Open Fractures

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Objectives
Open Fracture “Take-Home Points”

- Modern medicosurgical management has improved outcomes for patients with open fractures
- Open fractures, however, are infamous for complications
  - I.e., Infection, nonunion, malunion, chronic pain, physical and mental dysfunction
  - Increased risk with higher grade and compromised host
- Timely antibiotic administration, debridement, and fracture stabilization are of paramount importance
- Orthoplastic reconstruction is required for severe open fracture with soft tissue and/or bone loss
- Standard and innovative treatment strategies are required for limb salvage
- Amputation should be considered as part of the reconstructive armamentarium
History, BUT... We have made progress

- Open fractures were associated with high (~40%) mortality rate due to sepsis (Billroth 1866). In his series of 93 open tibia fractures: 36 deaths, 28 amputations.
- Today, timely antibiotics, thorough fracture debridement, and orthoplastic reconstruction can yield successful limb salvage for severe open fractures.
- Recent large database study showed that amputation rate for open tibia fracture between 2-3% (Mundy Orthopedics 2021). If mortality occurs after open tibia fracture today, often due to other injuries or medical complication.

Two young men with 3B open tibia fractures s/p orthoplastic reconstruction sharing their experiences of limb salvage.
Mechanism - Low Energy

- Frailty
- Poor skin quality
- Osteoporosis

- Geriatric open ankle fracture/dislocation (lateral malleolar insufficiency fracture & deltoid tear) with typical transverse medial wound
- Valgus moment on thin skin causing tearing and herniation of distal tibia

Geriatric open distal third tibia fracture requiring soft tissue coverage procedure for limb salvage
Mechanism - High Energy

- Young or old patient
- i.e., MVA, MCA, ped vs motor vehicle
- Large zone of injury
- Devitalized bone and soft tissue

Open femur fracture after high-speed traffic accident with critical-sized bone defect and soft tissue loss after open fracture care
Open Fracture from Lawn Mower

Open midfoot fracture/dislocation from lawn mower injury managed with serial I&D, limited internal fixation, trans-articular wire fixation, and hybrid ex fix

- Grossly contaminated
- Severe bone and soft tissue injury
Open Fracture from Gunshot Wound (GSW)

- Variable degree of bone and soft tissue injury based on energy/velocity of projectile
  - Low-energy gunshot treated with local wound care/fracture stabilization
  - High-energy gunshot treated with formal I&D with removal of all devitalized soft tissue and bone

Ayoub & Tarkin. Best care paradigm to optimize functionality after extra-articular distal humeral fractures in the young patient. J Clin Orthop Trauma 2018 (with permission from Elsevier)
High-Energy GSW

35yo s/p high-energy GSW treated with \textbf{I&D (x3)}, nail, antibiotic beads

Delayed autogenous bone grafting/supplemental plate fixation

50-caliber muzzleloader rifle at short range with sabot (plastic) from projectile in thigh
Impending Open Fracture

Urgent reduction/fracture stabilization necessary to avoid open fracture

Skin buttonholed in proximal humeral fracture

Open humeral shaft fracture after attempted closed management using Sarmiento brace in alcoholic

Skin tenting from clavicle fracture can cause necrosis and open fracture

Open Fracture Mechanisms
Inside Out vs Outside In

Fracture displacement causes penetration of the soft tissue envelope and open wound

vs.

Environmental object directly penetrates skin and soft tissue sleeve causing fracture/wound

Inside out - Multiply co-morbid patient with low-energy open tibia fracture
Predisposition to injury based on poor bone and skin quality

Outside in - Dirt bike handlebar
Epidemiology

- Open fracture mechanisms
  - MVC ~30%
  - Motorcycle ~20%
  - Fall ~20%
  - MVC vs pedestrian ~15%

Open fracture more common when subcutaneous bones involved (i.e., tibia, ankle)
# Classification of Open Fractures


- **Type I** – wound <1 cm, minimal contamination, comminution, soft tissue damage
- **Type II** – wound 1-10 cm, moderate soft-tissue damage, minimal periosteal stripping
- **Type IIIA** – severe soft tissue damage and contamination, coverage adequate
- **Type IIIB** – severe soft tissue damage and contamination, coverage inadequate
- **Type IIIC** – arterial injury requiring repair

*(Okike et al. *JBJS* 2006)*

• Meant to be applied after initial debridement!
Disadvantages of Gustilo-Anderson Open Fracture Classification

• Meant to be applied after initial debridement!
• Interobserver reliability ~60%
• Only directly applicable to tibia fractures
• Does not consider degree of bone loss after open fracture care
• Does not consider host factors related to healing/immune response
Gustilo-Anderson Type I & II Open Fractures

The difference in Type I vs II is *not* only wound size. Type II injuries will have greater degree of soft tissue and bone injury.

Rate of complications such as infection and nonunion for Type I-II injuries, however, are significantly less than Type III Injuries.
Gustilo-Anderson Type III Open Fractures

High-energy injuries with significant damage to the soft tissue sleeve and bone
Heightened risk of complication (infection, nonunion, chronic pain/dysfunction)

IIIA open tibia fractures will have sufficient soft tissue coverage

IIIB open tibia fractures will require soft tissue coverage, typically rotational or free flap

Significant debridement of crushed dysvascular tissue, particularly muscle, is typically the rule!
Critically ill polytrauma patient s/p MCA with 3C open contaminated tibia fracture with significant bone loss, profound degree of nonviable muscle, and pulseless foot secondary to vascular injury

Amputation performed as definitive reconstructive option using multi-disciplinary decision-making process
Classification of Open Fractures (OTA)

OTA classification
(OTA Study Group- *JOT* 2010)
• Based on 5 categories:
  1) Skin injury
  2) Muscle injury
  3) Arterial injury
  4) Contamination
  5) Bone loss

May be superior to Gustilo-Anderson in predicting outcomes (Hao et al. *JOT* 2016)
Open Fracture-Associated Conditions
Nerve Injury

Peripheral nerves are vulnerable to injury, with greater fracture displacement typically seen with open fractures secondary to direct injury and/or stretch.

Type I open segmental humeral fracture associated radial nerve neuropraxia
Radial nerve injury infamously at risk with distal 1/3 fractures (Holstein-Lewis)
Open Fracture-Associated Conditions

Vascular Injury

Reverse saphenous vein graft for arterial injury after open elbow fracture/dislocation
Open Fracture-Associated Conditions
Tendon and Ligament Injuries

• Beyond critical neurovascular structures, optimal functionality predicated on uneventful healing of tendon and ligament injuries
• Either acute or delayed reconstruction indicated to promote best outcomes
Open Fracture-Associated Conditions
Compartment Syndrome

Open fractures are at increased risk for CS necessitating fasciotomy—especially high-energy cases.

Floating knee (open fractures of the femur and tibia) managed with I&D of open wounds, retrograde femoral nail, antegrade tibial nail, and fasciotomies of the thigh and leg for associated compartment syndrome.

Necrotic muscle from delayed compartment release in open tibia fracture.

Low threshold to perform fasciotomy in case of high-energy open fracture to avoid compressive ischemia of traumatized muscle.
Antibiotics – Timing & Type

- Crucial to start antibiotics early
  - Obremskey et al. *JOT* 2014 – 86% of orthopaedic trauma surgeons responded that <1 hour to antibiotics is optimal after open fracture

- Antibiotic determined by severity of fracture
  - Ancef for Type I & II (clinda/vanc if penicillin allergic) (Garner et al. *JAAOS* 2020)
  - Gentamicin can be added for Type III, though fallen out of favor given concerns for kidney toxicity
  - Zosyn appropriate alternative to Ancef+Gent (Redfern et al. *JOT* 2016)

Grossly contaminated Type IIIA open distal femur fractures with traumatic knee arthrotomies received Zosyn within 1 hour of presentation. Tetanus was up to date.
Antibiotics - Duration

24 hours adequate for Type I and II open fractures (Hoff et al. *J Trauma* 2011)

Longer for Type III (72 hours?), though length is controversial (Chang et al. *JBJS Rev* 2015)

Contaminated Type III fractures of distal femur, proximal tibia, and tibial pilon given Zosyn within 1 hour of presentation and continued for 72 hours

Judgment!... Duration of therapy dictated on host and injury factors (ie severity of wound, patient co-morbidities)
Antibiotics - Local

May be role for local antibiotics as well (Morgenstern et al. Bone Joint Res 2018)
Can be with or without carrier (e.g. beads/spacer)

Open femur fracture from industrial grinder accident (grossly contaminated with bone defect)
Staged by on-call surgeon with cement beads in bone defect as antibiotic carrier

Bone healing after delayed bone grafting/plating over retained nail
Initial Care in Emergency Department

- Antibiotics! Tetanus, betadine/saline gauze, temporizing immobilization (splint, skeletal traction, external fixation)

Field splint by EMS with traumatic wound covered with betadine-impregnated gauze

Type I??
Determine after debridement!

"Halt the Cycle of Injury!"

Mehta et al 2010 JAAOS
Timing of Operative Debridement

Earlier the better! from the “Journal of Common Sense”
As long as competent resources are available and patient physiologically stable

The Science

• “6-hour rule” - based on guinea pig study in 1898

• No difference in infection rates between early and late debridement (Schenker et al. JBJS 2012)

• However, no argument that highly contaminated wounds should go to OR ASAP
Principles of Open Fracture Wound Care

- Extend the traumatic wound to appreciate zone of injury/facilitate comprehensive debridement
- Preserve vascularity to the traumatic wound
- AVOID sharp angles when extending wound (<90 degrees)
- Optimize base width of skin flap to maximize vascularity from subdermal plexus
Debride Open Fracture Through Surgical Wound

- Extension of traumatic wound commonplace for open fracture care
- However, if wound over exposed bone and cannot be closed primarily or delayed, flap coverage necessary

Alternative- close traumatic wound(s) over exposed bone and make surgical wound to debride open fracture, which typically will require a split-thickness skin graft (STSG)
Debridement of Open Fracture

Remove any dysvascular, nonviable tissue that will ultimately serve as nidus for infection (skin, subcutaneous tissue, MUSCLE, and bone)

Healthy muscle will contract with electrocautery stimulation
-less reliable after muscle has produced granulation tissue in response to NPWT
Osseous Debridement

Remove bone without meaningful soft tissue attachment

Debride IM canal (hidden environmental contamination)

“Tug Test” (Southam et al. JOT 2017)

Critical-sized bone defect after debridement

Debridement and Irrigation

FLOW Investigators *NEJM* 2015 -RCT
- Low-pressure irrigation an acceptable alternative to high flow.
- Reoperation rate lower in saline group (vs soap)

Pendulum has swung toward low-pressure irrigation due to concerns about...
- Bone damage (Bhandari et al. *JOT* 1999)
- Propagation of bacteria into soft tissue with high-pressure irrigation (Hassinger et al. *CORR* 2005)

Traditional Teaching
- 3L for Type I
- 6L for Type II
- 9L for Type III
Fracture Reduction
Take advantage of traumatic wound to obtain fracture reduction
Traumatic Wound Care

Primary closure preferred if skin edges are free of significant tension after suture repair (Scharfenberger et al. JOT 2017)
Zone of Injury
Case 2

• Open femur fracture/traumatic knee arthrotomy in young woman after MCA
• Traumatic wounds extended to appreciate extent of bone, joint, and soft tissue injury
• Organized debridement to remove all devitalized soft tissue and bone
• Bone ends delivered to debride IM canal
Principles of Open Fracture Care

Nonviable tissue (including bone) serve as a nidus for infection and should be excised

Type IIIA open distal femur fracture after MCA
- Bone without meaningful vascular attachment removed

Level of aggressiveness debatable BUT... “When in Doubt Take It Out”


Remove Environmental Contamination

- Extent of contamination may not be obvious
- The entire zone of injury needs to be explored to remove environmental debris in addition to nonviable tissue
- IM canals need to be exposed and debried as well
Skeletal Stabilization of Open Fracture - External Fixation

- Polytrauma - damage-control orthopaedics (DCO)
- Complex peri-articular fractures

- Critically ill, under-resuscitated polytrauma patient with multiple open fractures
- Rapid I&D/ex fix as temporizing skeletal stabilization

External fixation
Definitive skeletal stabilization for severe open fracture

Indications:
• Gross environmental contamination
• Contraindication to internal fixation present
• Anticipated need for lengthening procedure
Internal Fixation for Open Fracture

• If a clean wound bed achievable after open fracture care, definitive fixation is INDICATED at index procedure
• Intramedullary nailing is the “workhorse” for most open diaphyseal and extra-articular meta-diaphyseal cases of the lower extremity
• Plate osteosynthesis is typically employed for open peri-articular cases

Exacting reduction of intra-articular fractures is of paramount importance for best outcomes
Intramedullary Nailing for Open Fracture

Nailing limits surgical exposure necessary for fracture stabilization - “biologic fixation”
Avoids tension on soft tissue sleeve (vs plating), thereby facilitating traumatic wound closure

42yo with Type II open tibia fracture after MCA
Traumatic wound closed primarily after I&D with reamed nail
Intramedullary Nailing for Open Fracture

Excellent bridging device for open diaphyseal fractures with bone loss
Intramedullary Nailing for Open Fracture
Positioning plate as adjunct in open tibia

Reduction with open manipulation through wound

69yo s/p fall down steps with Type II open distal 1/3 tibia fracture
Segmental Open Tibia Fracture

Nailing adjuncts

- Small fragment plate used as preliminary reduction tool prior to nailing
- Plate prevents segmental piece from “spinning” during reaming process
- Increases construct rigidity
Nailing for Open Femur Fracture

18yo polytrauma patient with Type I open femur fracture after MVC s/p retrograde IMN with uneventful healing

- Retrograde nail is an effective and efficient technique for open femur fracture in the polytrauma patient
- Zone of injury is explored through extension of traumatic wound
- Nonviable skin, subcutaneous tissue, fascia, MUSCLE, and bone excised
- Bone ends harvested and IM canals debrided
Open Peri-Articular Fracture - Goals of Care

- Anatomic joint reconstruction (with intra-articular involvement)
- Alignment of reconstructed articular block to shaft
- Restoration of length, alignment, rotation of articular block to shaft
Managing Bone and Soft Tissue Defects after Open Fracture

• Early primary closure should be attempted if soft tissues allow
• Soft tissue coverage should be obtained within 7-10 days (Melvin et al. JAAOS 2010) if critical-sized soft tissue defect
• Bone grafting strategies should typically be performed delayed once soft tissue envelope has healed/revascularized without signs of infection
Open Fracture Wound Management

- Early primary closure of the traumatic open fracture wound preferred
- Healing the traumatic wound integral to avoiding infectious complications
- **Caveat** - Skin edges vascularized and closure without excessive tension
Negative Pressure Wound Therapy (NPWT)
Temporizing option for critical-sized soft tissue defect associated with open fracture

- Protects/seals open fracture wound from environmental contamination (nosocomial infection)
- Negative pressure applied to traumatic wound promotes neovascularization/wound granulation and removes deleterious edema fluid
- Prepares tissue bed for soft tissue coverage (e.g., flap)

- 3B open tibia fracture in polytrauma patient
- Wound vac/ex fix used as temporizing measure as part of damage-control orthopaedics

Tarkin. The versatility of negative pressure wound therapy with reticulated open cell foam for soft tissue management after severe musculoskeletal trauma. JOT 2008.
Soft Tissue Coverage after Open Fracture

- Options depend on location of injury and presence of exposed bone (Boss and Buehler *JAAOS* 1994)
- For tibia fracture with exposed bone and/or joint
  - Proximal third - gastrocnemius rotational
  - Middle third - soleus rotational
  - Distal third - free flap

Timing of coverage after open tibia < 7 days with interval vac coverage recommended

D'Alleyrand *JOT* 2014,
Hou *J Trauma* 2011
Pincus *JOT* 2019

Rotational flap/STSG used to cover knee and fractures of the proximal/middle tibia
Management of Bone Defect Associated with Open Fracture

Autogenous bone grafting (delayed!)

Autogenous bone grafting strategies are reliable after...
- Soft tissue envelope has recovered (re-vascularized)
- Rigid mechanical environment present

Iliac crest bone graft—gold standard
- Osteoconductive
- Osteoinductive
- Osteogenic

Reamer Irrigator Aspirator (RIA) method as alternative

Quintero, Tarkin, Pape. Technical tricks when using the reamer irrigator aspirator technique for autologous bone graft harvesting. JOT 2010.
Posterolateral Bone Grafting

- Classic strategy for bone grafting open tibia fracture with nonunion and/or critical-sized bone defect
- Nonunion debrided of fibrous scar
- Medial portion of fibula decorticated
- Graft deposited on interosseous membrane from fibula to tibia
- “Creation of synostosis”
Management of Bone Defect after Open Fracture
Masquelet technique

- Critical-sized bone defect often realized after open fracture care
  - Sterilization of previously contaminated environment
  - Creates of vascularized space/envelope ideal for delayed bone grafting

- Open ulna fracture with critical-sized bone defect after open fracture care managed initially with plate osteosynthesis/antibiotic spacer
- Tricortical grafting then performed in delayed fashion
Open Distal 1/3 Tibia with Bone Defect
Induced membrane technique

- Critical-sized defect after debridement
- IM nail as bridging device
- Antibiotic beads applied to defect

26yo s/p multiple GSW

- Removal of beads
- Autograft applied in vascularized pocket
- Plate over retained nail
Open Supracondylar Femur Fracture
Masquelet technique

Figures from – Dugan, Tarkin et al. Open supracondylar femur fractures with bone loss in the polytraumatized patient—Timing is everything! *Injury* 2013 (with permission from Elsevier)
Management of Bone Defect after Open Fracture
Acute shortening (+/- lengthening)

- Technique used to simplify management of open fracture with both bone and soft tissue defects
- Typically reserved for severe cases in lower-demand hosts
- Option for delayed lengthening procedure

- Open pilon fracture with metaphyseal bone loss and transverse medial wound
- Traumatic wound could be closed without tension after shortening

- Bone transport options include those such as the Ilizarov technique (Cattaneo et al. CORR 1992) or newer techniques using magnetic intramedullary limb lengthening system (Barinaga et al. JAAOS 2018)
Salvage for Severe Open Fracture (limb threatening)

- Requires individualized treatment plan based on injury, host factors, patient goals and expectations
- Standard, unconventional, and innovative treatment options
- Think “Out of the Box” when standard treatments not reliable (Cole 2006)

Clinical judgment!!!

- Intramedullary nailing
- Open reduction internal fixation
- External fixation
- Selected fusion
- Arthroplasty
- Combinations of above or OTHER

Amputation (i.e., BKA, AKA) should also be considered as part of the treatment armamentarium (as opposed to “treatment failure”)

Clinical judgment!!!
Arthroplasty for Open Fracture
Lower extremity
Used for primary reconstruction or for nonunion, malunion, arthrosis after open peri-articular fracture - esp peri-prosthetic in geriatric host

Hoellwarth, Tarkin et al. Equivalent mortality and complication rates following periprosthetic distal femur fractures managed with either lateral locked plating or a distal femoral replacement. Injury 2018.

TEAMWORK!!!

78yo with open femur fracture after horseback riding accident failed ORIF with infected nonunion - staged DFR
Innovative Treatment Solutions for Open Fracture

25yo s/p close-range GSW to talus, which was not amenable to ORIF. Patient did not want to pursue TTC fusion.

Metal talus?
Formal Arthrodesis for open peri-articular fracture

Select open peri-articular fractures with profound cartilage injury or loss

Severe open talus fracture with bone/joint loss after MCC managed with TTC fusion and delayed bone grafting

Tricortical graft from pelvis to span tibia to calcaneus

Open distal radius fracture (transverse volar wound) with diminutive articular block treated with open fracture care and dorsal spanning plate to internally splint the fracture and soft tissue wound)
Decision for Limb Salvage

The decision for amputation vs salvage is typically not as clear as in this extreme case.
Amputation
Definitive reconstructive option after severe open fracture (ieBKA)

LEAP Study
• 601 patients
• Multicenter
• No significant difference in functional outcomes for limb salvage vs amputation


S/p open distal femur fracture and mangled leg managed with open fracture care after boating propeller - distal femur ORIF and BKA. Patient returned to water skiing with prosthesis

BKA with posterior myofascial cutaneous flap
Complications after Open Fracture

- Unfortunately common
  - Infection
  - Nonunion
  - Malunion
  - Arthrosis
  - Chronic pain
  - Physical dysfunction
  - Psychosocial distress
Open Fracture Complications

Infection

Etiology of infection after open fracture secondary to...

- environmental contamination,
- compromised soft tissue envelope (i.e., vascularity),
- delayed or frank failure of wound healing, and/or host factors (polytrauma, co-morbid conditions, nutritional deficiency)

Are you on call? One of my partners at [redacted] has an open pilon. Pt fell from a roof into mulch. He washed it out, ex fixed, but still needs definitive fixation and plastics

This is all mulch...
Open Fracture Complications

Nonunion

“Anticipated” nonunion - Critical-sized bone defect initially managed with antibiotic beads

Ineffective healing response after bridge plating

Open Fracture Complications
Deformity/Malunion

- Patient referred after treatment for open tibia fracture with ambulatory dysfunction secondary to varus malunion
- Post-traumatic reconstruction (osteotomy) required to restore mechanical axis

Infected nonunion/malunion (varus collapse) treated with serial debridements, interval external fixation, osteotomy, and tricortical wedge graft/Internal fixation

Open Fracture Outcomes

Infection, nonunion, and secondary amputation predicted by host factors and severity of injury

Functional outcomes improving, but significant impacts on health-related quality of life

Outcomes of severe open fractures most commonly predicated on “economic, social, and personal resources”

Bowen CORR 2005
N=195 open fractures
As compared to Type A (healthy) Hosts
• Type B had 2.86X infection risk
• Type C had 5.72X infection risk

Westgeest JOT 2016
N=791 open fractures
• Infection and higher Gustillo Grade associated with risk of fx nonunion

Giannoudis at al. Injury 2009- Grade 3B/C open tibia fractures associated with ongoing pain and difficulties with activities

Summary

• Open fractures are a surgical urgency requiring thorough debridement/irrigation and skeletal stabilization

• External and internal fixation, amputation, as well as innovative strategies are necessary for skeletal reconstruction of open fractures

• Orthoplastic reconstruction is often necessary for open fracture with soft tissue loss

• Complications are commonplace with open fracture including infection and nonunion as well as physical and psychosocial dysfunction

• Host, injury pattern, and treatment plan will influence outcome after open fracture
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Thank you for your attention...

s/p IIIB open tibia fracture enjoying his grandchildren