalkonium chloride, which do reduce the initial bacterial load, also appear to cause a later rebound bacterial count [94].

Tap water and normal saline solutions appear to have no great difference in terms of benefit in reducing bacterial load *in vitro* [95], although tap water consistently will grow pseudomonas when cultured in optimum conditions.

4.4. Surgical Debridement

Primary debridement should take place in a suitably sterile location. The fractured limb may benefit from a proximally based tourniquet especially when massive active blood loss is occurring or expected, although its use should be minimised to maximise tissue salvage, and prevent further ischaemia. Tourniquet use has been shown to increase the incidence of wound infection, more than likely due to worsening tissue hypoxia and acidosis [71, 96], but the benefits of a clearer working field, not covered in blood, may be of more benefit initially [1].

Cleansing of the wound and limb skin with soap and then a chlorhexidine scrub should occur, with povidone-iodine as an option. The use of hydrogen peroxide has been recommended to cleanse the area [97]. All foreign matter, as well as tissue whose viability is undetermined should be excised including muscle, bone, and the skin edges of the wound. This can aid exploration of the wound, although the finer structures of the limbs, nerves and tendons, are often found to be more resilient and should not be excised unless there non-viability is undoubted e.g. detached [15, 16]. If further wound opening, rather than excision is required, the fasciotomy lines should be used [1].

The actual amount of tissue to be excised is still a controversial point, with the only agreement being all non-viable tissue excised, although the definition of non-viable is not clear cut. Necrotic tissue should be radically excised [97], but tissue whose viability is questioned is a finer point, and may benefit from serial review of the wound and further debridement. This is key in degloving injuries where the amount of injury can be under-estimated [1].

Systematic exploration of each level of the wound, from superficial to deep, allows a reduction in any non-viable tissue being missed [1].

Wound edge debridement is often dependant on the surgeons experience [98, 99] and is often guided by the four C's which can be found in Table **3** [100,101].

Table 3. Excision of devitalised tissue 'The 4 C's'.

Colour	Red (not pale or brown/black)
Consistency	Non-waxy
Contractility	On being pinched
Capillary Bleeding	On being incised/cut

Prophylactic fasciotomy should be performed in vascular injuries associated with open fractures and significant crush injuries. Acute compartment syndrome is a severe threat to limb survival and distal limb ischaemia. An open fracture does not equate to an open compartment and it is key to remember that these patients can still develop this complication [96] and a low threshold for performing the procedure should be followed [102].

This risk is exaggerated in the patient who can tell the surgeon symptoms are worsened and inter-compartmental pressures may be mandatory in the unconscious or anaesthetised patient with a swollen limb [1].

There is traditional agreement that it is better to leave a traumatic wound open after the initial debridement [10, 103] although there is now a shift to early closure which may reduce osteomyelitis and non-union rates, although these factors are dependant on a satisfactory wound debridement in the first instance [104-106].

Repeat, or serial, debridement should take place between 24 and 48 hours and be performed under general anaesthesia allowing a full examination of the wound. Once the wound is deemed satisfactorily clean, closure of the wound is advised with whichever technique is best indicated.

The presence of granulation tissue at later debridement is an encouraging sign showing that a wound is capable of mounting a healing response on both local and systemic levels. It may help with tissue loss in terms of defect although long term wise it aids little with respect to flap coverage and ultimate function, potentially even causing functional impairment. As well as this, the formation of granulation tissue over the surface of necrotic muscle can obscure the true extent of any necrosis as well as harbouring bacteria. Its debridement should be considered throughout review of the wound [107].

4.4.1. Surgical Debridement Adjuncts

Bone that is present in the wound but potentially viable has also been reapplied to the injured site as a bone graft, and salvage techniques include washing in povidone-iodine, autoclaving and gentamycin soak with good results in a case study [108]. Currently bone that fails the 'tug test' should be excised [1].

Alongside this, several papers have assessed the use of laser Doppler flowmetry in the assessment of bone viability, with mixed results [109, 110].

Studies have also show relationships with the amount of oxygen in the tissues surrounding a fracture, stating higher concentrations around the injury site as compared to both the non-injured opposite limb and region of non-injury on the injured limb. This change is most evident during the first 4 days post injury and returns to normal by day 10, and may be able to be used as a predictor of complications [111, 112].

New studies are also looking at addition of Interleukin-12 as a way of reducing infection, particularly with nanocoating of any bone fixator used [113], as well as autologous platelet-rich plasma (PRP) gel [114].

5. POST EMERGENCY DEBRIDEMENT

The options available after emergency debridement are to leave the wound open, to temporarily cover or definitively cover. Negative Pressure Wound Therapy (NWPT) has revolutionised this area is now commonly used as a temporary dressing aiding in reducing both morbidity and the need for further surgery.

5.1. Negative Pressure Wound Therapy (NPWT)

NWPT has gained universal appeal and appear to help in both the reduction of wound bacterial load, and the amount of tissue required for definitive coverage. It is suggested that NPWT increases local blood flow, reduces oedema and promotes healthy granulation tissue formation [115].

It has been documented in even helping reduce compartment syndrome pain and has even saved a limb from amputation [116,117].

The scope for NPWT use is changing year on year, with the use of dermal regeneration templates and cryo-preserved dermis, [118,119] but it is important NPWT is used as an adjunct for delayed wound closure and not used as an alternative to this or debridement [1, 120-122].

NWPT should be used in any wound that is left open following debridement until definitive surgery is performed [1].

5.2. Bone Fixation and Soft Tissue Coverage

Definitive therapy in terms of bone fixation as well as soft tissue coverage reduces overall infection rates as well as long term morbidity. Adequate reduction and realignment of the limb allows normalising of landmarks and there is much debate over internal *versus* external fixation. Whichever is chosen should minimise further soft tissue trauma, allow further debridement or assessment of the wound and closure as require. External fixation has been the preferred choice as it is quick and less invasive, although it does have additional risks such as joint stiffness and pin-site infections [123-126].

Delayed definitive soft tissue coverage is now the accepted choice worldwide, with immediate wound closure the exception. The definition of early *versus* delayed coverage however, is not a set standard. The urgency of soft tissue cover, especially in grade III injuries suggested by Godina [97] in 1986 [within 72 hours of injury] has been shown to be less required as debridement, antibiotic therapy and wound care has improved [127]. Although the 'fix and flap' technique where immediate fracture fixation, debridement and flap coverage has been observed with results not dissimilar to delayed procedures [115,128].

Definitive soft tissue coverage should be aimed for within 7 days, and studies have shown this to improve long term morbidity in terms of infection rates, bone non-union time and rate of union in comparison with further delay [129], although this should be done dependant on the adequately skilled surgical team availability, the patient's condition and the ability to adequately consent the patient for long term morbidity. This is also dependant on the grade of injury, as grade I and even II injuries may be closed primarily [130].

If amputation is indicated, studies have shown the use of the amputated limb as a donor site for the new flap is possible and helps to reduce the remaining burden on the patient, and this if often best performed at first debridement by the suitable orthoplastic team [131].

6. PATIENT FACTORS

It has been commented that the injured patient must be assessed in terms not just relating to an open fracture wound. Outcome of open fractures has been linked to several pre-injury morbidities and this should be highlighted and taken into account before a definitive therapy is chosen.

The management protocol described above unfortunately does not always improve morbidity in the open fracture patient. Patient condition is a key factor, with diabetes increasing the risk of infection and subsequently changing the definitive management, often resulting in amputation to the more distal injury [132].

The general nutritional state of the patient is important, as open fractures with or without multiple traumas increases the physiological burden on the body, and poor nutrition and physical stores will reduce the host immunity as well as increase the healing process time. Smoking has a similar input, often resulting in increased infections, delayed union rates and definitive cover failure [133,134].

Likewise, HIV infection has been shown to increase the risk of infection and may alter the ultimate decision regarding type and timing of soft tissue and bone fixation [135].

CONCLUSION

Open fractures continue to be a source of debate. Their occurrence will often be seen, more so in wartime situations, but also in urban and rural situations. Although each injury is often different in site and cause they should all be managed in a clear, structured way so that the potential life-altering complications can be kept to a minimum. This structured approach, currently is best described by the BOA/BAPRAS guideline which are well defined by the two surgical associations most present in their management. These guidelines should be followed in the majority of injuries including children who should be treated, in terms of debridement, as in the recommendations for adults [1]. The basics suggested (assessment, antibiotics and debridement) appear to be the mainstay of therapy although there is the possibility of new suggestions and adjuncts which may revolutionise the therapy of open fractures, such as the now common addition of NWPT. It must be remembered that each of these injuries although may fit into a certain classification, are related to an individual and their pre-injury morbidity as well as social, psychological and end physical needs will always play an important part in their management.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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