Basic Principles of Internal Fixation

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Learning Objectives

- Bone Healing
- Fixation Constructs – Types
- Fixation Constructs – Optimizing
- Summary

Mechanobiology of Fracture Healing

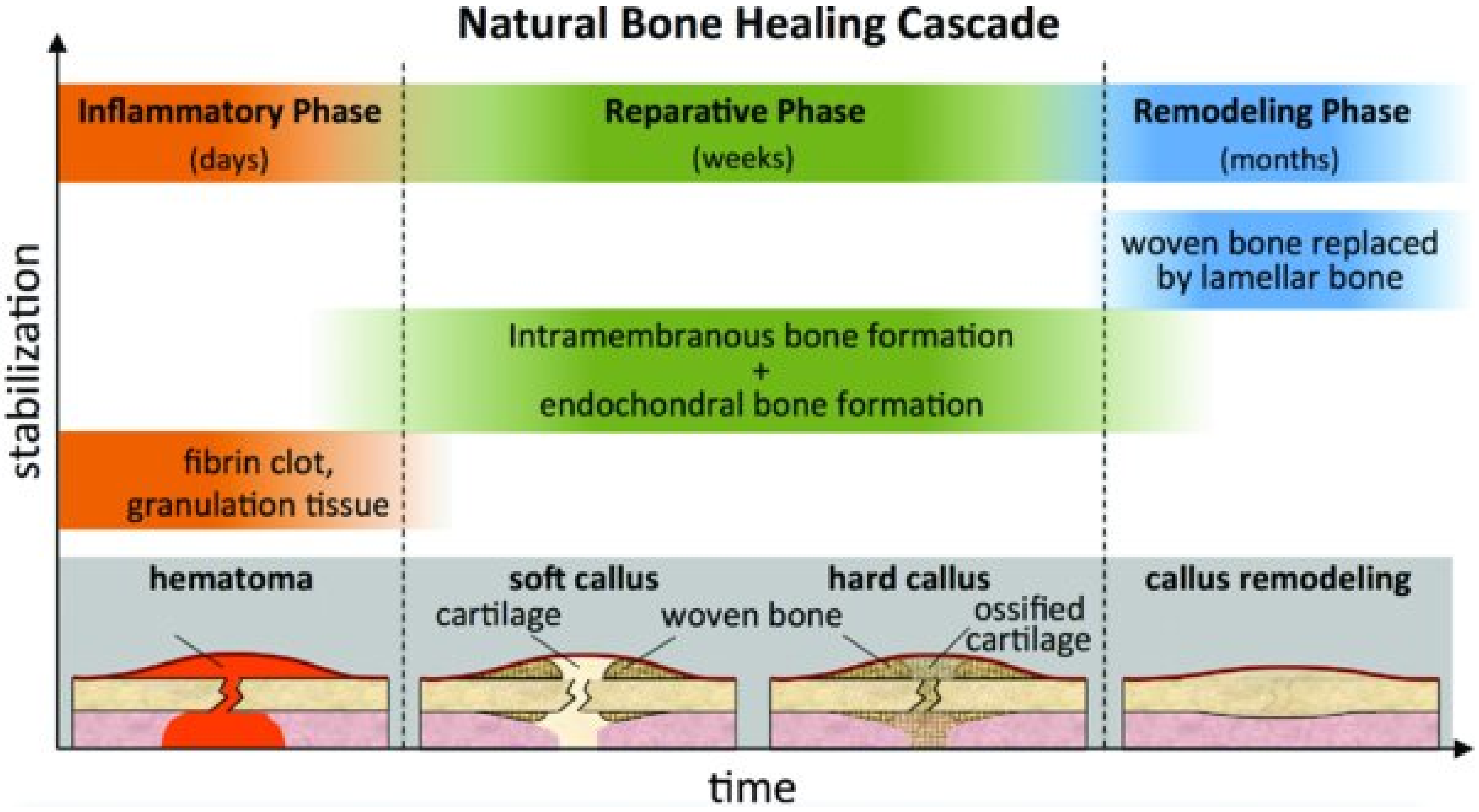
- Natural Bone Healing
- Primary Bone Healing

Natural Bone Healing – Most common

- “Secondary Bone Healing”
- A well established process with stages of healing that gradually improve the stability of the fracture
- Deposit tissue with increasing structural quality
- “CALLUS” formation – Classic

Secondary Bone Healing

- Early (days)
- Mid (weeks)
- Late



From: Rockwood and Green, 9th edition. Chapter 1. Page 14 (Figure 1-12)

Secondary Bone Healing

- Early (days)
  - Tissues provide little stability
  - Can tolerate deformation (up to 100%)

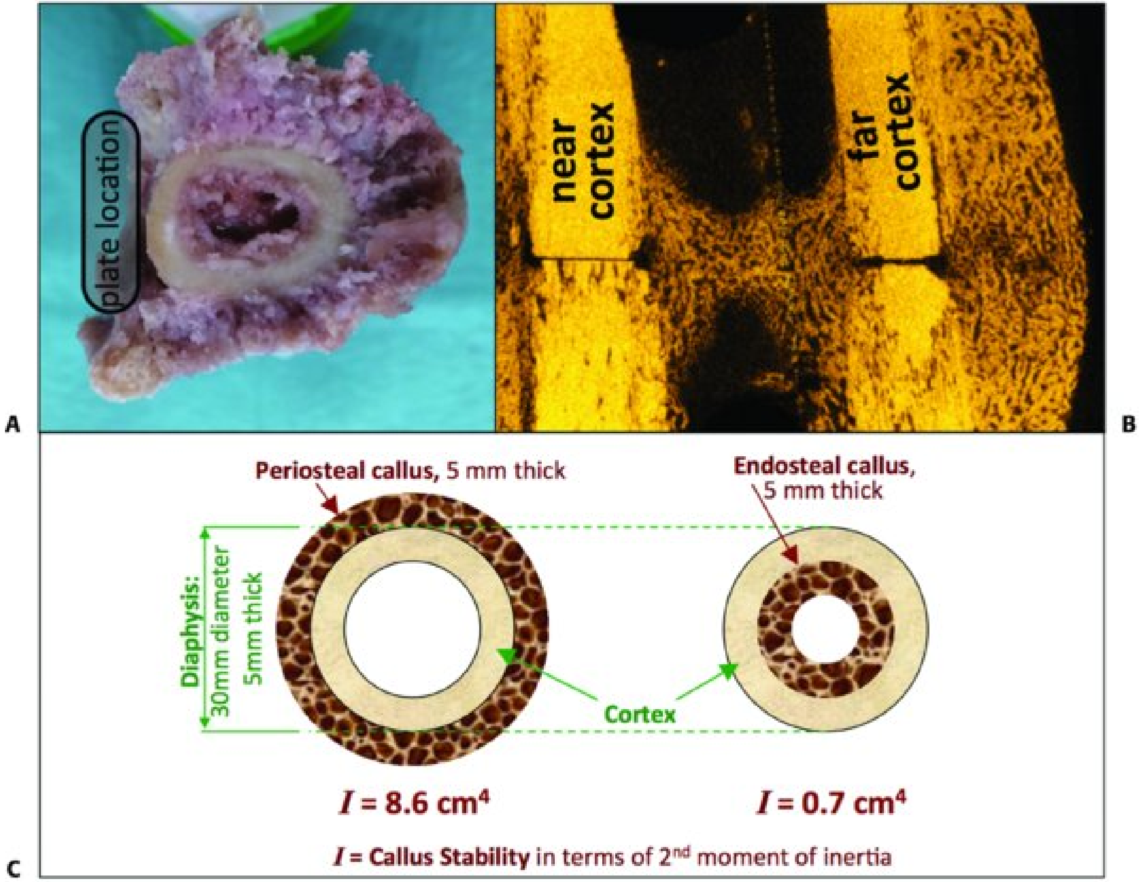
Tissue	Maximum Strain (%)	Ultimate Tensile Strength (N/mm^2)
Hematoma	100	0.1
Soft callus	10–12.8	4–19
Hard callus	2	130

From: Rockwood and Green, 9th edition. Chapter 1.
Page 15 (Table 1-6)

Secondary Bone Healing

- Mid (weeks)
  - Cartilage (soft callus) deposited
  - Offers some stability
  - Less tolerant to deformation
  - As soft callus increases in size, the stability increases further
  - Endochondral ossification occurs further stabilizing

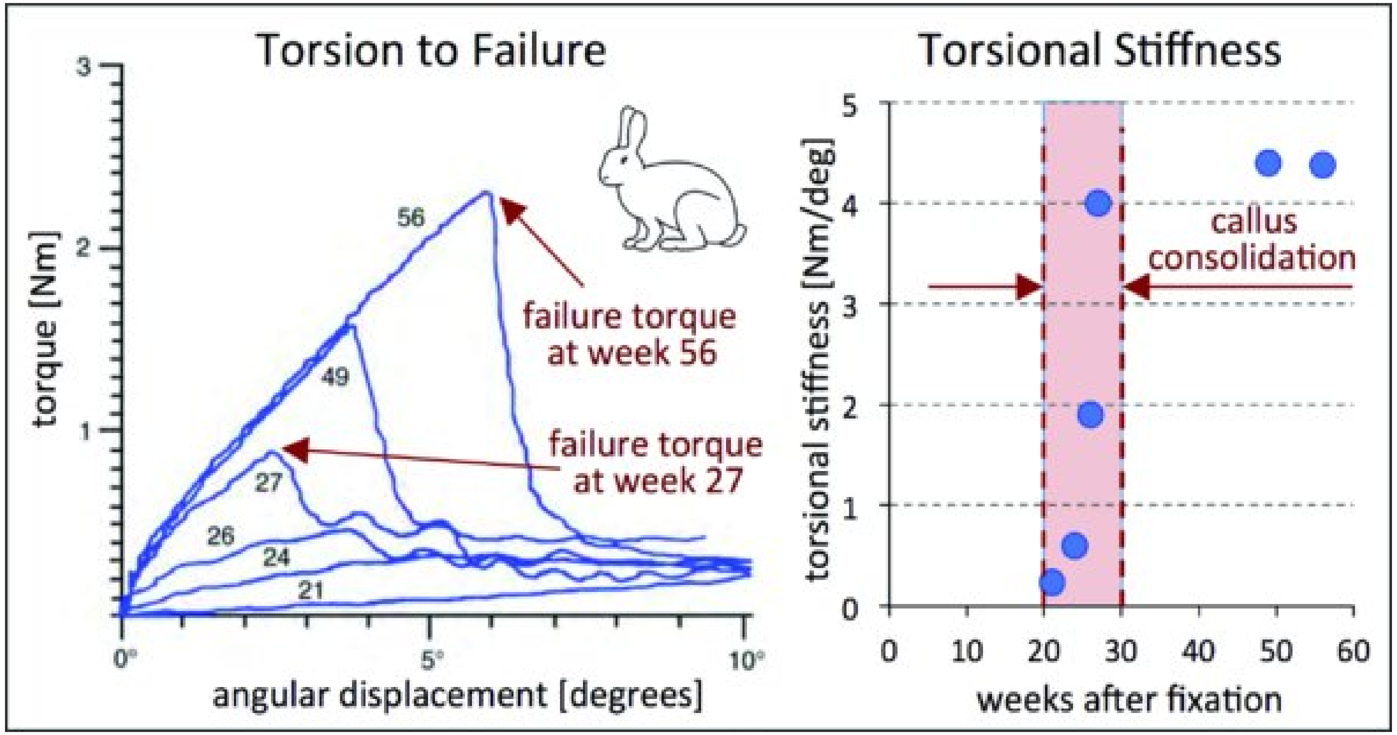
  - There is an optimal amount of strain IFS that leads to the most abundant bone formation (10-30%)



From: Rockwood and Green, 9th edition.
Chapter 1. Page 15 (Figure 1-13)

Secondary Bone Healing

- LATE
  - Remodeling
  - Over time, strength increases
  - Final result – fracture site often stronger then native bone (increased diameter)



From: Rockwood and Green, 9th edition. Chapter 1. Page 16 (Figure 1-14)

Primary Bone Healing

- Relies on direct remodeling of bone
- Osteoclast form cutting cones across the fracture and osteoblasts form new bone
- Similar process to “normal” bone remodeling in response to stress
- Does not pass through intermediate stages of less organized tissue

Primary Bone Healing

- Residual Gaps will prevent osteoclasts from crossing the fracture site
- Even the most anatomic reduction will have small gaps that can be filled in by lamellar bone and then remodeled, but this must involve a very small cross-sectional area
- Direct bone remodeling requires very little motion (< 0.15mm) and low strain (<2%)

What we know

- A simple fracture treated with anatomic reduction and rigid fixation will heal by primary bone healing
  - Interfragmentary compression and neutralization plating
  - Compression plating

- A simple fracture treated with a NON-anatomic reduction (leaving a gap) and rigid fixation will leave an initial “high strain” environment and this fracture is at risk for:
  - Fibrous tissue formation and nonunion

Primary Bone Healing

- To be successful, the surgeon must:
  - Strive for meticulous anatomic reduction
  - Obtain compression
  - Only use this technique for simple plane fractures

Fracture Healing – Important Considerations

- Biological Environment

- Biomechanical Environment

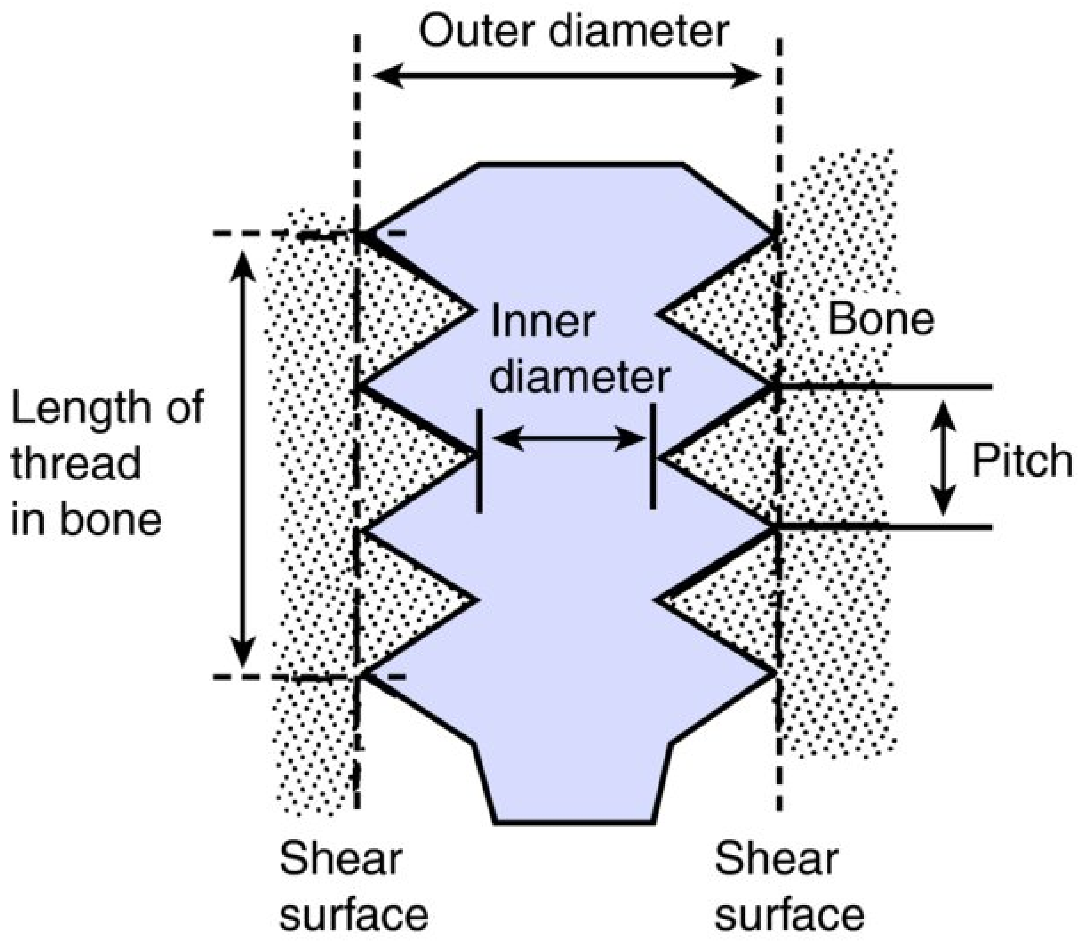
- These two requirements are often “competing”

Biomechanics of Internal Fixation – Screw Fixation

- Screws are used for various reasons:
  - Secure plate to bone
  - Compress fracture
  - Stabilize fracture (position screw)
  - Serve as an anchor

Anatomy of a Screw

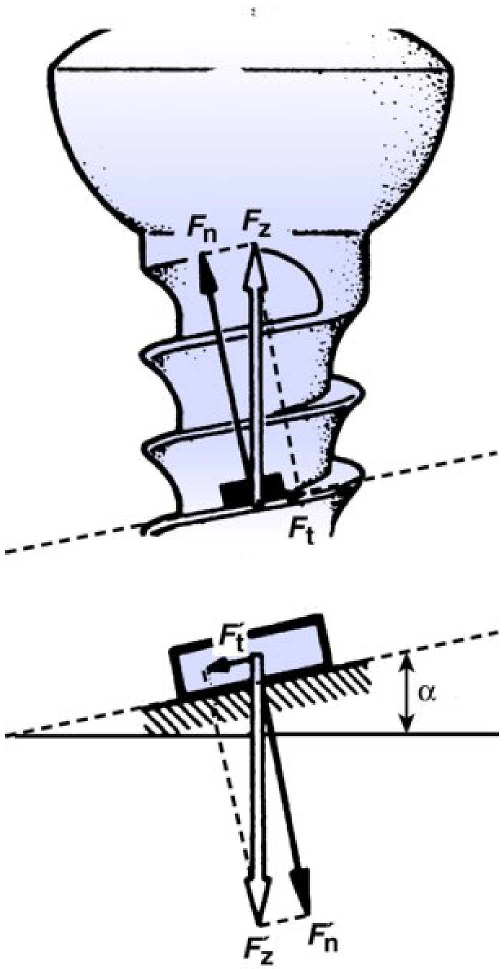
- Head/ shaft/ threads/ tip
- Inner diameter
- Outer diameter
- Thread Depth
- Pitch



From: Rockwood and Green, 9th edition. Chapter 11. Page 384 (Figure 11-34)

Anatomy of a Screw

- **Tip** – many have “cutting flutes” that are sharp to cut path for threads
- **Threads** purchase bone
- **Head** – screwdriver engagement and final buttress to plate or bone



From: Rockwood and Green, 9th edition. Chapter 11. Page 367 (Figure 11-6)

Biomechanics of Screw Fixation

- Resist Fatigue Failure
  - Increase the inner root diameter

- Increase Pullout strength
  - Increase outer diameter
  - Decrease inner diameter
  - Decrease Pitch

  - Increase thickness of cortex
  - Cortex with more density

Cortical vs Cancellous Screw

<u>Cortical Screw</u>

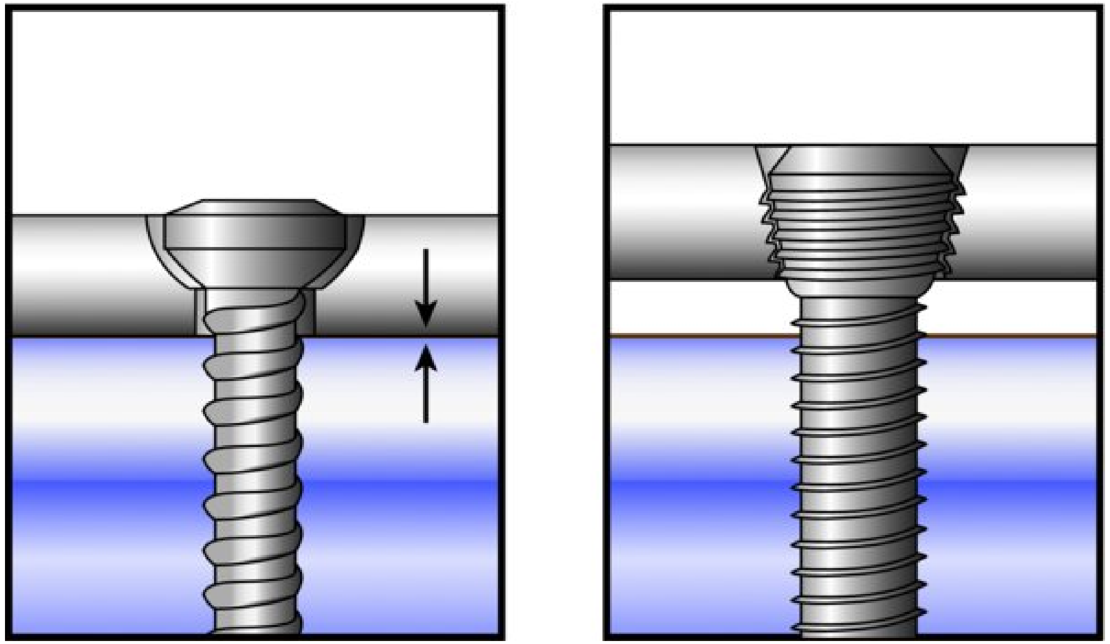
- Used in cortical bone
    - More dense/ small thickness
- Smaller pitch
- Thread depth smaller (not crucial)

<u>Cancellous Screw</u>

- Used in Cancellous Bone
    - More porous/ less dense but larger volume
- Larger pitch
- Deeper threads

Locking Screws

- Screw head "locks" to plate
- Becomes "fixed angle"
- Uniaxial vs Polyaxial mechanisms available
- Locked plate constructs don't rely on plate- bone friction for stability (less on screw purchase)
- Most have increased core diameter and smaller depth

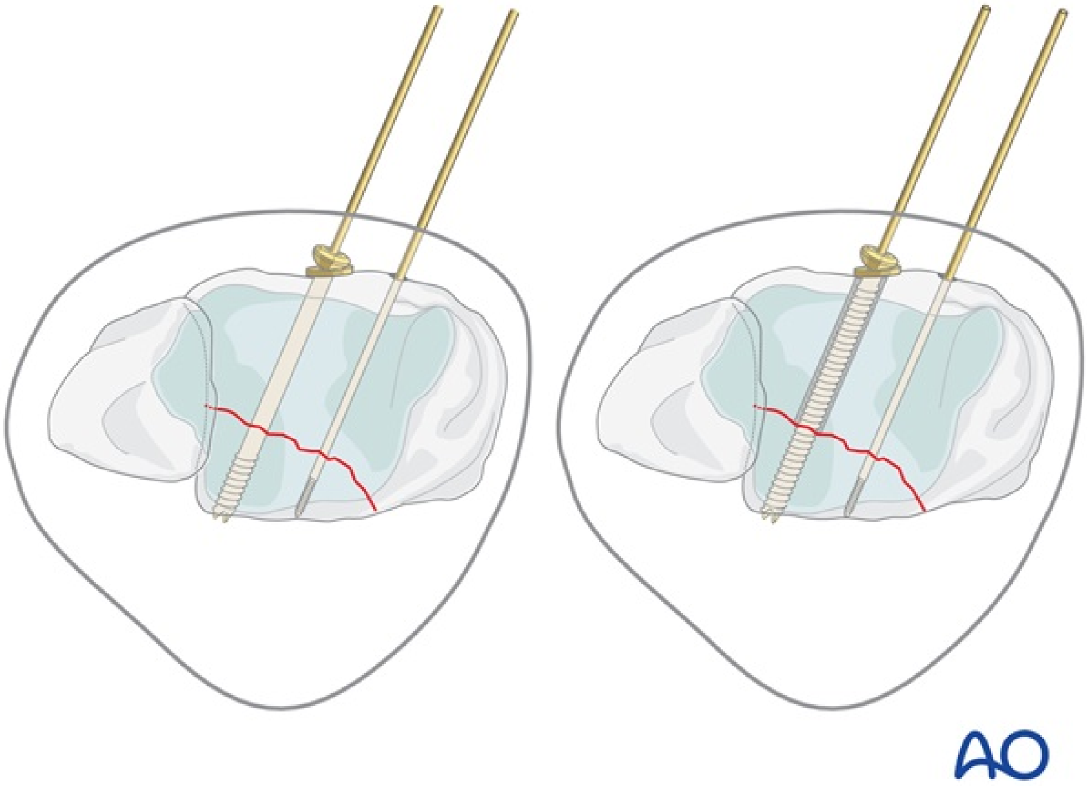


From: Rockwood and Green, 9th edition. Chapter 11. Page 368 (Figure 11-8)

Cannulated Screws

- Cannulated Screws
  - Allows placing screw over guidewire
  - Increased inner diameter required necessary for similar outer diameter
  - Relatively smaller thread depth results in lower pull out strength
  - Screw strength minimally affected

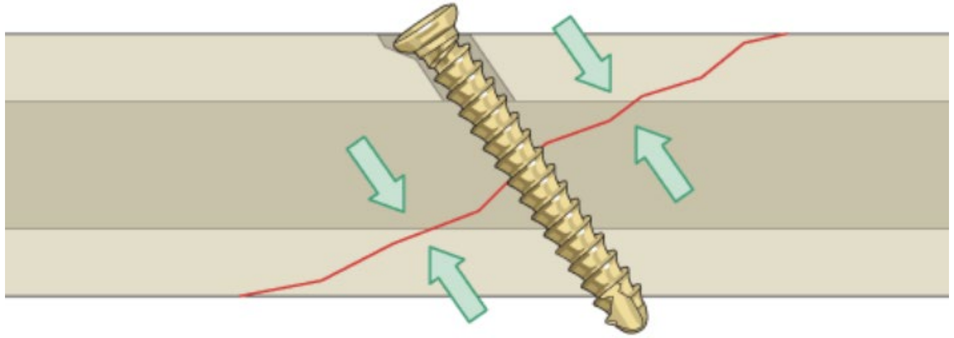
  ($\alpha\ r^4_{outer\ core} - r^4_{inner\ core}$)



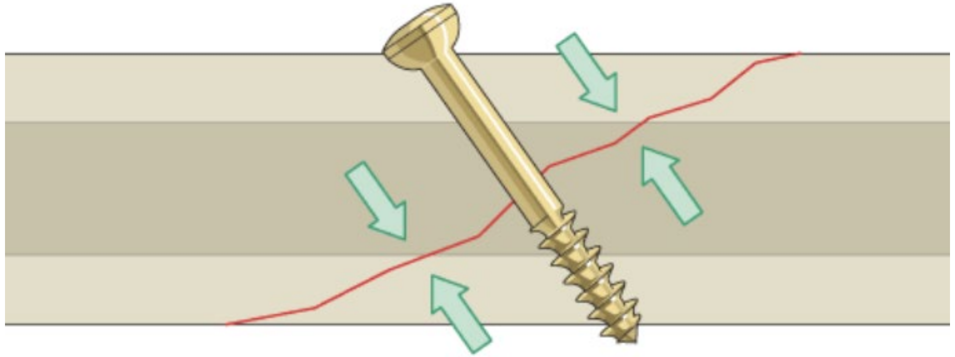
Images from AO Foundation

Lag Screw Technique

- Both offer compression of fracture
- Lag by “technique”



- Lag Screw by “Design”



Images from AO Foundation

Interfragmentary Screw - STEPS

Images from AO Foundation

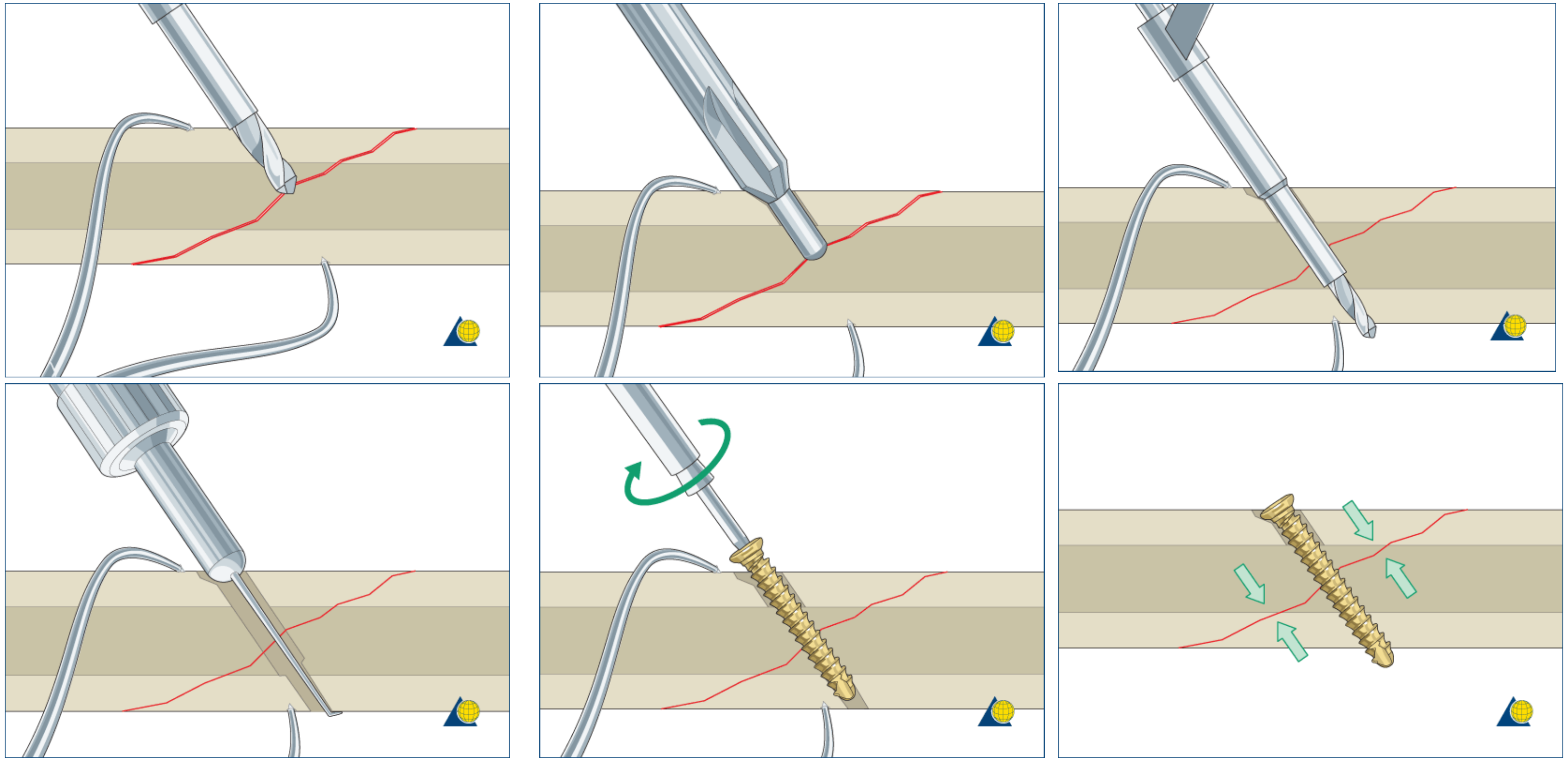
1) Drill Proximal Cortex (outer core diameter

2) Counter Sink

3) Measure Screw Size

4) Drill Distal Cortex (inner core diameter)

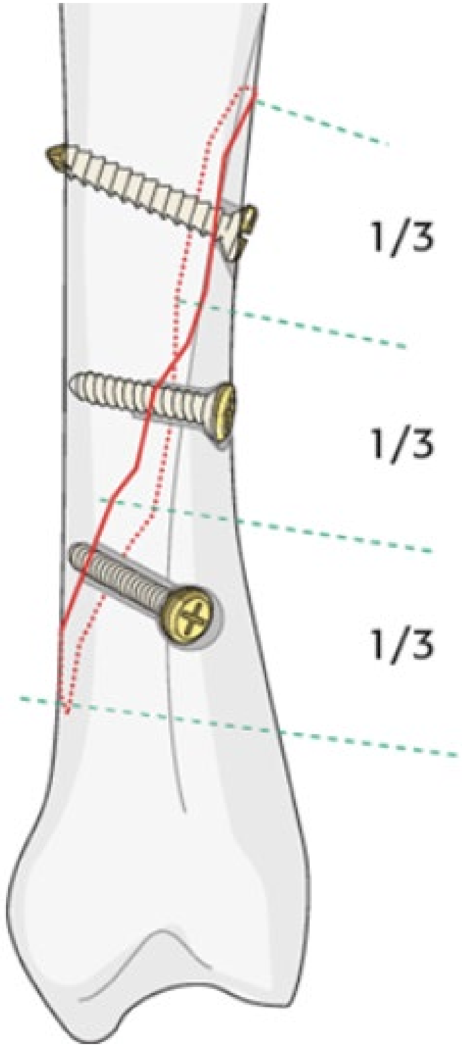
5) Screw engages Far cortex



Compression happens as Head engages near cortex

Interfragment Screw (obtain Fracture Compression)

- Number of Interfragmentary screws will be determined by "length" of fracture
- Long spiral fractures may be amenable to 2 or 3 interfragmentary screws



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Types of plates - Function

- Neutralization Plate
- Compression Plate
- Buttress Plate
- Antiglide Plate
- Bridge Plate

- PLATE ALWAYS HAS ONE OF THESE FUNCTIONS

Neutralization

- Used commonly in spiral pattern

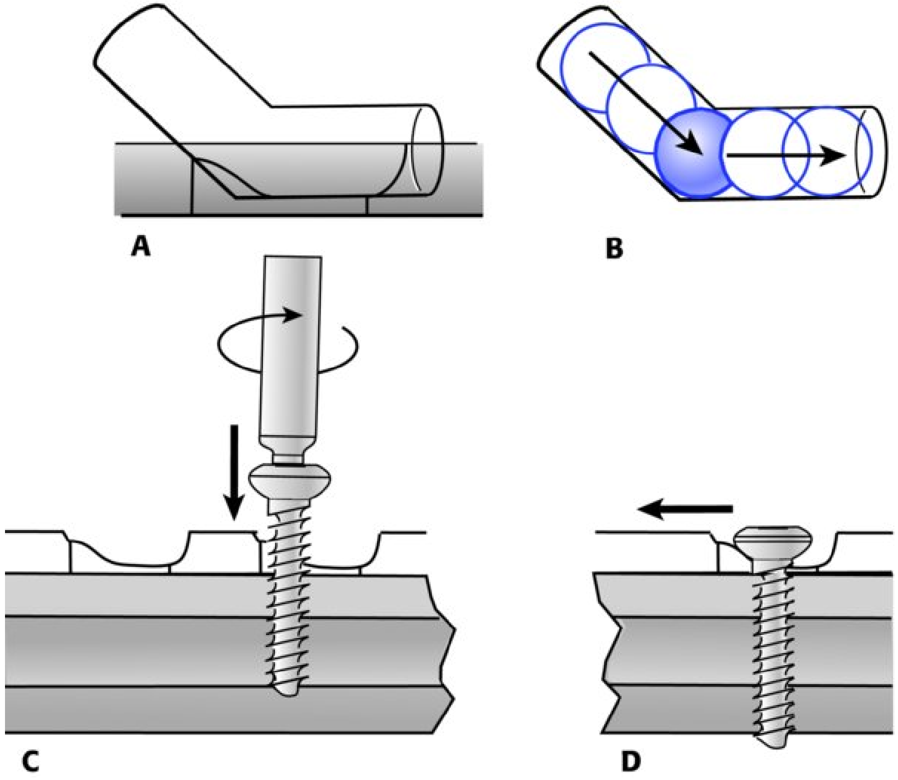
- 2 interfragmentary screws (here)
- Neutralization plate

- **Plate "protects" shear forces that could loosen interfragmentary screws**

Compression Plate – Short Oblique or Transverse Fracture Pattern

- Obtain absolute stability
- Achieve primary bone healing
- Need anatomic reduction

- Screw is placed Eccentric
- **As screw head engages plate, Compression obtained**

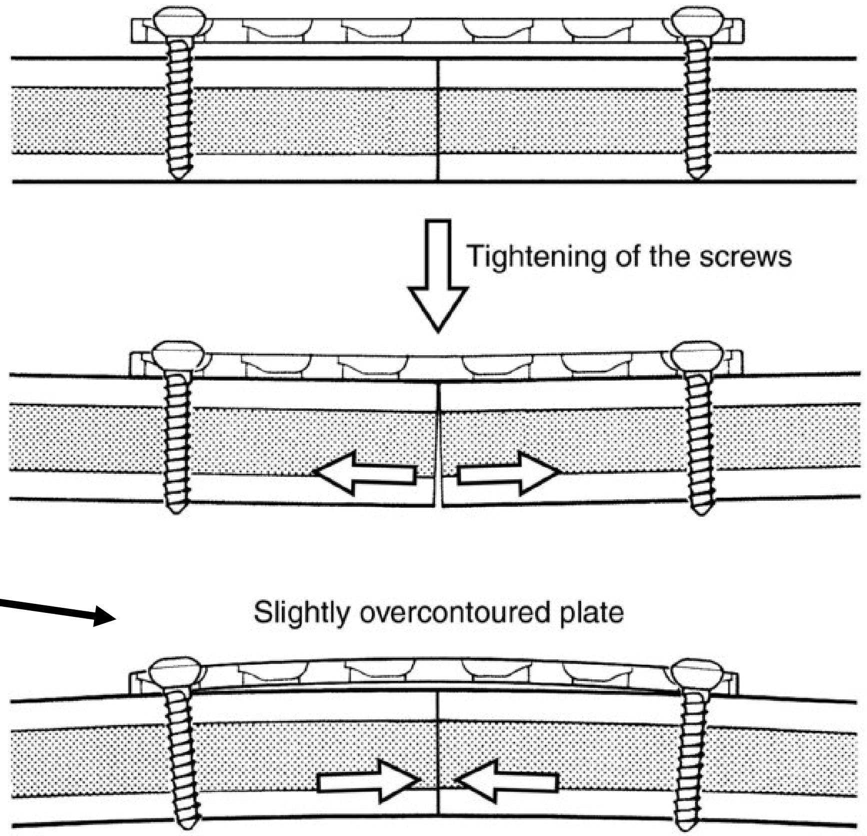


From: Rockwood and Green, 9th edition.
Chapter 11. Page 370 (Figure 11-12)

Compression Plate

- If compression is applied to "straight" plate, compression will occur at near cortex but distraction at far cortex
- By "pre-tensioning", i.e. overcontour, of plate, symmetric compression across the entire fracture will occur

- Avoid distraction at far cortex!



From: Rockwood and Green, 9th edition. Chapter 11. Page 370 (Figure 11-13)

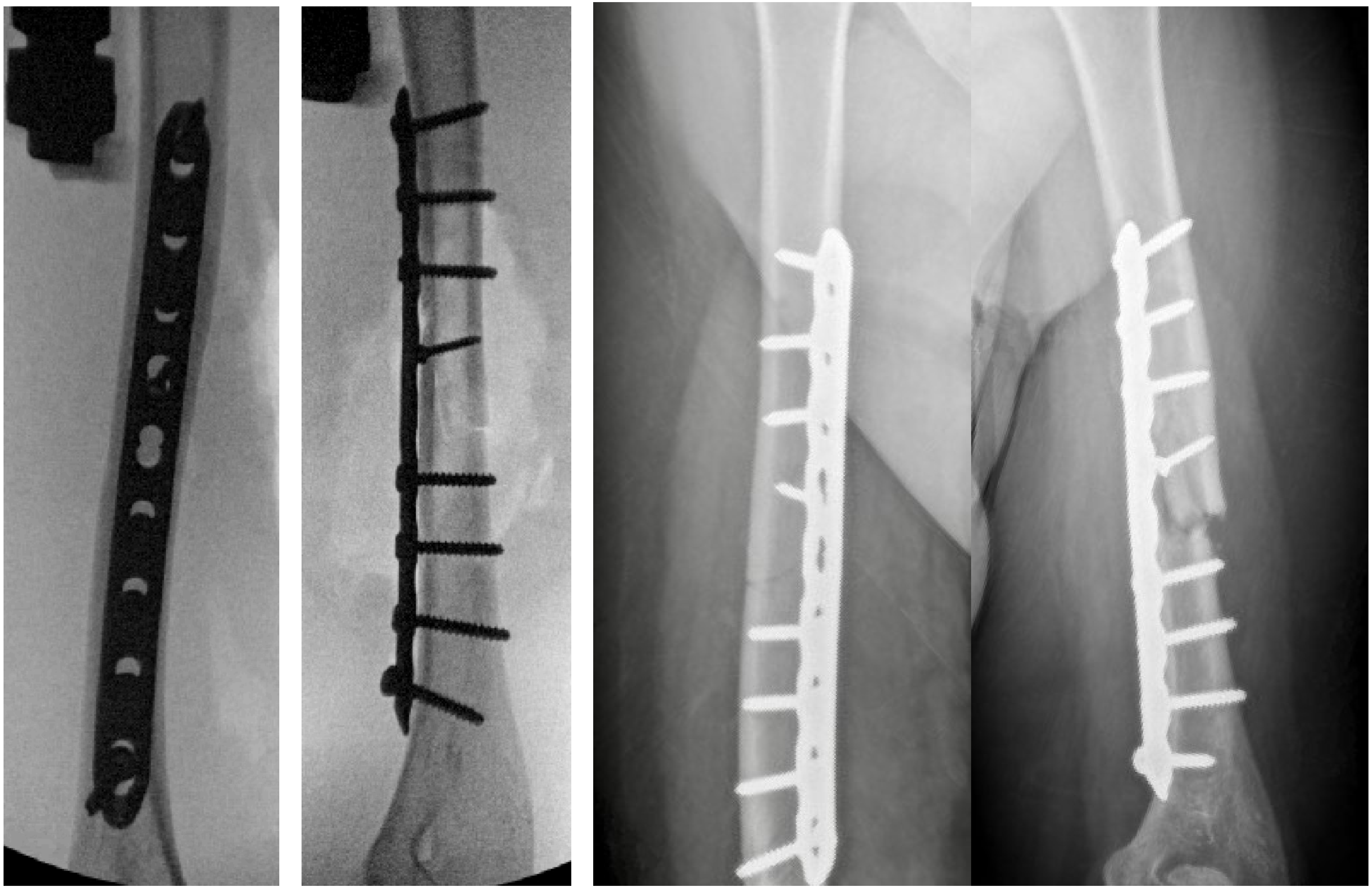
Case Example

- Isolated humerus fracture
- Decision to operate

- Short oblique
- Compression plate is good option

Small Gap on far side, eventual Nonunion can occur

Aim for compression across entire fracture

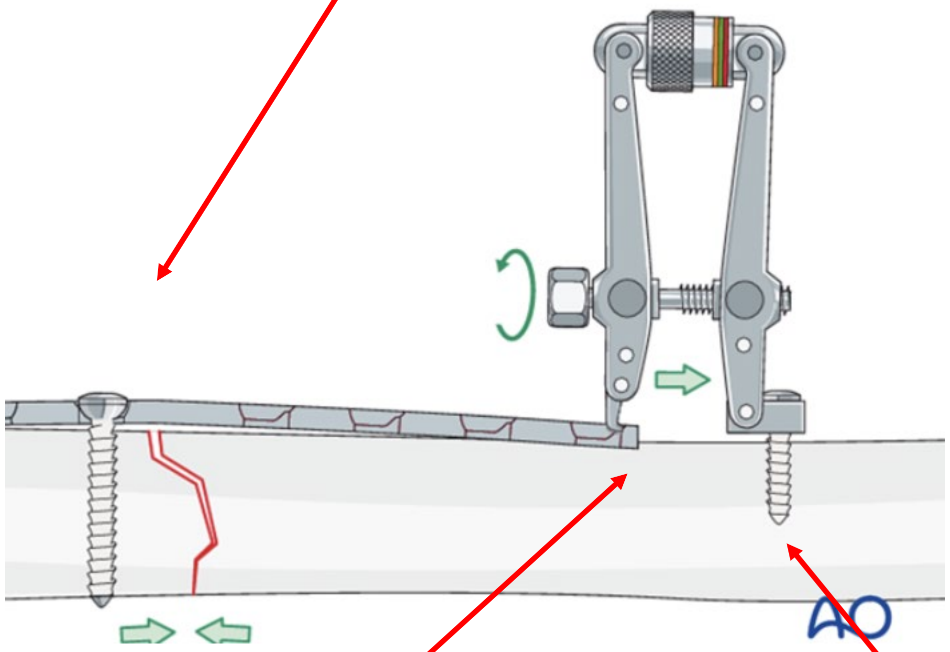


Compression Plate

- Another strategy:

Articulated Tensioning Device (ATD)

Screws are only placed on one side of fracture, preparing for compression



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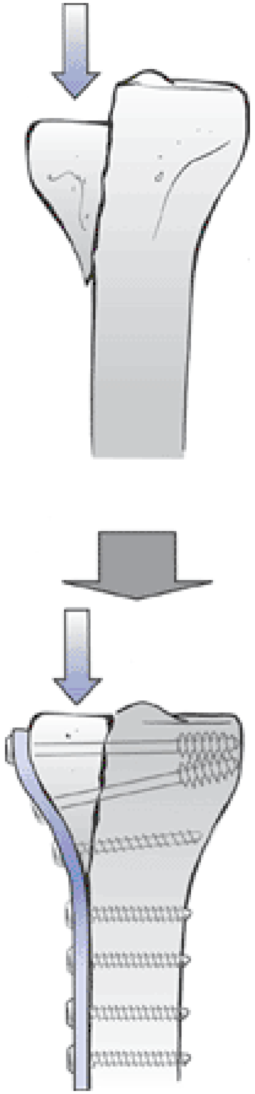
Next, this Device has ratchet to "tension", pulling plate distally and compress fracture

Screw placed for tension device, removed later

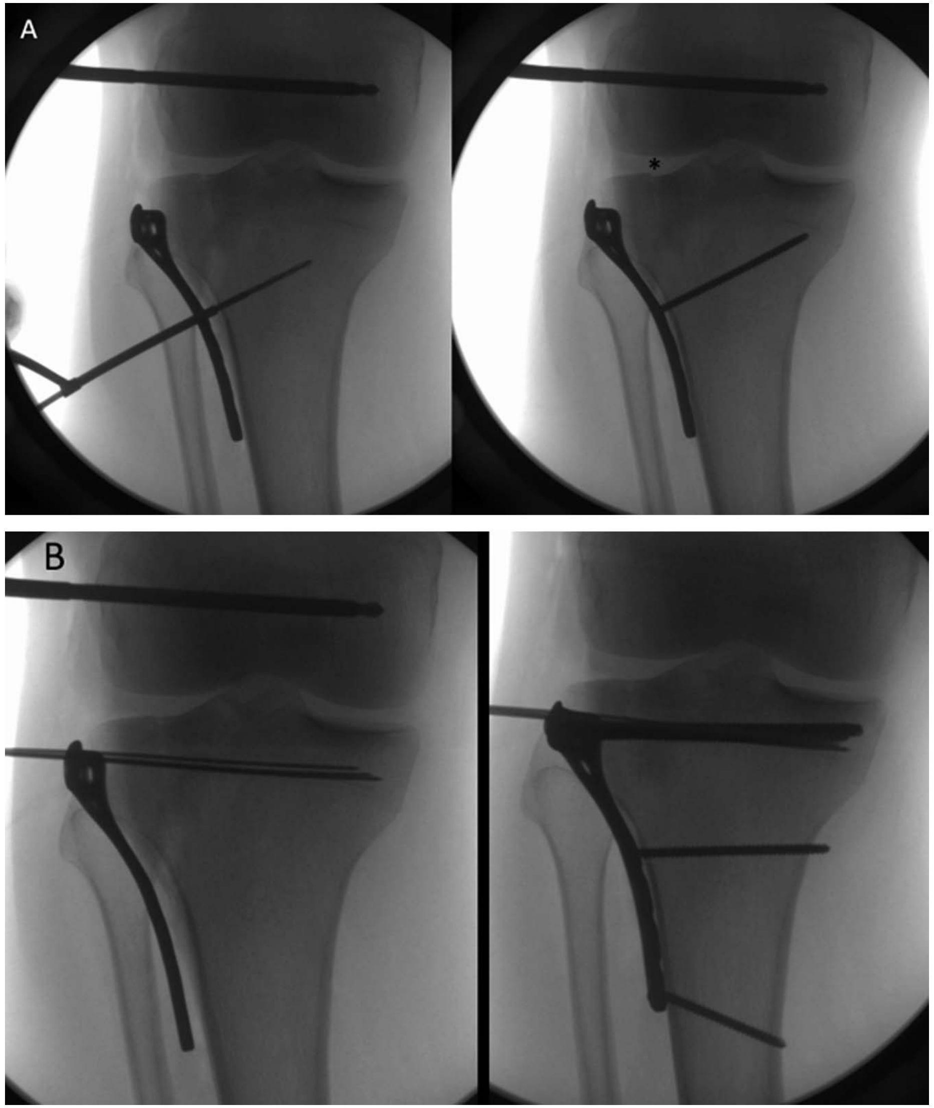
Buttress Plating

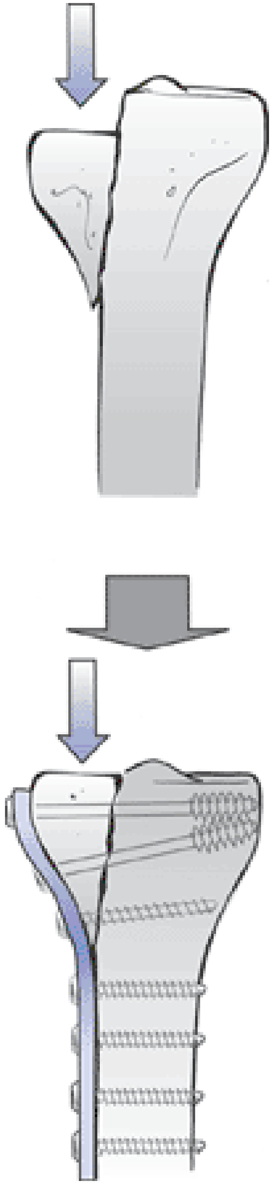
- Plate placed across "apex" of fracture
- If plate undercontoured then screw insertion at the apex will cause fracture compression



Buttress Plating

- Plate undercontoured, i.e., straighter than bone
- Compression occurs
- “over-reduction” due to stiffness of plate in this case
- This is corrected and result is anatomic reduction





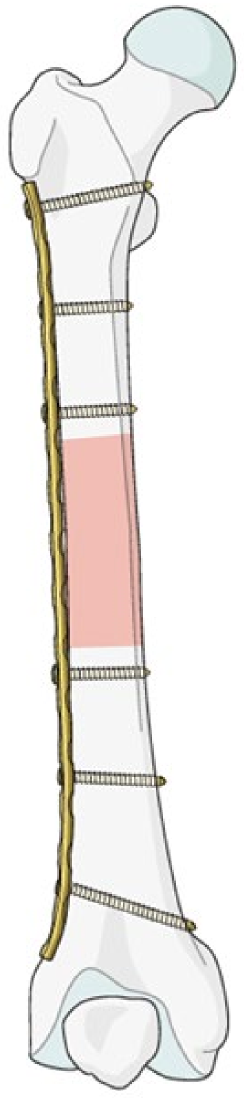
Anti-glide

- Similar to Buttress
- Placed over axilla of fracture
- **Prevents shearing/ shortening of fracture**
- Does not apply compression

From: Rockwood and Green, 9th edition.
Chapter 11. Page 372 (Figure 11-16)

Bridge Plating

- Used for comminuted fractures
- **“bridging the proximal portion to the distal portion and leaving all “intermediary fragments” unfixed**
- All stability is transferred through the plate
- No stability is conferred by bone (at first)



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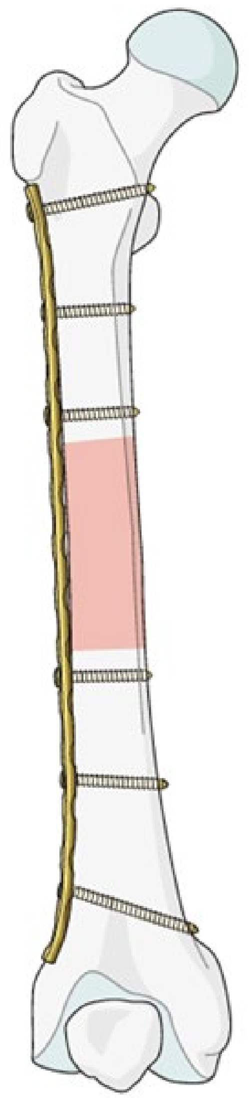
Bridge Plating

- Used for comminuted fractures
- Preserve fracture biology
- Can often insert ”percutaneous” and avoid opening near fracture (preserve biology)
- Nonanatomic reduction of comminution

- **RESTORE length/ alignment/ rotation**



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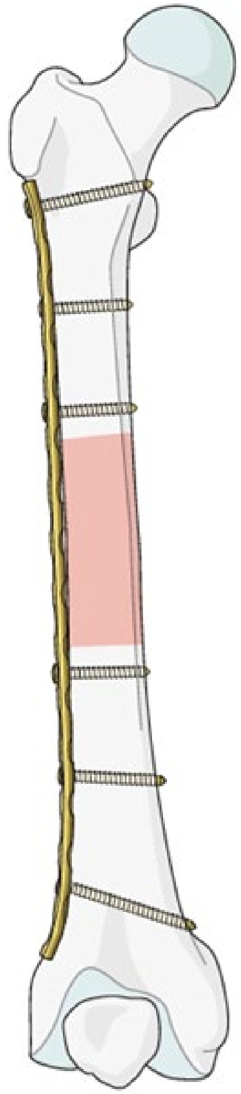
Bridge Plating - Biomechanics

- The optimal stiffness for optimizing bone healing remains unknown
- Perrins Strain Theory - recommended reading !!
- Healing is improved when a small amount of motioı and strain is allowed
- 10-30% strain is ideal environment (motion of 1 mn in a 3 mm gap)



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Theory of Strain with Different Fractures

- Comminuted Fractures can tolerate slightly more strain

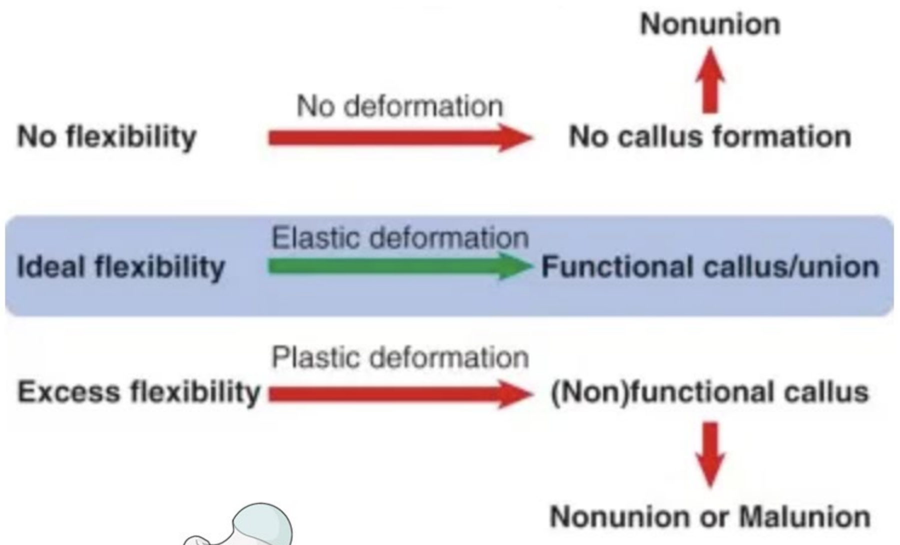
    Ie. Movement/ strain shared over multiple fragments

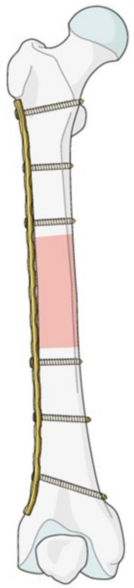
- Simple Fractures see more strain with any movement

    ie. All movement/ strain between 2 fragments

Bridge Plating - Biomechanics

- If construct is too stiff – no strain and therefore union is delayed, callus is small,
- If construct is flexible – some strain is seen, callous forms/ bone heals
- If construct is too flexible (unstable), callus tries to form but keeps getting disrupted and therefore nonunion forms (usually hypertrophic nonunion)





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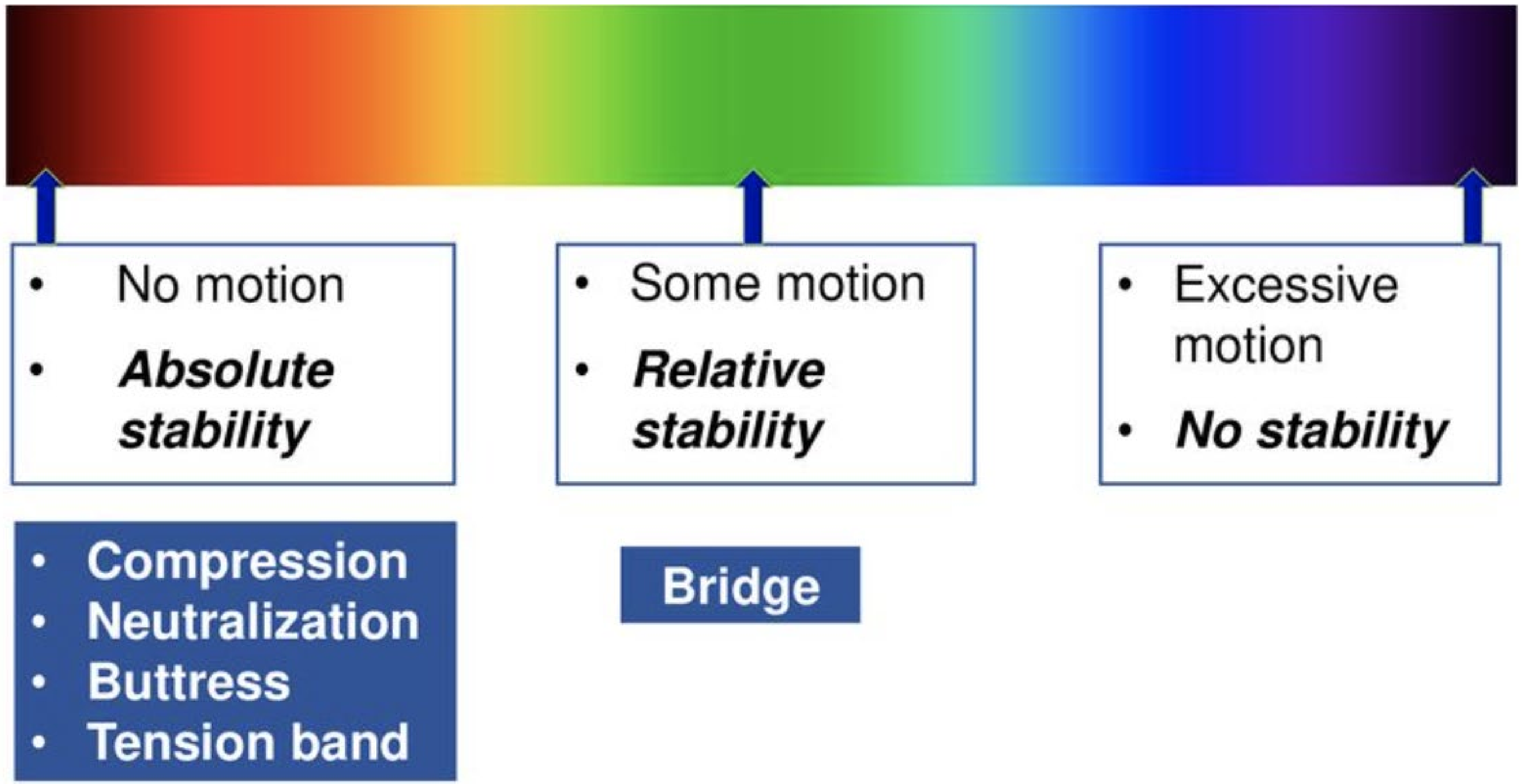
Spectrum of Stability



PreContoured (Anatomic) Plates

Advantages

- match normal anatomy (attempt)
- Allows plate to be lower profile
- Allows more screws in short segment (double row)
- More points of fixation in short segment
- Combi plates (nonlocking and locking)
- Can reduce bone to plate

Disadvantages

- These are designed for the average patient
- There is no “average” patient with the perfect fit
- It can also malreduce the fracture if not a good fit
- It can be prominent

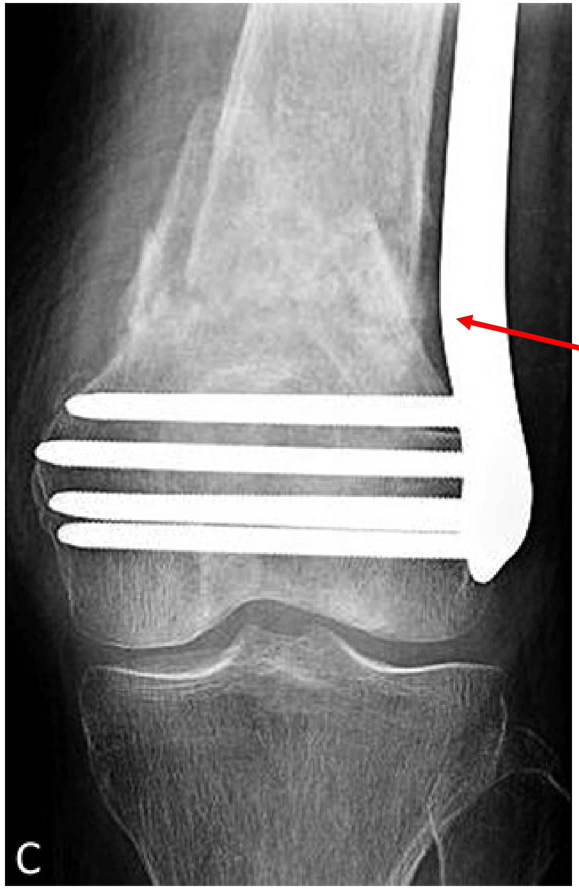


Plate mismatch

Linn et al. Journal of Orthopaedic Trauma: October 2015 - Volume 29 - Issue 10 - p 447-450 Figure 3.

How many ? When? Where?

- Number of screws (cortices) recommended on each side of the fracture:

Forearm	3	(4-6)
Humerus	3-4	(6-8)
Tibia	4	(7-8)
Femur	4-5	(8)

Good concept?

We can apply biomechanical principles

Use more logical approach

General concept: Less screws over a long span are better than more screws over a short span

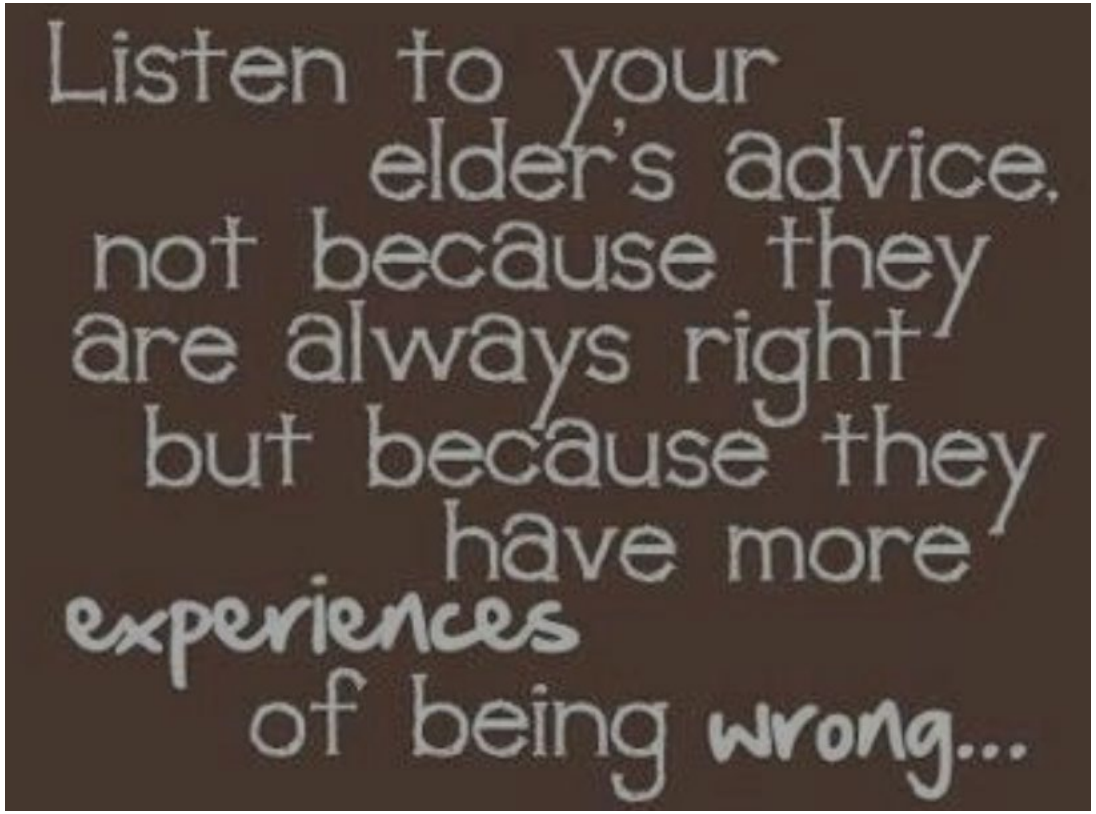
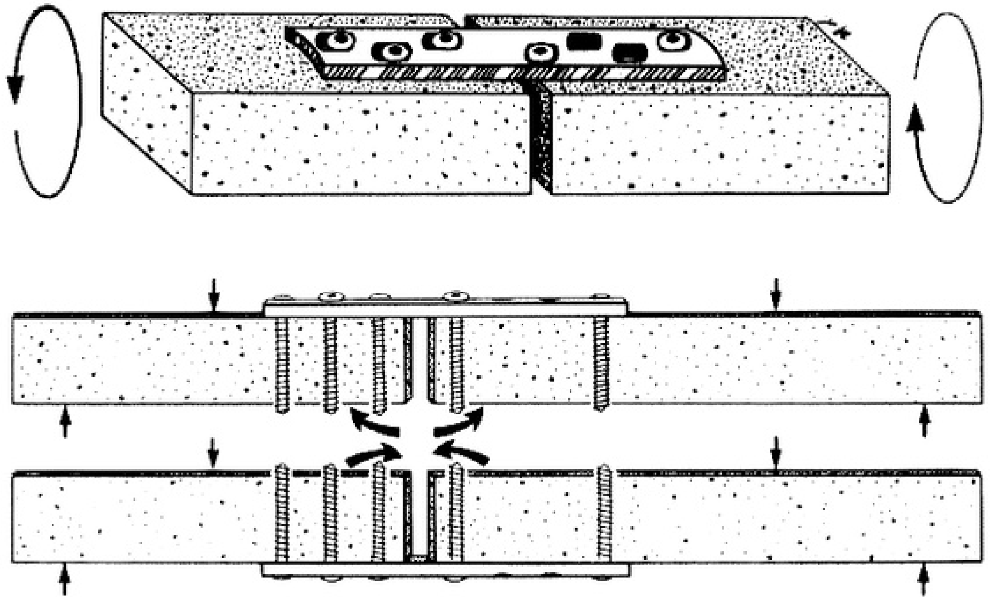


Plate Biomechanics – Screw Number and Spacing

- **Depends on what you are measuring**
  - **Axial load**
  - **Bending**
  - **Torsion**
  - **combined**



From: JOT 10(3), April 1996, p 204-208, Fig2-3
The Strength of Plate Fixation in Relation to the Number and Spacing of Bone Screws. Tornquist H et al.

Biomechanical testing

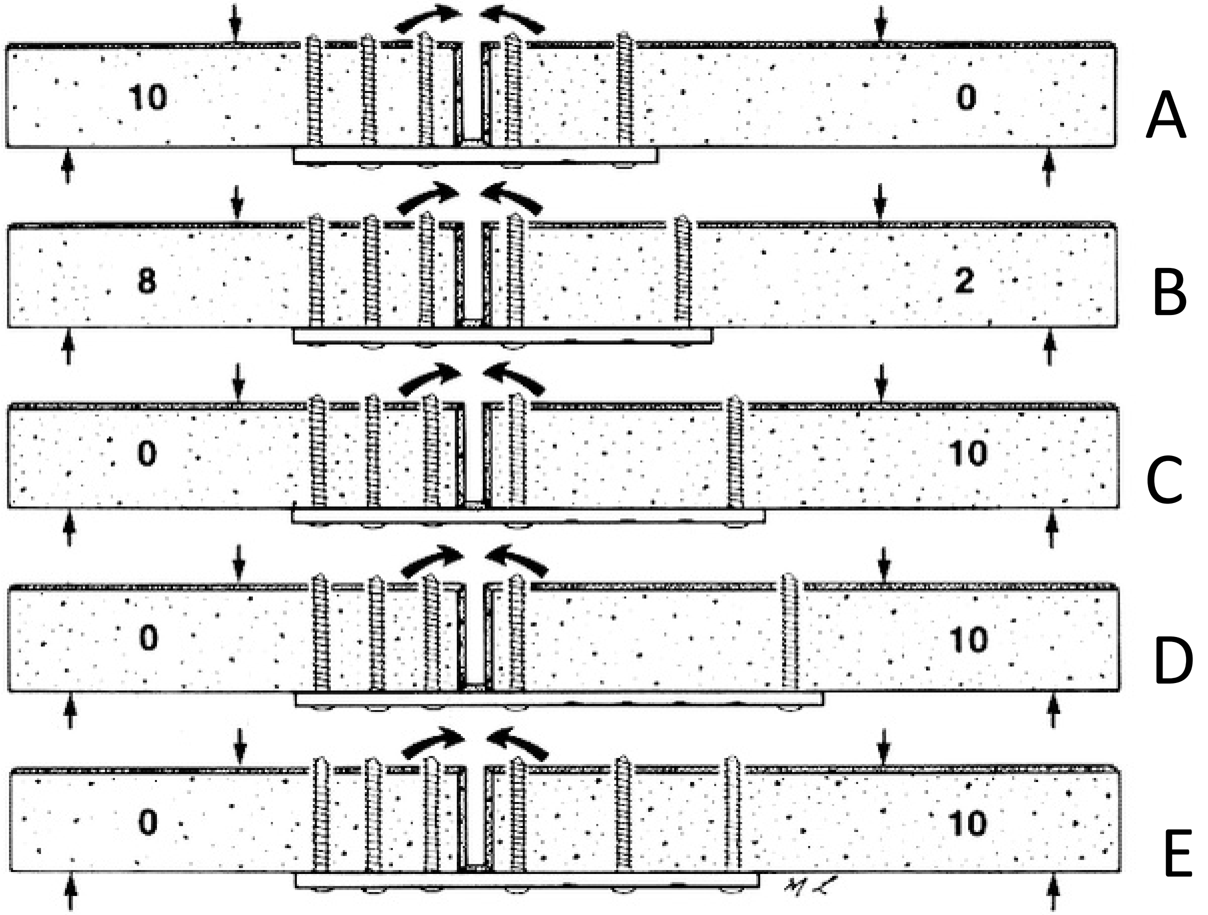
- Screw 1,2,3 (classic) > Screw 1 and 3

Screw 1,2,3 = Screw 1 and 4

Screw 1,2,3< Screw 1 and 5

Screw 1,3,6 ++ stronger

=working length is more important than screw number



From: JOT 10(3), April 1996, p 204-208, Fig 6
The Strength of Plate Fixation in Relation to the Number and Spacing of Bone Screws. Tornquist H et al.

Where should we put the screws

How stiff should construct be?

- Optimal Working length and bridge span not completely understood
- Longer working length equals more motion (less stiffness) and weaker construct
- Shorter working length equals less motion (more stiffness) and stronger construct)

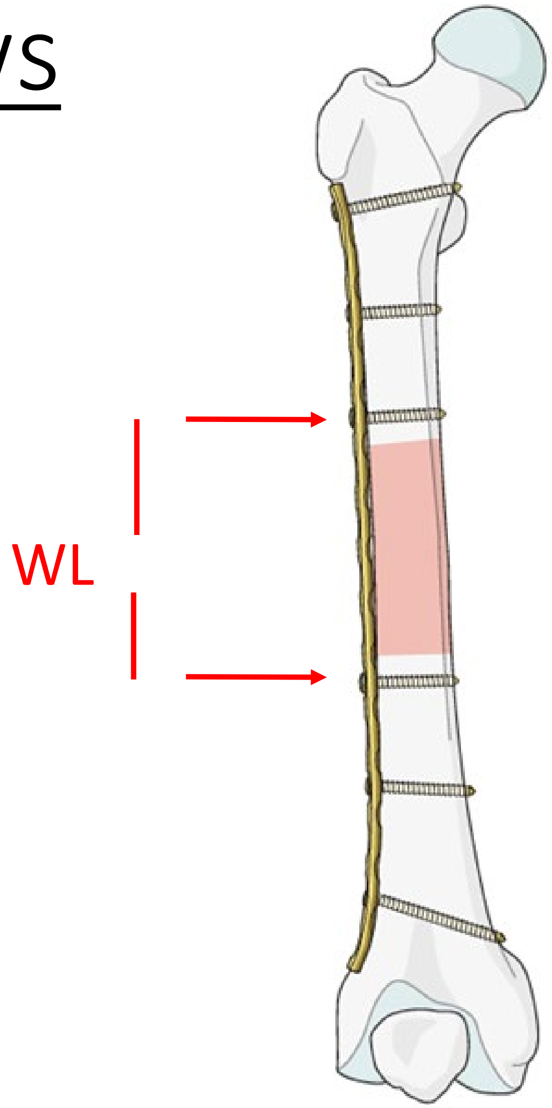
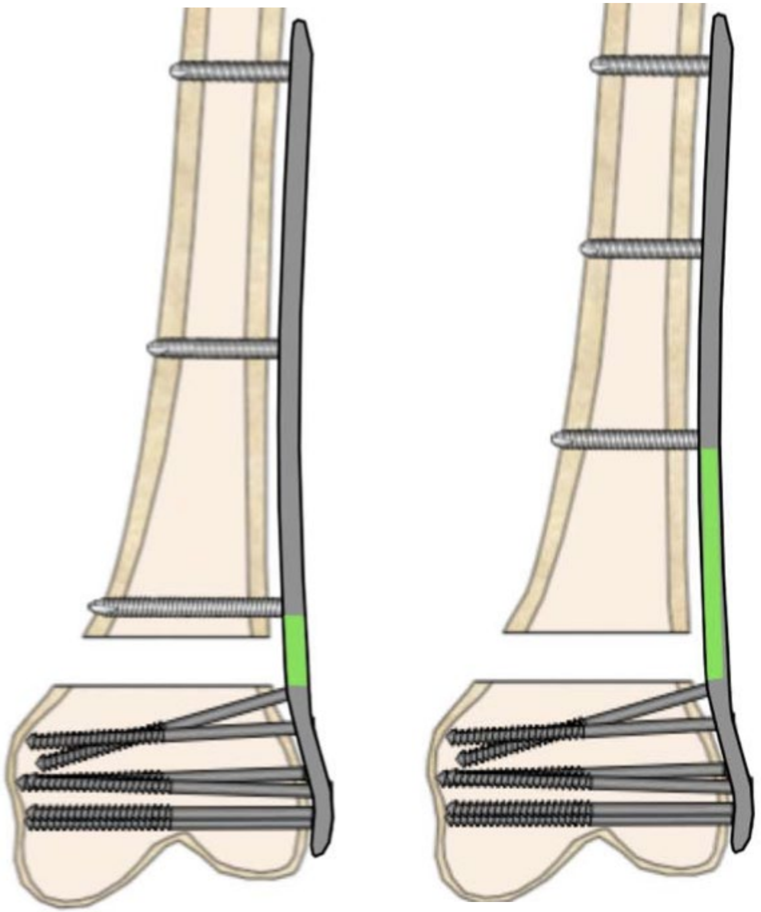


Image from AO Foundation

Where should we put the screws?

- Many factors influence decision
- For Bridge Plating
  - -Long Plate
  - -Wide Screw Span
  - -Leave 1-2 screw holes empty near fracture site
- Still unclear best ”strain environment” for fracture healing



From: JOT 2017 31 (10) p531-537. Fig 1
Comparison of 4 methods for Dynamization of Locking Plates: Differences in the Amount and Type of Fracture Motion
J Henschel et al

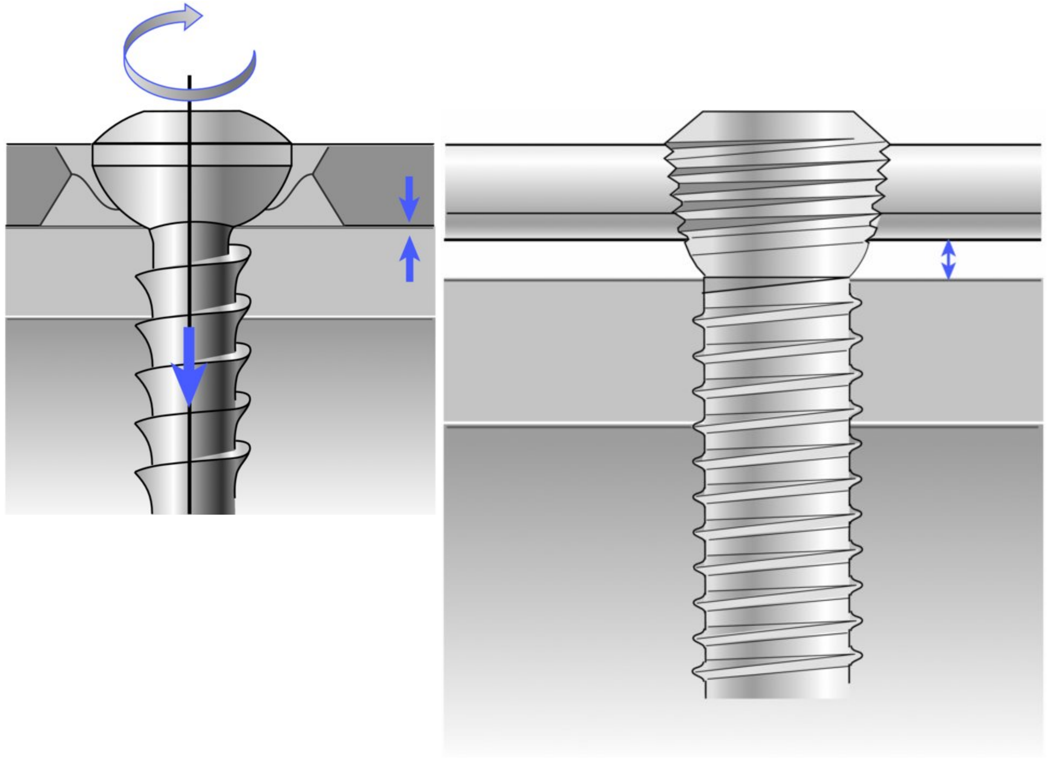
Locked Plating – How does the help?

Conventional Plating

- relies of friction at the bone plate interface generated by the screw

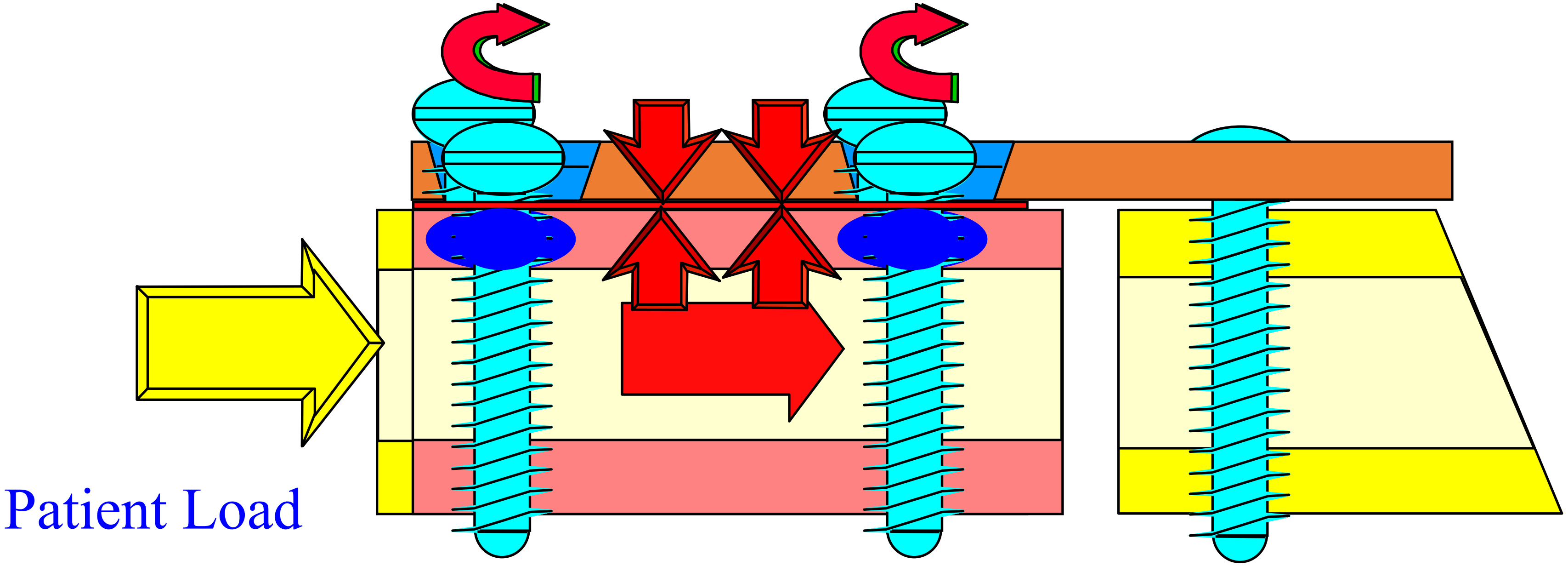
Locking Plate

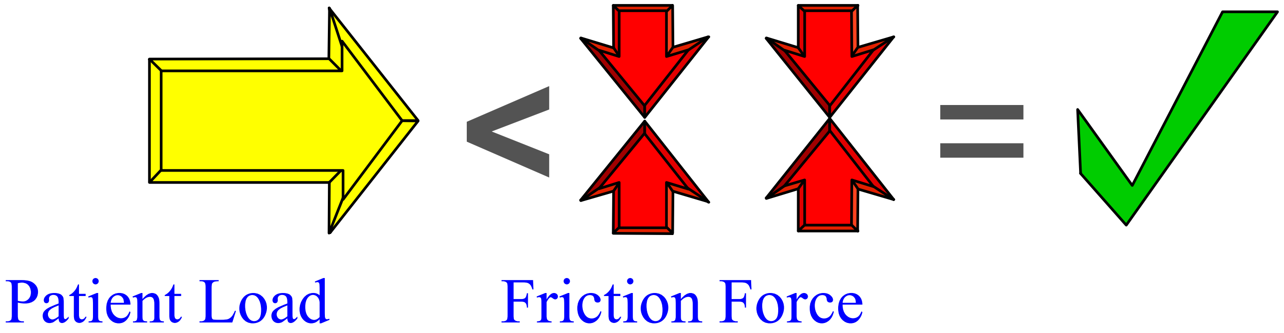
- "single Beam" Construct
- Does not rely on the purchase of the screw in bone
- Plate can "sit off" bone
- Converts any shear force into an axial compression force



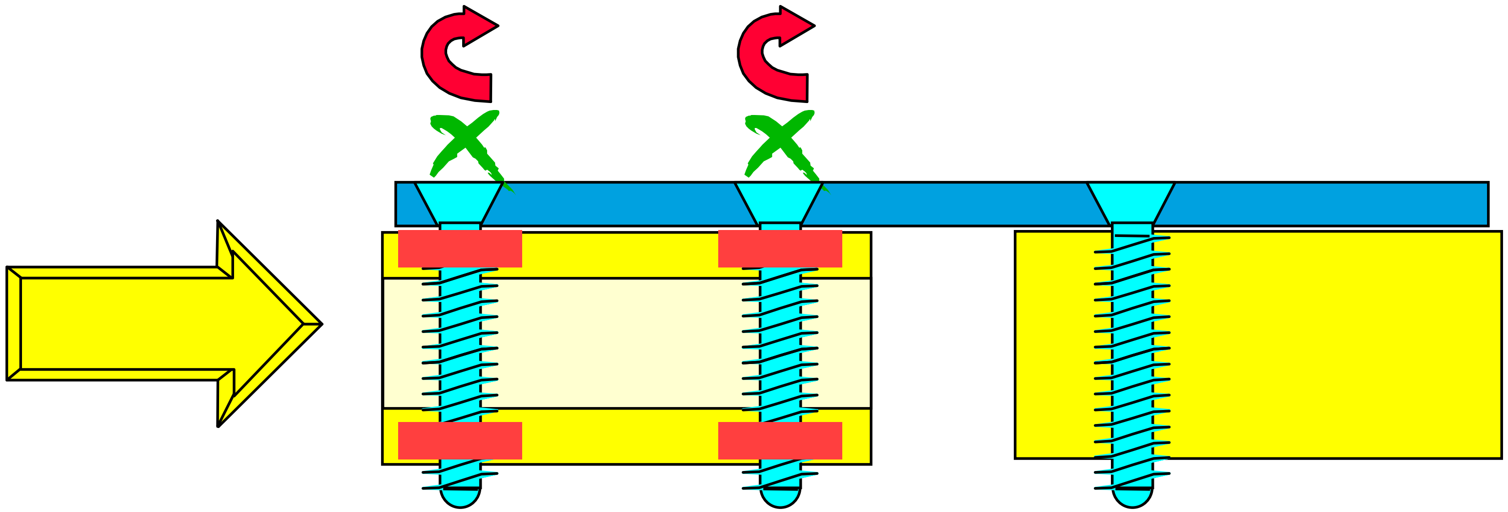
From: Rockwood and Green, 9th edition. Chapter 11. Page 368 (Figure 11-8)

Conventional Plate Fixation





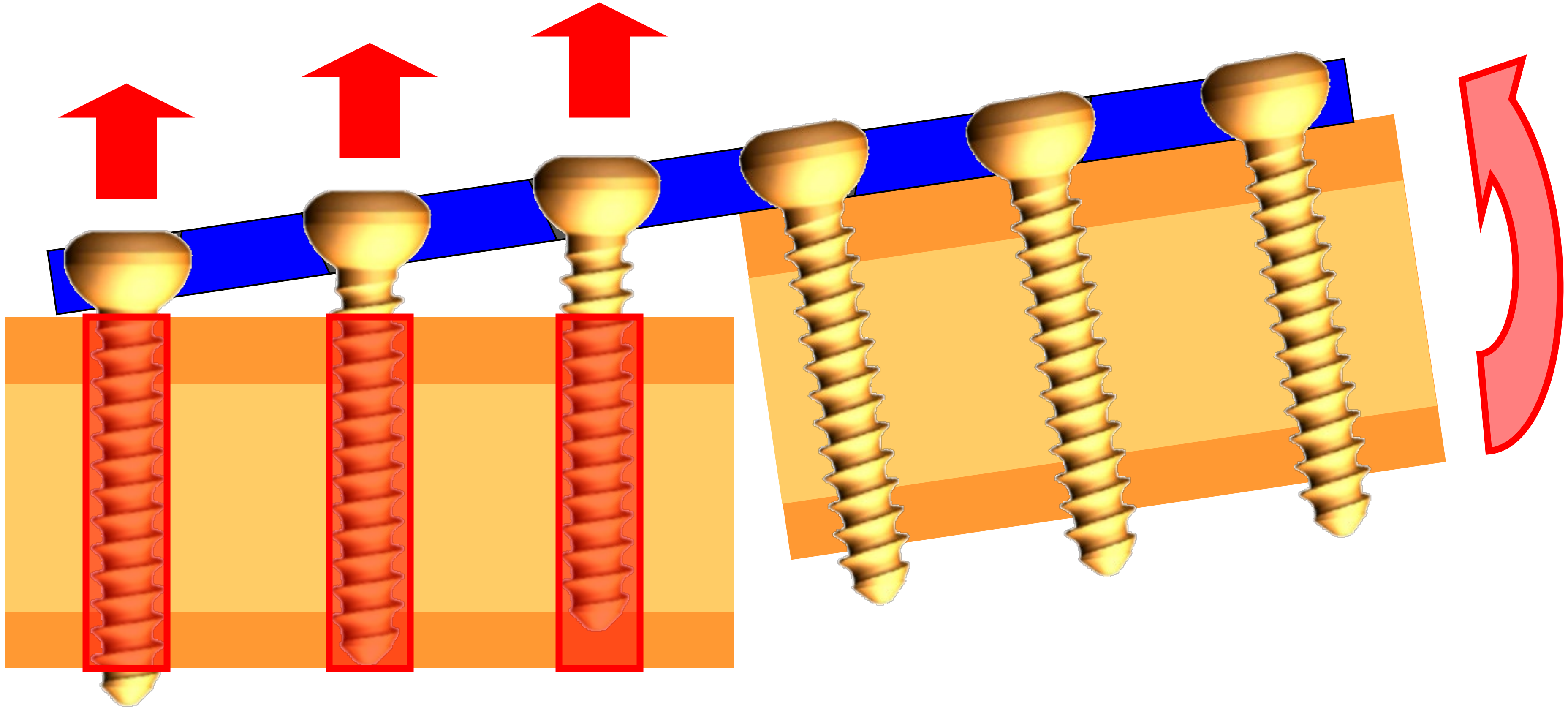
Locked Plate and Screw Fixation



< Compressive Strength of the Bone =

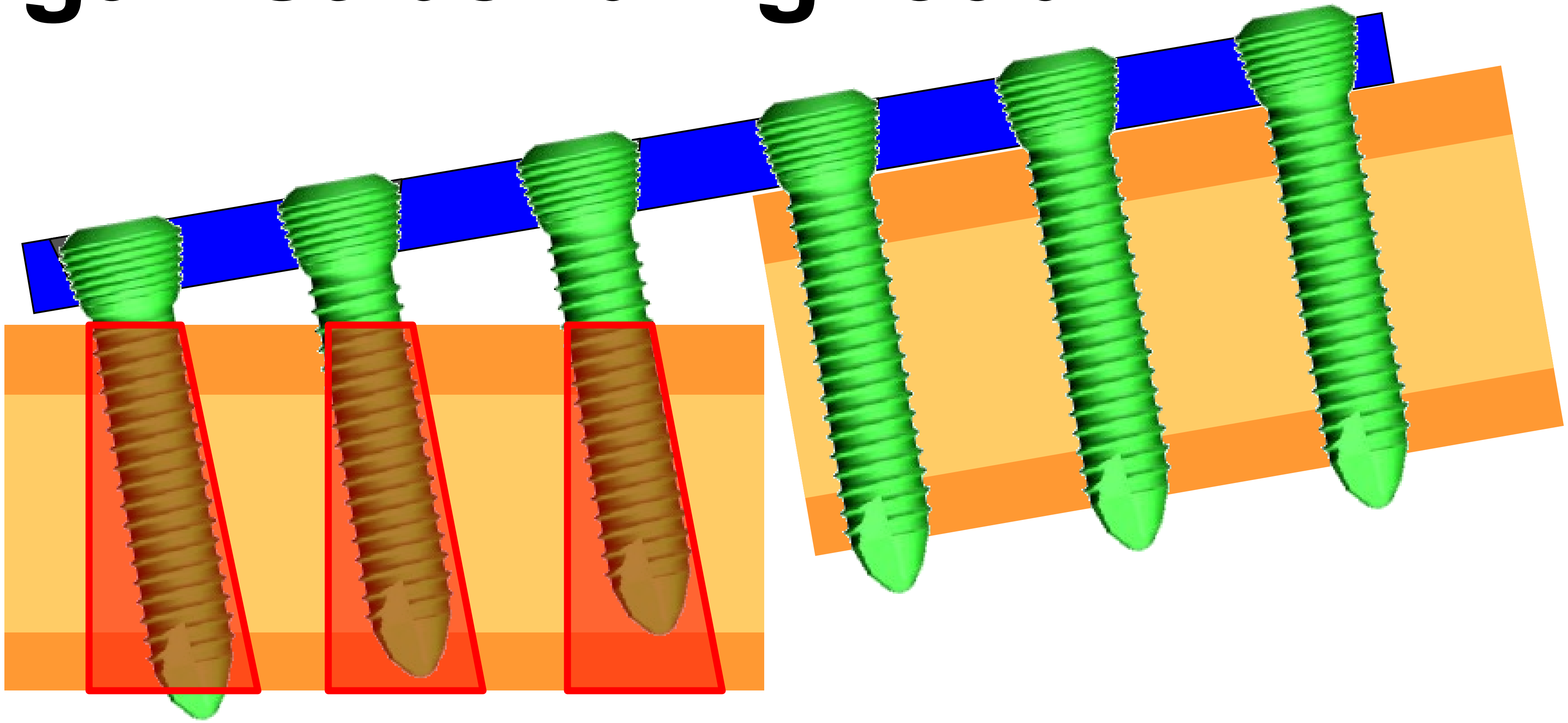
Patient Load

Pullout of regular screws



by bending load

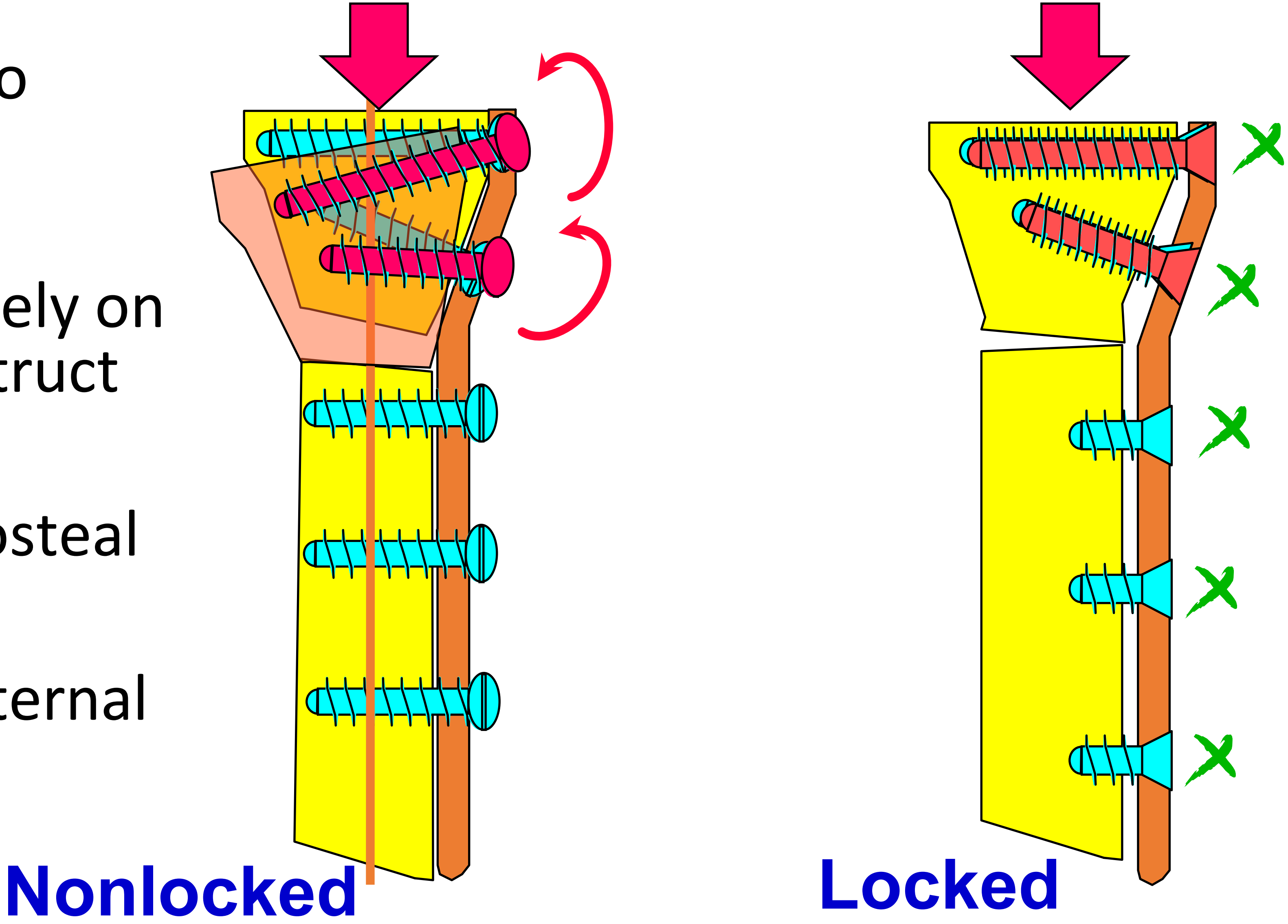
Higher resistant LHS against bending load



Larger resistant area

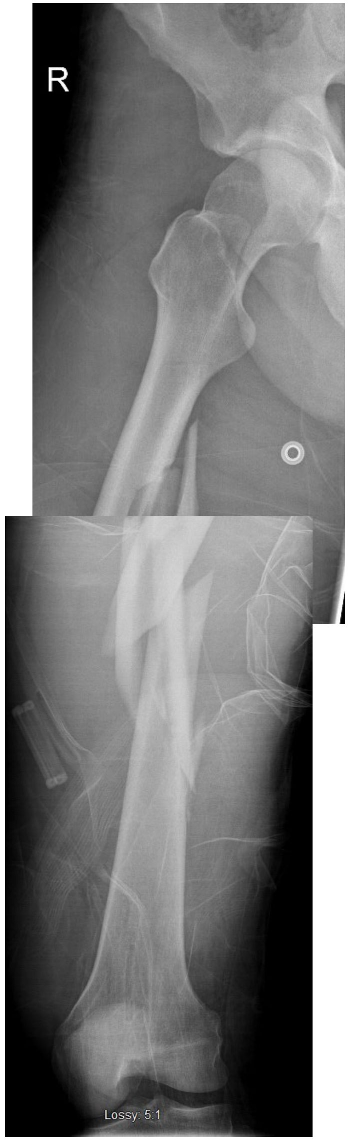
Angular Stability of Screws

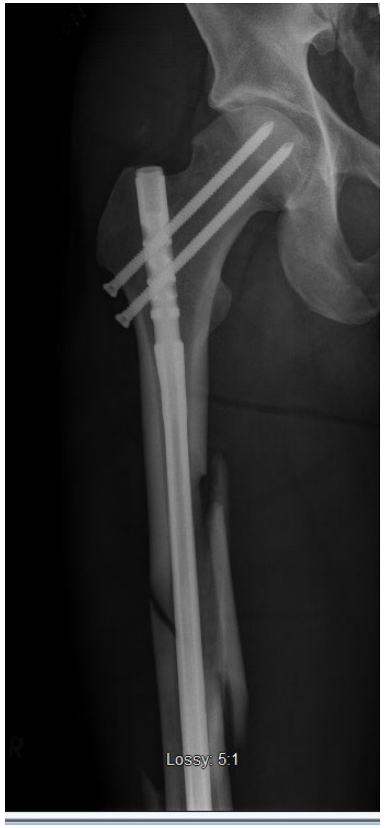
- Purchase of screws to bone not critical (osteoporotic bone)
- Strength of fixation rely on the **fixed angle** construct of screws to plate
- Preservation of periosteal blood supply
- Acts as “internal” external fixator



Intramedullary Nail

- Internal Splint
- Relative Stability with callus formation
- **Goal is to establish length/ rotation/ alignment (similar to bridge plating goals)**
- Anatomic Reduction of all pieces in NOT the goal



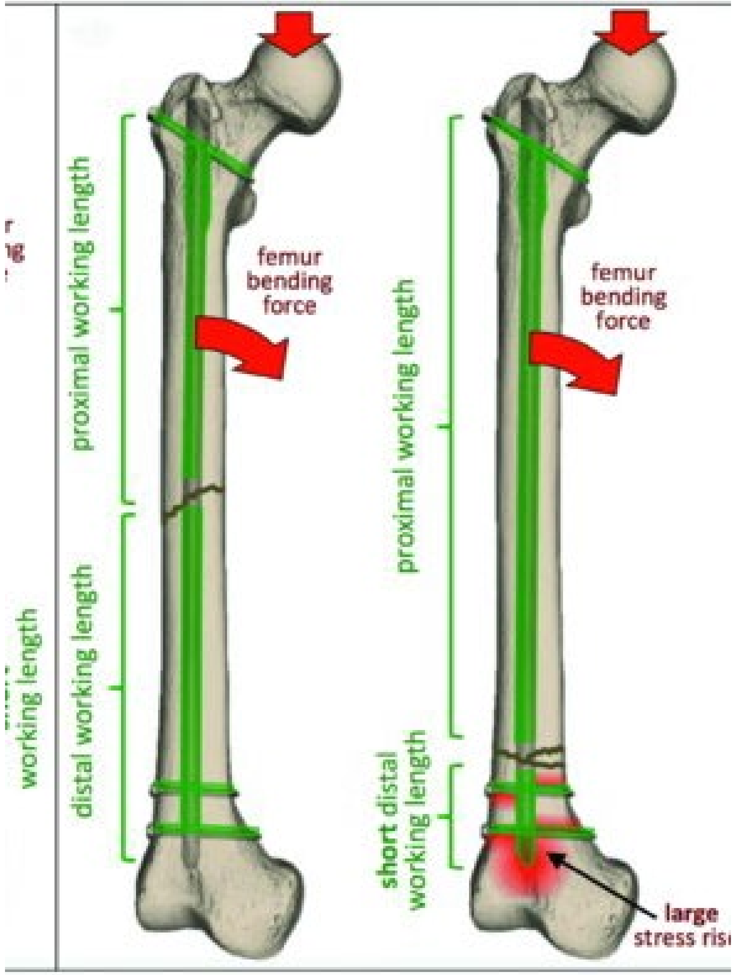


Intramedullary Nail- Options

- Reaming vs Unreamed
  - Larger Nail (increased stability)
  - Endosteal Damage
- Locked vs Unlocked
- Static Vs Dynamic
- **Reamed, Statically Locked Nail = Standard of Care**

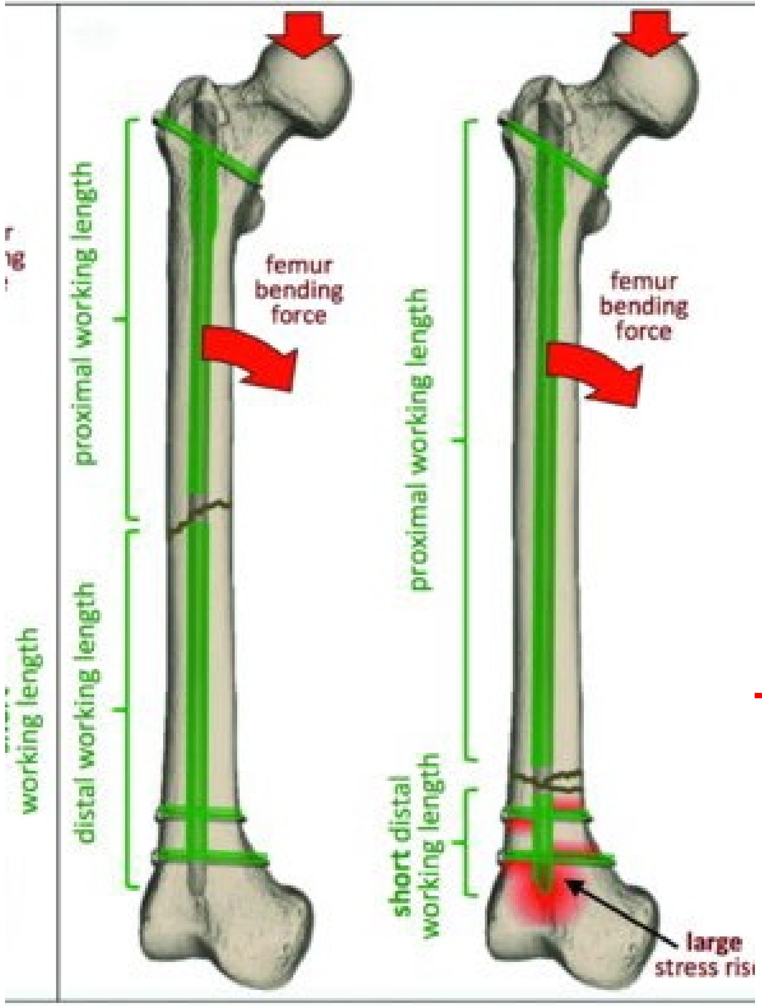
Intramedullary Nail – Stiffness Factors

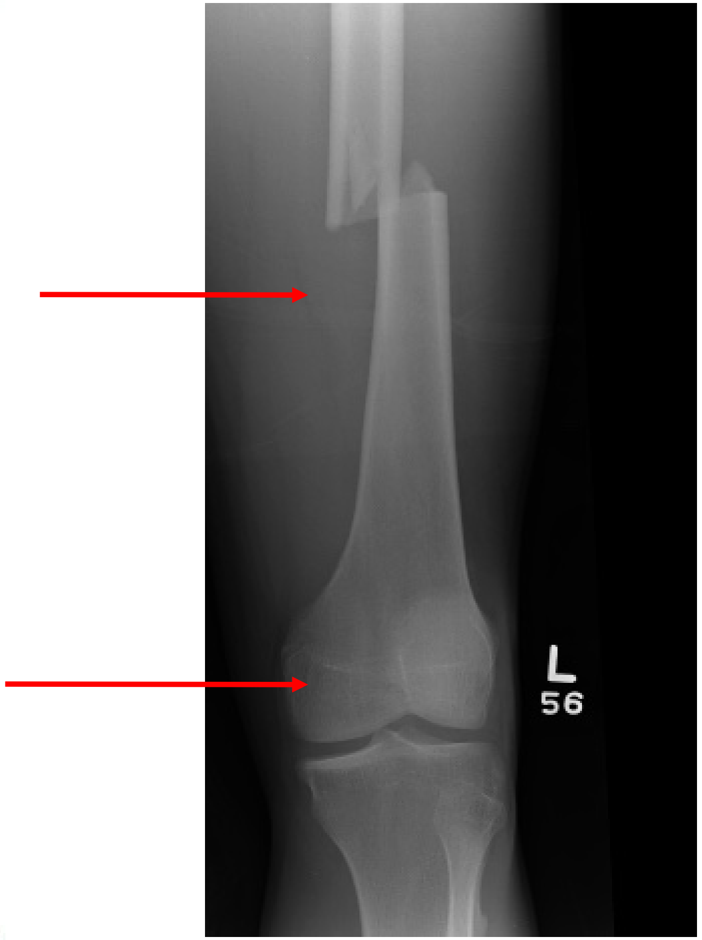
- Nail Diameter
- Nail Material
- Bony Anatomy
- Interlocking Screw technique
- Fracture location

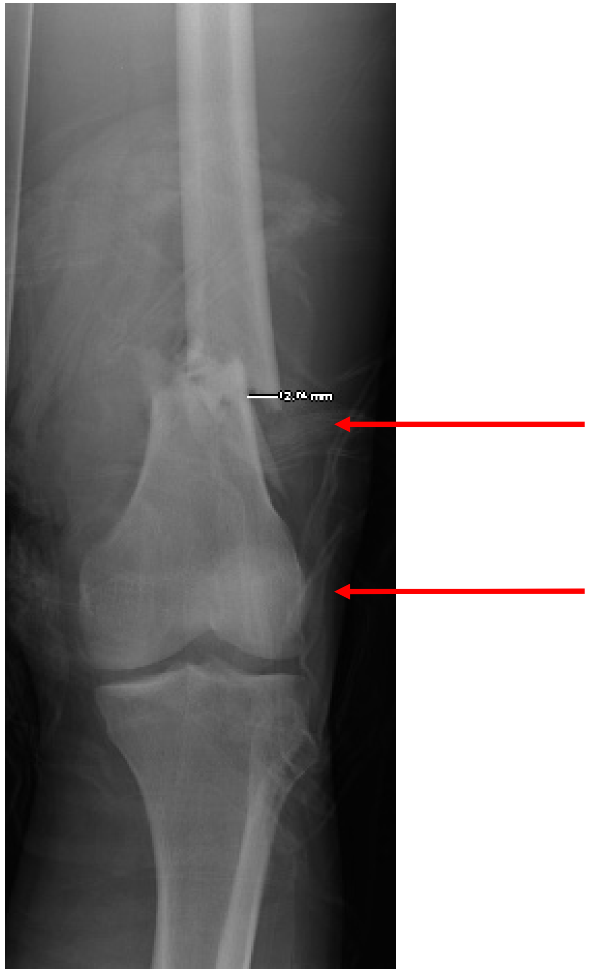


From: Rockwood and Green, 9th edition.
Chapter 1. Page 22 (Figure 1-22)

Intramedullary Nail – Biomechanics of Fracture



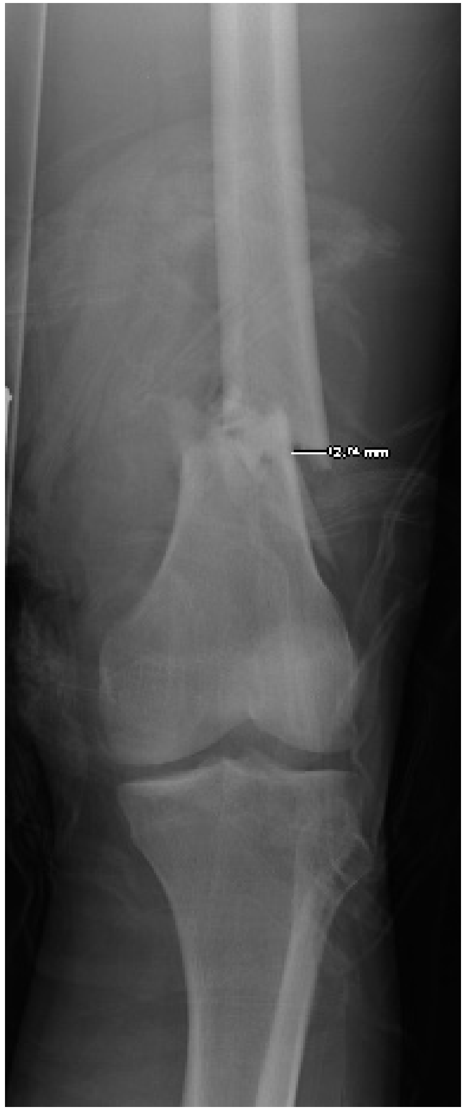


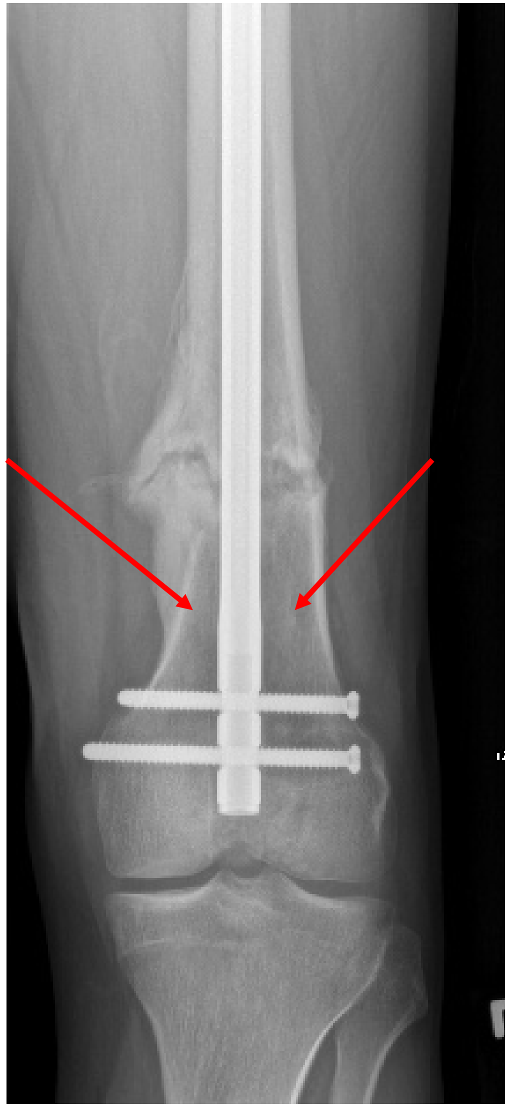


From: Rockwood and Green, 9th edition. Chapter 1. Page 22 (Figure 1-22)

Intramedullary Nail

- This Nail could be made more stable?
- Note Large space in Metaphysis

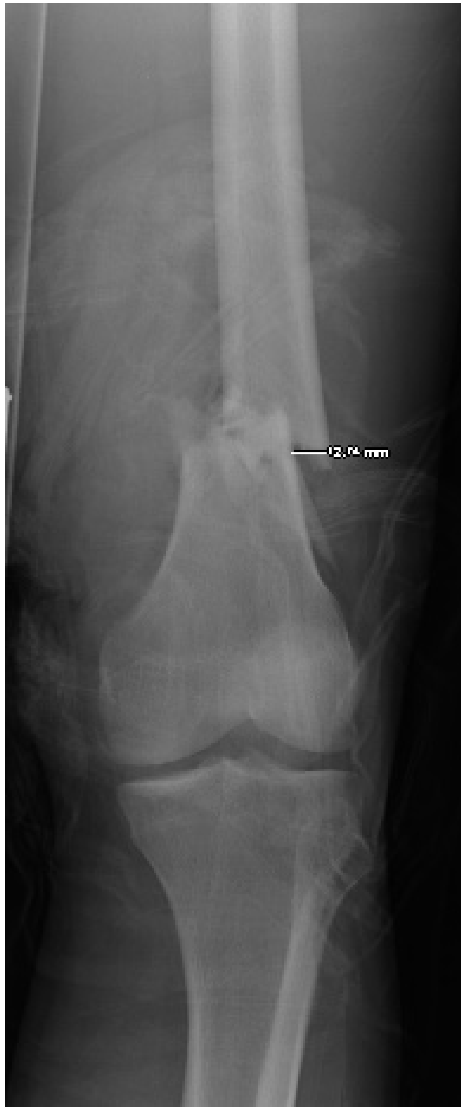


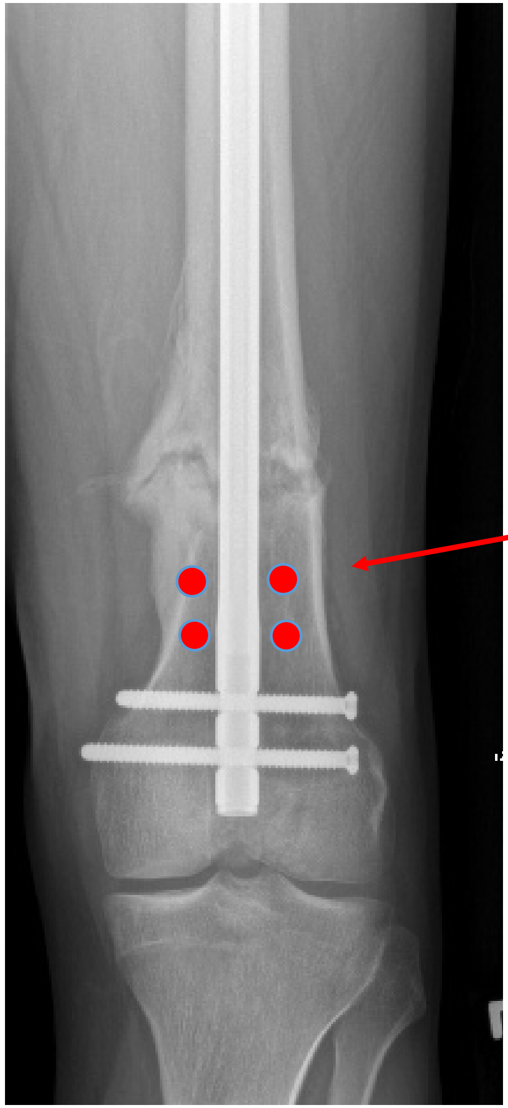


Intramedullary Nail

- This Nail could be made more stable?

- Larger Nail
- More Locking Screws
- Blocking Screws
- Add Plate



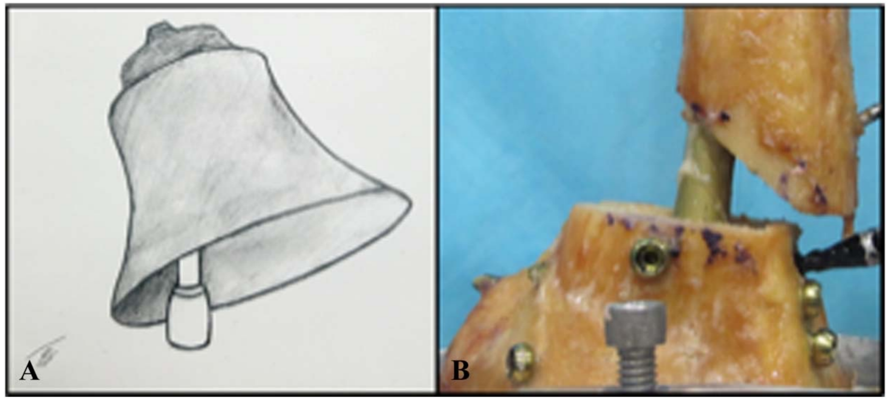


Blocking Screws

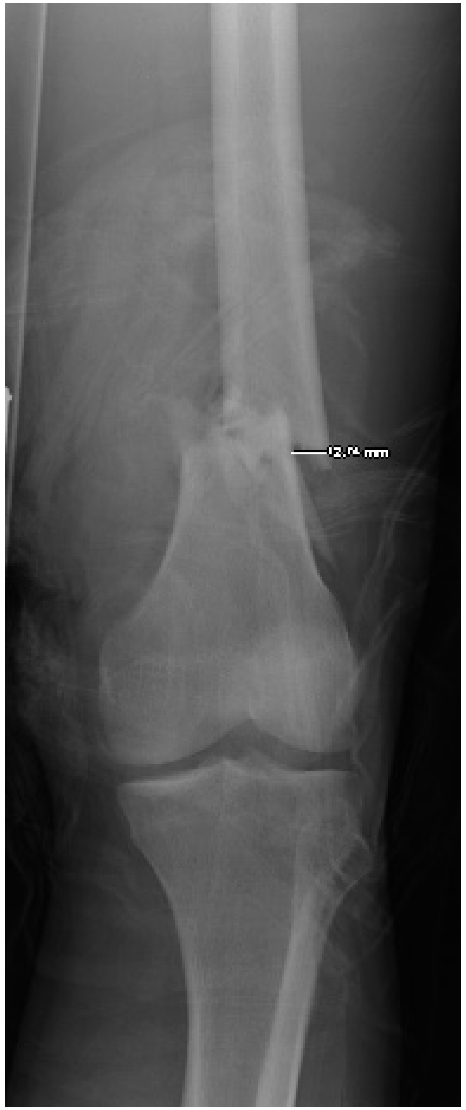
Intramedullary Nail

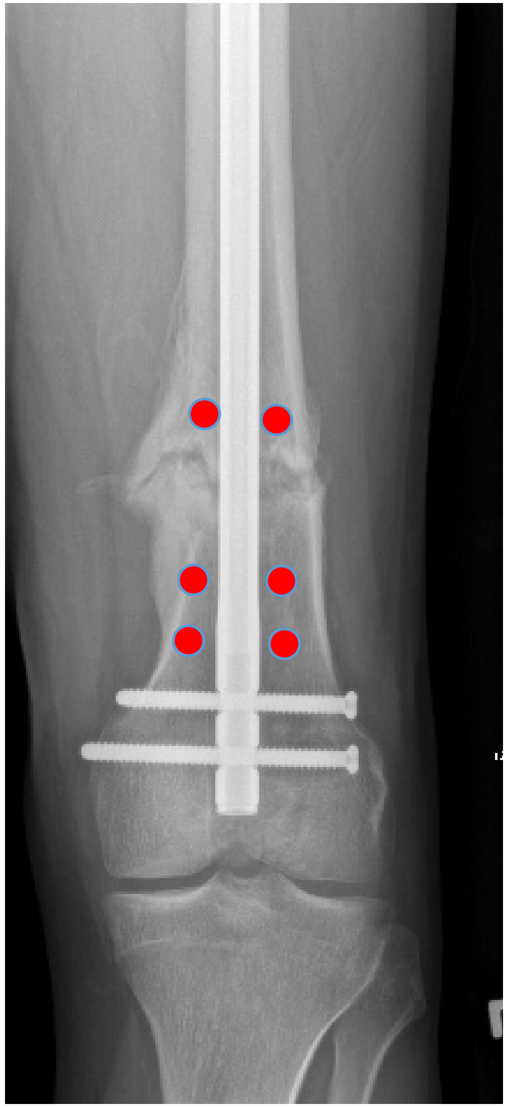
The Bell Clapper Effect

- Distal Femur Fractures well fixed in the distal femur fracture
- Will still have instability in the ”long Segment”
- Added Stability with blocking screws



JOT 2018 32 (11): 559-564. Fig. 3
D Auston et al. Long Segment Blocking Screws Increase the Stability of Retrograde Nail Fixation in Geriatric Supracondylar Femur Fracture: Eliminating the “Bell-Clapper” Effect .





Intramedullary Nail

- Consider Biomechanics in Each Case:

- Reduction
- Nail Size
- Locking Screws – How many?
- Blocking Screws
- Adjuvants – Cement/ Plate

Summary

- Fracture Personality and Patient Characteristics determine Construct
- Often, simple fracture patterns and Intra-Articular fractures are treated with anatomic direct reduction and absolute stability
- Complex and Comminuted Fractures are treated by Indirect Reduction and Relative Stability
- The exact amount of stability is still unclear and may differ for different fractures

Summary

- The goal of relative stability (IMN or Bridge Plating) is accurate restoration of length, alignment and rotation

- Regardless of fixation method, the tissues are biologic and therefore all effort should be given to minimize trauma and stripping of the soft tissues.

References

- Beltran MJ, Collinge CA, Gardner MJ. Stress Modulation of Fracture Fixation Implants. J Am Acad Orthop Surg. 2016 Oct;24(10):711-9.
- Bishop JA, Campbell ST, Graves ML, Gardner MJ. Contouring Plates in Fracture Surgery: Indications and Pitfalls. J Am Acad Orthop Surg. 2020 Jul 15;28(14):585-595.
- BongM R, Kmumer biomechanics and biology. J Am Acad Orthop Surg. 2007 Feb;15(2):97-106 FJ, Koval KJ, Egol KA. Intramedullary nailing of the lower extremity:
- Bottlang M, Lesser M, Koerber J, Doornink J, von Rechenberg B, Augat P, Fitzpatrick DC, Madey SM, Marsh JL. Far cortical locking can improve healing of fractures stabilized with locking plates. J Bone Joint Surg Am. 2010 Jul 7;92(7):1652-60.
- Claes L. Biomechanical principles and mechanobiologic aspects of flexible and locked plating. J Orthop Trauma. 2011 Feb;25 Suppl 1:S4-7.
- Mast J. (1989) *Planning and Reduction Technique in Fracture Surgery*. Springer
- Tornetta P. (2019) *Rockwood and Green's Fractures in Adults.* Wolters Kluwer