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Operative Techniques in
Orthopaedics

The Treatment of Open Fractures

Andrew R. Evans, MD

Patients with open fractures often present with severe soft-tissue injuries, bony injuries, and contamination that requires prompt treatment. Classifying the severity of injury is important for diagnostic and treatment purposes, including administering antibiotic prophylaxis, providing emergency room management, and executing timely surgical intervention. Surgery is performed to minimize contamination, eliminate necrotic and devascularized tissue, provide biological stabilization of the trauma-induced zone of tissue necrosis, and mechanically stabilize the soft tissues and bone. By approaching these fractures in a multi-disciplinary manner, the development of infection after open fractures can be minimized.
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Introduction

An open fracture is defined as a fractured bone that is exposed to a foreign environment associated with a risk of contamination. This can include any bone in the body that is exposed to the outside environment through a wound of any size. It can also include fractured bones exposed to unsterile regions of the body including contents of the gastrointestinal tract (eg, colon), reproductive tract (eg, vagina), or urinary tract (eg, urethra).

Open fractures present a unique series challenges to orthopaedic surgeons compared with closed fractures, as there is wound contamination and often a greater extent of injury-associated soft-tissue and bony injury. This often leaves the injury site more vulnerable to microorganism colonization and ultimately infection, as well as prone to prolonged healing.

Injury Severity Stratification

Orthopaedic surgeons are commonly faced with patients who sustain open fractures to the upper extremity, lower extremity, and pelvis (Table 1). Many of our current classification systems pertaining to open fractures and associated treatment protocols are based on studies of injuries predominantly to the lower extremities, with the prototypical example commonly being the open tibial fracture.[6,7] Whether these classification systems and treatment protocols can be extrapolated in a valid fashion to injuries of the upper extremities and pelvis remains a challenging question in need of further research.

Over the last 4 decades, many instruments have been created to serve as tools for measurement of open fractures and mangled limb injury severity.[1–5,8-10] Although formal definitions for what constitutes a mangled limb have been proposed, current literature and paradigm state that open injuries associated with fractures exist on a spectrum ranging from microscopic compromise in the soft-tissue barrier separating bone from a source of contamination (ie, bacterial translocation), all the way to traumatic amputation.

Tremendous efforts have been expended in trying to create an injury severity stratification tool that applies broadly to the entire spectrum of open fractures, including all those of the upper extremities, lower extremities, and pelvis.[1,11,12] The Gustilo and Anderson classification was derived from a study of 1025 open long-bone fractures, a significant majority of which were open fractures of the lower extremity.[6] The Gustilo and Anderson[7] classification was subsequently modified to include Types IIIA-C, which was based on a population of 87 patients with Type III open fractures, 86% of which were open fractures in long bones of the lower extremity. The studies that formulate the basis of the Gustilo and Anderson classification, and most of the literature on its application in clinical practice, does not provide sufficient evidence to demonstrate that the classification is valid when applied to open fractures of the upper extremities and pelvis.[13,14]

A variety of classification tools have also been created to assess the severity of open fractures of the extremities, many of which have attempted to correlate their index of severity with

University of Pittsburgh Medical Center, Pittsburgh, PA.
E-mail: evansar@upmc.edu

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Table 1 Various injury severity stratification classifications

Acronym	Title	Source
MESS	Mangled Extremity Severity Score	Johansen et al[1]
PSI	Predictive Salvage Index	Howe et al[2]
LSI	Limb Salvage Index	Russell et al[3]
NISSSA	Nerve Injury, Ischemia, Soft-Tissue Injury, Skeletal Injury, Shock, and Age of patient	McNamara et al[4]
HFS-97	Hanover Fracture Scale-97	Tscherne et al[5]

the ability to predict or determine whether a patient would be able to successfully pursue limb salvage vs amputation.[1-5,15-18] All of the tools listed in Table 1 were examined as part of the Lower Extremity Assessment Project Study and were found to be sub-optimally calibrated instruments for measuring injury severity or predicting amputation.[19,20]

The Orthopaedic Trauma Association (OTA) open fracture classification is an open fracture severity stratification tool that has been shown to be applicable to open fractures of the upper extremity, lower extremity, and pelvis.[21] It is able to be employed reproducibly by emergency department physicians, trauma surgeons, orthopaedic surgeons, and by resident physicians at all levels of training in each of those specialties.[22] It has been validated, and has been shown to have predictive capabilities pertaining to injuries requiring multiple debridements, negative-pressure wound therapy (NPWT), antibiotic-impregnated cement beads or spacers, and even amputation.[23]

Management of Infection Risk

Antibiotic prophylaxis protocols have largely been guided by a framework established in connection with the Gustilo and Anderson classification system.[6,7,24] Many of our current protocols are based on the work of Gustilo et al,[24] Patzakis et al,[25,26] and Dellinger et al.[27] These studies and their results were also strongly influenced by microbial profiles of open fractures in the 1970s and 1980s, some of which have changed, particularly with the development of antibiotic-resistant bacterial species. Recent studies have demonstrated that infection rates for open fractures still approach 10%, and are largely attributable to methicillin-resistance *Staphylococcus aureus* (MRSA), Gram-negative bacteria, or polymicrobial infections that are poorly covered by our current antibiotic prophylaxis protocols.[28]

Emergency Treatment

Principles of emergency management for open fractures require assessment of the patient's global condition before focusing on the open injury. Advanced Trauma Life Support protocols provide the conceptual framework by which patients with trauma should be initially evaluated.[29] The primary survey, consisting of sequential assessment and restoration of functional status to the patient's airway, breathing, circulation, neurologic disability, as well as achieving exposure of the patient and understanding their level of trauma or injury exposure, must be repeated as necessary and completed successfully. Open fractures most commonly affect the "circulation" component of the primary survey because of fracture-related hemorrhage. Adjuncts to the primary survey, including the plain anteroposterior chest and pelvis radiographs, are obtained immediately following successful completion of the primary survey.

When possible, spot or traction radiographs of limb injuries associated with open wounds, deformity, or instability, should be obtained to provide additional information. Radiographic assessment of musculoskeletal injuries early in a trauma resuscitation provides valuable information about features of the primary or secondary survey, which can be addressed to enhance the pace or quality of resuscitation. The secondary survey typically provides the greatest opportunity for clinical and radiographic evaluation of open fractures.

Clinical evaluation of patho-anatomic characteristics of open fractures has proven to be an extremely useful tool for assessing injury severity. Direct assessment of skin injury, muscle injury, arterial perfusion, bony comminution or periosteal stripping, and observable contamination serves as the conceptual basis behind the OTA open fracture classification (Fig. 1). Validity of the OTA classification has been most extensively tested in the operating room at the time of initial debridement.[22,23] However, the design of the classification also allows for it to serve as a tool for communication between physicians and may be employed during the initial phases of treatment. These observations adequately allow physicians to stratify open fractures according to the Gustilo and Anderson classification, as well as the OTA open fracture classification.

Classification of open fractures using these tools for injury severity stratification assist physicians with early treatment decisions including prophylactic antibiotic selection, and acuity with which the patient must be brought to the operating room for initial debridement. All patients with open fractures must receive tetanus prophylaxis if not reliably up to date. Critical timing for administration of prophylactic antibiotics has not been definitely established. However, best-practice is typically considered administration of prophylactic antibiotics as early in the treatment course as possible once the appropriate selection of antibiotics has been established. Antibiotic selection for prophylaxis in the setting of open fractures is typically based on guidelines shown in Table 2. Exceptions often involve the administration of vancomycin to patients with a penicillin allergy, a history of MRSA infection or colonization, or in patients who screen positively for nasal MRSA colonization. Evidence in not well established on the efficacy or safety of employing vancomycin, clindamycin, trimethoprim-sulfamethoxazole, or other broad-spectrum