

Pediatric Tibial Shaft Fractures

Kyle Schweser MD
University of Missouri



Disclaimer

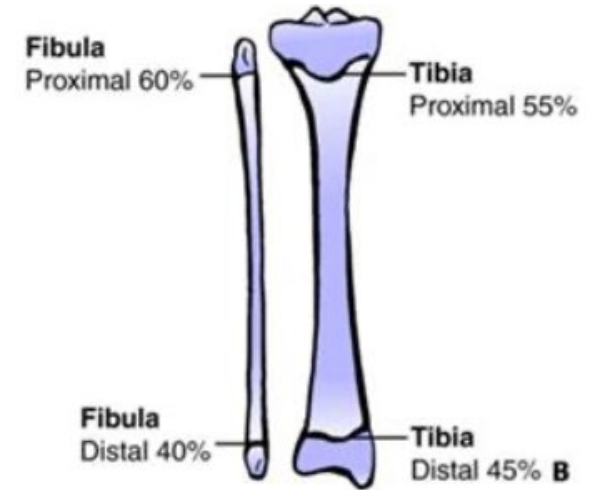
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Objectives

- Discuss important initial evaluation of tibial shaft fractures
- Create an algorithm for treatment of tibial shaft fractures
- Identify specific fracture types and complications
- This lecture also contains a **Compartment Syndrome Supplement at end of presentation**

Growth of the Tibia/Fibula

- Growth from two physes
 - Proximal tibia: 6mm/yr
 - Distal tibia: 5mm/yr
 - Proximal fibula: 6.5mm/yr
 - Distal fibula: 4.5 mm/yr
- Proximal tibial physis closes posterior to anterior
- Tibial tubercle closes proximal to distal
- Distal tibial physis closes central to medial then lateral



Waters, P. M., Skaggs, D. L., Flynn, J. M., & Rockwood, C. A. (2020). Chapter 5: Physeal Injuries and Growth Disturbances. In *Rockwood and Wilkins' fractures in children* (pp. 930-966). Philadelphia, PA: Wolters Kluwer.

Incidence

- 15% of all long bone injuries in children
 - 39% in the diaphysis
 - Third most common (femur>humerus>tibia)
- Average age: 8
- Boys > Girls
- 26% of abused children
 - Second most common fracture in abuse
 - 1st is humerus
 - Most commonly occurs in the proximal metaphysis in abuse

Mechanism and Characteristics

- Younger children
 - Torsional mechanism
- Older children
 - Sports/motor vehicle trauma
- Short oblique/transverse is most common pattern
- 2/3 have no fibula fx
 - Risk of varus malalignment
- 1/3 have an associated fibula fx
 - Risk of valgus malalignment
- Malalignment risk regardless of operative vs conservative management
 - Up to 40% malunion risk even in operative patients



Evaluation

- History
 - Mechanism important in pediatric fractures
 - History of multiple fractures should raise concerns
- Physical Exam
 - Examine entire body
 - Don't miss an open fracture
- Imaging
 - Image entire fractured bone
 - Image joint above and below
 - Skeletal survey if abuse suspected



History

- History
 - Same for adults
 - Mechanism, quality/quantity of pain, location of fracture, etc
 - Different from adults
 - Need to rule out abuse
- Most pediatric tibia fractures present after a known trauma
 - NAT should always be considered in the young children
 - Especially non-ambulatory
 - Most NAT injuries are metaphyseal

Exam

- Evaluation of the whole body
 - Bruising/skin lesions common in abuse
 - Areas of tenderness/deformity
 - Especially in those who can't communicate
- Anteromedial tibia is subcutaneous
 - Any laceration should raise concern for an open fracture
- Perform a good neurovascular exam
 - Doppler pulses if not palpable
- Children do not malingering
 - Refusal to bear weight is a sign something is wrong
 - Limping, but an ability to walk, does not eliminate fracture
 - Toddler's fracture



Compartment Syndrome

- Incidence
 - Up to 11% of pediatric tibia fractures
 - 40% of pediatric compartment syndrome due to tibia fxs
 - >80% associated with high energy
- The 6 P's for older children can still apply
 - Pain out of proportion, paresthesias, pulselessness
 - Pallor, poikilothermia, and paresis
- Typical findings unreliable in younger children
 - Use the three A's
 - Analgesic requirement increasing
 - Anxiety
 - Agitation

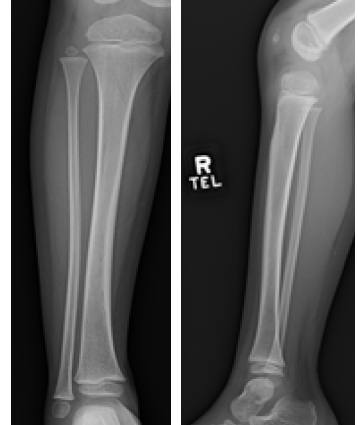


*Hak DJ. Acute Compartment Syndrome in Children. 2019 Sep 3. In: Mauffrey C, Hak DJ, Martin III MP, editors. *Compartment Syndrome: A Guide to Diagnosis and Management*. Cham (CH): Springer; 2019. Chapter 13

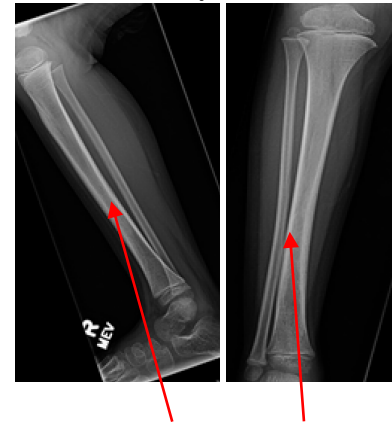
Imaging

- All tibia fractures should include
 - 2 view full length tibia films
 - Ankle and knee joints must be included
 - Can forgo in young children if the tibia film captures the foot and distal femur
- If initial x-rays negative, but high clinical suspicion
 - Protect, repeat x-rays in 1-2 weeks
- If abuse is suspected
 - Skeletal survey
- Advanced imaging often not necessary
 - Distal third fractures may require CT to evaluate joint/physeal involvement

Injury film



3w f/u XR



Periosteal reaction now visible

Fracture Patterns

- Fracture pattern associated with mechanism
 - Low energy → rotational
 - Spiral fractures of the tibia
 - Fibula fracture either
 - At a different level
 - Not present
 - Direct impact (sports, nonaccidental)
 - Transverse fracture
 - High energy
 - Short oblique or butterfly fragment
 - Comminuted (axial load)
 - Fibula fracture close to the same level



Low energy torsion-no
fibula fracture



High Energy
Core Curriculum V5

Classification

- No current classification system
 - Describe location (proximal, midshaft, distal)
 - Describe pattern (oblique, transverse, segmental, etc)
 - Describe mechanism and age



Treatment

- Algorithm based on multiple factors
 - Patient factors
 - Fracture characteristics
- The majority can be treated closed
- Most heal quickly
 - Toddlers: 3-4 weeks
 - Juvenile: 6-12 weeks
- Nonunions are rare
 - Usually occur in the setting of infection, open fractures, bone loss
 - Certain treatment methods can increase nonunion rates (i.e. external fixators)

3m f/u (5y/o)



Closed Treatment

- Most uncomplicated tibial shaft fractures can be casted
 - Cost-effective
- Goal is acceptable alignment
 - Acceptable initial alignment controversial
 - Based on age
 - Older patients accept less deformity
 - Secondary to limited remodeling potential
- Intact periosteal hinge (especially low energy) facilitates reduction
- As age increases → more consideration for surgery



*Hogue GD, Wilkins KE, Kim IS. Management of Pediatric Tibial Shaft Fractures. J Am Acad Orthop Surg. 2019 Oct 15;27(20):769-778

Closed Treatment

Acceptable initial alignment for closed treatment*

Younger than 8

- Coronal
 - Varus: 10°
 - Valgus: 5°
- Sagittal
 - Apex anterior: 10°
 - Apex posterior: 5°
- Shortening: 10 mm
- Rotation: 5°
- Cortical Overlap > 50%

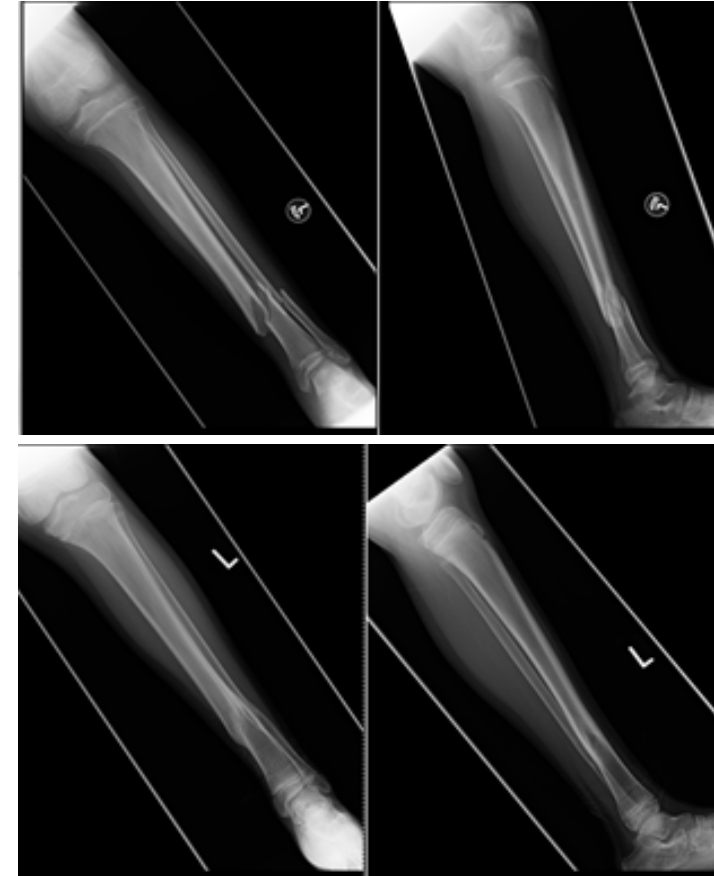
Older than 8

- Coronal
 - Varus: 5°
 - Valgus: 5°
- Sagittal
 - Apex anterior: 5°
 - Apex posterior: 0°
- Shortening: 5 mm
- Rotation: 5°
- Cortical Overlap > 50%

Waters, P. M., Skaggs, D. L., Flynn, J. M., & Rockwood, C. A. (2020). Chapter 25: Fractures of the shaft of the tibia and fibula. In *Rockwood and Wilkins' fractures in children* (pp. 930-966). Philadelphia, PA: Wolters Kluwer.

Closed Treatment

- Remodeling is limited and not reliable in the tibia
 - Capacity is greatest in the plane of joint motion
- Apex anterior easily accommodated with knee flexion for ambulation
 - Apex posterior requires knee hyper-extension
- Initial slight varus > valgus alignment potentially ok with intact fibula because of a tethering effect
 - With an intact fibula, the overgrowth in healing occurs only on the tibia, causing a valgus force as the tibial growth is temporarily increased compared to the fibula
 - However, must be monitored as an intact fibula is a risk factor for eventual varus malalignment
- Rotation poorly corrected with remodeling



10 y/o M with 10month f/u

Closed Treatment

- Casting principles
 - Long leg (above knee) cast
 - Can provide rotational control if necessary
 - Can prevent weight bearing if knee is bent
 - If applying the cast in stages (for young children who can't cooperate)
 - Apply cast for a short leg, creating your mold, allowing to set
 - Then apply long leg component with knee flexed 20-40 degrees

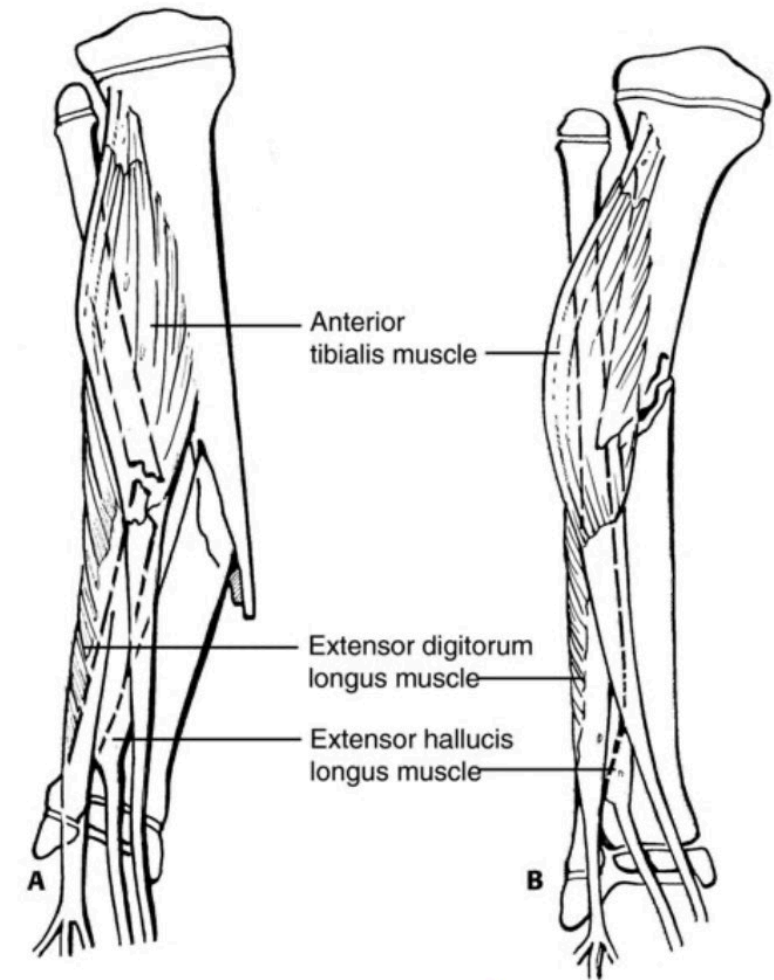


Closed Treatment

- Tibia fracture with associated fibula fracture
 - Apply a varus mold
 - Valgus collapse is common
- Tibia fracture with intact fibula
 - Apply a valgus mold
 - Varus collapse is common → 60%
- Foot plantarflexion can prevent apex posterior angulation

Associated fibula fx

Intact fibula



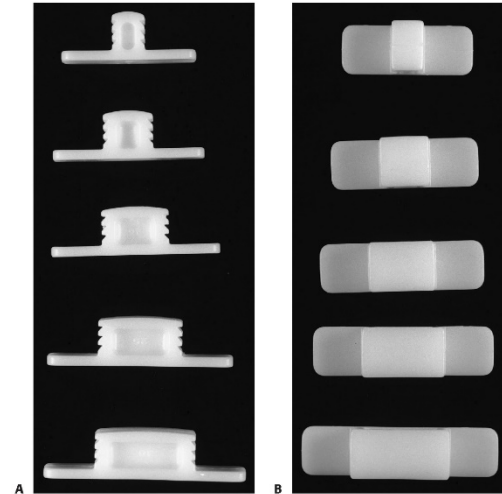
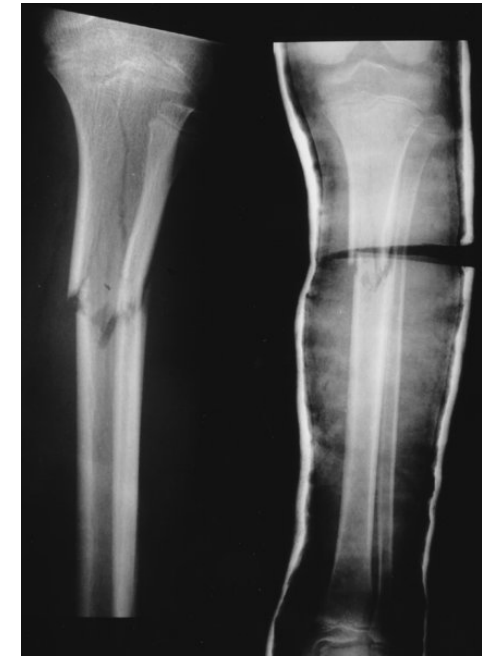
Waters, P. M., Skaggs, D. L., Flynn, J. M., & Rockwood, C. A. (2020). Chapter 5: Physeal Injuries and Growth Disturbances. In Rockwood and Wilkins' fractures in children (pp. 930-966). Philadelphia, PA: Wolters Kluwer.

Closed Treatment

- Bivalve cast in patients with swelling concerns
- Consider overnight inpatient monitoring in those requiring reduction
- Weekly radiographs are taken until bridging callus is seen
- Cast wedging in clinic can be utilized to correct interval displacement
 - Can be done within first 3 weeks from fracture

Closed Treatment: Wedging

- Technique
 - An opening is made in the patients cast
 - Typically done at the apex of deformity
 - Opening wedges can have cast material, or premade wedges, inserted in the gap
 - Once corrected, the cast is overwrapped with new cast material
 - Care must be taken to protect soft tissue



Proprietary cast wedges

*Hogue GD, Wilkins KE, Kim IS. Management of Pediatric Tibial Shaft Fractures. J Am Acad Orthop Surg. 2019 Oct 15;27(20):769-778

Closed Treatment

- Tibial diaphyseal fractures
 - Long leg cast for 4-6 weeks
 - Transition to patellar-tendon bearing cast vs short leg cast vs removable for further protected weightbearing
 - No immobilization necessary after sufficient healing noted



*Hogue GD, Wilkins KE, Kim IS. Management of Pediatric Tibial Shaft Fractures. J Am Acad Orthop Surg. 2019 Oct 15;27(20):769-778

*Raducha, Jeremy E. MD1; Swarup, Ishaan MD2; Schachne, Jonathan M. BA2; Cruz, Aristides I. Jr. MD, MBA3; Fabricant, Peter D. MD, MPH2 Tibial Shaft Fractures in Children and Adolescents, JBJS Reviews: February 2019 - Volume 7 - Issue 2 - p e4

Closed Treatment

- Cast controversies
 - WB vs NWB
 - Low-energy tibia fractures can weightbear as tolerated- but with increased risk of displacement
 - Kids tend to self regulate, especially the younger they are
 - Toddler's fractures are typically stable enough to allow WB

*Silva, Mauricio, et al. "A comparison of two approaches for the closed treatment of low-energy tibial fractures in children." *JBJS* 94.20 (2012): 1853-1860.

*Joshua W.B. Klatt, MD; Alan K. Stotts, MD; John T. Smith, MD Isolated Pediatric Tibial Shaft Fractures Do Not Need to be Treated in Above-Knee Cast, Fri., 10/15/10 Knee, Tibia & Pediatrics, Paper #61, OTA-2010

Bauer, Jennifer M. MD, MS; Lovejoy, Steven A. MD† Toddler's Fractures: Time to Weight-bear With Regard to Immobilization Type and Radiographic Monitoring, *Journal of Pediatric Orthopaedics*: July 2019 - Volume 39 - Issue 6 - p 314-317



Open Fractures

- Treat the same as adults initially
 - **Early antibiotic administration**
 - Type 1 and 2 → First generation cephalosporins
 - Type 3 → Add aminoglycoside
 - Soil contamination → Add penicillin
 - Fresh water contamination → Add fluroquinolone
 - **Confirm tetanus status and update if needed**



Open Fractures

- Timing to debridement
 - Controversial
 - Consider all factors
 - Emergent
 - Compartment syndrome
 - Neurovascular injury
 - Significant contamination
 - Urgent
 - Moderate contamination
 - Skin at risk
 - Irreducible fracture
 - Within 24 hrs
 - Clean wounds
 - Reduced fractures
 - Stable patients



Surgical Treatment

- Indications for surgery
 - Open fractures
 - Compartment syndrome
 - Soft tissue defect not conducive to casting
 - Multiple extremity fractures
 - Unacceptable alignment after closed reduction
 - Segmental fractures
 - Neurovascular injuries



Surgical Treatment

- Majority of surgical patients tend to be
 - Older (> 10 years)
 - Both tibia and fibula fractured (length instability issues)
 - High degree of initial displacement



Surgical Treatment

- Surgical options
 - Pinning and casting
 - External fixators
 - Uniplane
 - Multiplane
 - Intramedullary nails
 - Rigid
 - Flexible
 - Plate fixation
- While most can be treated closed, surgical fixation rates are increasing



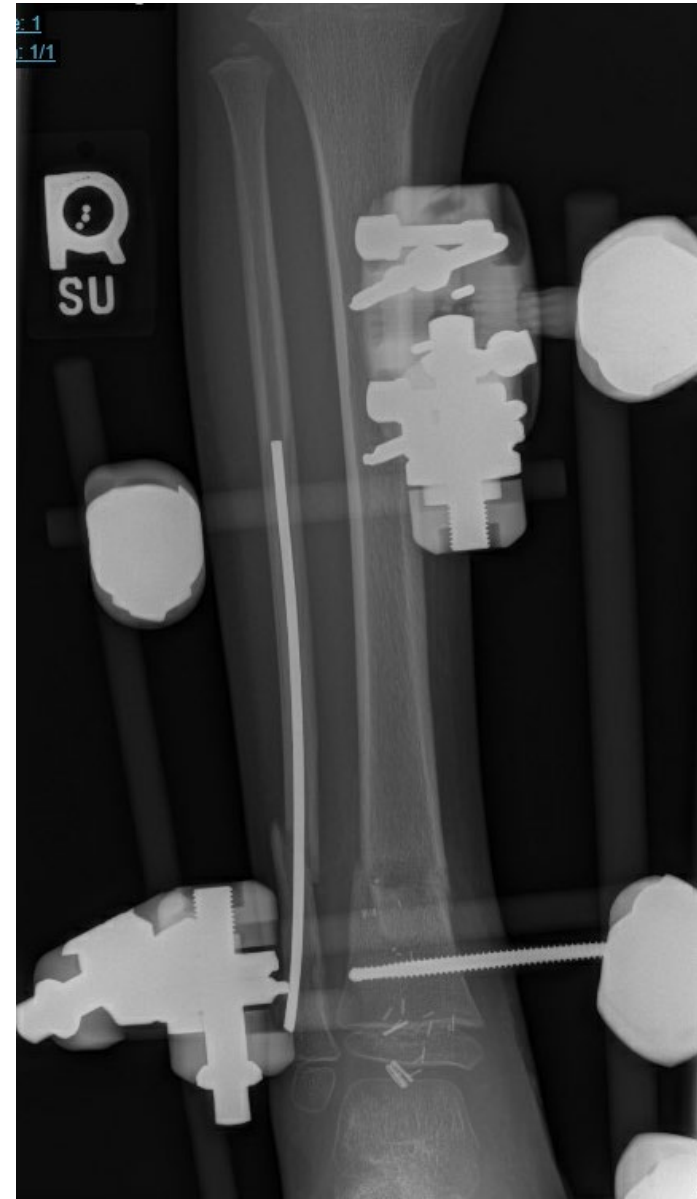
Surgical Treatment

- Pinning and Casting
 - Typically utilized with unstable patterns and compromised soft tissue
 - Type 1 open, transverse fracture
 - *Type 2 and 3 open fractures typically require more rigid stabilization than wires provide*
 - Can be used in both open and closed fractures
 - When possible, pins should be placed away from compromised tissue
 - Pins should avoid tendons/sheaths and neurovascular structures
 - Cast placed over pins
 - Pins removed at 4 weeks
 - Additional casting vs boot depending on healing



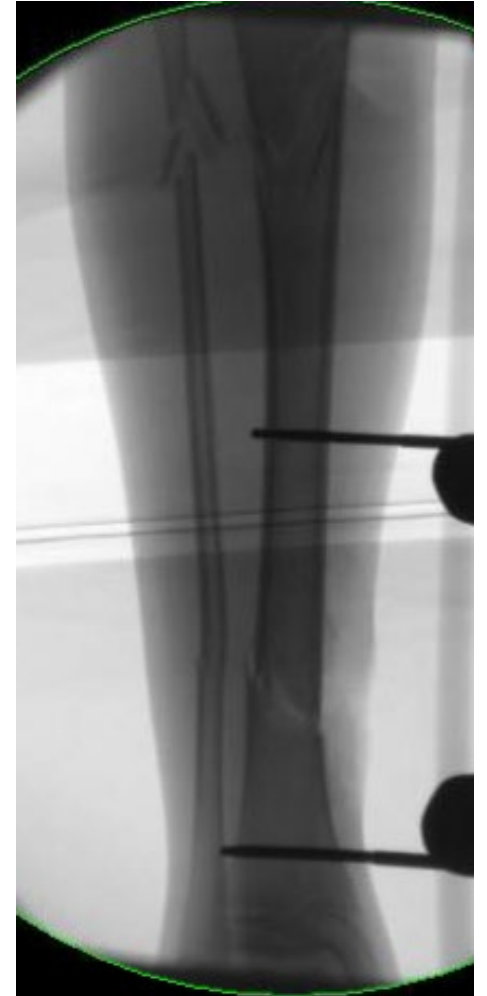
Surgical Treatment

- External fixation
 - Indications similar to adults
 - High energy fractures
 - Soft tissue not amenable to fixation or casting
 - Length unstable fractures
 - Can be used for definitive, or temporary treatment
 - Unique complications compared to other operative techniques
 - Pin site infections
 - Slower union rates
 - Requires procedure for removal



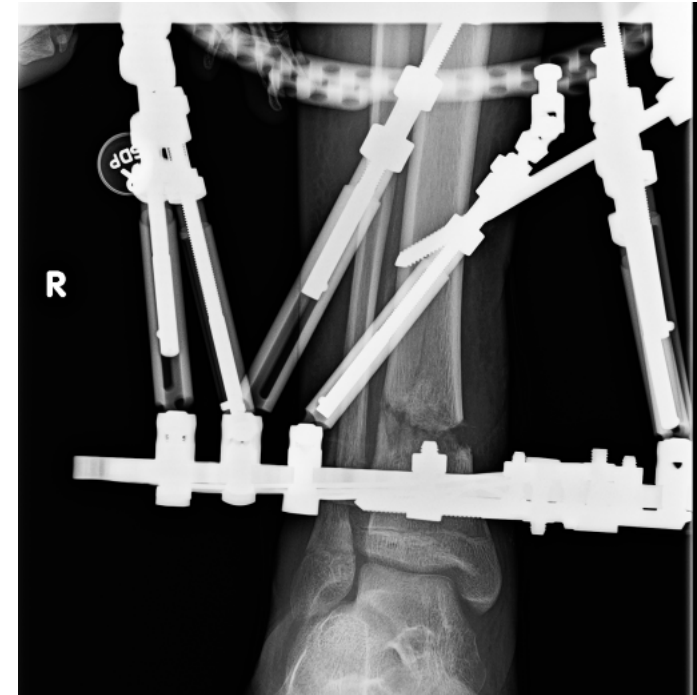
Surgical Treatment

- Uniplane external fixators
 - Typically used in an acute traumatic setting
 - Converted to other forms of treatment when able
 - Can convert to casting once soft tissue stabilize
 - Can be used definitively
 - Prolonged NWB period
 - Older patients (>12 y/o) have increased risk of
 - loss of reduction
 - Delayed healing
 - Younger patients have increased risk of leg length discrepancy
 - Secondary to local hyperemia or growth factor release stimulating physeal growth



Surgical Treatment

- Multiplane external fixators
 - Typically reserved for
 - Significant bone loss
 - Significant soft tissue injury
 - Allows flap placement/management
 - Late presentation/malunion with large deformity
 - Benefits
 - More stable than uniplane
 - Allows for immediate WB
 - Ability to adjust alignment (especially multi-directional correction)
 - Constructs are bulky and expensive



Surgical Treatment

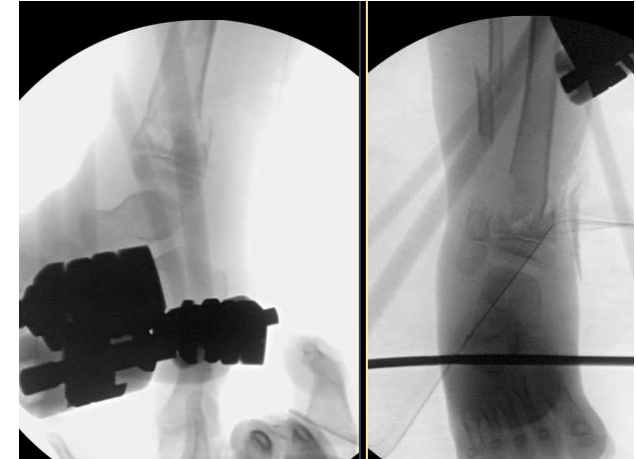
- External Fixator
 - Pin placement should be outside of the zone of injury
 - Zone of injury includes the soft tissue injury, not just bony injury



Picture of an adult patient, but demonstrates the consequences of pin placement w/in zone of injury

Surgical Treatment

- External Fixator
 - Ok to span the knee, or ankle, if necessary
 - Plan pin/bar/strut placement to allow for treatment/coverage of soft-tissues
 - Circular fixation allows multiple smooth tensioned wires in short segments and small bones
 - Can combine with AFO splint to prevent equinus contracture
 - Pins should not be placed closer than 1cm to the physis



Surgical Treatment

- Flexible nails
 - Can be utilized in both open or closed fractures
 - Similar rates of infection in open fractures when compared to closed
 - Fractures need to be length stable
 - Ideal is a transverse, diaphyseal fracture



Surgical Treatment

- May require immobilization after insertion
 - Shorter than with casting alone
- Indications:
 - Unacceptable alignment after CRC
 - Polytrauma
 - Floating knee injuries
 - Extensive soft-tissue injury
 - Associated compartment syndrome
 - Spastic patients



Surgical Treatment

- Flexible nails
 - Benefits
 - Avoids the physes
 - Soft tissue friendly
 - Shorter immobilization time compared to casting
 - Earlier WB when compared to casting
 - Require additional procedure for removal
 - 9-12 months post op
 - Implant can irritate the skin
 - Union 8-20 weeks



Surgical Treatment

- Flexible nails
 - The nails should be contoured prior to insertion
 - Entry site is distal to the proximal physis in the metaphysis
 - Equal sized nails are used
 - Stability is imparted through:
 - Three-point fixation in the canal (similar to three point mold on a cast)
 - Fracture reduction/bone contact
 - Nails should cross proximally and distally in the canal only
 - Do NOT twist nails
 - The apex of the curves should be at the same level in the mid-diaphyseal region



Surgical Treatment

- Flexible nails
 - Do not twist the nails
 - Loses three point fixation
 - Nails should be same size
 - Larger nail exerts more force
 - Potential deformity



Deformity secondary
to larger medial nail



Twisted nails

Surgical Treatment

- Flexible nails
 - Complication rates of 15-20%
 - Rates increase with age of patient
 - In delayed in union in age > 14years



Gordon JE, Gregush RV, Schoenecker PL, Dobbs MB, Luhmann SJ. Complications after titanium elastic nailing of pediatric tibial fractures. J Pediatr Orthop. 2007 Jun;27(4):442-6. doi: 10.1097/01.bpb.0000271333.66019.5c. PMID: 17513967.

Surgical Treatment

- Flexible nails
 - 20% compartment syndrome rate
 - Higher rates in those >50kg
 - Increased forces needed for reduction
 - Increased rates with comminuted fractures
 - Tend to be higher energy fractures
 - Initially short, then brought out to length with nail
 - Loss of periosteal support
 - Higher rate in those presenting with a neurologic injury
 - More soft tissue energy
 - Higher energy mechanisms



Pandya NK, Edmonds EW, Mubarak SJ. The incidence of compartment syndrome after flexible nailing of pediatric tibial shaft fractures. J Child Orthop. 2011 Dec;5(6):439-47. doi: 10.1007/s11832-011-0374-y. Epub 2011 Nov 1. PMID: 23205145; PMCID: PMC3221761.





10 months post op

Post op removal

Surgical Treatment

- Rigid IMNs
 - Indicated in those with narrow or closed proximal tibial physis/apophysis
 - Nearing skeletal maturity
 - Very limited data regarding their use in skeletally immature
 - Nail principles are the same as in adults
 - Stability imparted by a “press fit” of the nail within the canal augmented by locking
 - If considering, and proximal physis is open
 - Obtain a bone age assessment
 - Tanner and Whitehouse method for calculation
 - Ensure that IMN spans to proximal physis
 - Theoretical decreased chance of physeal bar formation



Surgical Treatment

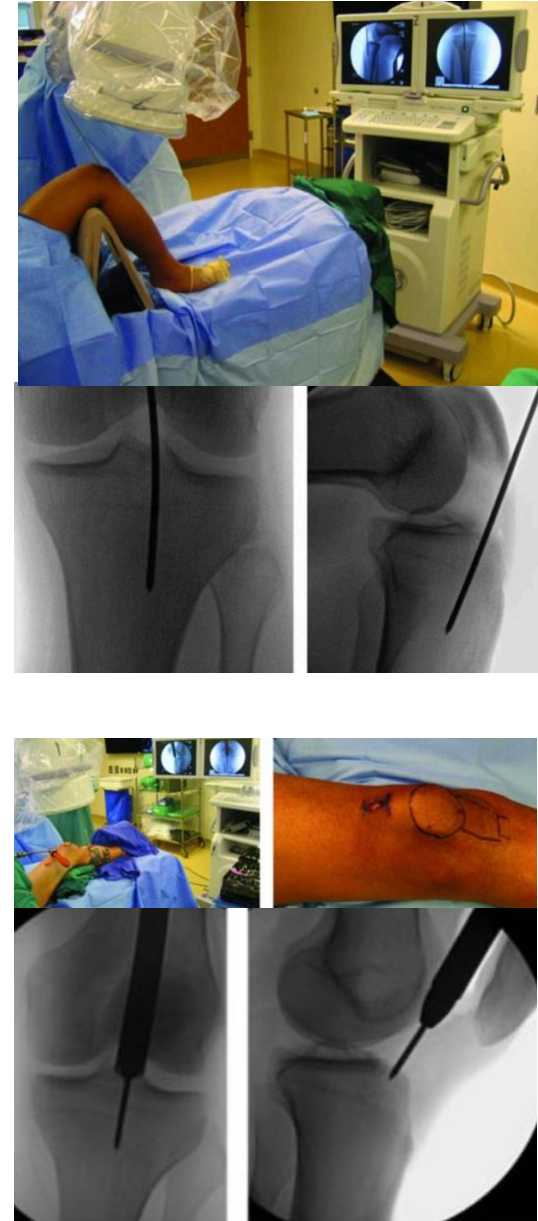
- Rigid nails
 - Benefits
 - Allows for immediate weight bearing (load sharing)
 - High level of stability
 - Soft tissue friendly
 - No need for immobilization
 - No patient weight limit
 - Anterior knee pain
 - Can cause physeal arrest and growth disturbances
 - Court-Brownt et al. examined 36 patients with open physes (age 13-16)
 - No evidence of shortening or growth arrest

*Court-Brown CM, Byrnes T, McLaughlin G. Intramedullary nailing of tibial diaphyseal fractures in adolescents with open physes. Injury. 2003 Oct;34(10):781-5.



Surgical Treatment

- Rigid nailing
 - No study comparing supra- vs infra-patellar starting sites in adolescents
 - Both safe in existing adult literature
 - Ensure proper start site on a true AP and lateral of the knee
 - Do not cross physis with proximal locking screws
 - Reaming is similar for adults, and intramedullary press fit is desired
 - Ensure guide wire does not cross distal physis



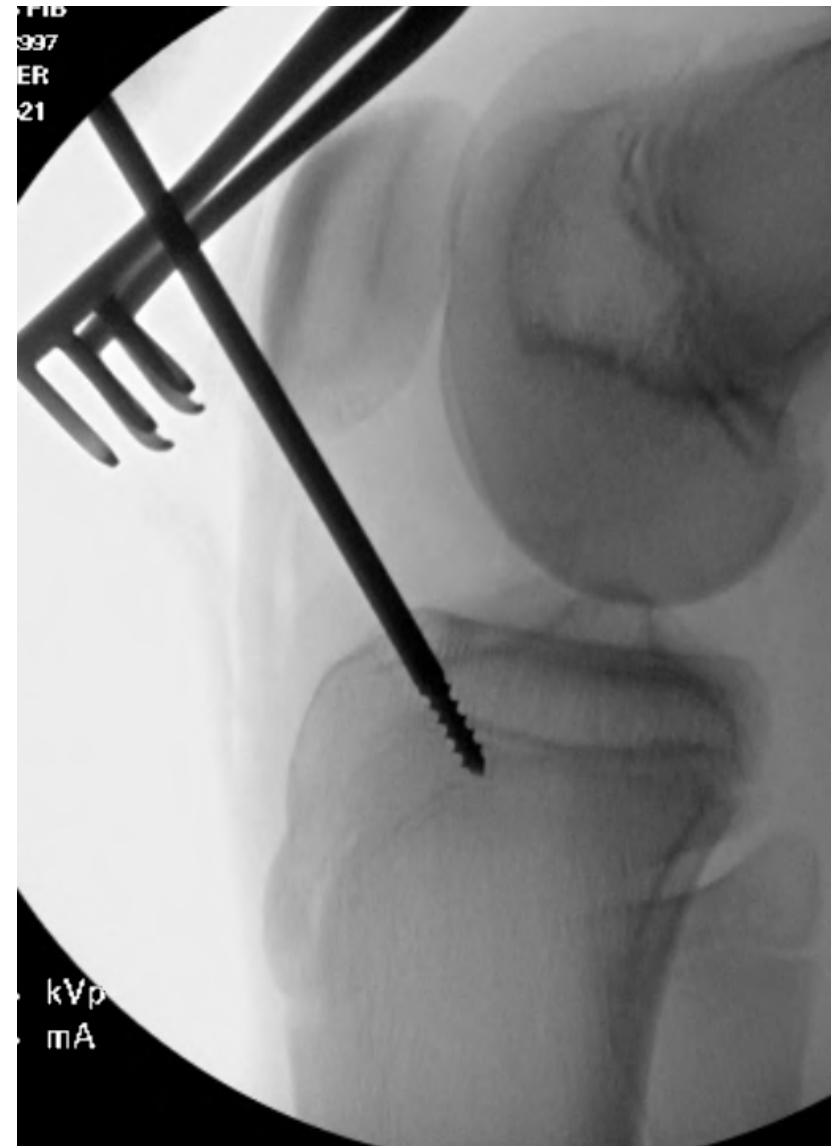


15 year old male, MVC, Type 3a open

Post debridement/External fixation



Hand X-ray to determine bone age



Intraoperative fluoro image of start site



Immediate Post op



12 months post op

Surgical Treatment

- Plate osteosynthesis
 - Difficult to give true indications
 - When done properly, is appropriate for all ages/fracture types
 - Can be done in both open, and closed, fractures
 - Open fractures should have minimal contamination and allow for soft tissue coverage
 - Should be done in a soft tissue friendly way
 - Open fractures can expose the fracture for you, allowing for easy access for fixation
 - Percutaneous bridge plating possible for comminuted fractures
 - Acts as an internal “external” fixator
- Simple fractures should undergo rigid fixation



Murphy M, et al. Minimally Invasive Medial Plate Osteosynthesis of High-Energy Pediatric Tibia Fractures. J Orthop Trauma. 2020;34(8): e272-e281

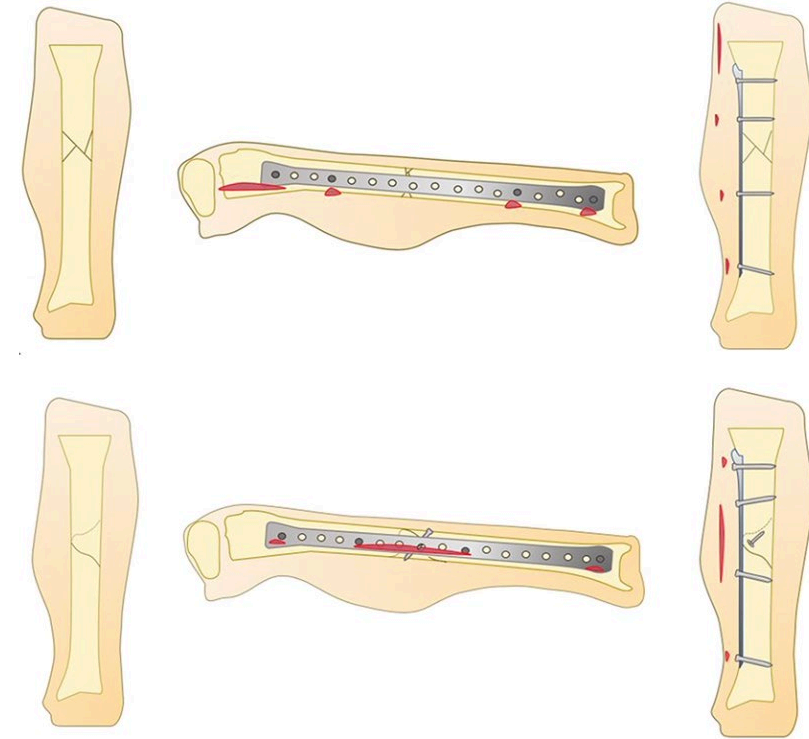
Surgical Treatment

- Plate osteosynthesis
 - Benefits
 - Allows early mobilization
 - Earlier weight bearing than cast or external fixator
 - Lower cost
 - Can remain extra-physeal
 - Can plan to remove screws that bridge the physis if required to adequate fixation
 - Medially based plates can irritate soft tissues
 - Requires larger incisions than other methods
 - Can compromise blood supply if done improperly



Surgical Treatment

- Plate osteosynthesis
 - Bridge plating
 - Small incision are made both proximally and distally on the tibia
 - Length and alignment are held manually, or with an external fixator
 - A submuscular path is created, followed by plate insertion
 - Several screws are then placed proximal and distal to the fracture
 - Needs to have a long working length in comminuted fractures



Murphy M, et al. Minimally Invasive Medial Plate Osteosynthesis of High-Energy Pediatric Tibia Fractures. J Orthop Trauma. 2020;34(8): e272-e281

Surgical Treatment

- Plate osteosynthesis
 - Compression plating
 - Direct fracture reduction (open fractures, small incisions) is necessary
 - Oblique fracture: lag screw/neutralization plate
 - Transverse fracture: compression plate
 - Alternative: percutaneous lag screw with percutaneous neutralization plate insertion



Murphy M, et al. Minimally Invasive Medial Plate Osteosynthesis of High-Energy Pediatric Tibia Fractures. J Orthop Trauma. 2020;34(8): e272-e281



Specific Fractures

- Toddler's fracture
- Proximal tibial metaphyseal fracture
- Distal tibial metaphyseal fractures
- Bicycle spoke injuries
- Pathologic fractures

Toddler's Fracture

- Childhood accidental spiral tibial fracture (CAST fracture)
 - Young, ambulatory child
 - 9 months - 3 years old
 - Low energy twisting mechanism
 - Tripping
 - Falling
 - Spiral or oblique tibia fracture
 - Fibula frequently intact



Toddler's Fracture

- Presents with limping or “toe touch” standing
- Above knee vs below knee cast vs walker boot
 - Evidence supports below knee for 3-4 weeks
 - Newer evidence suggests walker boot is sufficient
- Inherently stable fractures (thick periosteum)
- Child will self-regulate weight bearing
- Rapid healing
 - ~4w



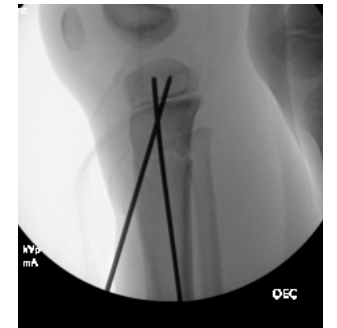
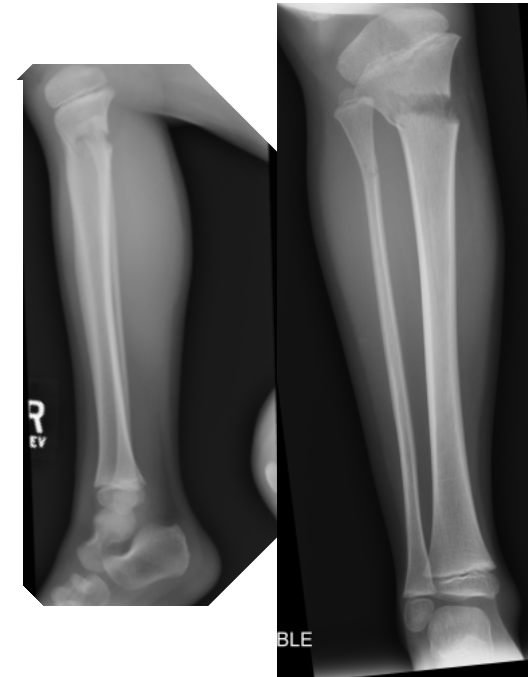
Proximal Tibial Metaphyseal Fracture

- Common area of injury
 - Most commonly seen in 3-6 year old
- Low energy mechanism
 - Jumping on a trampoline—hyperextension
 - Going down a slide and leg gets caught—valgus
- Typically involves tibial tubercle physis



Proximal Tibial Metaphyseal Fracture

- Treated closed with above knee cast
 - Varus mold may help prevent deformity
- If unable to get closed reduction, soft tissue may be interposed
- CRPP required for fractures with unacceptable reduction in the cast



Proximal Tibial Metaphyseal Fracture

- Cozens phenomenon
 - Transient valgus overgrowth deformity of tibia
 - Remodeling typically occurs over 12-24 months
- Surgery rarely required
 - Lateral temporary hemiepiphysiodesis if spontaneous correction does not occur



Waters, P. M., Skaggs, D. L., Flynn, J. M., & Rockwood, C. A. (2020). Chapter 5: Physeal Injuries and Growth Disturbances. In Rockwood and Wilkins' fractures in children (pp. 930-966). Philadelphia, PA: Wolters Kluwer

Distal Tibial Metaphyseal Fracture

- Often a greenstick injury
 - Anterior cortex impacted
 - Posterior cortex displaced
- Aim of treatment is prevention of recurvatum deformity
- Closed treatment
 - Long leg cast
 - Foot in plantarflexion (helps reduce posterior displacement)
 - Can combine with percutaneous pinning
- Open treatment
 - ORIF with plating for significant instability/loss of reduction





10 year old male with a type 2 open fracture. Pins removed at 6 weeks, 1 year follow up shown

Bicycle Spoke Injuries

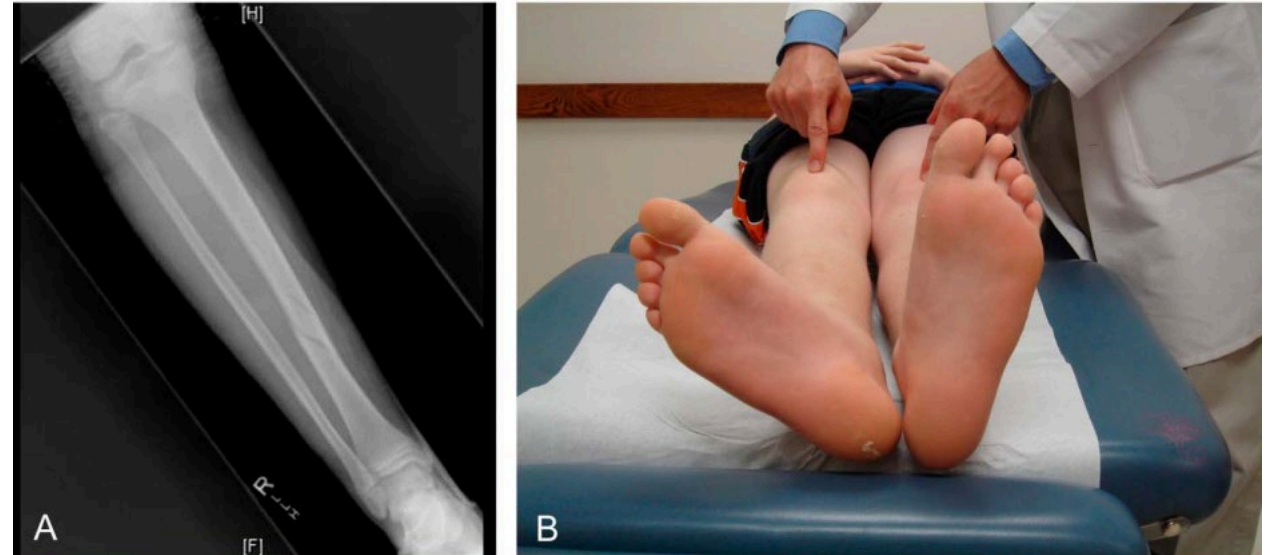
- This is a **soft tissue injury** with an underlying fracture
- Occurs when a child's foot becomes trapped in bike wheel
- Tibia often a spiral fracture
- Management is concerning soft tissue of the foot
 - Should be admitted and observed for 24-72 hrs
 - Well padded splint with elevation initially
 - Observe the skin and treat accordingly
- Tibial management
 - Cast after soft tissue improvement
 - External fixator appropriate for severe soft tissue injuries

Pathologic fractures

- Common tibial pathology
 - Fibrous dysplasia
 - Typically Heals with conservative therapy
 - Nonossifying fibroma
 - Heals with conservative therapy
 - Aneurysmal bone cyst
 - Requires surgery for both the cyst and fracture
 - Unicameral bone cysts
 - Heals with conservative therapy
 - Surgery to resolve persistent cyst and prevent refracture
 - Malignant lesions
 - Nonoperative first during tumor workup
 - Definitive management developed in conjunction with tumor therapy

Complications

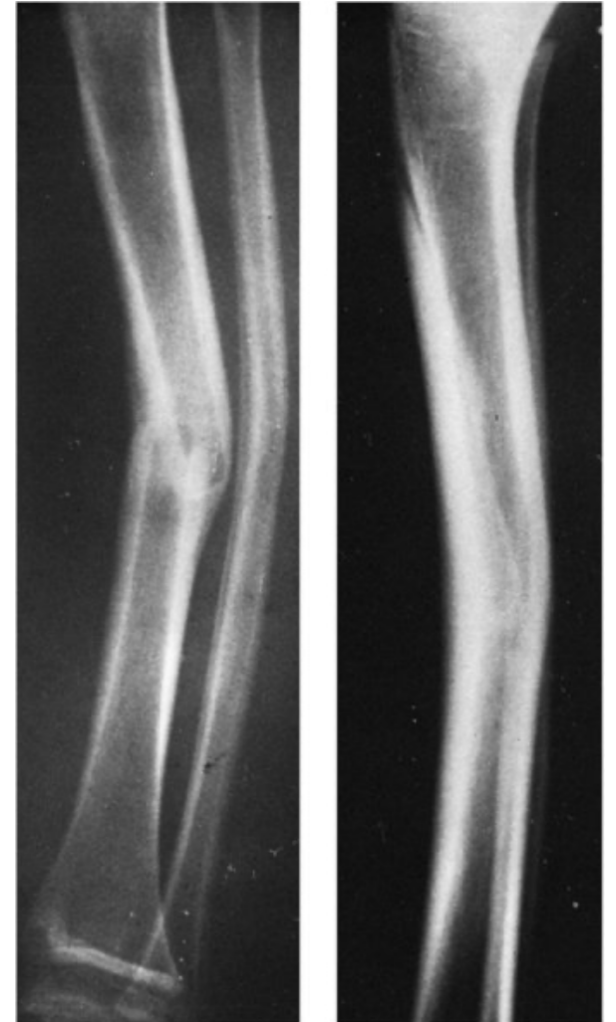
- Compartment syndrome
- Angular deformity
- Rotational deformity
 - Does not remodel
- Growth arrest
- Infection



Lovejoy SA, Mehlman CT. The Community Orthopaedic Surgeon Taking Trauma Call: Pediatric Tibia Fracture Pearls and Pitfalls. J Orthop Trauma. 2017;31 Suppl 6: S22-S26

Angular Deformity

- Correction overtime after union based on age
 - Girls 1-8, Boys 1-10: moderate correction after union
 - Girls 9-12, Boys 11-12: about half of the angulation corrected over time
 - Over 13: about a quarter of the angulated corrected
- Single plane deformity corrected better than multiplanar
- Varus corrects more than valgus
- Most correction occurs in first 18 months after injury



Waters, P. M., Skaggs, D. L., Flynn, J. M., & Rockwood, C. A. (2020). Chapter 5: Physeal Injuries and Growth Disturbances. In Rockwood and Wilkins' fractures in children (pp. 930-966). Philadelphia, PA: Wolters Kluwer

Angular Deformity

- *Unacceptable malunion* is not well documented
 - Long term data regarding outcomes is not available
- Guided growth can be used for metaphyseal deformities in skeletally immature
- Osteotomy is mainstay form of malunion corrective surgery



Core Curriculum V5

Leg-Length Discrepancy

- Shortening at fracture site
- Growth arrest
 - Proximal/distal tibial fractures
 - Fracture extension into the physis
 - Treatment violates the physis
- Tibial overgrowth
 - Fracture healing stimulates the physis
- General age cut off: 10 years
 - Younger—overgrowth
 - Older—arrest
- Treatment depends on size of discrepancy and age of patient



Infection

- Less common than in adult population
- More common in open injuries
 - 2-10% occurrence
 - Higher Gustilo-Anderson type → higher the risk
- Treatment options depend on situation
 - Must control infection
 - Debride to healthy, bleeding tissue
 - Treatment mirrors adults in terms of source control, staging, antibiotics
 - Abx coated nails in those approaching skeletal maturity



*Cruz AI Jr, Raducha JE, Swarup I, Schachne JM, Fabricant PD. Evidence-based update on the surgical treatment of pediatric tibial shaft fractures. Curr Opin Pediatr. 2019 Feb;31(1):92-102



14 year old with type 3a open fracture after an MVC, status post external fixation/debridement



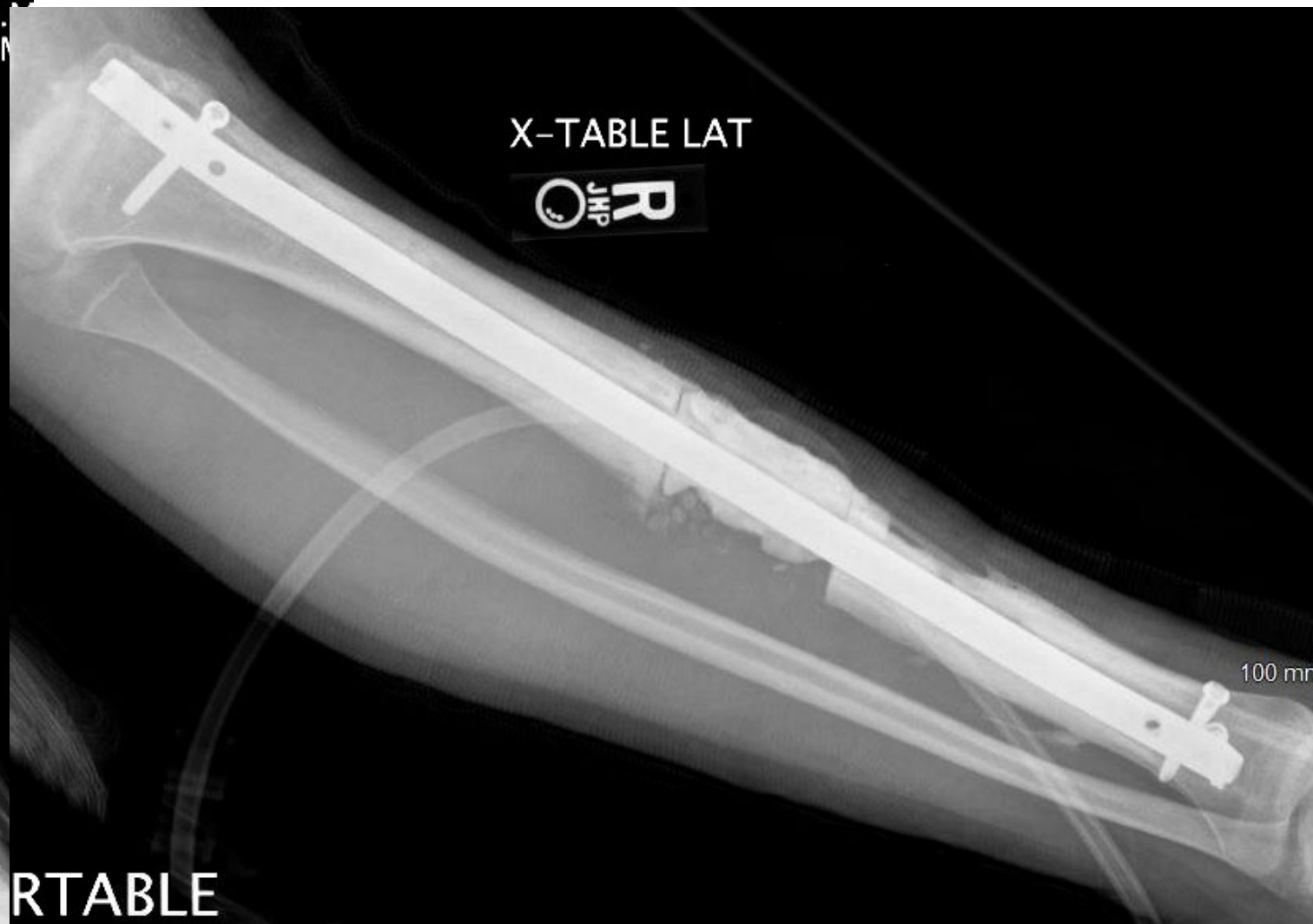
Treated with Rigid IMN



2 months post op: periosteal reaction, increased fracture gap, draining wound



Treated with debridement, hardware removal, antibiotic nail insertion, and IV antibiotics



Treated with further debridement, antibiotic spacer placement, and rigid intramedullary nailing



Bone grafted with autograft and graft substitute utilizing a pseudomembrane induced staged osteosynthesis (Masquelet technique)

*Masquelet AC. Muscle reconstruction in reconstructive surgery: soft tissue repair and long bone reconstruction. Langenbecks Arch Surg. 2003 Oct;388(5):344-6.



18 months s/p bone grafting

Summary

- Most pediatric tibial shaft fractures can be treated conservatively
 - Casting is cost effective
- However, surgical management is increasing in frequency
 - Allows earlier weight bearing/mobilization
- NAT and compartment syndrome should not be missed
- Treatment is typically dictated by age, fracture type, location, and soft tissue
- Remodeling occurs less in the tibia than the femur
- Remodeling occurs less in older patients

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- Waters, P. M., Skaggs, D. L., Flynn, J. M., & Rockwood, C. A. (2020). Chapter 5: Physeal Injuries and Growth Disturbances. In *Rockwood and Wilkins' fractures in children* (pp. 930-966). Philadelphia, PA: Wolters Kluwer.
- Raducha, Jeremy E. MD1; Swarup, Ishaan MD2; Schachne, Jonathan M. BA2; Cruz, Aristides I. Jr. MD, MBA3; Fabricant, Peter D. MD, MPH2 *Tibial Shaft Fractures in Children and Adolescents*, JBJS Reviews: February 2019 - Volume 7 - Issue 2 - p e4
- Hak DJ. Acute Compartment Syndrome in Children. 2019 Sep 3. In: Mauffrey C, Hak DJ, Martin III MP, editors. *Compartment Syndrome: A Guide to Diagnosis and Management*. Cham (CH): Springer; 2019. Chapter 13
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- Joshua W.B. Klatt, MD; Alan K. Stotts, MD; John T. Smith, MD Isolated Pediatric Tibial Shaft Fractures Do Not Need to be Treated in Above-Knee Cast, Fri., 10/15/10 Knee, Tibia & Pediatrics, Paper #61, OTA-2010

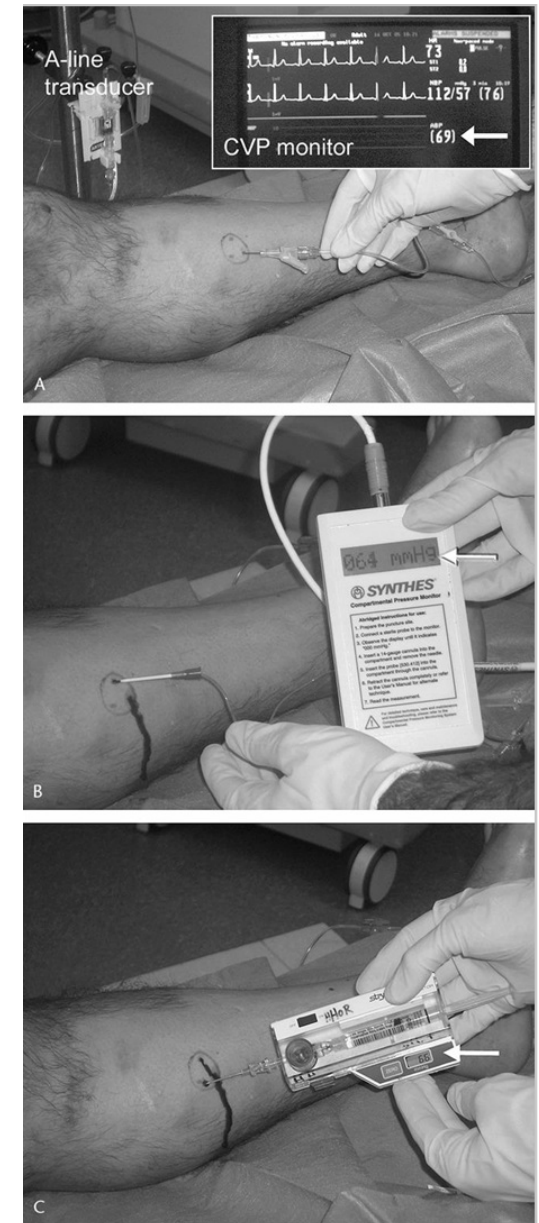
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Compartment Syndrome Supplement

Compartment Syndrome

- Diagnosis is clinical most commonly
- **When** to use invasive (pressure) monitoring
 - Obtunded or preverbal patients
 - Unclear clinical picture with high suspicion
 - Atypical presentation (e.g. atraumatic, DVT, etc.)
 - Exertional compartment syndrome
- **Ways** to monitor invasively
 - Transducer-tipped catheters
 - Arterial line set up



Collinge C, Kuper M. Comparison of Three Methods for Measuring Intracompartmental Pressure in Injured Limbs of Trauma Patients. J Orthop Trauma. 2010;24(6):364-8.

Compartment Syndrome

- Diagnosing with pressure monitoring
 - *Less clear in children*
 - *Children have higher resting compartment pressures*
 - Calculate Delta P (ΔP)
 - Subtract compartment pressure from Diastolic blood pressure (DBP)
 - $\Delta P = \text{DBP} - \text{compartment pressure}$
 - If $\Delta P \leq 20$ mm Hg (30 mm Hg in adults)
 - Diagnostic for compartment syndrome
 - Can subtract from mean arterial pressure as well
 - If within 30 mm Hg of MAP, then diagnostic
 - Blood pressure should be taken prior to anesthesia, if possible

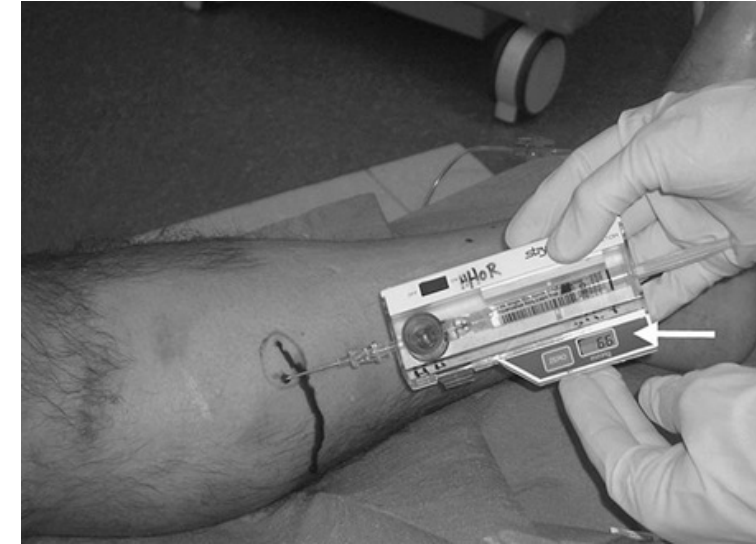


Compartment Syndrome

- Measure within 5 cm of the fracture
- Where to take the Pressure
 - Lateral compartment
 - Just anterior to the posterior border of the fibula
 - Must be taken in the peroneal muscle belly
 - Anterior compartment
 - 1 cm lateral to anterior tibia
 - May be less depending on size of patient
 - Deep posterior compartment
 - Immediately posterior to the posteromedial border of the tibia
 - Superficial posterior compartment
 - Two finger breadths posterior to posteromedial border of the tibia
 - Alternative: middle of medial calf

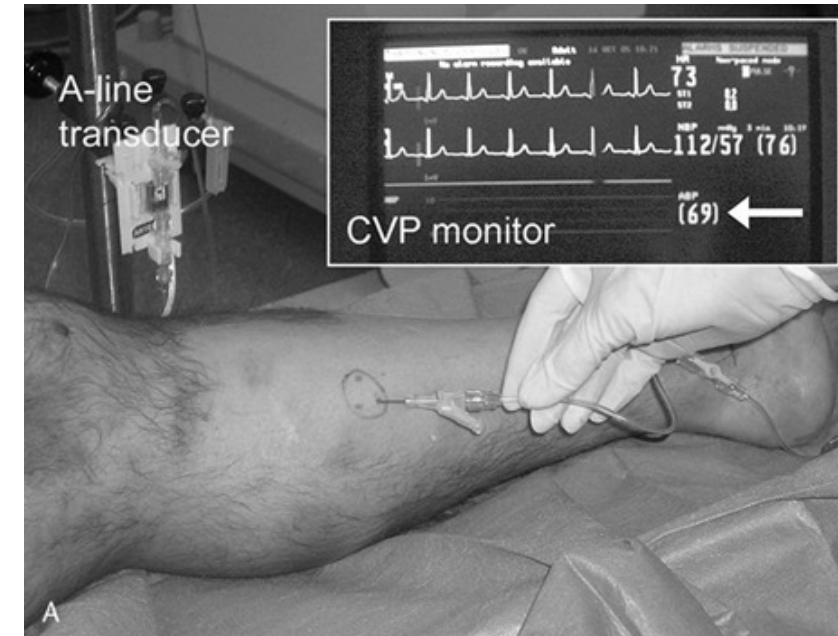
Compartment Syndrome

- Tips on pressure monitoring
 - Zero the system just prior to needle insertion
 - Zero the system with the needle at the angle its being inserted
 - Insert needle perpendicular to skin
 - Insert until a “pop” is felt to ensure entry into compartment
 - Monitor pressure within 5 cm of the fracture (if present)
 - Strongly consider sedation for children
 - Document BP prior to induction



Compartment Syndrome

- Arterial line monitoring equipment
 - 18-gauge needle
 - High-pressure tubing
 - Pressure transducer
 - Associated equipment
 - Adjustable transducer stand
 - Pressure monitor
 - 10—20mL syringe
 - Three-way stopcock
 - Sterile saline with pressure bag



Compartment Syndrome

- Arterial line technique
 - Set up the arterial line transducer, tubing, pressure bag as normal
 - Adjust transducer to be at the same height as the leg
 - Attach stopcock to transducer tubing
 - Opposite to the tubing, insert needle (can have its own tubing)
 - On the remaining opening, attach syringe
 - Flush the system with saline from the bag
 - Level the needle at site of compartment measuring
 - Zero the monitor
 - Insert the needle without changing position of hand
 - Close system off to transducer and inject 1cc saline
 - Open system to transducer and monitor pressure

*Steps can vary depending on system. Alternate description in video: <https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731429/acute-compartment-syndrome-of-the-lower-extremity>



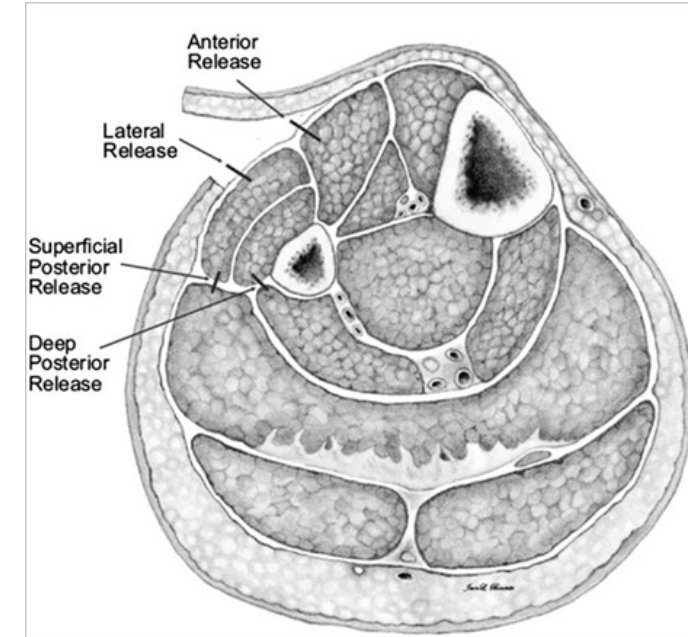
Compartment Syndrome

- Requires emergent surgical intervention
- In the setting of delayed (> 24 hrs) presentation
 - No change in treatment for acute presentation
 - Children have improved recovery rates compared to adults in this setting
 - Limit initial muscle debridement, even if ischemic, as recovery is likely

Lin, James S.^a; Samora, Julie Balch^{a,,b} Pediatric acute compartment syndrome: a systematic review and meta-analysis, Journal of Pediatric Orthopaedics B: January 2020 - Volume 29 - Issue 1 - p 90-96 doi: 10.1097/BPB.0000000000000593

Compartment Syndrome

- Dual vs Single incision fasciotomy
 - Limited evidence in pediatric literature
 - Adult literature shows no difference
 - Primary closure
 - Infection
 - Need for coverage
 - No difference, as long as complete release of all compartments



Neal M, et al. The Efficacy of a Single-Incision Versus Two-Incision Four-Compartment Fasciotomy of the Leg J Orthop Trauma. 2016;30(5):e164-8

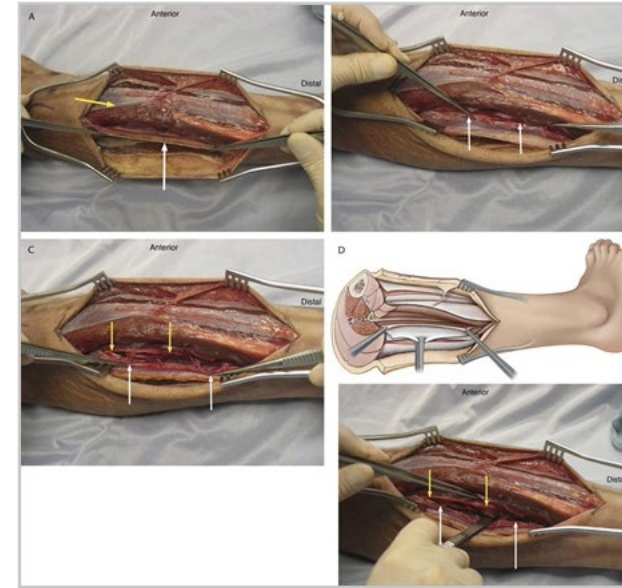
Bible JE, McClure DJ, Mir HR. Analysis of single-incision versus dual-incision fasciotomy for tibial fractures with acute compartment syndrome. J Orthop Trauma. 2013 Nov;27(11):607-11. doi: 10.1097/BOT.0b013e318291f284. PMID: 23515126.

Compartment Syndrome

- Dual incision
 - Anterolateral incision
 - Incision along length of fibula
 - Length varies in pediatric population
 - Avoid proximal neck and distal subcutaneous fibula
 - Find intermuscular septum
 - Incise 1 cm on either side of septum for anterior and lateral compartment release
 - *Protect superficial peroneal nerve at distal incision*
 - Posteromedial
 - Incision posterior to posterior border of tibia
 - Distance from posterior border of tibia varies in pediatric population
 - Incise fascia overlying superficial posterior compartment
 - Find Soleal bridge attached to tibia and release for deep posterior
- Video for technique: <https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16776673/dual-incision-release>

Compartment Syndrome

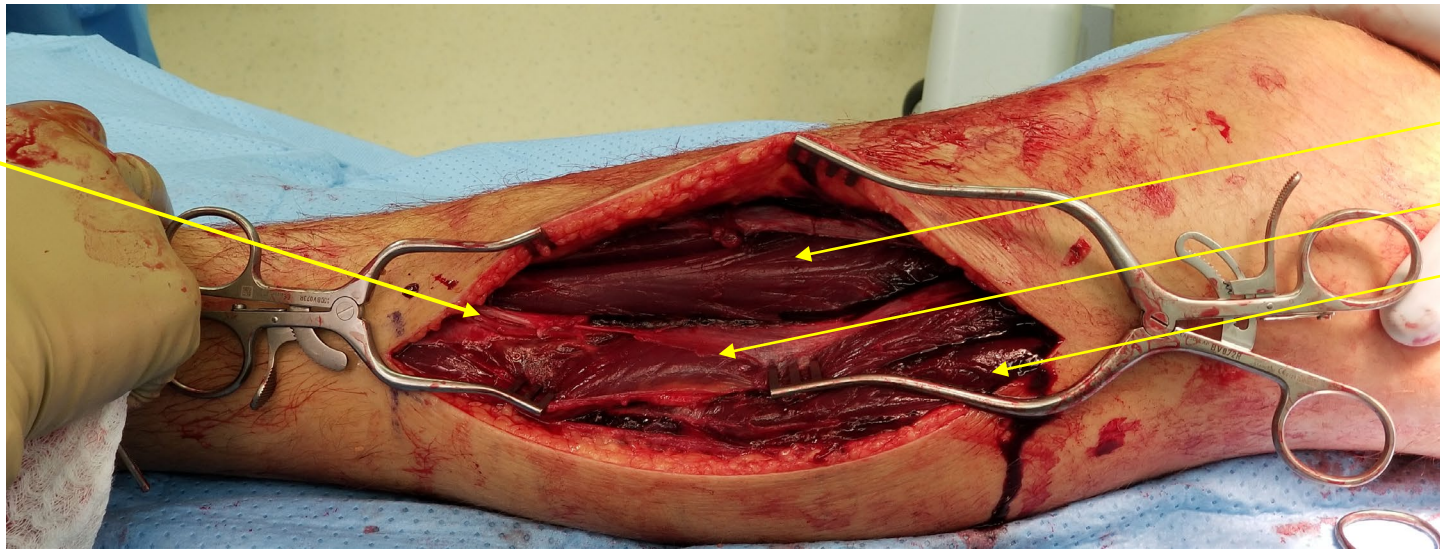
- Single Incision
 - Same as anterolateral incision in dual incision technique
 - First find intermuscular septum
 - Incise 1 cm on either side for anterior and lateral compartment
 - Continue further posterior to lateral compartment
 - Release fascia over superficial posterior compartment
 - Deep posterior is found
 - In the interval between superficial posterior and lateral compartments
 - Follow the interosseous membrane along back of fibula
 - Release the deep compartment off this membrane
- Images for technique on slides 22-27
- Video for technique: [Single Incision Four Compartment Parafibular Fasciotomy | Procedures & Techniques | OTA Online Trauma Access](#)







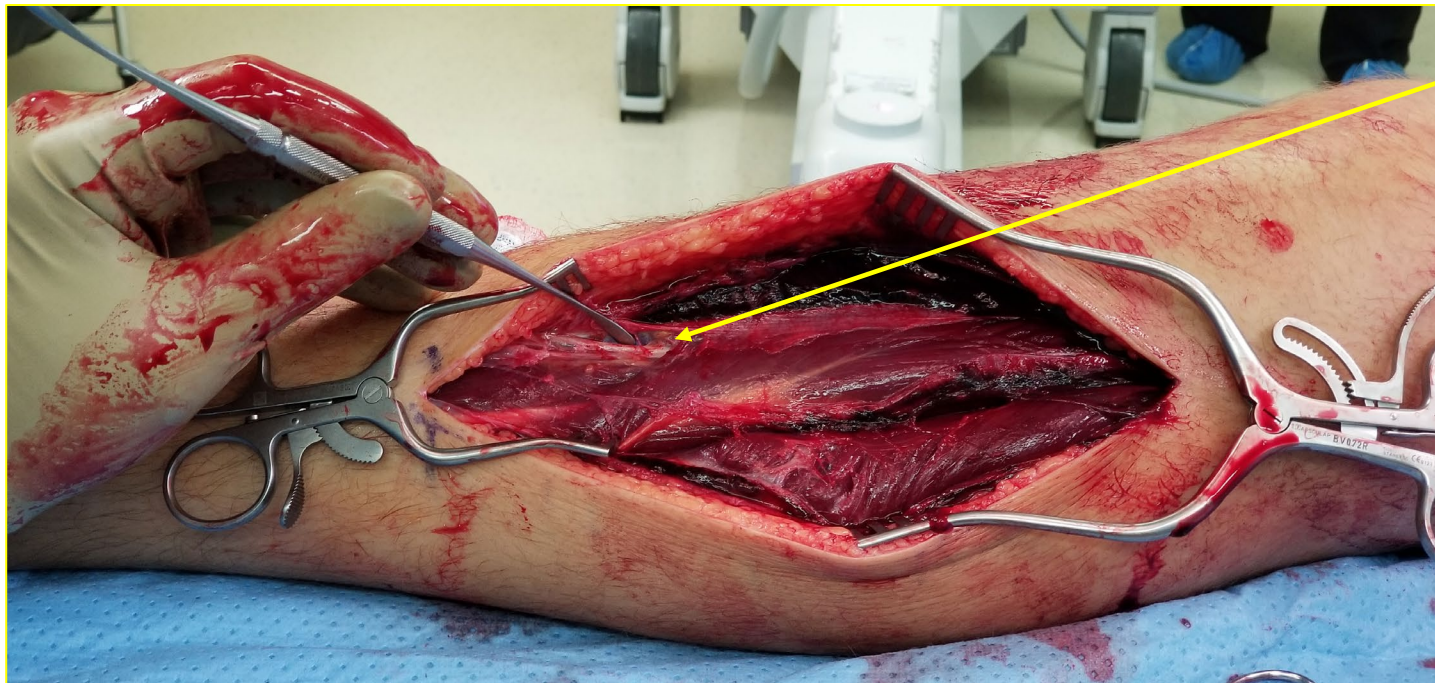
Superficial peroneal n.



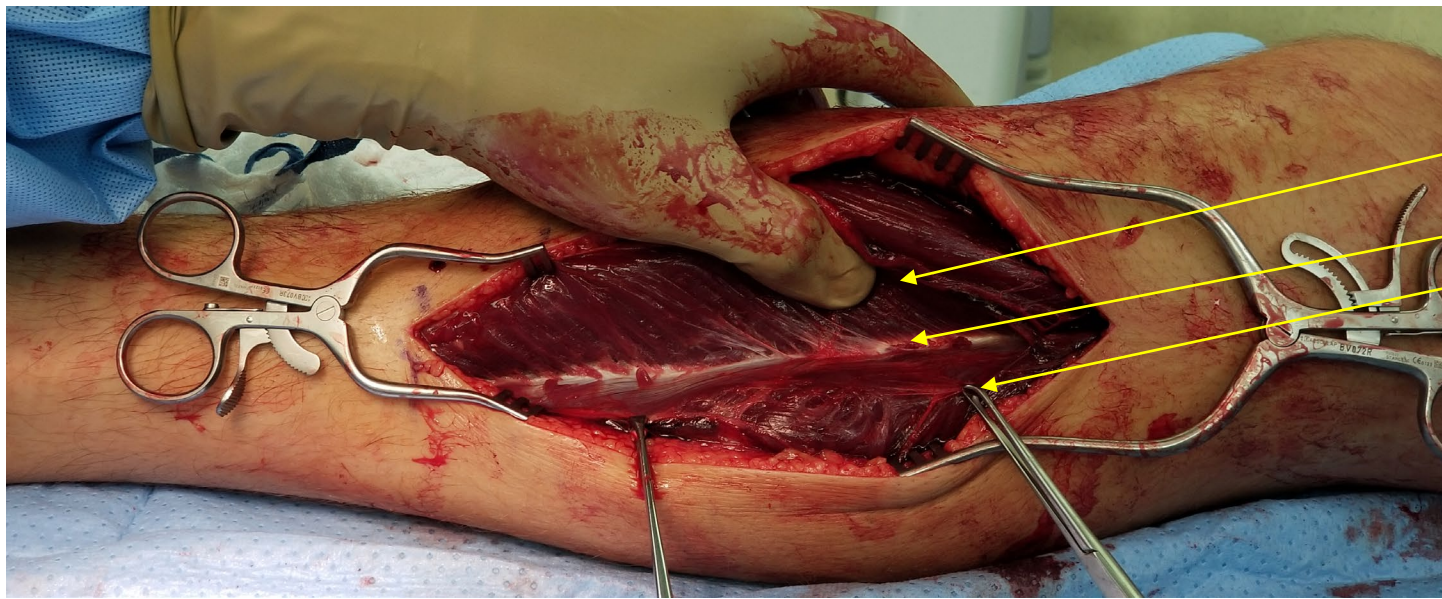
Anterior compartment

Lateral compartment

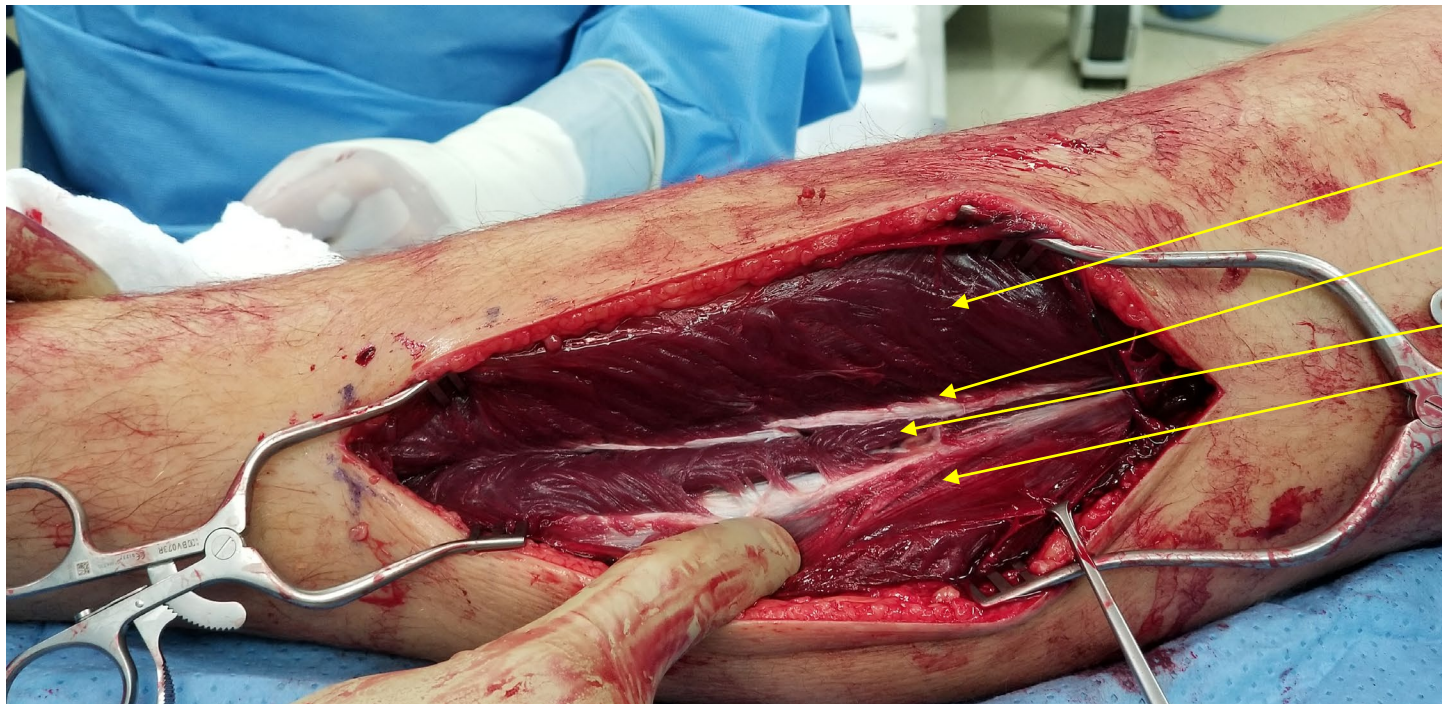
Superficial posterior compartment



Superficial peroneal n.



Lateral compartment
Fibula
Superficial posterior
compartment



Lateral compartment
Fibula
Flexor Hallicus Longus m.
Superficial posterior
compartment