Malunion

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Aknowledgements

• Andrew Schmidt, MD
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Malunion

• “For the arm when shortened may be concealed and the mistake will not be great but a shortened thighbone will leave a man maimed”
  • Hippocrates De fracturis
Malunion Upper Extremity

Emily Benson, MD
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Objectives

• Discuss common sites of upper extremity malunion in regards to the following:
  • anatomic considerations
  • clinical & radiographic evaluation
  • treatment strategies
Clavicle
Clavicle - Anatomy

- “S”-shaped bony strut
- Medial - sternoclavicular joint
- Lateral - acromioclavicular joint and coracoclavicular ligaments
- Muscle attachments:
  Medial: sternocleidomastoid
  Lateral: Trapezius, pectoralis major, deltoide
Clavicle - Physical Examination

**Inspection**
- Evaluate deformity and/or displacement
- Inspect scapula position and tracking/winging
- Measure length from jugular notch to lateral tip of acromion
- Compare to opposite side
Clavicle - Physical Examination

• Palpation
  Evaluate for pain at fx site
  Look for instability with stress

  Neurovascular examination
  Must be done thoroughly and documented!

  Measure shoulder range of motion
Clavicle - Radiographic Evaluation

- Anteroposterior View
- 30-degree Cephalic Tilt View
Clavicle - Radiographic Evaluation

- **Quesada Views**
  45-degree angle cephalad and caudal views
  Provide better assessment of the extent of displacement

  **CT scan** may be helpful to determine extent of union
Clavicle - Malunion Definition

• > 2cm shortening
• greater than 100% displacement
• There is evidence that the outcome of nonoperative management of displaced middle-third clavicle fractures is not as good as traditionally thought, with many patients having significant functional problems.
Deficits following nonoperative treatment of displaced midshaft clavicular fractures

• 30 patients after nonoperative care of a displaced midshaft fracture of the clavicle.

• At a minimum of twelve months (mean 55 mos), outcomes were measured with the Constant shoulder score and the DASH patient questionnaire. In addition, shoulder muscle-strength testing was performed.

Deficits following nonoperative treatment of displaced midshaft clavicular fractures

• The strength and endurance was impaired:

  81% for max flexion, 75% for endurance of flexion,  
  82% for max abduction, 67% for endurance of abduction,  
  81% for max ext rotation, 82% for endurance of ext rotation,  
  85% for max int rotation, and 78% for endurance of int rotation  
  (p < 0.05 for all)

• Mean Constant score = 71 points
• Mean DASH score = 24.6 points, indicating substantial residual disability.

Conclusion of McKee study

• Displaced midshaft clavicle fractures can cause significant, persistent disability, even if they heal uneventfully.
Clavicle - Treatment

• Symptoms of pain, fatigue, cosmetic deformity.
• Initially treat with strengthening, especially of scapulothoracic stabilizers.
• Consider osteotomy, internal fixation in rare cases in which nonoperative treatment fails.

Correction of malunion with thoracic outlet sx
Clavicle - Treatment

• **Principles:**
  1. Restore length of clavicle
     May need structural bone graft
  2. Rigid internal fixation, usually with a plate
  3. Possible Iliac crest bone graft
     Role of bone-graft substitutes not yet defined.
Clavicle - Treatment ORIF

• Traditional means of ORIF
• Plate applied superiorly or inferiorly
  Inferior plating associated with lower risk of hardware prominence.
• Used for acute displaced fractures and nonunions/malunions.
• Other less common options: IM fixation
Clavicle - Treatment: Outcomes

• 15 patients with malunion after nonoperative treatment of a displaced midshaft clavicle fracture of the clavicle. Average clavicular shortening was 2.9 cm (range, 1.6 to 4.0 cm).
• Mean time from the injury to presentation was three years (range, 1 to 15 years).
• Outcome scores revealed major functional deficits.
• All patients underwent corrective osteotomy of the malunion through the original fracture line and internal fixation.

Clavicle - Treatment: Outcomes

- At follow-up (mean 20 months postoperatively) the osteotomy site had united in 14 of 15 patients.
- All 14 patients satisfied with the result.
- Mean DASH score for all 15 patients improved from 32 points preoperatively to 12 points at the time of follow-up (p = 0.001).
- Mean shortening of the clavicle improved from 2.9 to 0.4 cm (p = 0.01).
- There was 1 nonunion, and 2 patients had elective removal of the plate.
Functional Outcome of Surgical Treatment of Symptomatic Nonunion and Malunion of Midshaft Clavicle Fractures

- 13 cases plate fixation / autogenous grafting of a clavicle nonunion / malunion, followed mean 41 months.
- All united
- 46% returned to previous job and sport
- Constant scores remained lower than opposite arm
- <25% free of pain.
Clavicle Malunion Treatment: Outcomes

• Does Timing of Surgery Matter?
• Matched group comparison of 15 patients who underwent early compression plate fixation to 15 other patients who had operative repair of a malunion/nonunion at avg of 63 months.

Does Timing of Surgery Matter?

- **Outcome**
  - **Early**
  - **Delayed**
  - **Strength**
    - =
  - **Endurance**
    - 109%
    - 80% (p=.05)
  - **Constant score**
    - 95
    - 89 (p=.02)
  - **DASH score**
    - 3.0
    - 7.2 (p=.15)
  - **Satisfaction**
    - exc
    - exc

Does Timing of Surgery Matter?

• Conclusion: Late reconstruction provides outcome similar to acute repair, except for subtle decreases in endurance strength.

• Such information might be of value in initial decision-making.

Humerus
Humerus - Anatomy

- Humeral retroversion -6 to 50%
- Neck shaft angle is 130-140 deg
- Elbow is in 30 degrees of flexion
- Carrying angle of elbow is 6 degrees valgus
Humerus - Anatomy

- Malalignment may occur within any of the 4 major parts of the proximal humerus
- Diaphyseal fracture alignment determined by the location of the fracture relative to the major muscle attachments, most notably the pectoralis major and deltoid attachments

GREATER TUBEROSITY: supra/infraspinatus insertion

LESSER TUBEROSITY: subscapularis insertion

SURGICAL NECK/SHAFT: deltoid/pectoralis major largely dictates fx behavior
- compression: stable
- shear: unstable

Reprinted with permission figure 35-11
Tornetta, P., III (Ed.) (2020) Rockwood and Green’s Fractures in Adults (9e). Wolters Kluwer
Deforming Forces

• Fracture distal to pectoralis major and proximal to deltoid

• Adduction of proximal fragment
• Fracture distal to deltoid
• Abduction of proximal fragment
• Shortening occurs at fracture site due to pull of biceps and triceps
Humerus - Physical Examination

• Detailed History
• Inspection:
  • pain
  • swelling
  • deformity
• Measure length from lateral tip of acromion to tip of olecranon
• Compare to other side
• Document:
  • neurovascular exam
  • shoulder/elbow ROM
Humerus - Imaging

- Standard radiographic examination
  - 3 views of shoulder
  - AP
  - Lateral view
  - Both joints

- CT to evaluate amount of union
- MRI for rotator cuff, labrum
What is Acceptable Alignment?

• Because the shoulder and elbow are joints capable of wide ranges of motion, the humerus is thought to be able to accommodate the following without a significant compromise of function or appearance:
  • 20 degrees of anterior or posterior angulation
  • 30 degrees of varus (less in thin patients)
  • 3 cm of shortening
  • *Kleenerman, JBJS-B, 48:105 (1966)*
Humerus - Treatment

• If surgical intervention is elected, the following options are available:
  • Plate osteosynthesis (gold standard)
  • Intramedullary fixation

• Both work for acute fractures
• Malunion/nonunion principles may be different
Humerus - Treatment: ORIF

• The best functional results after surgical management of humeral shaft fractures, both acute and chronic, have been reported with the use of plates and screws
• Direct fracture reduction and stable fixation without violation of the rotator cuff
Humerus - Treatment: ORIF

• **Results:**
  • Union rates average 96% with significant complications ranging from 3% to 13%
  • motion restrictions at the elbow or shoulder usually due to other severe bony or soft-tissue injuries to the same extremity
Humerus - Treatment: IM Nail

- IMN (Intramedullary Nails) offers biologic and mechanical advantages over plates and screws
- IMN can be inserted without direct fracture exposure, minimizing soft-tissue scarring
- Because the implant is closer to the mechanical axis than a plate, they are subject to smaller bending loads than plates and are less likely to fail by fatigue
- Useful in osteoporotic bone, hypertrophic nonunions, large diameter arms, poor skin condition
- Risk of iatrogenic radial nerve injury while reaming and reducing fracture
Forearm
Forearm - Anatomy

- Elbow, wrist, DRUJ, PRUJ
- Radial bow allows for full pronation/supination
Forearm - Physical Examination

- Detailed History
- Inspection:
  - pain
  - swelling
  - deformity
- Compare to other side
- Document:
  - neurovascular exam
  - wrist/elbow ROM
  - pronation/supination!
Forearm - Imaging

• standard 2 views of forearm
• evaluate length of radius vs. ulna
• measure angulation
• note DRUJ and PRUJ articulations
Forearm - Malunion Definition

• There is Loss of Motion with >10 degrees of angulation

• Decreased Grip Strength occurs with loss of the radial bow
  • Schemitsch, EH & Richards RR JBJS 1992:74A:1068-78
Forearm - Treatment

• If surgical intervention is elected, the following options are available:
  • Plate osteosynthesis
  • Intramedullary fixation

• Both work for acute fractures
• Malunion/nonunion principles may be different
Principles of Fixation

• Restore Anatomic Reduction
• Restore Ulna & Radial Length
  • Prevents subluxation of either proximal or distal radioulnar joints
• Restore Rotational alignment
• Restore Radial Bow
  • Essential for rotational function of forearm
Forearm - ORIF

• Indications: Treatment of choice for most forearm malunions
• Plate Fixation consistently provides stable strong anatomic fixation that eliminates the need for external casting, & allows early functional motion with excellent union rates.
• Consider bone graft for defects
Forearm - ORIF

- **Locking Plating:**
  - Advantages: bridging preserves biology with enough mechanical stability to allow early motion & function. Heals with callus formation.
  - Disadvantages: bridging techniques more difficult to achieve anatomic reduction. Without lag screw or dynamic plate compression, possibly more likely to have a residual gap and nonunion. More expensive.
  - Good for fractures where compression cannot be achieved

- **Compression Plating:**
  - Advantages: improved mechanical stability that allows early motion and function. Heals by primary bone healing. (When compression is achieved)
  - Disadvantages: reduction techniques that strip the periosteum may damage the biology increasing the risk of nonunion or infection.

- **Hybrid Combination** of compression techniques and locking screw plating may be useful combining the advantages of both techniques.
Intramedullary Fixation of Forearm Fractures

• Indications: Controversial in adults, common in children
  • Acts as an internal splint only
  • Problems of rotational instability, loss of radial bow, shortening, and nonunion
  • May have improved results with contoured rods
• May be useful when soft tissues compromised
• Or in Pathologic fractures or impending fractures
  • where the device protects the whole bone
Pediatric fractures

• Intramedullary fixation for pediatric acute and chronic fractures works well
  • Supplemented by cast immobilization (because rigid fixation is not achieved)
Distal Radius
Distal Radius - Anatomy

• radial inclination 23 degrees
• radial height 12mm
• neutral ulnar variance

• volar tilt 11 degrees
Distal Radius - Physical Examination

• Detailed History
• Inspection:
  • pain
  • swelling
  • deformity
• Compare to other side
• Document:
  • neurovascular exam
  • wrist ROM
Distal Radius - Imaging

• 2 vs. 3 views of wrist
• evaluate length of radius vs. ulna
• measure angulation
• note DRUJ articulations

• Consider CT to assess union
• Consider MRI for soft tissue concerns
Distal Radius - Malunion Definition

- > 4mm loss of radial height
- > 4mm loss of ulnar variance
- > 15 degrees change in radial inclination
- > 15 degrees loss of volar tilt
- > 20 degrees increase in volar tilt
- > 2mm of articular displacement
Distal Radius - Treatment

- Non-operative: malunion can be tolerated well, especially in the elderly
- Osteotomy, ORIF with locked plate is gold standard
- pinning
- ex-fix
- dorsal bridge plating
- consider bone grafting
- consider ulnar sided procedure

• Hill et al, JBJS 1997;79B: 537-9


Literature - Humerus

Literature - Forearm/Distal radius

- Schemitsch, E.H.: Forearm Fractures in *Orthopaedic Knowledge Update. Trauma 2*, Fischer, T.J. Section editor. AAOS, Rosemont, Il. pp 53-64, 2000
Malunion: Principles of Evaluation and Management, Lower Extremity

Basic Science, Fracture Healing

John Michael Yingling DO
Introduction

• A malunion results from a fracture healed in a non-anatomic position to a degree that becomes symptomatic or causes functional impairment.
Deformity

- Length (cm)
- Translation (mm)
- Angulation (degrees)
- Rotation (degrees)
- Combined
• Length
• Translation
• Angulation
• Rotation
• Combined
- Length
- **Translation**
- Angulation
- Rotation
- Combined
• Length
• Translation
• **Angulation**
• Rotation
• Combined
• Length
• Translation
• Angulation
• Rotation
• Combined
• Length
• Translation
• Angulation
• Rotation
• Combined
Characterize

- Location
  - Articular, metaphyseal, metadiaphyseal, diaphyseal,
- Severity
  - Magnitude in Degrees, Centimeters, Millimeters
- Direction
  - Distal segment relative to proximal
Clinical evaluation

- History & physical
- Nature / timing
- All past procedures / soft tissue coverage
- Infection
- Nutrition status
- Motivation / insight **
  - (gradual correction takes a compliant patient with support)
Clinical evaluation

• Physical exam
  • Inspection – skin / wounds / atrophy / sores
  • Palpation – focal areas of pain – deep / superficial / functional / constant
  • ROM – joint above and below
    • Flexible or fixed
      • (will tolerate correction if flexible or may need addressed as well if rigid, separately)
Radiographic evaluation

• Full-length 51-inch bilateral radiograph
  • AP standing, both feet pointed straight forward
  • Lateral, each lower extremity showing the hip, knee, and ankle with the limb in full extension
• CT scanogram / EOS
Mechanical Axis

The mechanical axis of the femur and tibia is determined by drawing a line from the center of the femoral head to the center of the knee joint and from the center of the knee joint to the center of the ankle joint.
Anatomic Axis

Draw a line through the midpoint of two lines drawn perpendicular to the long axis of the bone spanning from both cortices.
Joint Orientation Angles

A. TH line
B. FN line
C. DFJOL
D. PTJOL
E. DTJOL
F. SDFJOL
G. SPTJOL
H. SDTJOL

Joint Orientation Angles

### Joint Orientation Angles

<table>
<thead>
<tr>
<th>Angle</th>
<th>Angle Formed by</th>
<th>Mean (degrees)</th>
<th>Range (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur: frontal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical lateral proximal femoral angle</td>
<td>Mechanical axis – Trochanteric tip to head center line</td>
<td>90</td>
<td>85-95</td>
</tr>
<tr>
<td>Mechanical lateral distal femoral angle</td>
<td>Mechanical axis – Distal femoral joint orientation line</td>
<td>88</td>
<td>85-90</td>
</tr>
<tr>
<td>Anatomic medial proximal femoral angle</td>
<td>Anatomic axis – Trochanteric tip to head center line</td>
<td>84</td>
<td>80-89</td>
</tr>
<tr>
<td>Anatomic neck shaft angle</td>
<td>Anatomic axis – Femoral neck line</td>
<td>130</td>
<td>124-136</td>
</tr>
<tr>
<td>Anatomic lateral distal femoral angle</td>
<td>Anatomic axis – Distal femoral joint orientation line</td>
<td>81</td>
<td>79-83</td>
</tr>
<tr>
<td>Femur: sagittal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatomic posterior distal femoral angle</td>
<td>Mid-diaphyseal line – Sagittal distal femoral joint orientation line</td>
<td>83</td>
<td>79-89</td>
</tr>
<tr>
<td>Tibia: frontal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical medial proximal tibial angle</td>
<td>Mechanical axis – Proximal tibial joint orientation line</td>
<td>87</td>
<td>85-90</td>
</tr>
<tr>
<td>Mechanical lateral distal tibial angle</td>
<td>Mechanical axis – Distal tibial joint orientation line</td>
<td>89</td>
<td>83-92</td>
</tr>
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<td>Anatomic axis – Proximal tibial joint orientation line</td>
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<td>Tibia: sagittal</td>
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<td>Anatomic posterior proximal tibial angle</td>
<td>Mid-diaphyseal line – Sagittal proximal tibial joint orientation line</td>
<td>81</td>
<td>77-84</td>
</tr>
<tr>
<td>Anatomic anterior distal tibial angle</td>
<td>Mid-diaphyseal line – Sagittal distal tibial joint orientation line</td>
<td>80</td>
<td>78-82</td>
</tr>
<tr>
<td>Knee: frontal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical axis deviation</td>
<td>Distance on horizontal plane from line drawn from center of femoral head through center of ankle joint to knee joint center</td>
<td>Normal range: 1-15 mm medial to center of knee joint</td>
<td></td>
</tr>
</tbody>
</table>
Limb Alignment

• Mechanical axis deviation (MAD)
• Center of femoral head to center of ankle
• Distance from center of knee joint
  • if MA >15mm medial
  • =varus
  • if MA >3mm lateral
  • =valgus
Center of Rotation Angulation

- Intersection of the proximal and distal segment anatomic axis
- The bisector line is drawn dividing the medial and lateral angle
- Any point along this line can act as a CORA without secondary translation
*For articular segments use JOA from contralateral or standard means (prior table)
*if CORA lies outside of bone – multiapical or translational component exists
Correction Axis

- Seen when the point at which the correction occurs when the deformity is corrected or bone is realigned after the osteotomy – and thus dependent on the osteotomy type.

Assessment of Deformity Types

- Angular
- Length
- Rotation
- Translation
Angular

• Direction and Magnitude
• Flexion / extension, varus / valgus
• Magnitude – degrees
• Affect on MAD
Angular

Direction and Magnitude
• Flexion/extension, varus/valgus
• Magnitude – degrees
• Affect on MAD

CORA on AP and lateral:

- same level = oblique deformity
- different level – translation
- more than one – multi-apical
Angular

Direction and Magnitude
- Flexion/extension, varus/valgus
- Magnitude – degrees
- Affect on MAD

CORA on AP and lateral:
- **same** level = oblique deformity
- **different** level – translation
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Angular

Direction and Magnitude
• Flexion/extension, varus/valgus
• Magnitude – degrees
• Affect on MAD

CORA on AP and lateral:
- **same** level = oblique deformity
- **different** level – translation
- more than one – multi-apical
Length

• Measured from joint center to joint center
  • Magnitude (cm)
  • XR or CT scanogram
    • +/- blocks to adjust for pelvis compensation or purely radiographic
  • Compare to contralateral side
Length

• Important*
  • Chronic or congenital
    • Neurovascular structures short
  •*may preclude acute correction
• Acute
  • NV structures, recently at equal length
•Note* valgus malunions of the knee are prone to peroneal nerve injury if corrected too quickly
Length

• “In the lower extremity, up to 2 cm of shortening may be treated with a shoe lift; tolerance for a 2- to 4-cm shoe lift is poor for most patients, and most patients with shortening of greater than 4 cm will benefit from restoration of bone length”


* Rotational malunion of the femur is the most common malunion of long bones of the lower extremity usually following intramedullary nailing
Rotation
Rotation


Translation

- Distal anatomic axis horizontal distance (mm) from anatomic axis of proximal reference segment
- Anterior, posterior, medial, lateral

(*reversed for humeral/femoral heads)
Treatment

• **Acute**
  - Usually plates, nails, external fixators
    - Simple, smaller magnitude, NV structures on convexity of deformity

• **Gradual**
  - Usually tensioned small wire ringed fixators, unilateral external fixators, lengthening nails
    - Complex multiplanar, larger magnitude, NV structures on concavity of deformity
Osteotomy

- Wedge
- Dome
- Transverse
- Oblique
Wedge

Drawbacks: can change length, increased exposure, can alter ligaments if near a joint, void may require graft
Avoids bone loss, does not affect length, be careful to not translate, ensure the osteotomy does not go through the CORA, the axis of correction* should be centered in the CORA
Osteotomy

- Wedge
- Dome
- Transverse
- Oblique
Transverse

allow translation, translation and length
Types – singular

- Angular
- Rotation
- Length
- Translation
Combined deformities

- Angulation and rotation
- Angulation and length
- Length and translation
Angulation and rotation

Can correct with single oblique osteotomy and some math

The direction and magnitude of the combined angulation–rotational deformity are both characterized in the oblique axis.

The angle of the oblique correction axis, which is perpendicular to the plane of the necessary osteotomy, can be approximated using trigonometry:

\[
\text{axis angle} = \tan^{-1}\left(\frac{\text{rotation}}{\text{angulation}}\right); \ \text{orientation of plane of osteotomy} = 90 - \text{axis angle}
\]
Angulation and rotation

A

45° angular deformity
25° rotational deformity

B

29°

61°

CORA

Axis inclination
\[ \arctan \left( \frac{\text{rotation}}{\text{angulation}} \right) \]
\[ \text{arctan} \left( \frac{25}{45} \right) \approx 29° \]

Osteotomy inclination
\[ \arctan \left( \frac{\text{angulation}}{\text{rotation}} \right) \]
\[ \arctan \left( \frac{45}{25} \right) \approx 61° \]

With a 45° angular deformity and 25° of rotational deformity, the correction axis is calculated to be 29°, which corresponds to an osteotomy inclination of 61°.
Angulation and rotation

To correct rotational deformity:
1. Rotate osteotomy axis in transverse plane by \( \frac{\text{rotation in } 2 \text{ direction opposite of malrotation.}}{2} \)
2. In this case with \(25^\circ\) of external malrotation, internally rotate on transverse plane by \( \frac{25^\circ}{2} = 12.5^\circ \)

C

D

51° of rotation through osteotomy site to correct both angular and rotational deformity

Extremely rotated

25°

45°

CORA

The magnitude of angular correction about the axis of inclination can be calculated using the graphical method by creating a triangle using rotation of 25° on x-axis, and angulation of 45° on y-axis to calculate hypotenuse of 51°.

Length of hypotenuse (51) equals magnitude of rotation at the osteotomy site to correct both the angular and rotational deformity as they are both corrected simultaneously.
Angulation and Length

• 1) Acute correction of angulation
• 2) Acute correction of length up to 2-4cm
• Intramedullary nail preferred for shaft (load sharing and in line with anatomic axis), fixed angle plate constructs and circular frames near articular surface (fine tune/exacting correction)

• Fill void with graft (step cut osteotomies may obviate)
• Autograft – iliac crest, RIA, BMAC + allograft
• Allograft – per company – ensure has osteogenic, conductive, inductive properties
Angulation and Length

• Gradual correction
• acute correction of angulation and gradual correction with lengthening nail, uni-plane fixator with nail as railing, ringed fixators through distraction osteogenesis.

*Usually at a rate of ~0.5mm / day

Now within 1.5cm and can tolerate shoe insert
Length and translation

- Can be corrected with single oblique osteotomy acutely
- Or acutely correct translation and gradual lengthening
7cm short LLD, no coronal plane angular deformity, small sagittal translation component
Transverse osteotomy with acute correction of translation and gradual correction of length with growing rod (precise nail)
8 months,
Femoral shaft

• Though possible, ringed fixation systems are poorly tolerated in the thigh,

• Intramedullary or plate fixation should be used if possible
Articular

• Intra articular malunions free of post traumatic arthritis can be treated with wedge osteotomies and plate or ringed/hybrid fixators
• Arthritic conditions are treated with arthroplasty
Tibial shaft

• Same principles for all shaft correction, tolerate ringed fixators better than the thigh, add fibula osteotomy to prevent tethering correction
Methods

• Plate screw – compression, rigid angular correction, may require large exposure

• Intramedullary rod – load sharing, intramedullary alignment, limited soft tissue insult, meta- and diaphyseal correction, limited in periarticular
Advantages of the Ilizarov Technique

Minimally invasive/percutaneous bony fixation with minimal soft-tissue dissection

Capable of correcting angular, length, rotational, translational, or a combination of these deformities acutely or gradually

Obviates the need for bone graft in the setting of correction of a shortened deformity with distraction osteogenesis

Capable of bony fixation in small periarticular bone segments

External bony fixation remote from the deformity allows this technique to be used in the setting of infection

Deformity correction can be adjusted over time

Allows for immediate weight bearing as weight is distributed from the bone to the tensioned wires, then across the frame via struts or threaded rods, and back to the distal bone segment via tensioned wires; the tensioned wires also allow axial loading/unloading to be experienced at the osteotomy/corticotomy site with weight bearing

Versatile in terms of anatomic location, deformity type, and soft-tissue status where an open procedure may not be possible and limited to a lesser degree by soft tissue

*requires compliant patient
Post operative management

• Pending implant choice, stability, patient compliance, soft tissue envelope and presence of infection

• The goal is to allow function as soon as possible without interfering with correction, IM rods and some spatial frames will allow weight bearing as tolerated immediately post op.
Special thanks to Frank A Liporace MD for case example slides