PLEASE CLICK ON THE FOLLOWING LINK TO WACH THE LECTURE ONLINE :

http://https://www.youtube.com/live/N9uoB_qQMUk

Biomechanics of Fractures and Fixation

Ghayth Adaileh.MD

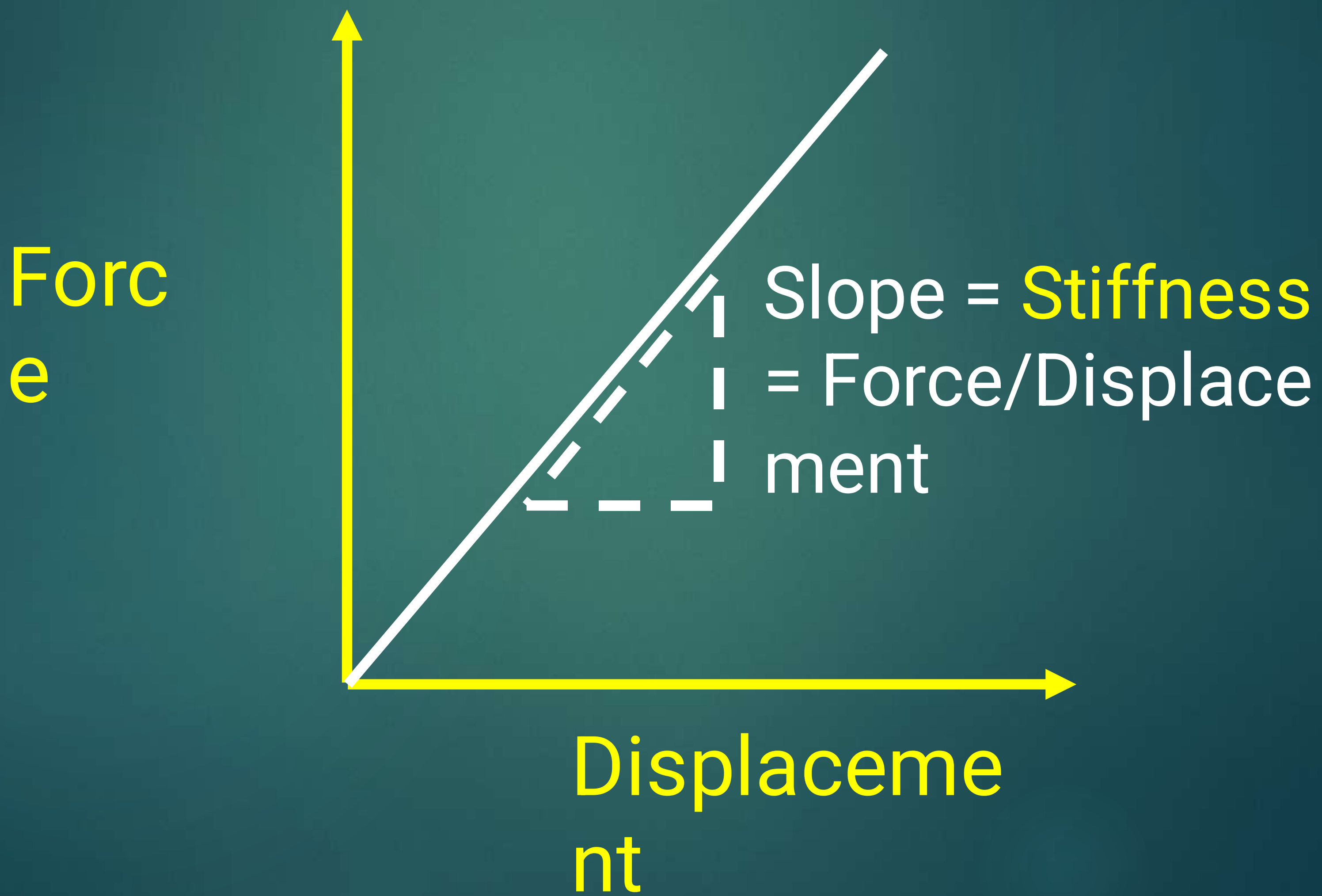
Basic Biomechanics

- Material Properties
  - Elastic-Plastic
  - Yield point
  - Brittle-Ductile
  - Toughness
- Independent of Shape!

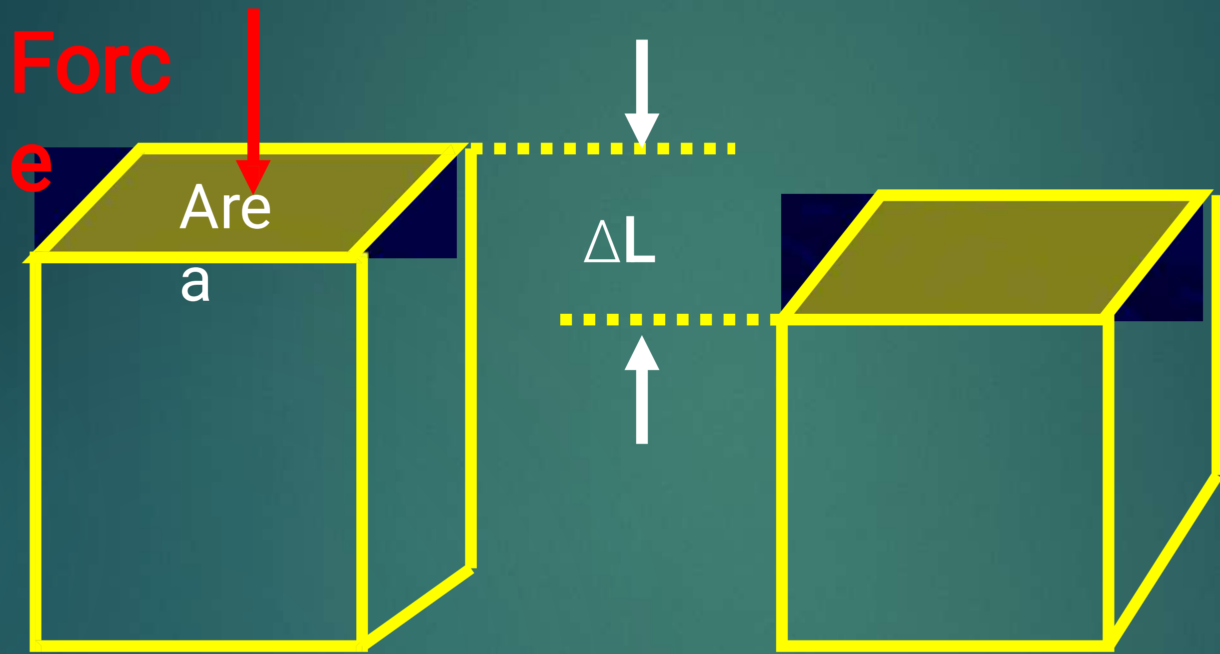
- Structural Properties
  - Bending Stiffness
  - Torsional Stiffness
  - Axial Stiffness
- Depends on Shape and Material!

Basic Biomechanics

Force, Displacement & Stiffness



Basic Biomechanics



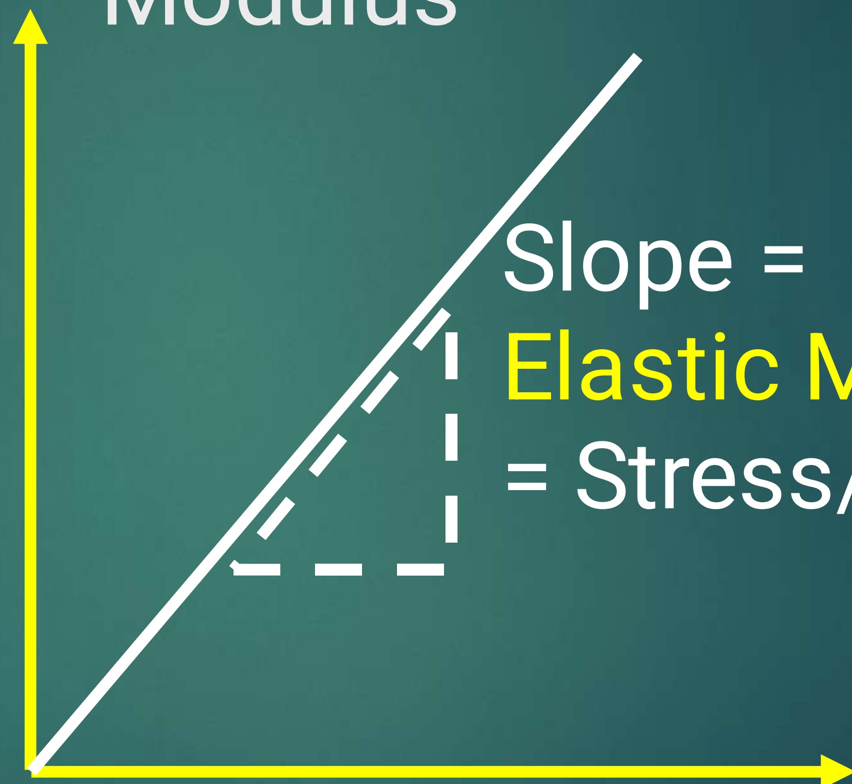
Stress = Force/Area

Strain Change Height (ΔL) / Original Height(L_0)

Basic Biomechanics

Stress-Strain & Elastic Modulus

Stress = Force/Area



Slope = Elastic Modulus = Stress/Strain

Strain = Change in Length/Original Length ($\Delta L / L_0$)

Basic Biomechanics

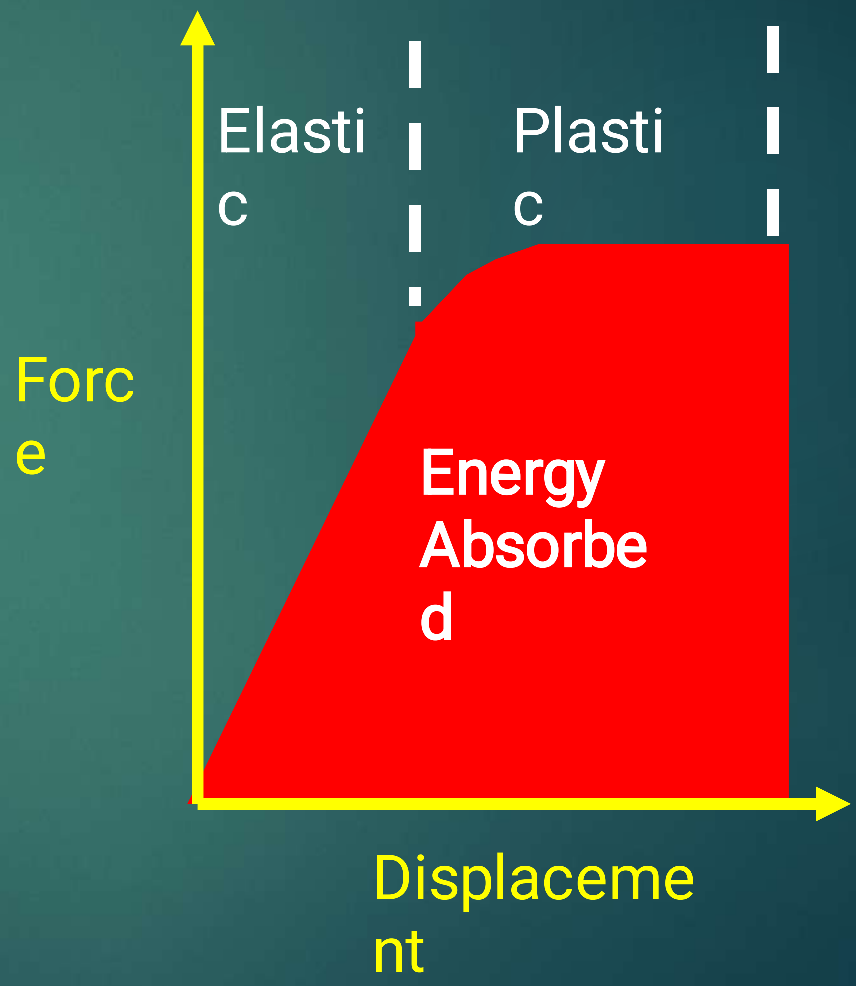
Common Materials in Orthopaedics

- Elastic Modulus (GPa)

- Stainless Steel 200
- Titanium 100
- Cortical Bone 7-21
- Bone Cement 2.5 -3.5
- Cancellous Bone 0.7 -4.9

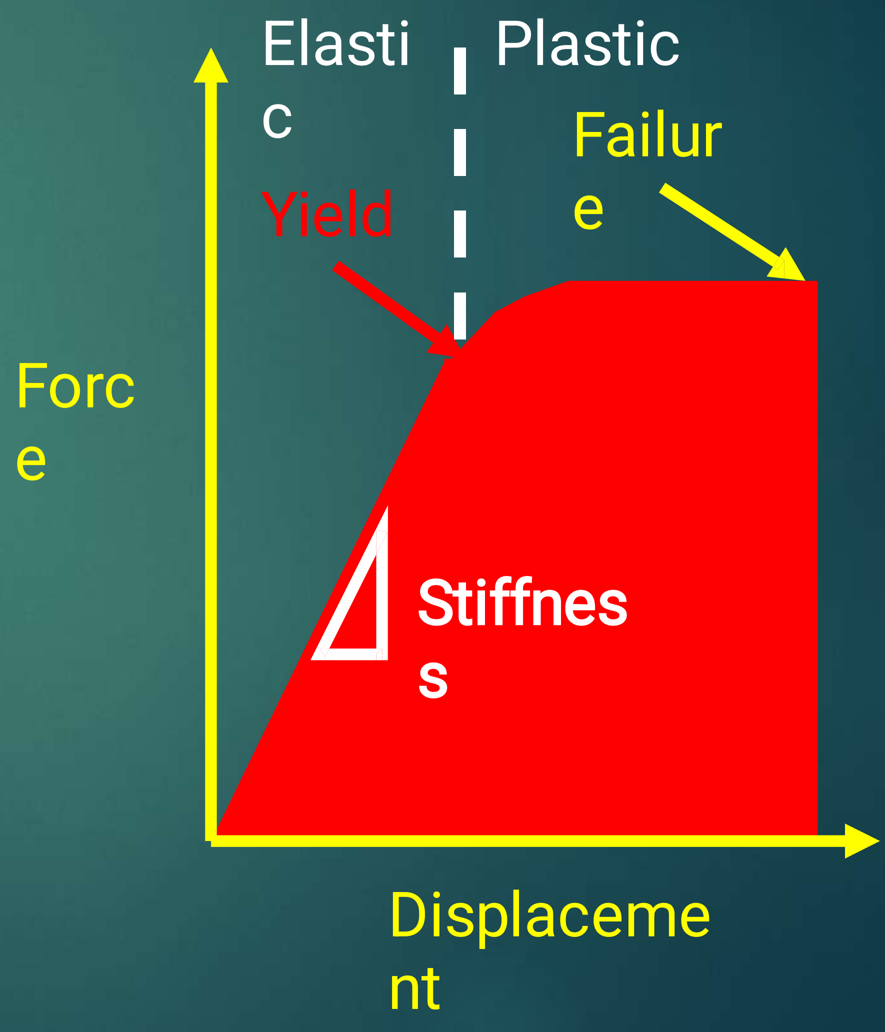
Basic Biomechanics

- Elastic Deformation
- Plastic Deformation
- Energy



Basic Biomechanics

- Stiffness-Flexibility
- Yield Point
- Failure Point



Basic Biomechanics

- Load to Failure
  - Continuous application of force until the material breaks (failure point at the ultimate load).
  - Common mode of failure of bone and reported in the implant literature.
- Fatigue Failure
  - Cyclical sub-threshold loading may result in failure due to fatigue.
  - Common mode of failure of orthopaedic implants and fracture fixation constructs.

Basic Biomechanics

- Anisotropic
  - Mechanical properties dependent upon direction of loading
- Viscoelastic
  - Stress-Strain character dependent upon rate of applied strain (time dependent).

Bone Biomechanics

- Bone is anisotropic - its modulus is dependent upon the direction of loading.
- Bone is weakest in shear, then tension, then compression.
- Ultimate Stress at Failure Cortical Bone

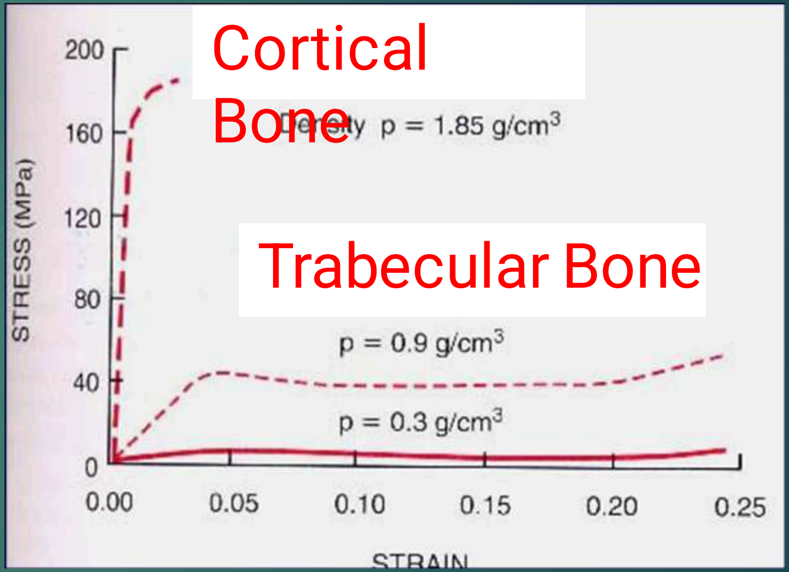
Compression	$< 212\ N/m^2$
Tension	$< 146\ N/m^2$
Shear	$< 82\ N/m^2$

Bone Biomechanics

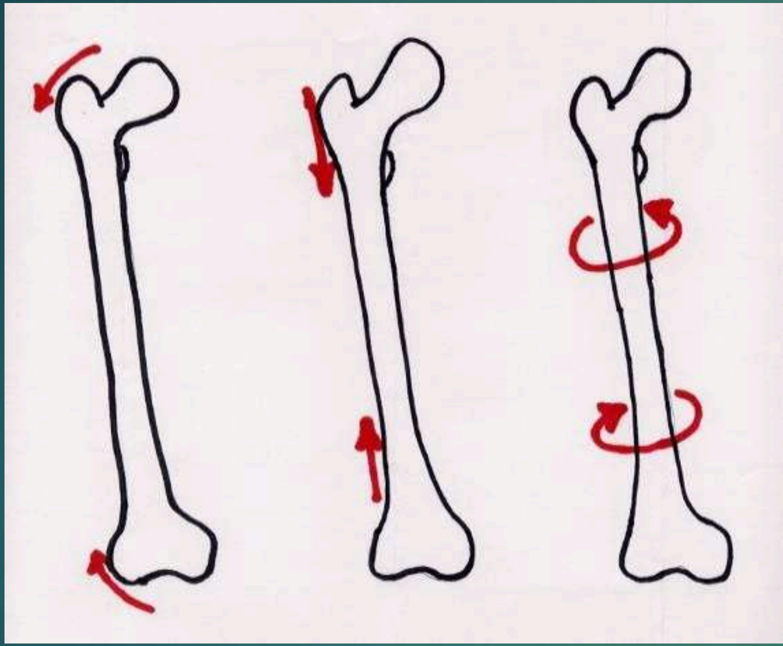
- Bone is viscoelastic: its force-deformation characteristics are dependent upon the rate of loading.
- Trabecular bone becomes stiffer in compression the faster it is loaded.

Bone Mechanics

- Bone Density
  - Subtle density changes greatly changes strength and elastic modulus
- Density changes
  - Normal aging
  - Disease
  - Use
  - Disuse



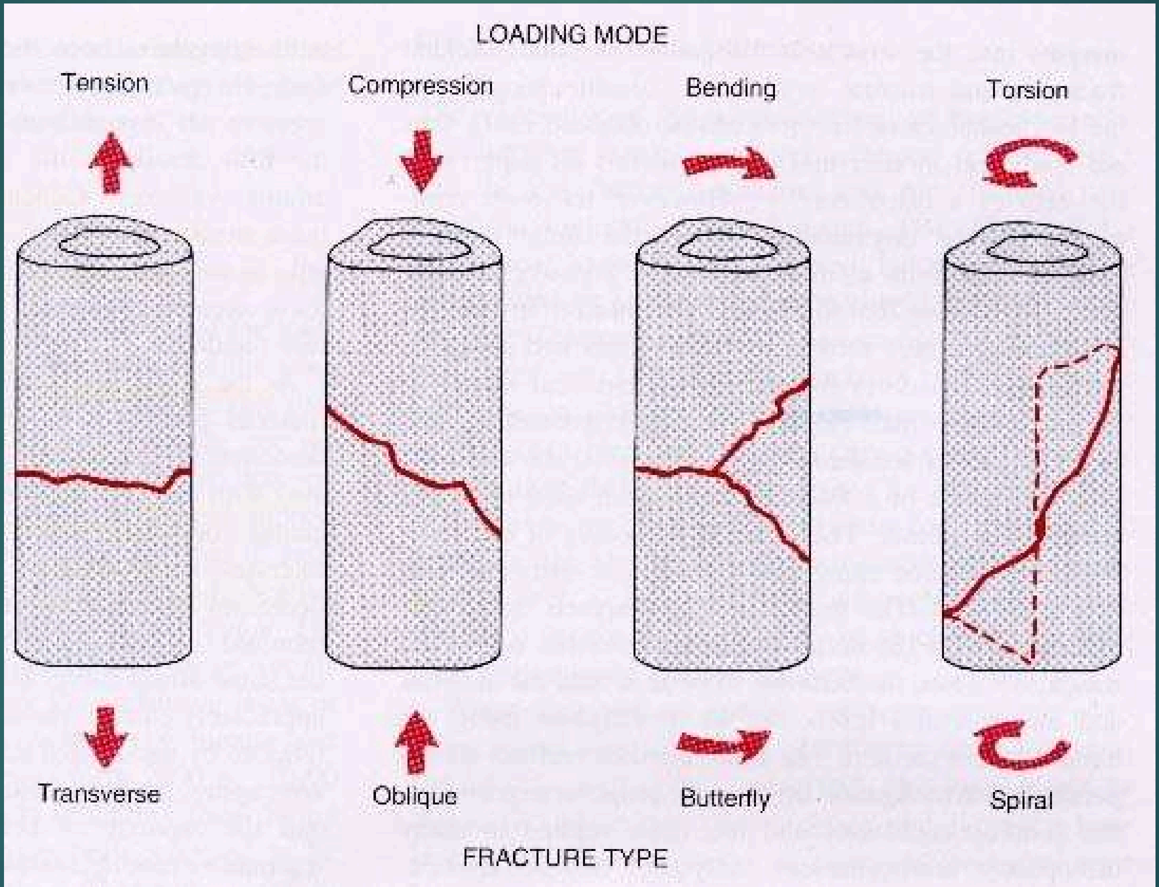
Basic Biomechanics



Bending Compression Torsion

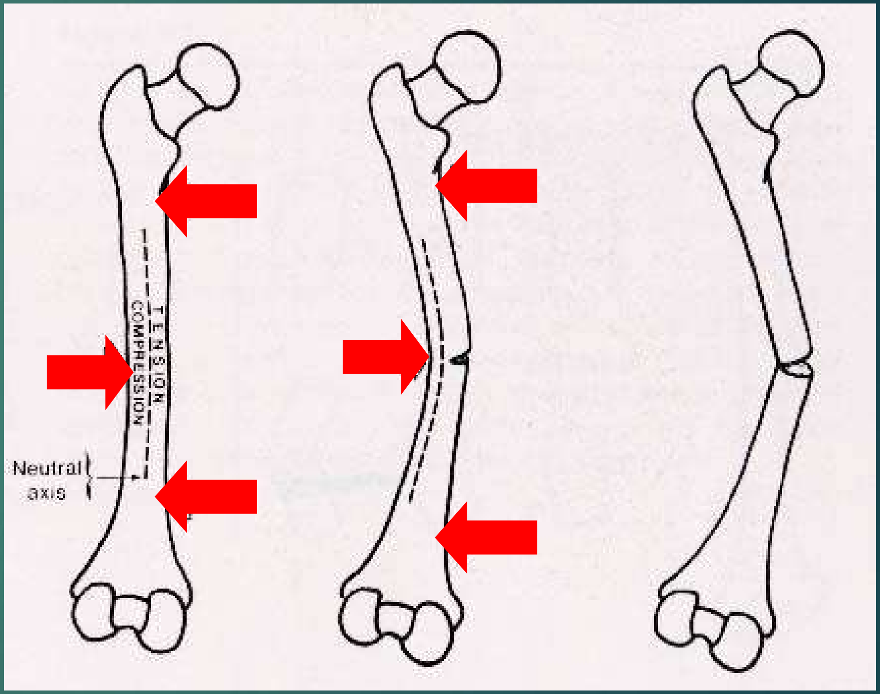
- Bending
- Axial Loading
  - Tension
  - Compression
- Torsion

Fracture Mechanics



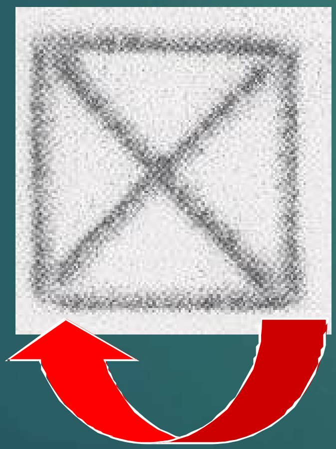
Fracture Mechanics

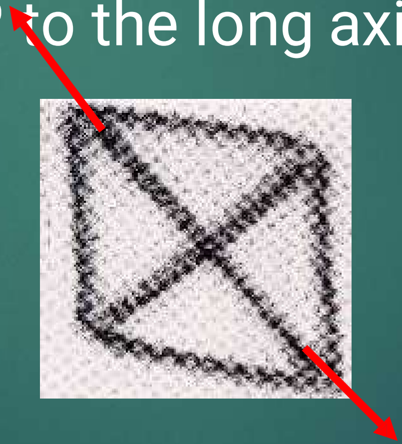
- Bending load:
  - Compression strength greater than
    tensile strength
  - Fails in tension

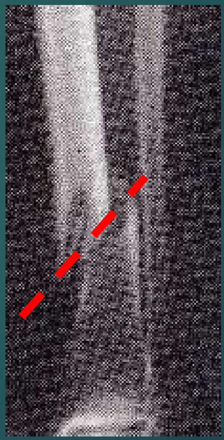


Fracture Mechanics

- Torsion
  - The diagonal in the direction of the applied force is in tension – cracks perpendicular to this tension diagonal
  - Spiral fracture 45º to the long axis

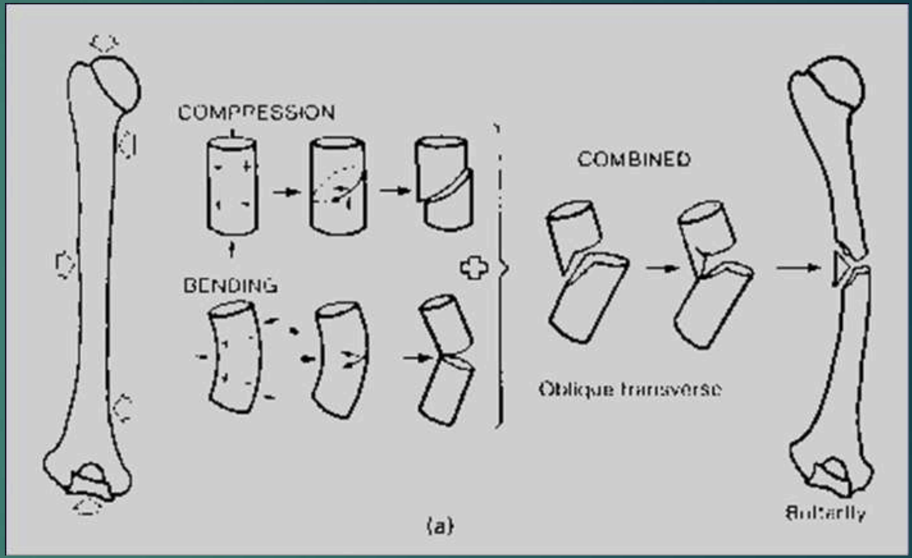






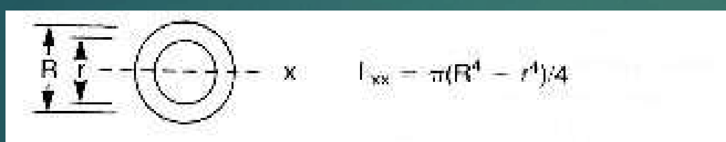
Fracture Mechanics

- Combined bending & axial load
  - Oblique fracture
  - Butterfly fragment

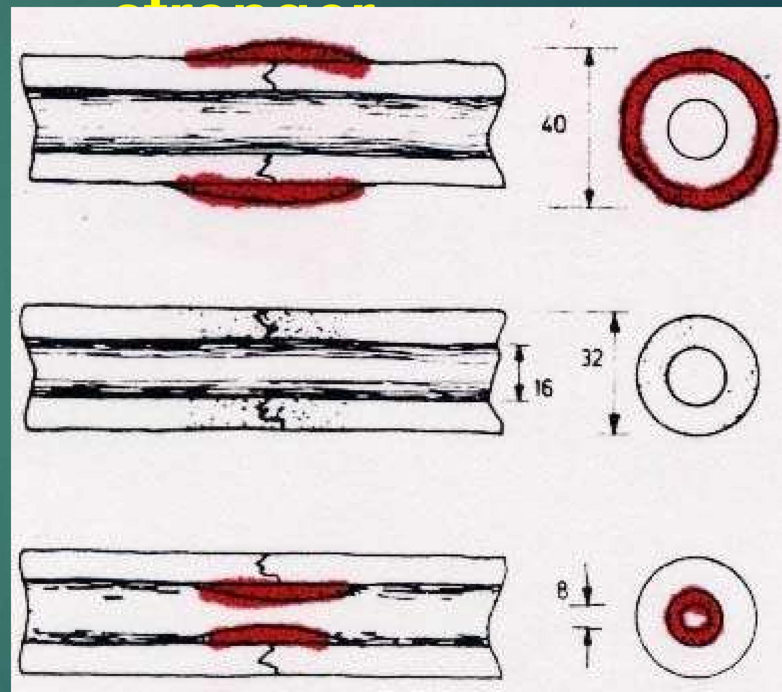


Fracture Mechanics

- Fracture Callus
  - Moment of inertia proportional to r^4
  - Increase in radius by callus greatly increases moment of inertia and stiffness



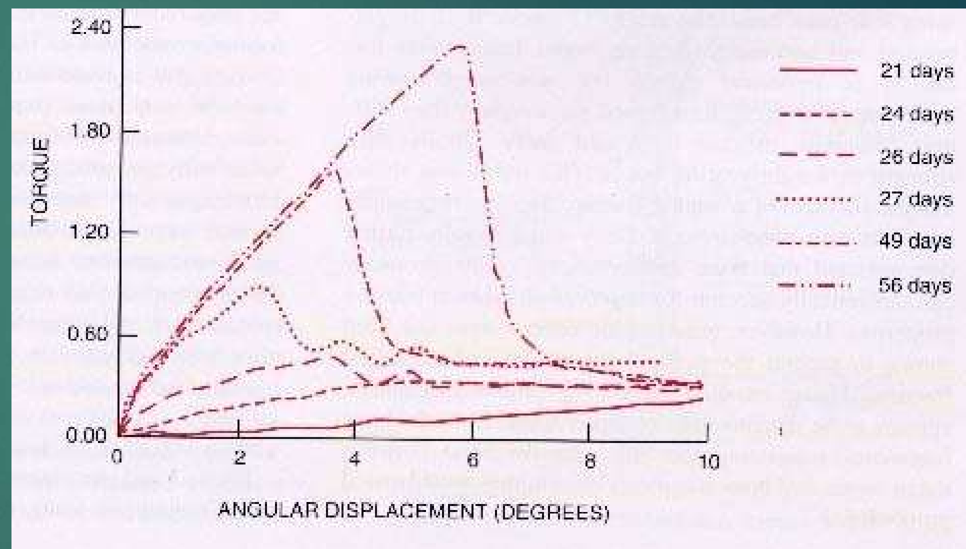
1.6 x



0.5 x weaker

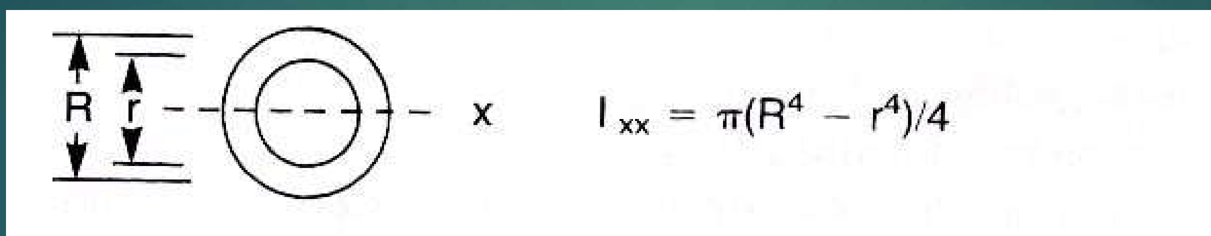
Fracture Mechanics

- Time of Healing
  - Callus increases with time
  - Stiffness increases with time
  - Near normal stiffness at 27 days
  - Does not correspond to radiographs

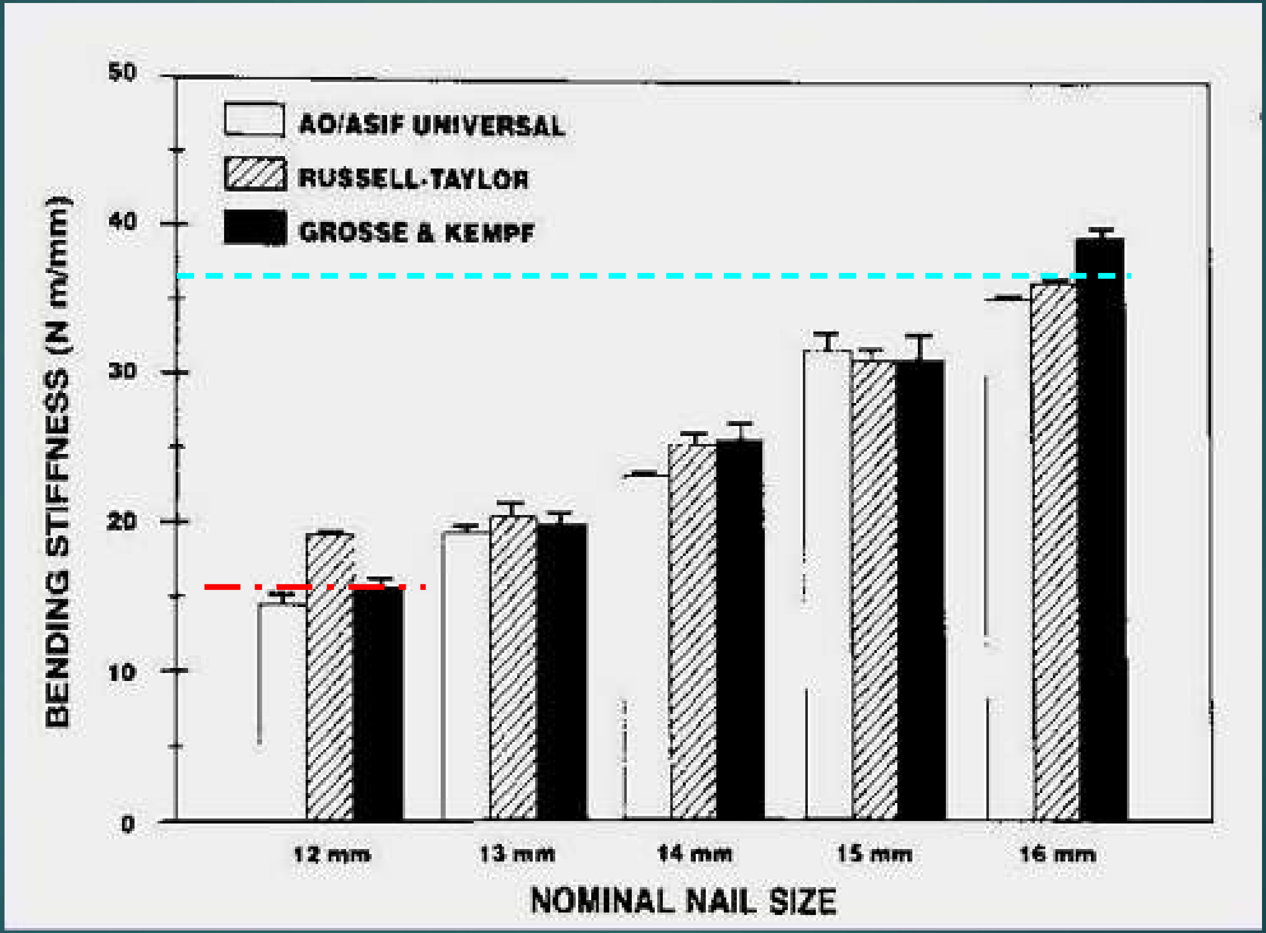


IM Nails Moment of Inertia

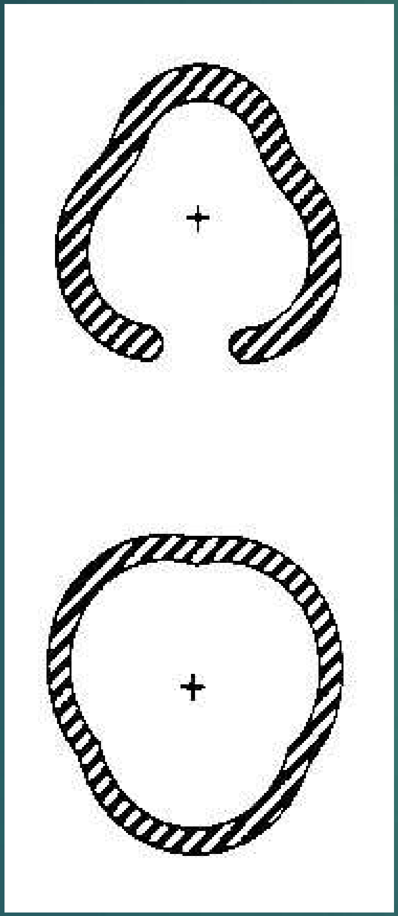
- Stiffness proportional to the 4^{th} power.



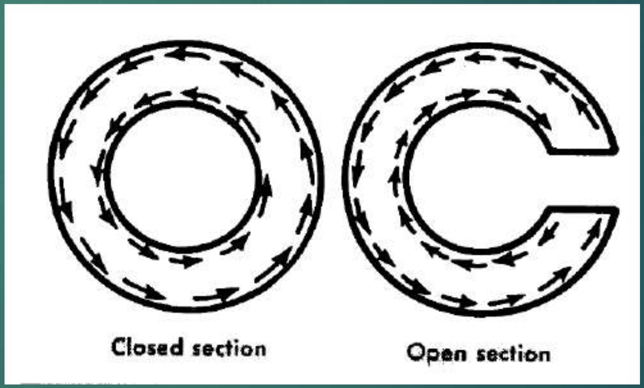
IM Nail Diameter



Slotting

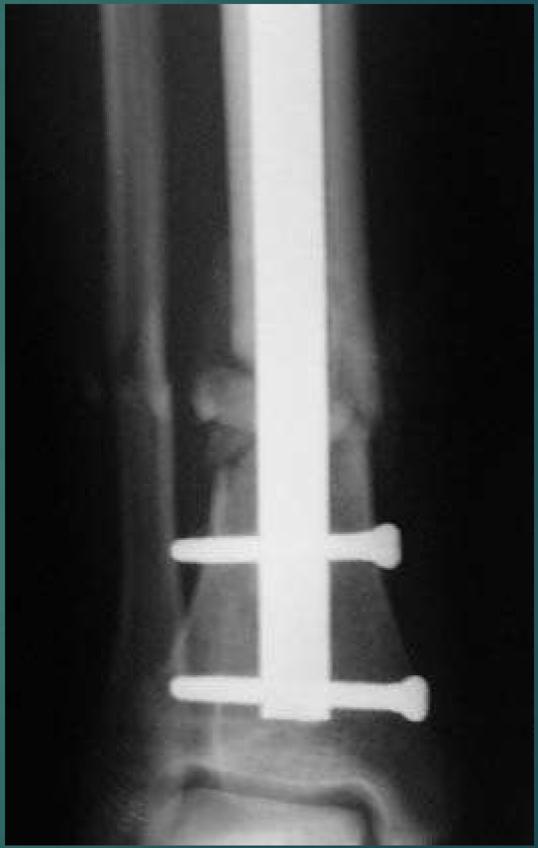


- Allows more flexibility
  - In bending
- Decreases torsional strength



Interlocking Screws

- Controls torsion and axial loads
- Advantages
  - Axial and rotational stability
  - Angular stability
- Disadvantages
  - Time and radiation exposure
  - Stress riser in nail
- Location of screws
  - Screws closer to the end of the nail expand the zone of fxs that can be fixed at the expense of construct stability



Biomechanics of Internal Fixation

Biomechanics of Internal Fixation

- Screw Anatomy
  - Inner diameter
  - Outer diameter
  - Pitch

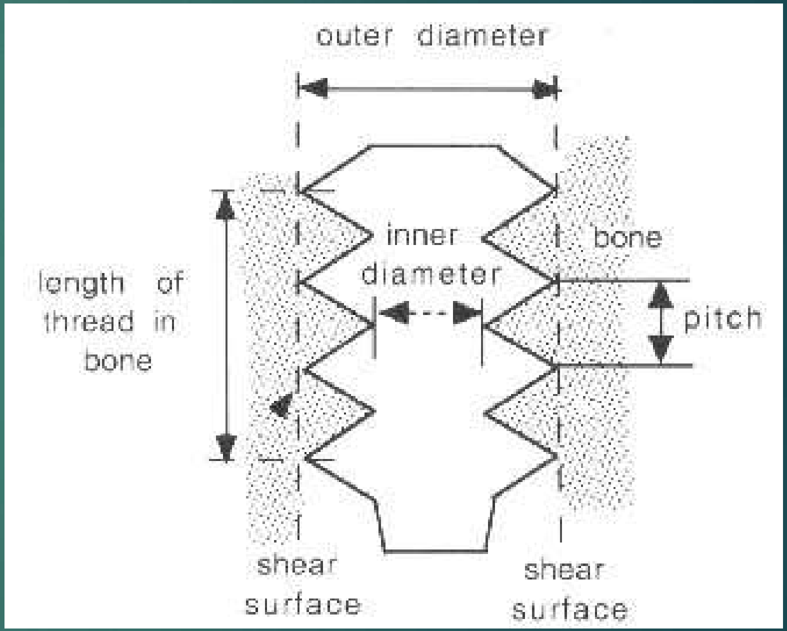


Figure from: Tencer et al, Biomechanics in OrthopaedicTrauma, Lippincott, 1994.

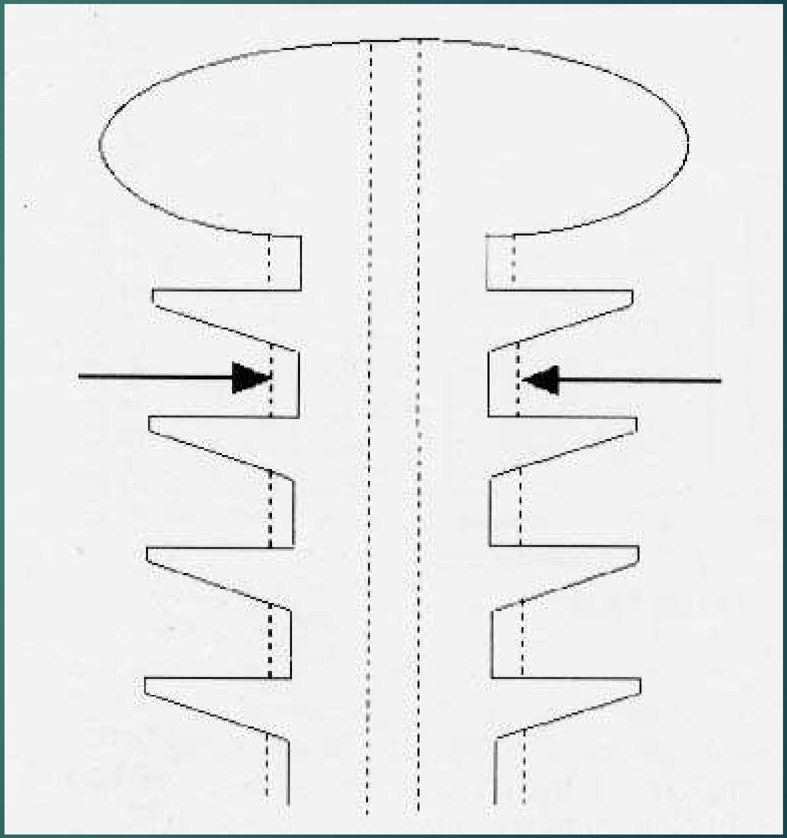
Biomechanics of Screw Fixation

- To increase pull out strength of screw in bone:
  - Increase outer diameter
  - Decrease inner diameter
  - Increase thread density
  - Increase thickness of cortex
  - Use cortex with more density.
- To increase strength of the screw & resist fatigue failure:
  - Increase the inner root diameter

Biomechanics of Screw Fixation

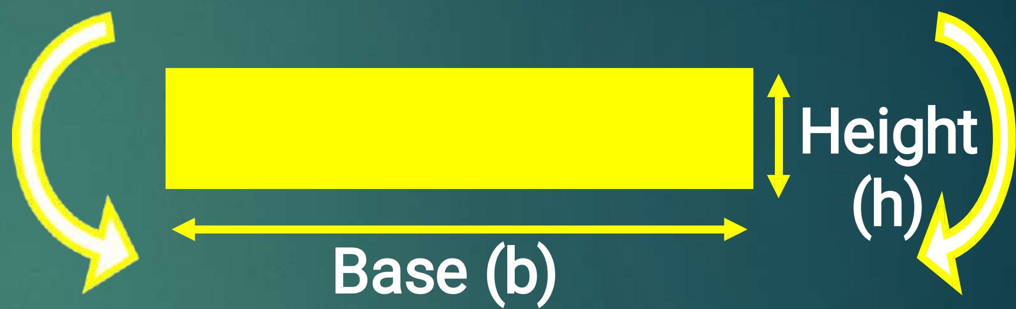
- Cannulated Screws
  - Increased inner diameter required
  - Relatively smaller thread width results in lower pull out strength
  - Screw strength minimally affected

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



Biomechanics of Plate Fixation

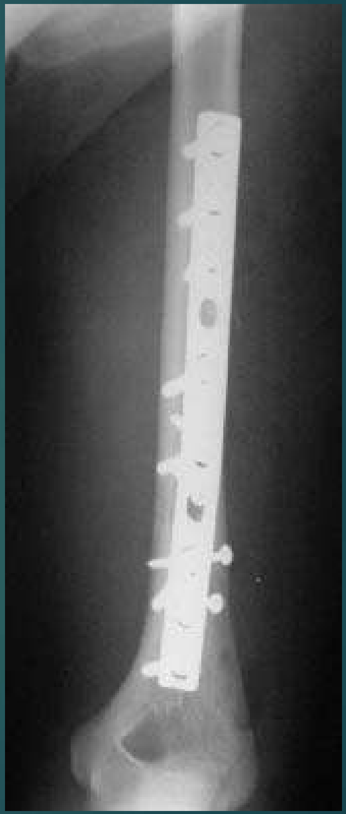
- Plates:
  - Bending stiffness proportional to the thickness (h) of the plate to the 3rd power.



$$I = bh^3/12$$

Biomechanics of Plate Fixation

- Functions of the plate
  - Compression
  - Neutralization
  - Buttress
- "The bone protects the plate"

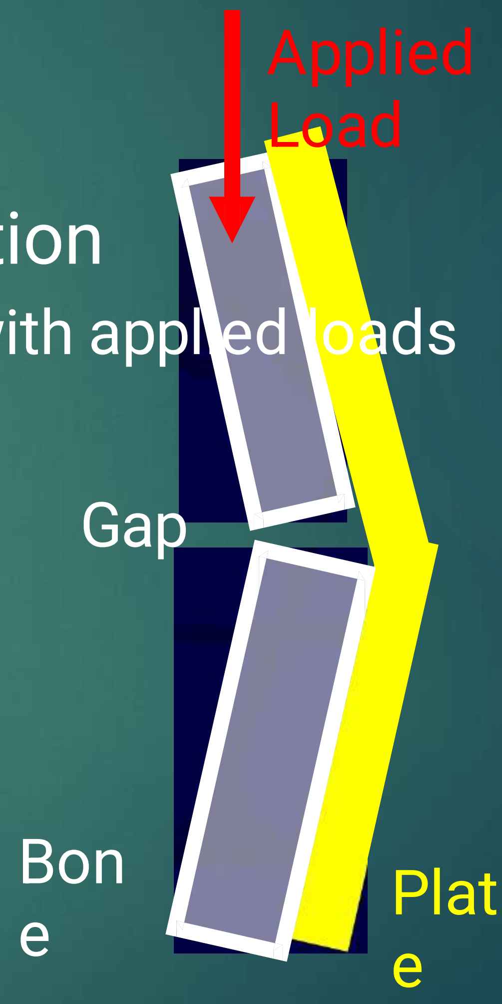



Biomechanics of Plate Fixation

- Unstable constructs
  - Severe comminution
  - Bone loss
  - Poor quality bone
  - Poor screw technique

Biomechanics of Plate Fixation

- Fracture Gap /Comminution
  - Allows bending of plate with applied loads
  - Fatigue failure

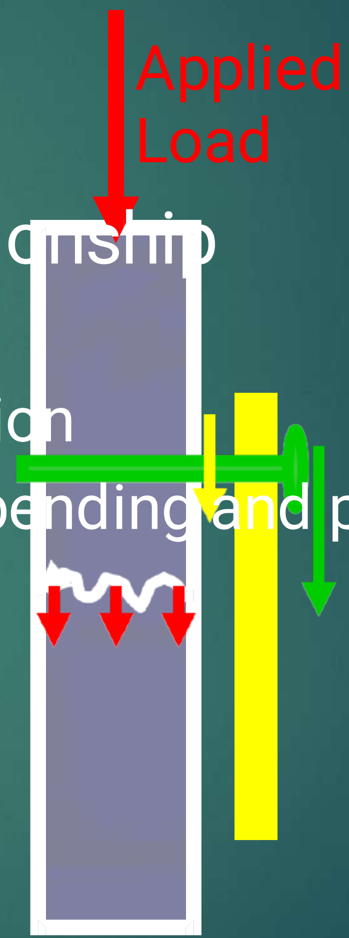


Biomechanics of Plate Fixation

- Fatigue Failure
  - Even stable constructs may fail from fatigue if the fracture does not heal due to biological reasons.

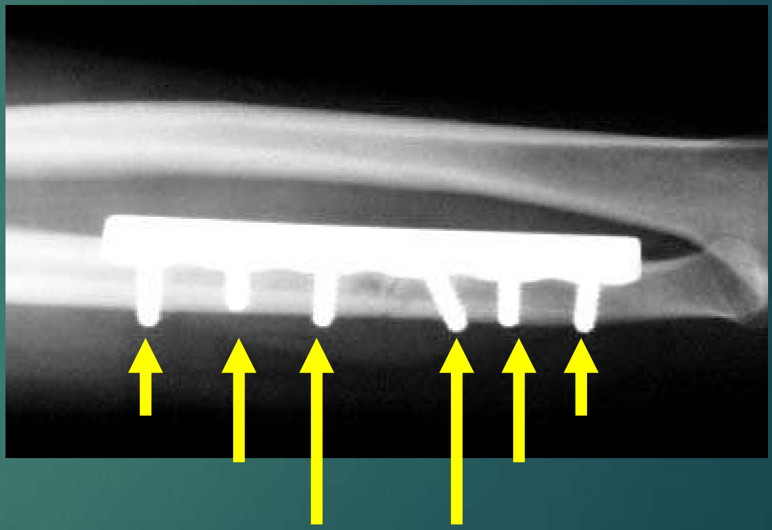
Biomechanics of Plate Fixation

- Bone-Screw-Plate Relationship
  - Bone via compression
  - Plate via bone-plate friction
  - Screw via resistance to bending and pull out.



Biomechanics of Plate Fixation

- The screws closest to the fracture see the most forces.
- The construct rigidity decreases as the distance between the innermost screws increases.



Biomechanics of Plate Fixation

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

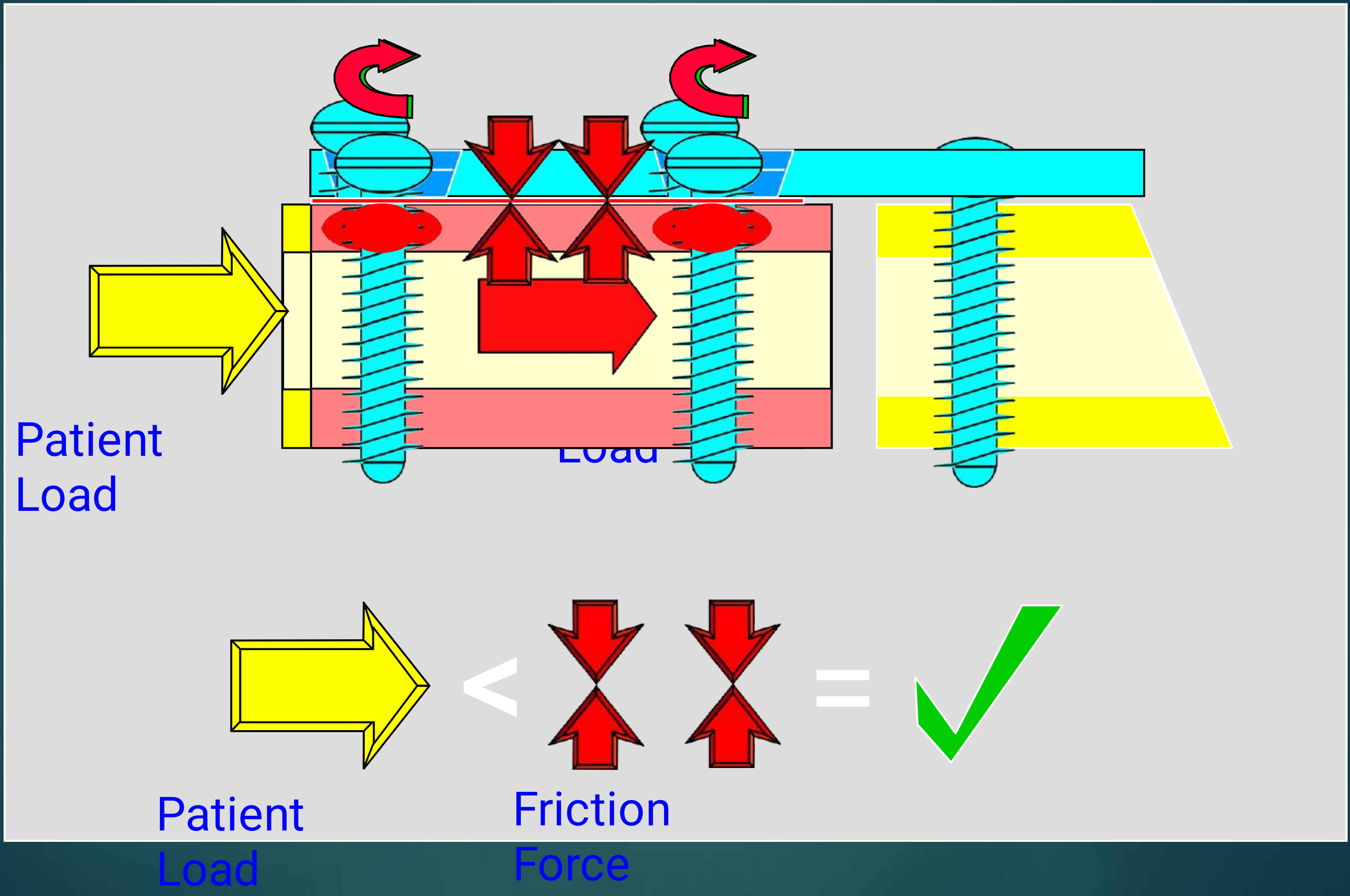
Forearm	3	(5-6)
Humerus	3-4	(6-8)
Tibia	4	(7-8)
Femur	4-5	(8)

Biomechanics of Plating

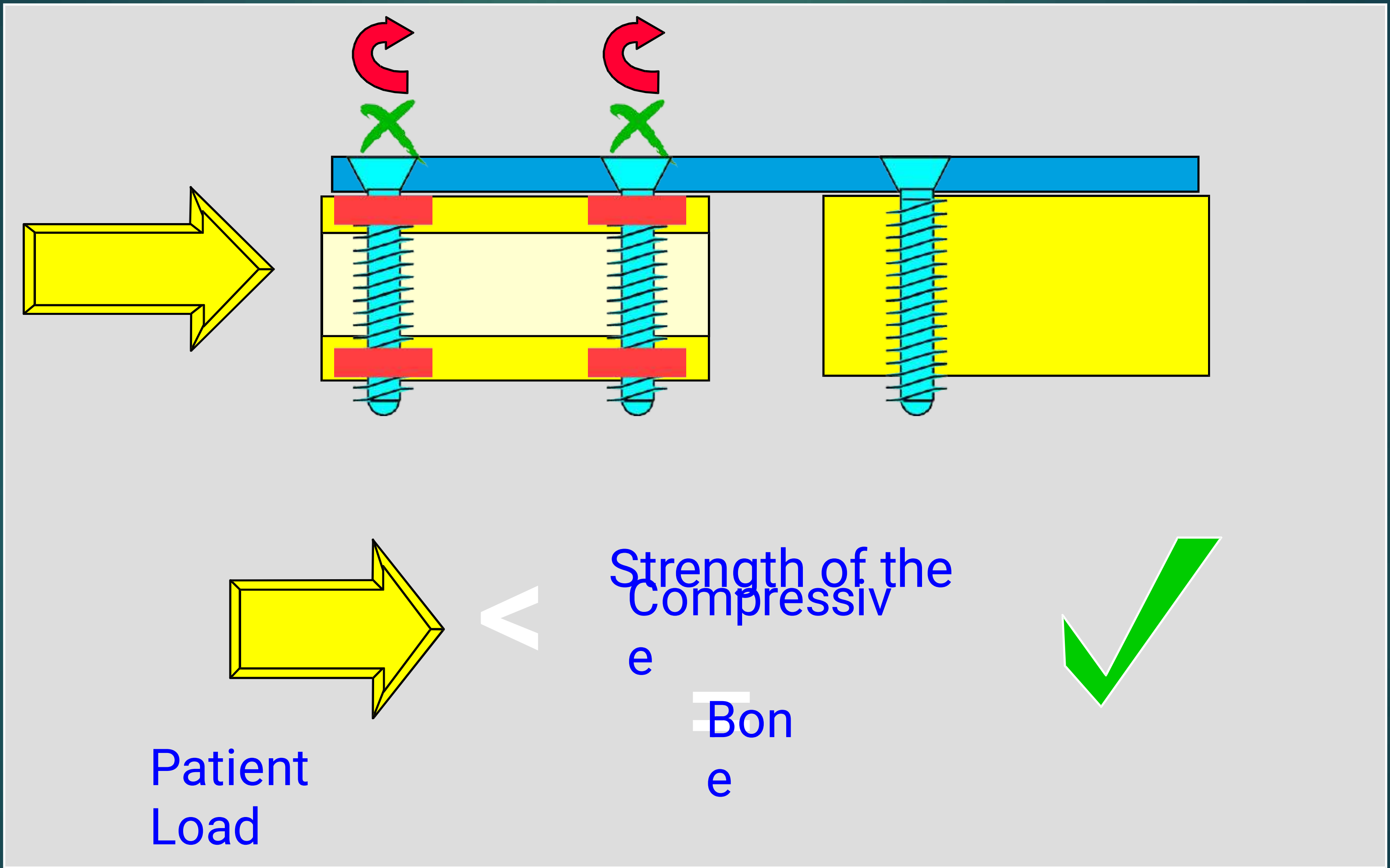
- Strength of plate fixation ~ number of screws & spacing (1 3 5 > 123)
- Torsional strength ~ number of screws but not spacing

Biomechanics of Locked Plating

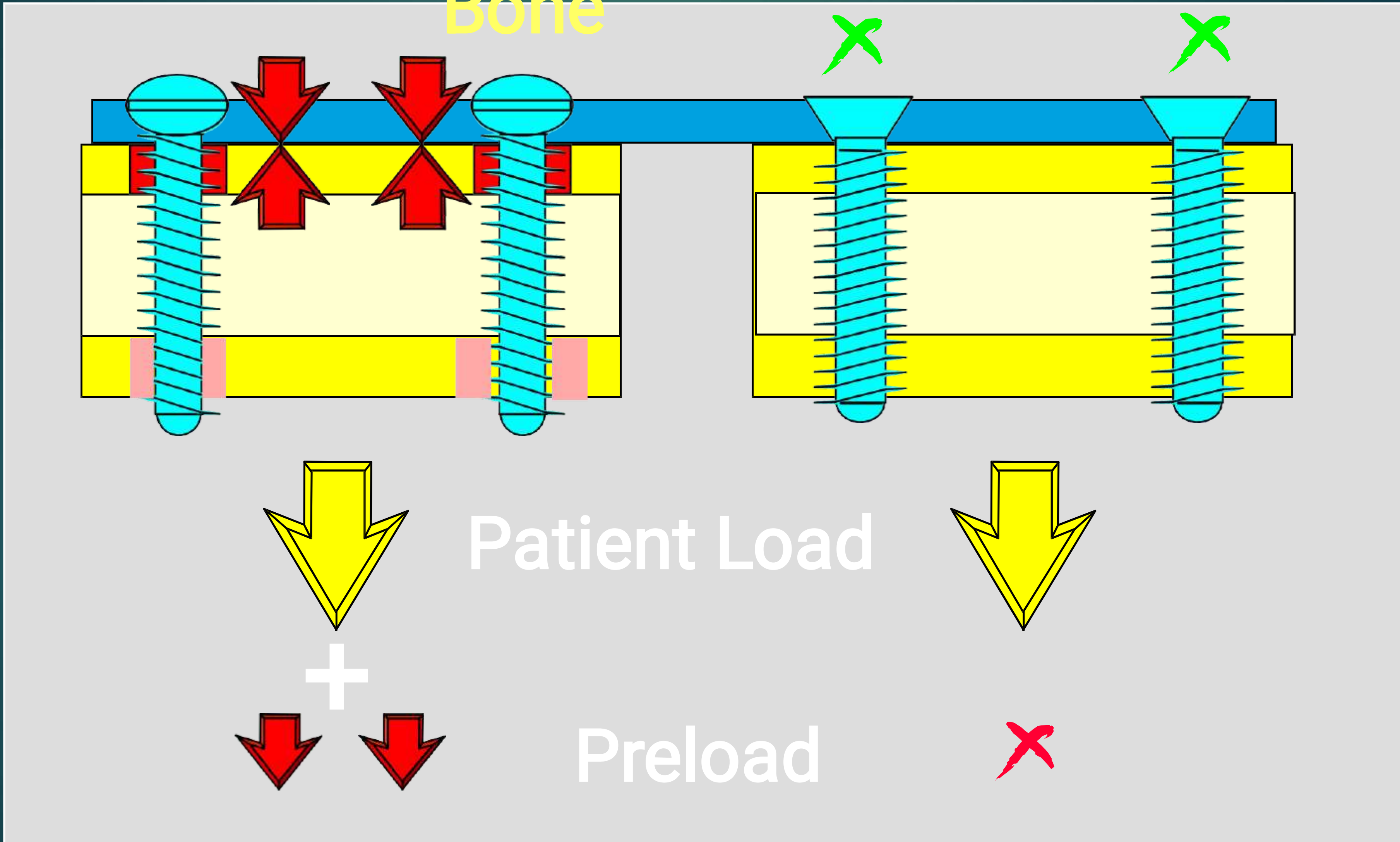
Conventional Plate Fixation



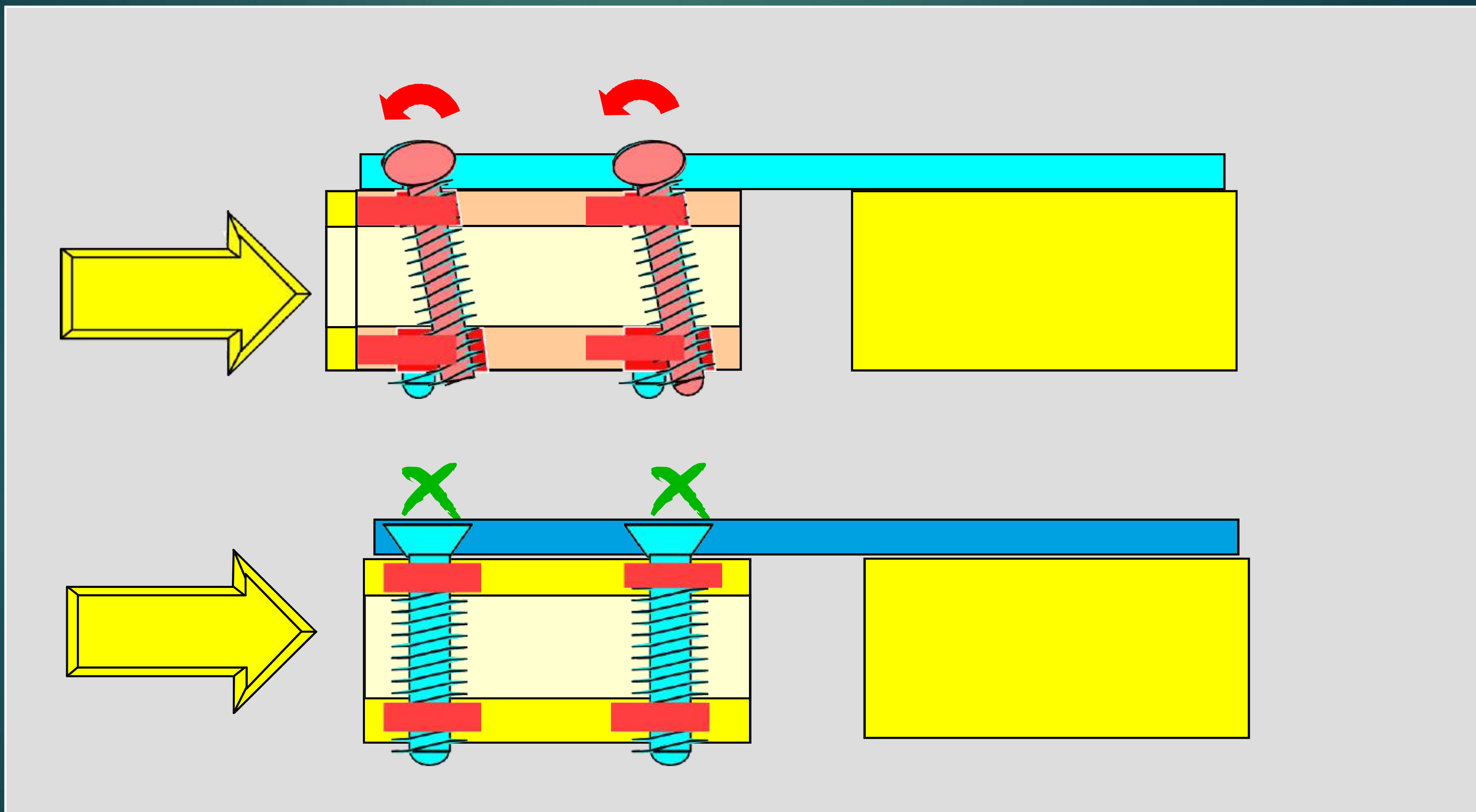
Locked Plate and Screw Fixation



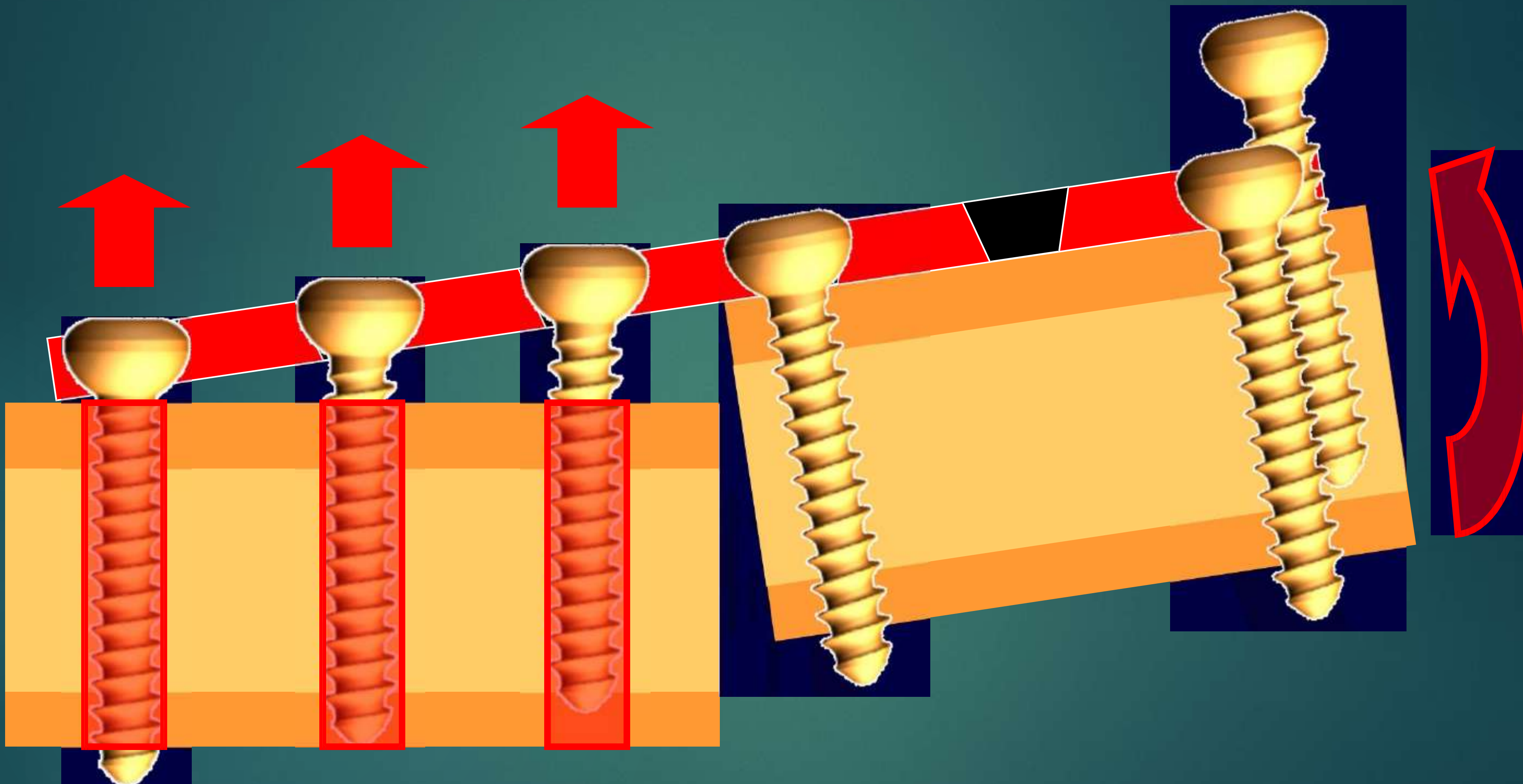
Stress in the Bone



Standard versus Locked Loading

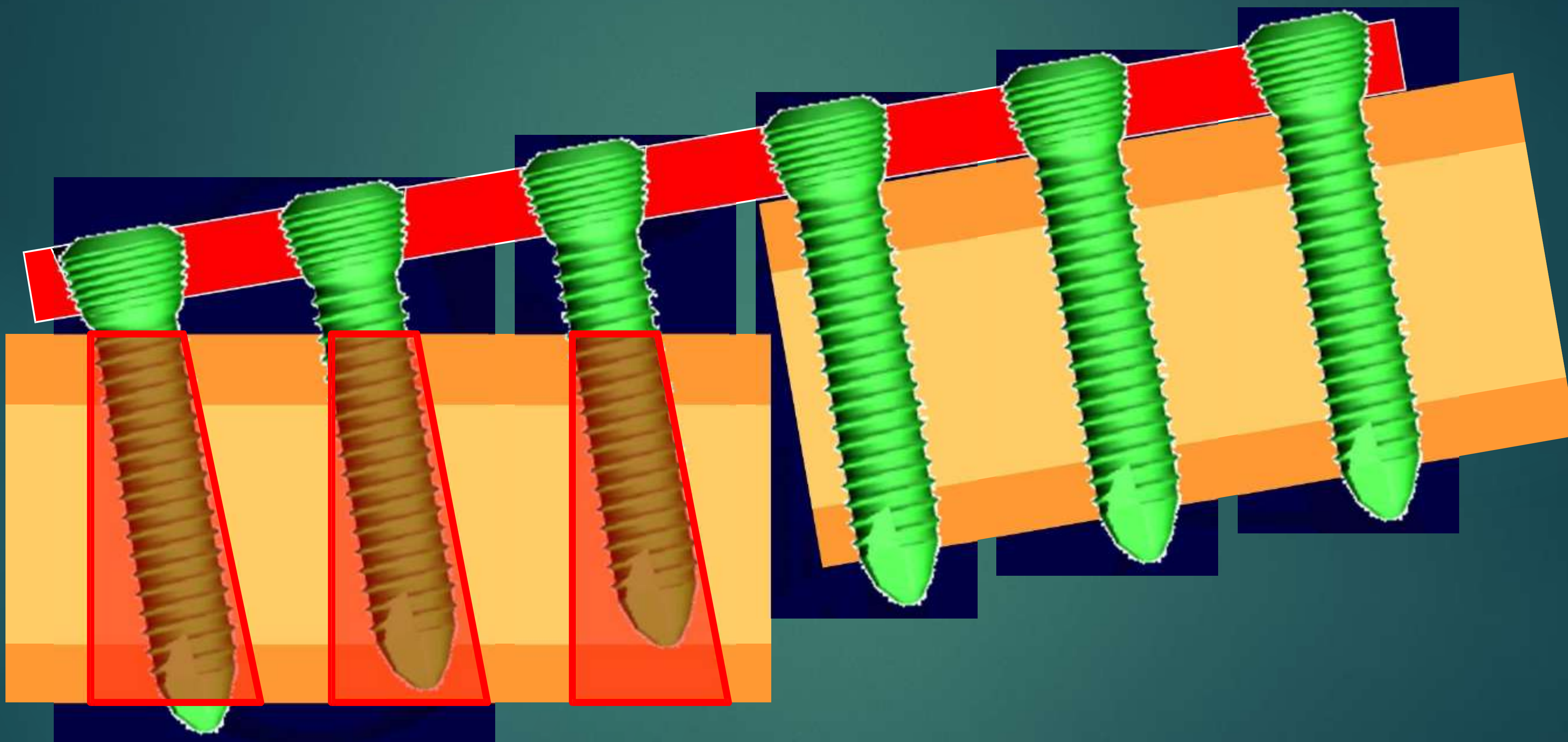


Pullout of regular screws



by bending load

Higher resistant against bending load

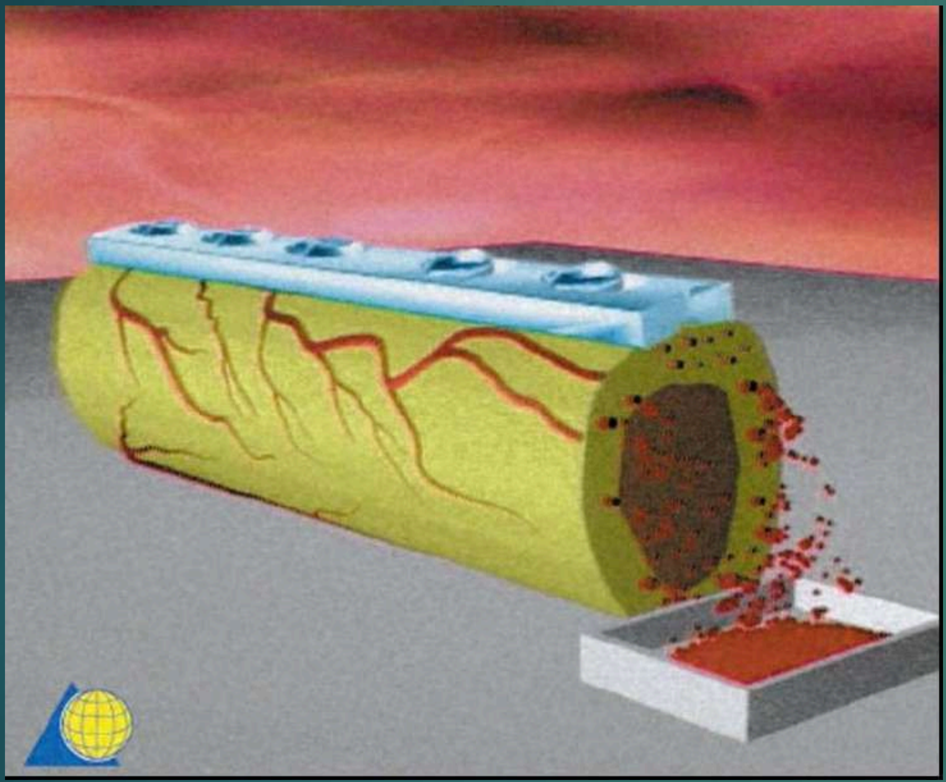


Larger resistant area

Biomechanical Advantages of Locked Plate Fixation

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

Preservation of Blood Supply
Plate Design

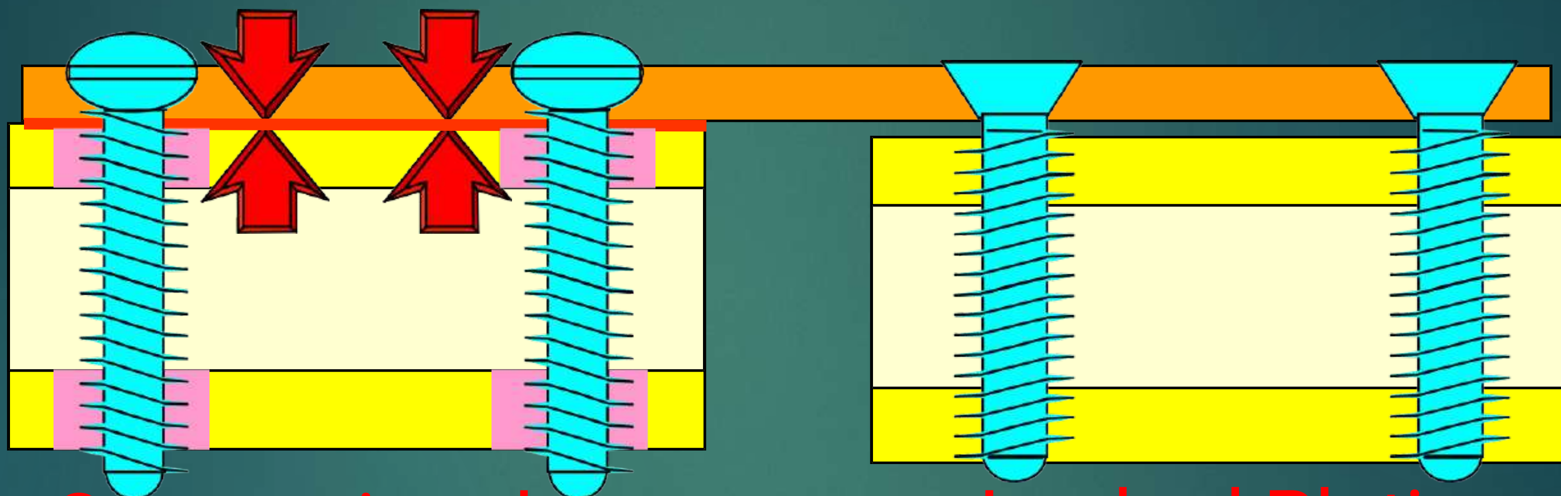


DCP

LCDCP

Preservation of Blood Supply

Less bone pre-stress



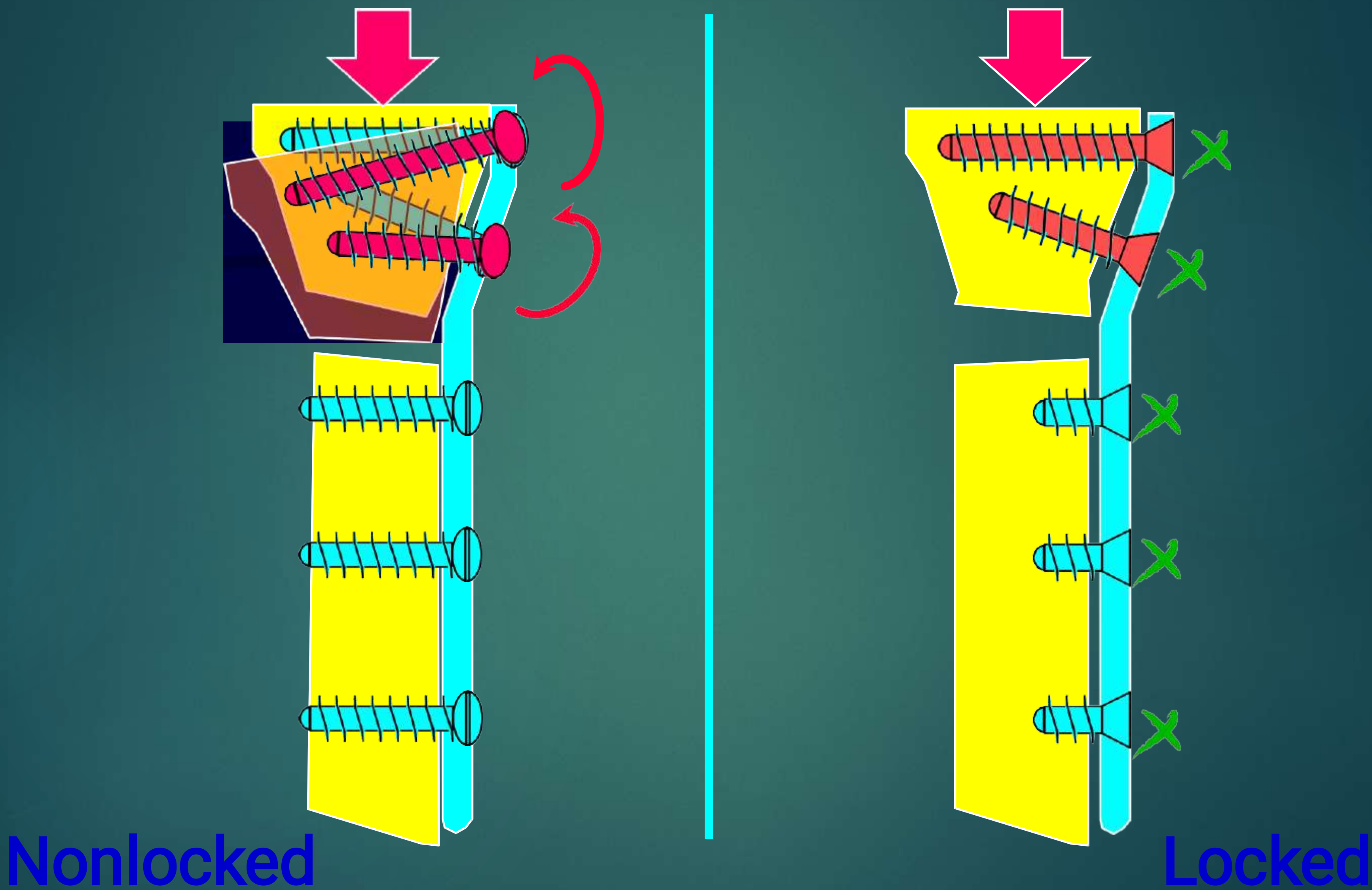
Conventional Plating

- Bone is pre-stressed
- Periosteum

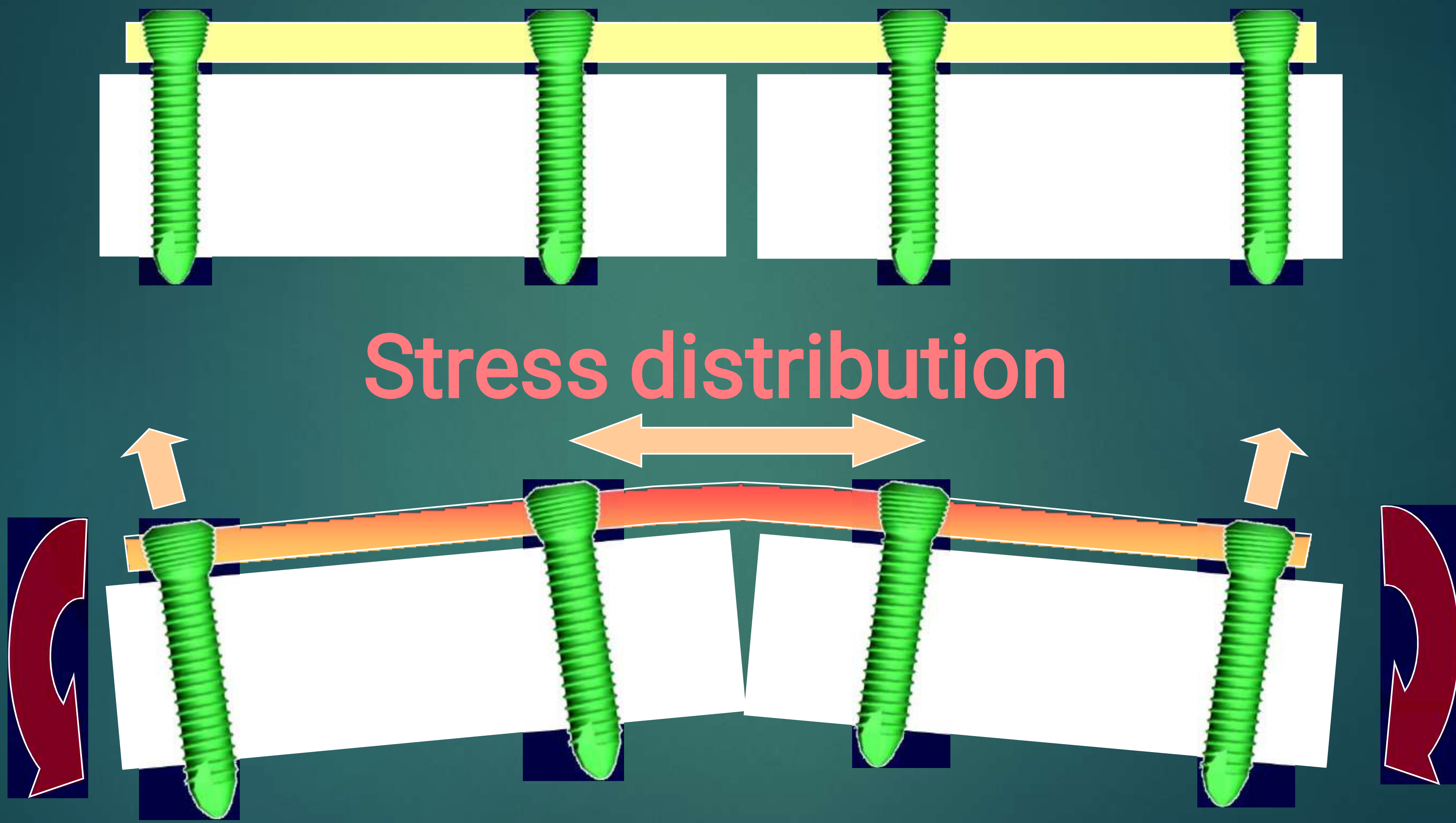
Locked Plating

- Plate (not bone) is pre-stressed
- Periosteum preserved

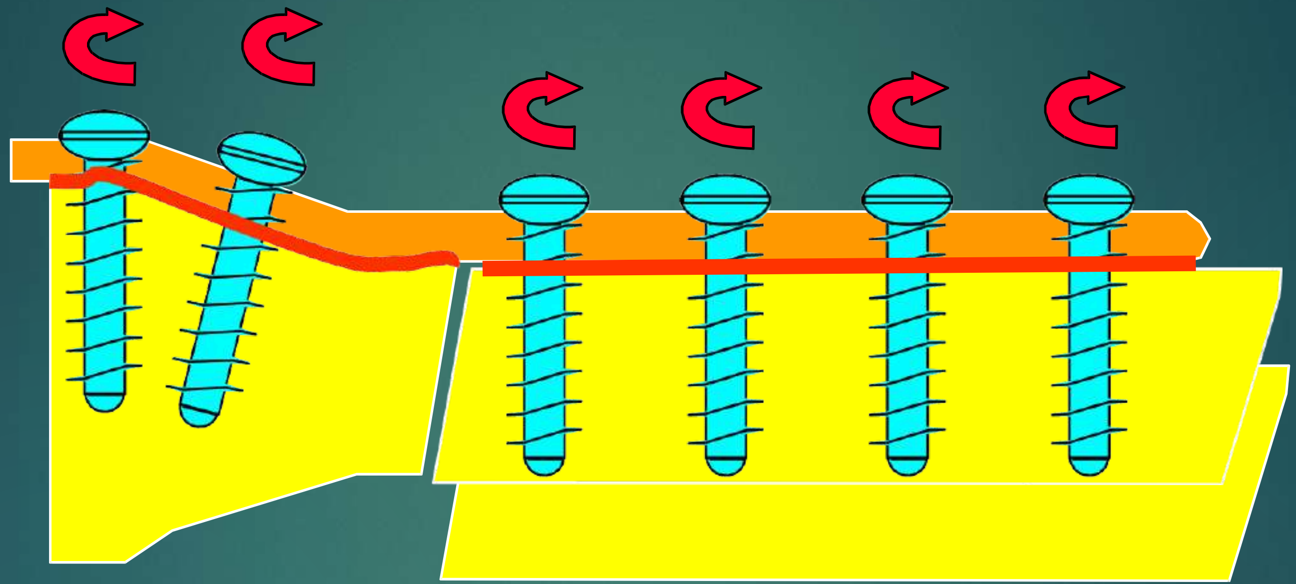
Angular Stability of Screws



Biomechanical principles similar to those of external fixators



Surgical Technique
Compression Plating



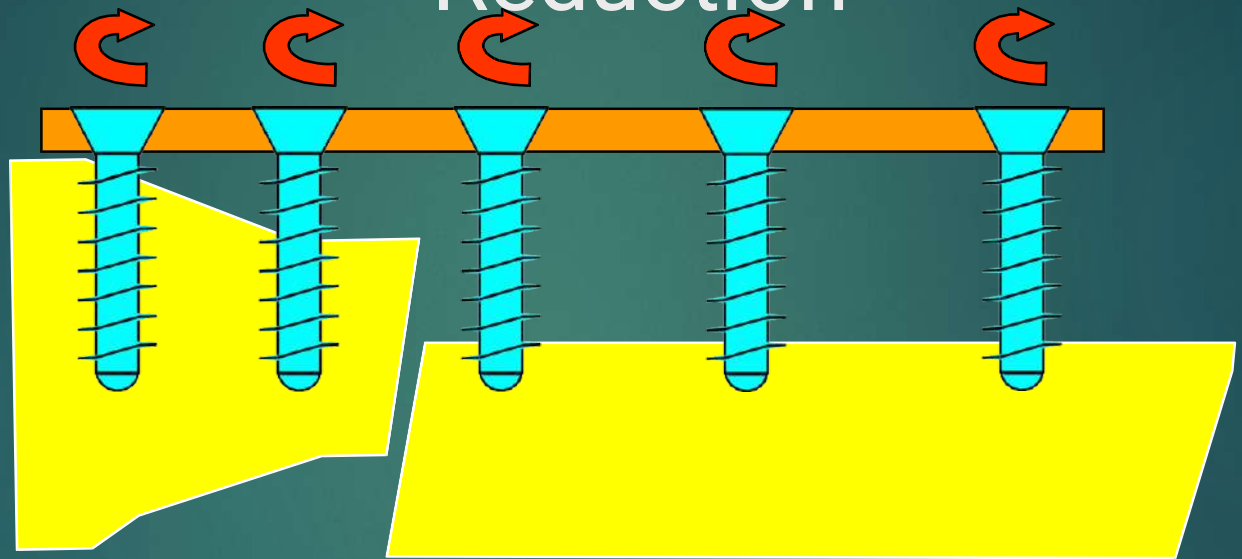
- The contoured plate maintains anatomical reduction as compression between plate and bone is generated.
- A well contoured plate can then be used to help reduce the fracture.

Traditional Plating

Courtesy of Synthes- Robi Frigg

Surgical Technique

Reduction



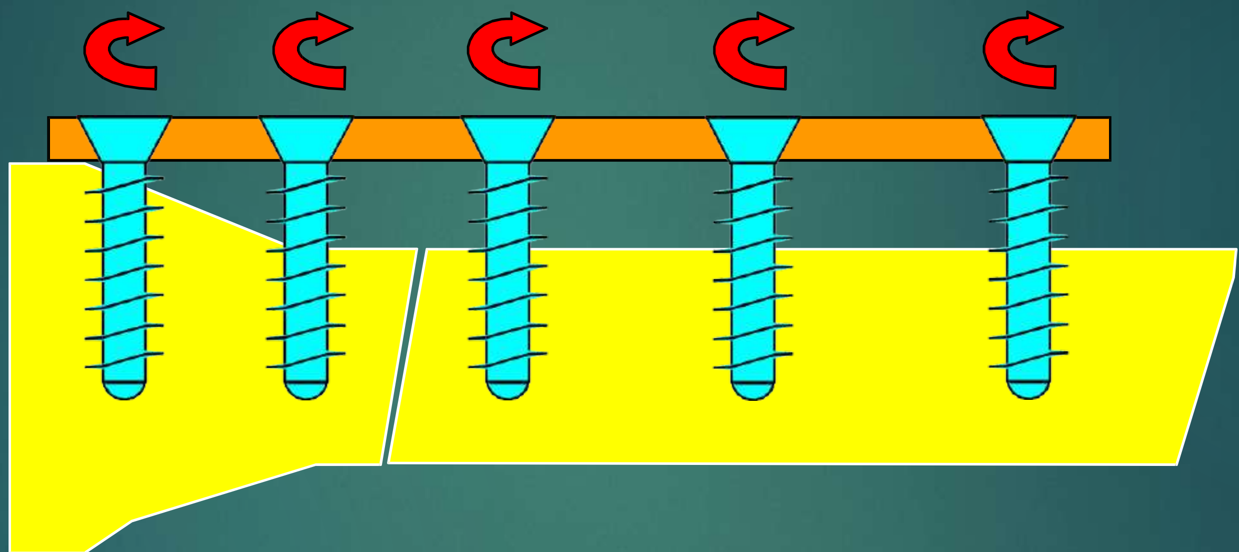
If the same technique is attempted with a locked plate and locking screws, an anatomical reduction will not be achieved.

Locked Plating

Surgical Technique

Reduction

Courtesy of Synthes- Robi Frigg



Instead, the fracture is <u>first</u> reduced and then the plate is applied.

Locked Plating

Surgical Technique
Precontoured Plates

Conventional Plating

1. Contour of plate is important to maintain anatomic reduction.

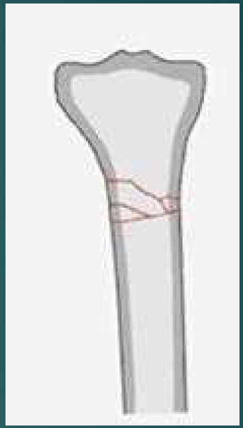
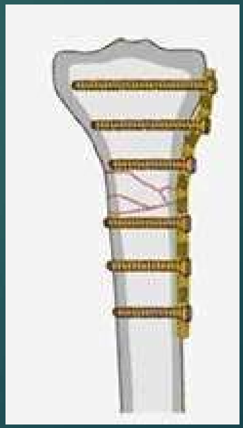
Locked Plating

1. Reduce fracture prior to applying locking screws.

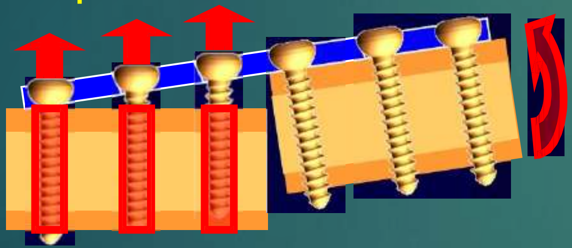
Unlocked *vs* Locked Screws

Biomechanical Advantage

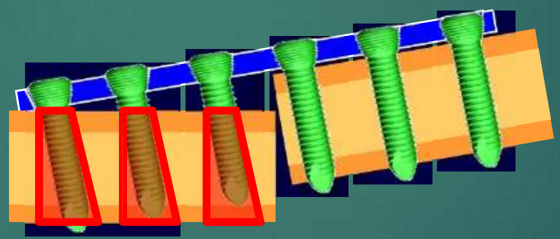
1. Force distribution
2. Prevent primary reduction loss
3. Prevent secondary reduction loss
4. “Ignores” opposite cortex integrity
5. Improved purchase on osteoporotic bone

Sequential Screw Pullout



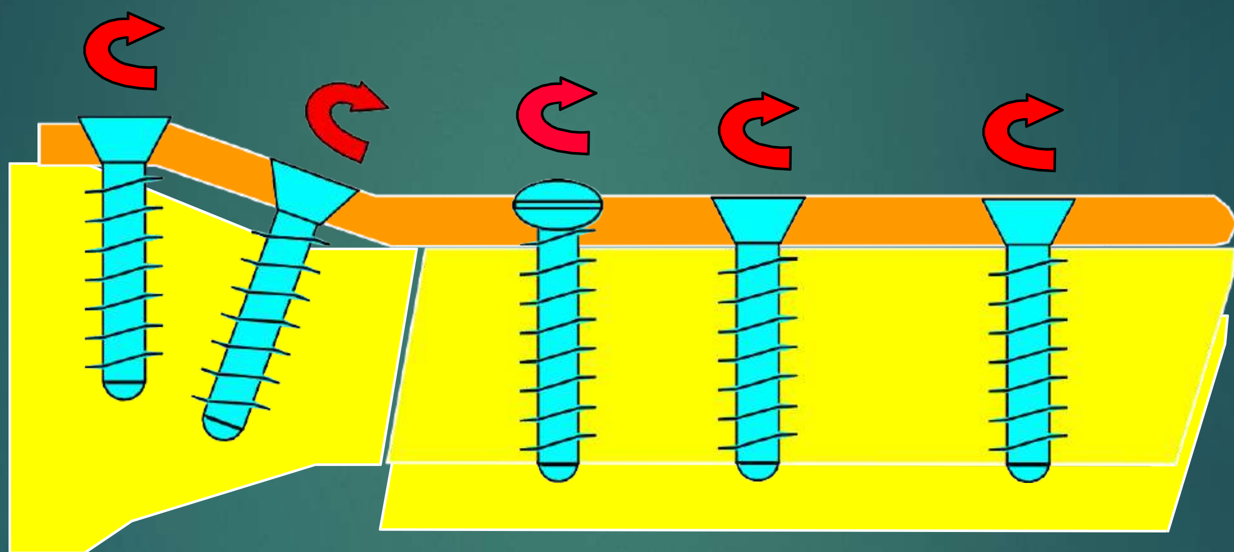
Larger area of resistance



Courtesy of Synthes- Robi Frigg

Surgical Technique

Reduction with Combination Plate



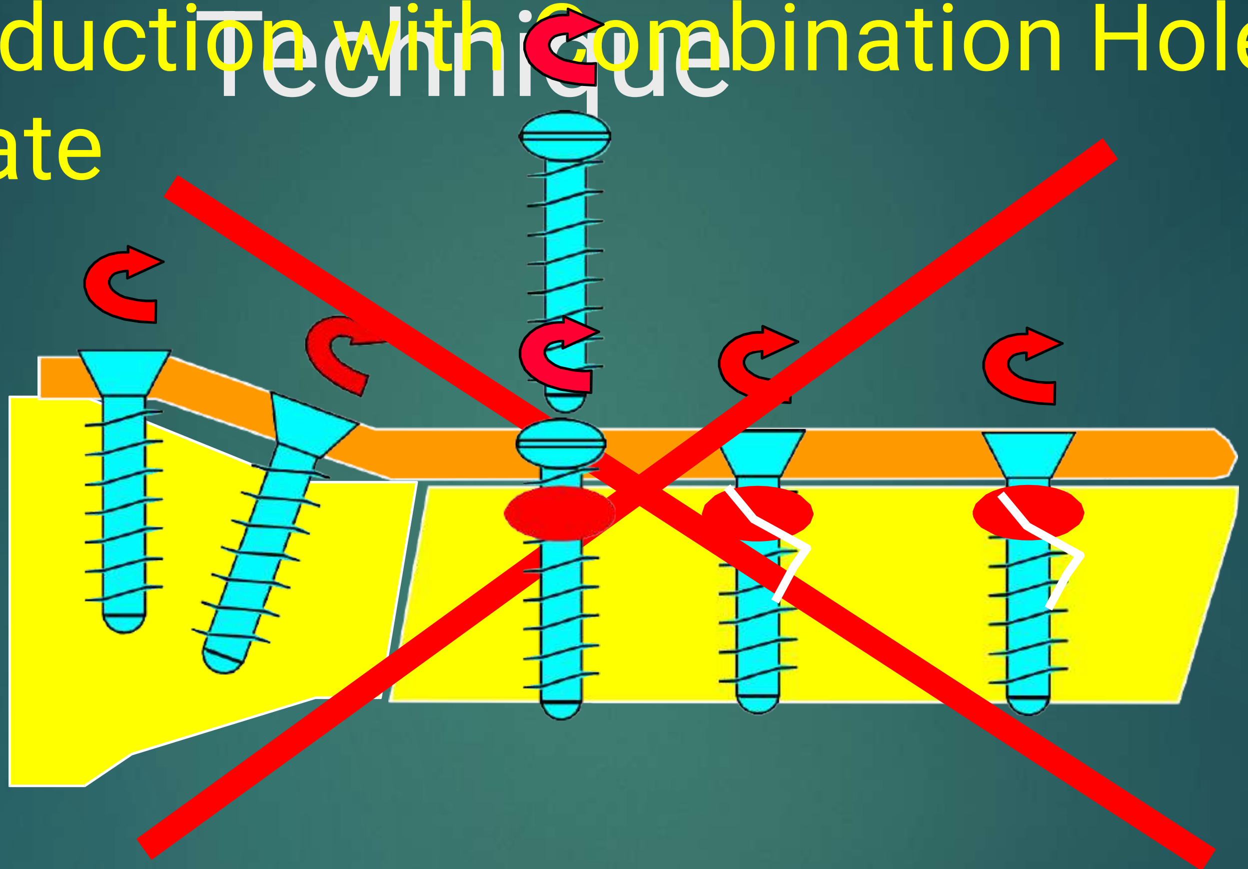
Lag screws can be used to help reduce fragments and construct stability improved w/locking screws

Locked Plating

Courtesy of Synthes- Robi Frigg

Surgical Technique

Reduction with Combination Hole Plate



Lag screw must be placed 1st if locking screw in same fragment is to be used.

Locked Plating

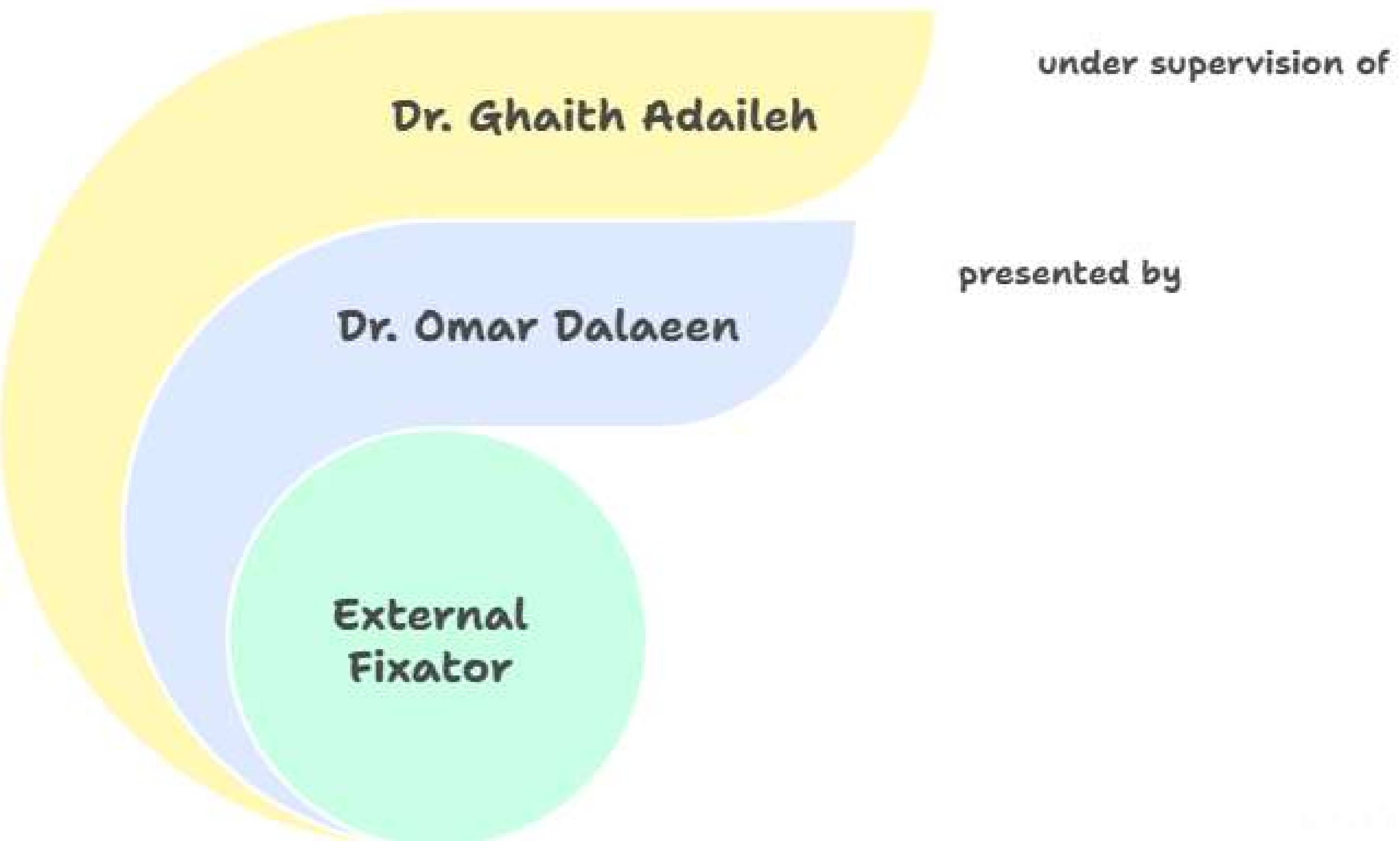
Hybrid Fixation

- Combine benefits of both standard & locked screws
- Precontoured plate
- Reduce bone to plate, compress & lag through plate
- Increase fixation with locked screws at end of construct

Length of Construct

- Longer spread with less screws
  - "Every other" rule (3 screws / 5 holes)
- < 50% of screw holes f lled
- Avoid too rigid construct

Principles of external fixation



Definitions

External Fixation

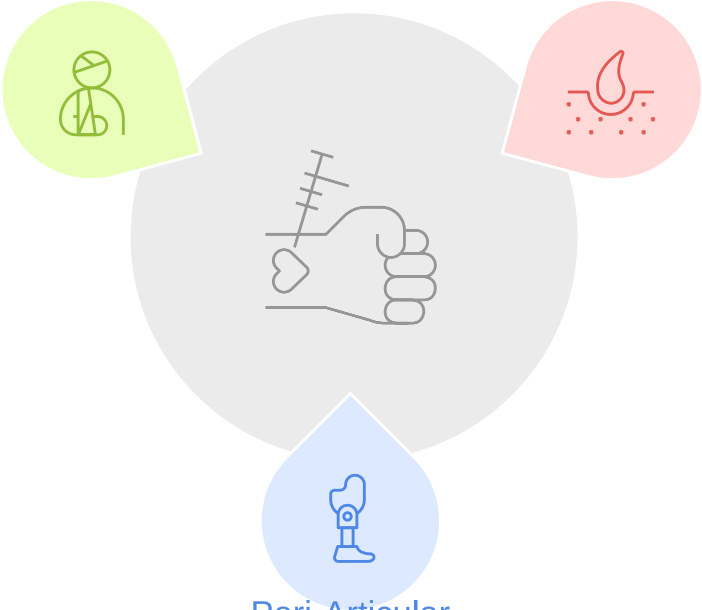
Fixation of fractured bones by splints, plastic dressings, or trans-fixation pins.

External Fixator Device

is a device placed outside the skin which stabilizes the bone fragment through wire or pins connected to one or more longitudinal bar or ring.

INDICATIONS :

Definitive Fracture Care



Pediatric Fracture Care

Specialized approaches for children's unique healing processes

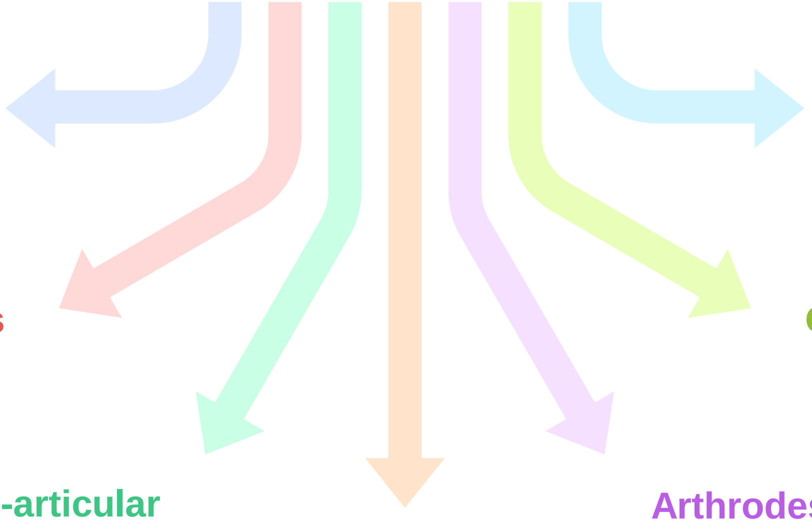
Open Fracture Management

Immediate attention to prevent infection and promote healing

Peri-Articular Fracture Treatment

Careful treatment to maintain joint function and stability

Temporary fracture care



Damage Control

Temporizes long bone fractures to stabilize the patient and in **Pelvic Ring Injury**
.

Distraction osteogenesis

Peri-articular Fractures

Manages fractures near joints, and for soft tissue optimization, like in pilon fractures.

Malunion/Nonunion

Corrects fractures that haven't healed properly.

Arthrodesis

Osteomyelitis

Limb Deformity/Length Inequality

congenital or acquired

External fixation

Pros

1. Minimally invasive

Minimally invasive procedure reduces trauma and recovery time for patients.

2. Flexible design

Flexible design allows customization to fit individual patient needs.

3. Quick application

Quick application ensures timely stabilization and treatment.

4. Versatile use

Versatile use as both temporary and definitive stabilization device.

5. less worry of infection

Low infection risk minimizes complications and enhances patient safety.

Cons

1. distraction of Fracture site

Fracture distraction can hinder proper healing and alignment.

2. Inadequate immobilization

Inadequate immobilization may lead to instability and delayed recovery.

3. Pin failure

Pin failure can compromise stability and require revision surgery.

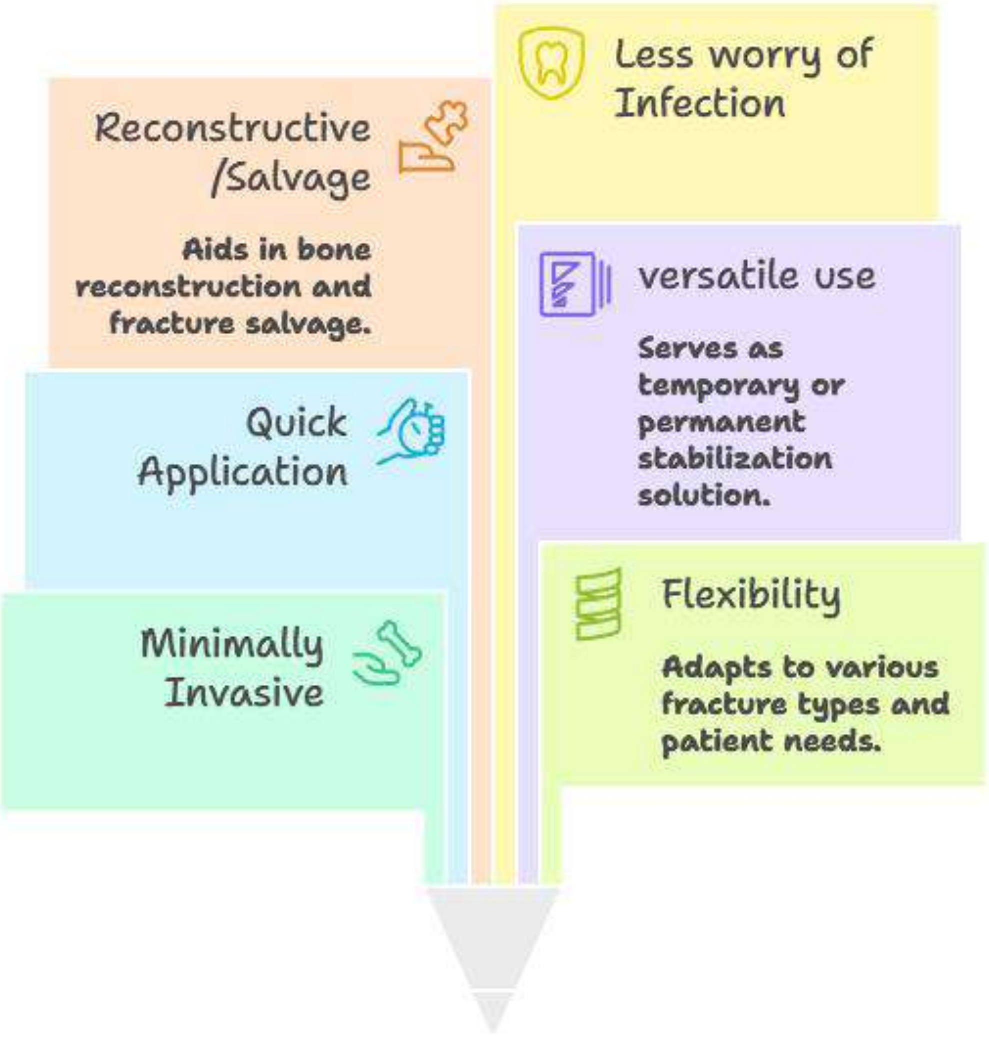
4. Weight and bulk

5. Re-fracture risk

6. biologic disadvatage

infection (pin track)
NVB injury
muscle tethering
soft tissue contracture

Advantages of External Fixation



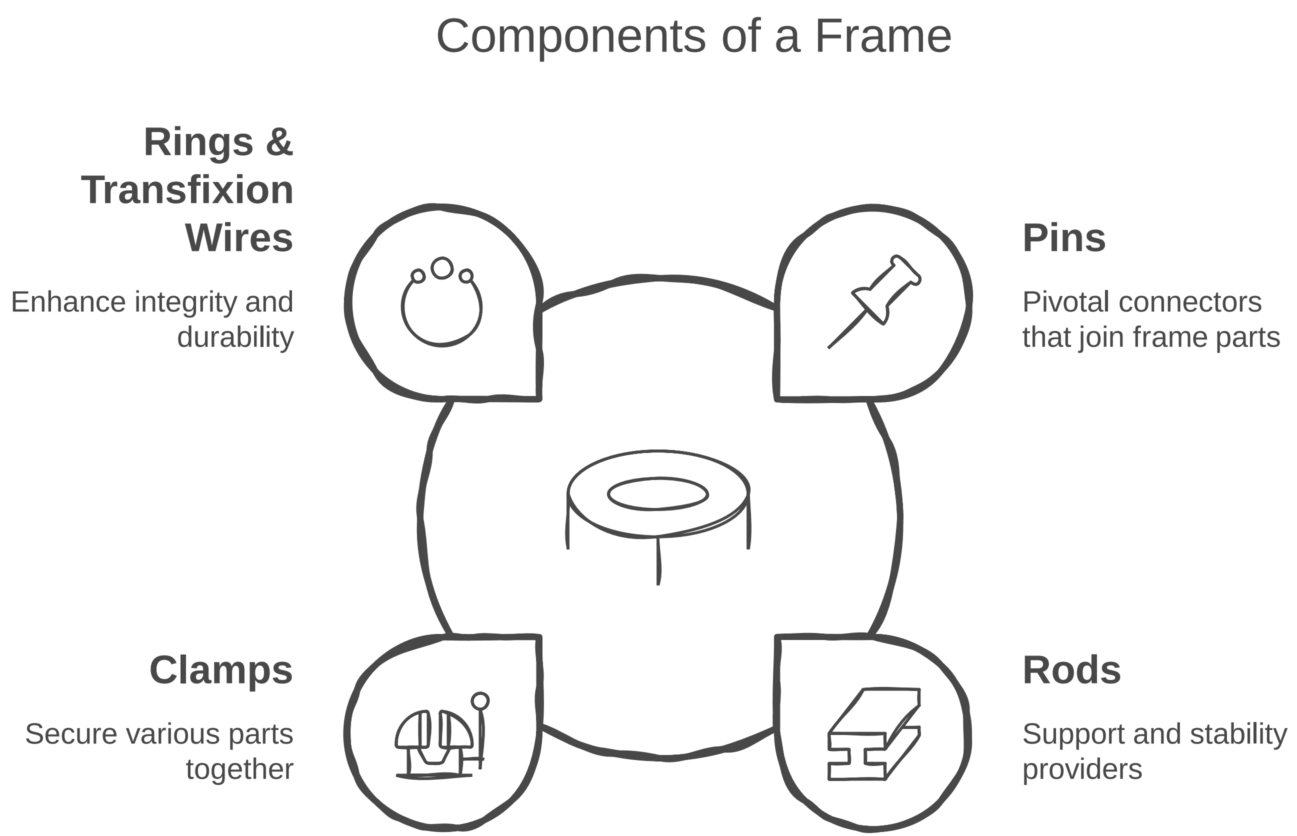
What are the disadvantages of external fixation?

Mechanical disadvantages

* distraction of the fracture site
* inadequate immobilization,
* pin-bone interface failure
*weight/bulk
* re-fracture.

Biologic disadvantages

* infection(pin-track)
* neurovascular injury
* muscle tethering
* soft tissue contracture.



Components of a Frame
Rings & Transfixion Wires
Enhance integrity and durability
Pins
Pivotal connectors that join frame parts
Clamps
Secure various parts together
Rods
Support and stability providers

Pins

Connecting rods

clamps

pins

- The pin is the critical link between the bone and the frame.
- **Pin diameter?**
  - Pin must be < 1/3 bone diameter to prevent pin hole fractures;
- **Bending stiffness**
  - proportional to r^4 , the single most important factor with frame strength is the pin size.
- 5mm pin 144% stiffer than 4mm pin
- 6 mm pin is more than twice as stiff as a 5 mm pin

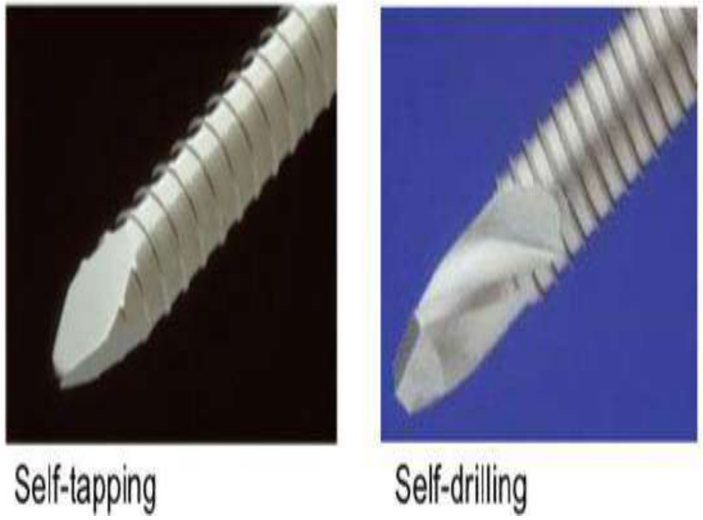
Pin Diameter Guidelines

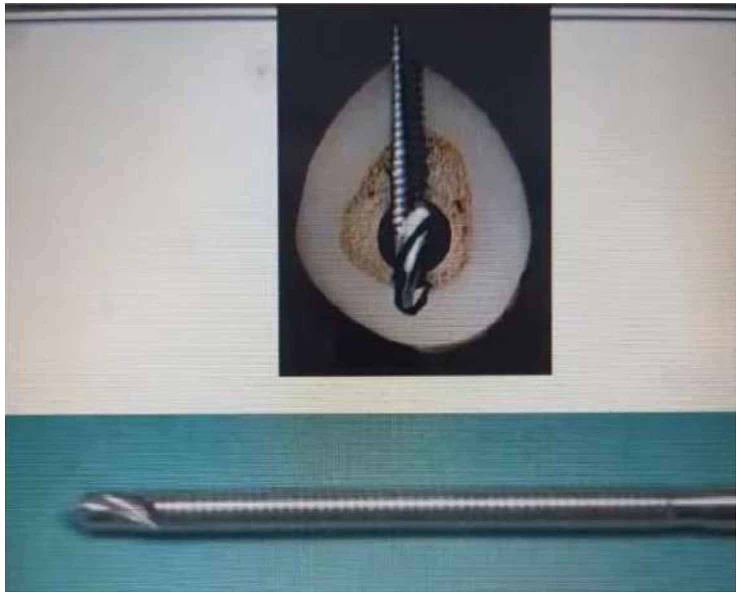
- Femur – 5 or 6 mm
- Tibia – 5 or 6 mm
- Humerus – 5 mm
- Forearm – 4 mm
- Hand, Foot – 3 mm

Various diameters , lengths and designs

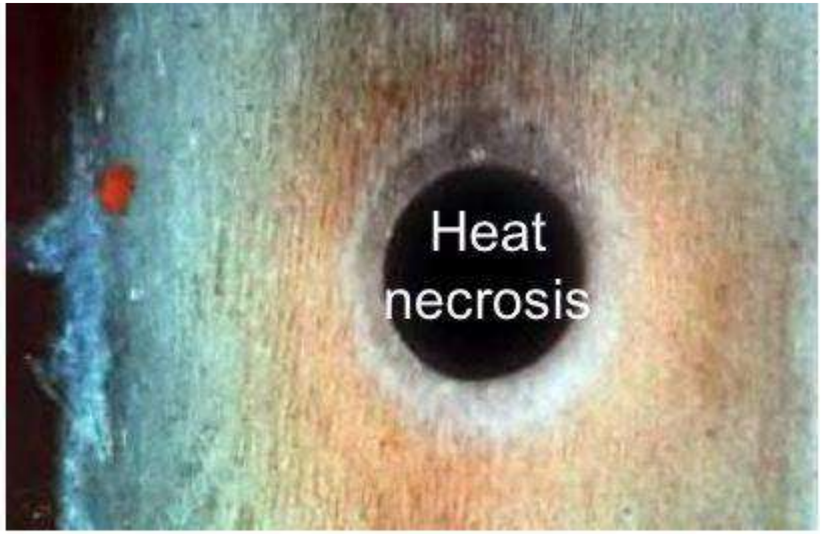
- 2.5 mm pin
- 4 mm short thread pin
- 5 mm predrilled pin
- 6 mm tapered or conical pin
- 5 mm self-drilling and self tapping pin
- 5 mm centrally threaded pin

- **Pin Geometry**
  - Blunt pins
    - Straight
    - Conical
  - Self Drilling and Tapping
- **Materials**
  - Stainless steel
  - Titanium
    - More biocompatible
    - Less stiff
- **Self drilling pin:**
  - Short drill flutes
    - thermal necrosis eventually lead to loosening
    - stripping of near cortex with far cortex contact
  - Quick insertion
  - Useful for short term applications

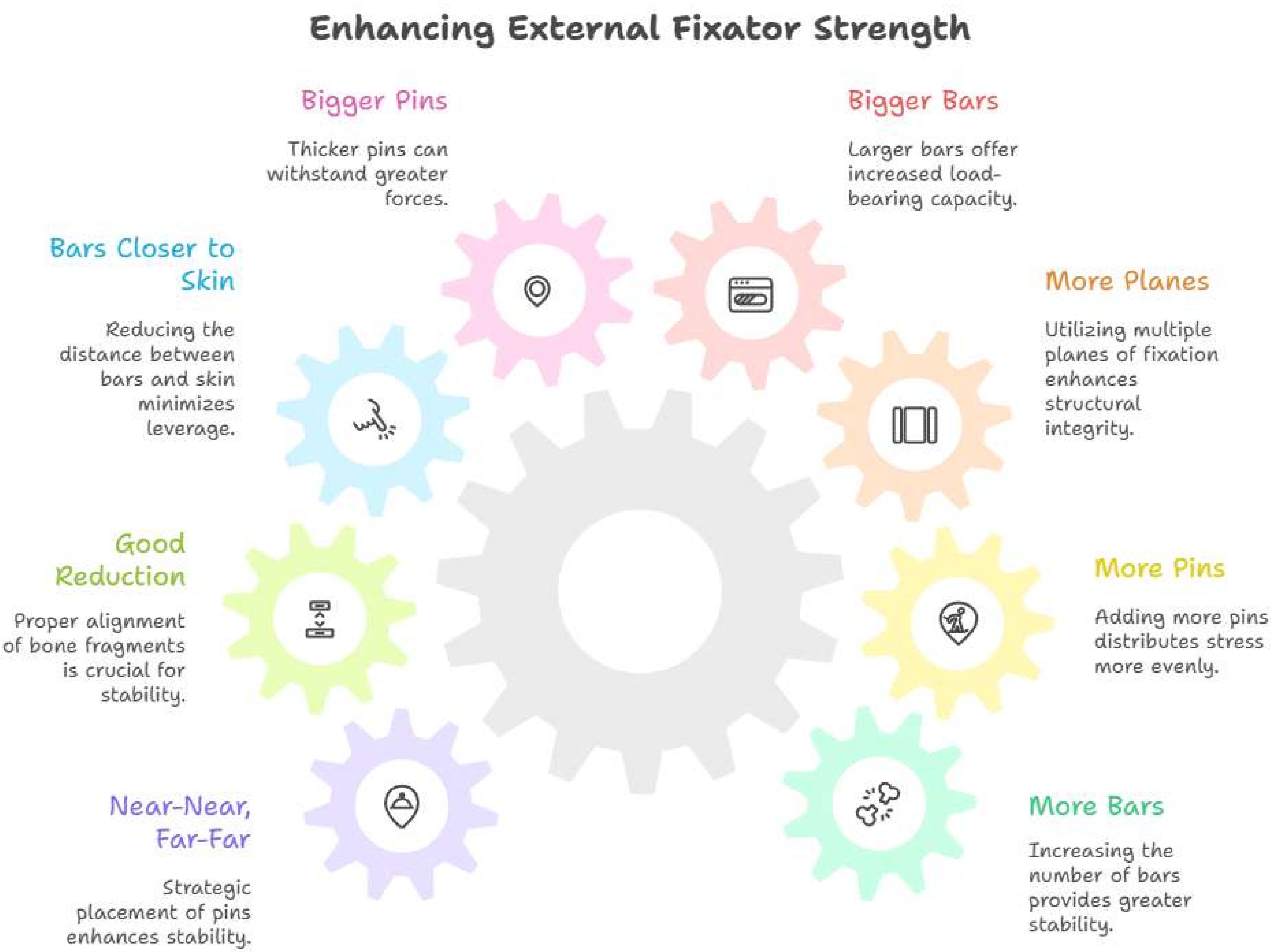


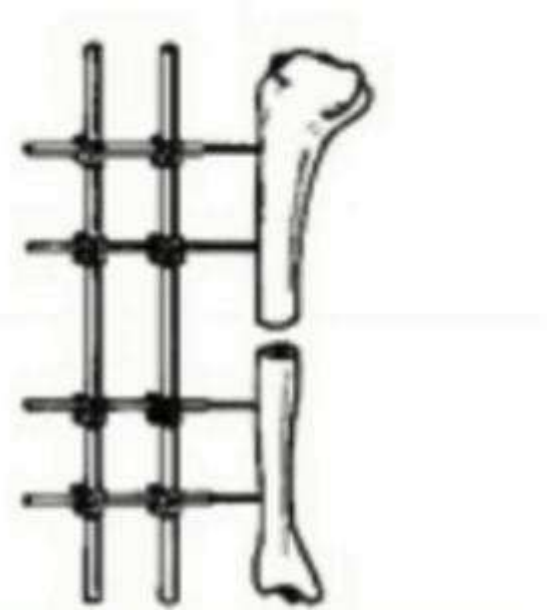


- Always irrigate during drilling/insertion in cortical bone
To reduce thermal necrosis of bone and pin loosening .

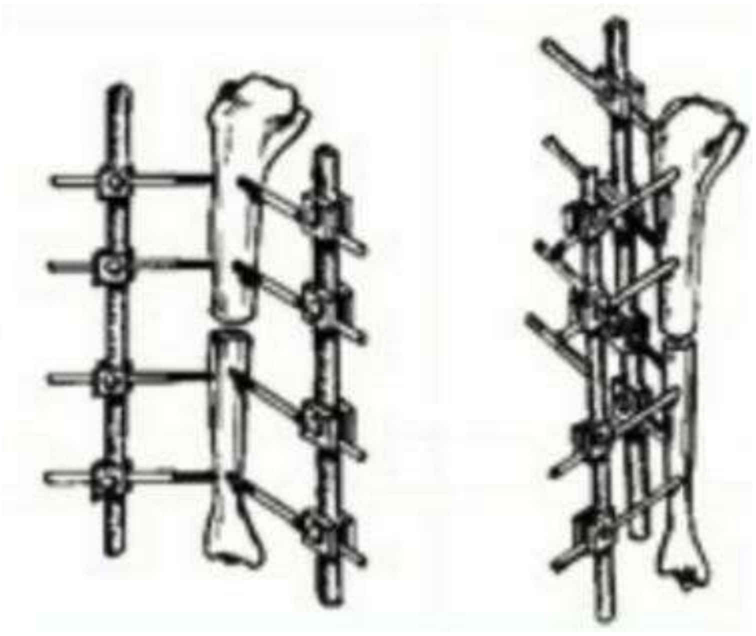


The "8" Things That Make Ex-Fixes Stronger !!!


Enhancing External Fixator Strength
Bigger Pins
Thicker pins can withstand greater forces.
Bigger Bars
Larger bars offer increased load-bearing capacity.
Bars Closer to Skin
Reducing the distance between bars and skin minimizes leverage.
More Planes
Utilizing multiple planes of fixation enhances structural integrity.
Good Reduction
Proper alignment of bone fragments is crucial for stability.
More Pins
Adding more pins distributes stress more evenly.
Near-Near, Far-Far
Strategic placement of pins enhances stability.
More Bars
Increasing the number of bars provides greater stability.

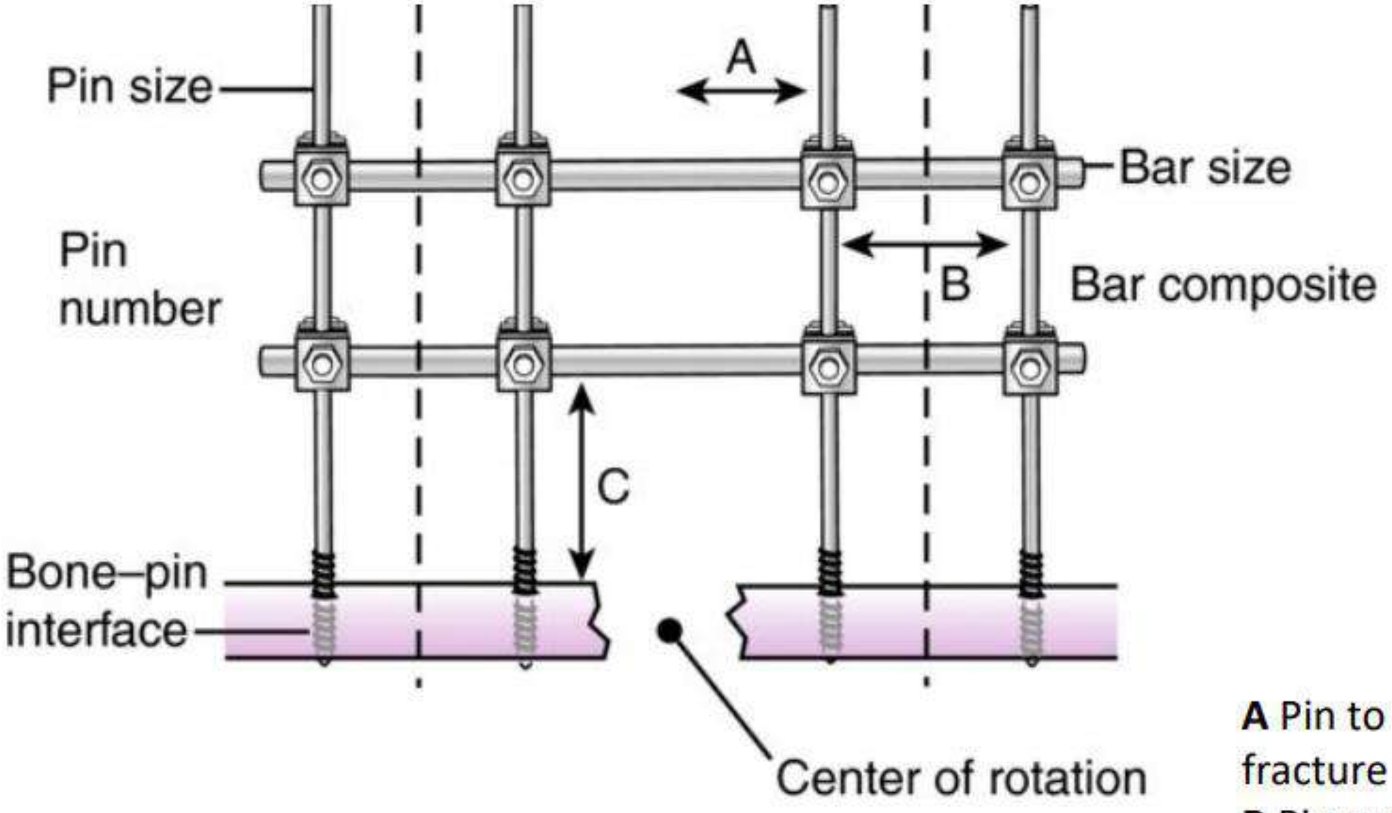


More bars
More pins



More planes

Factors affecting Stability of Monolateral Frame

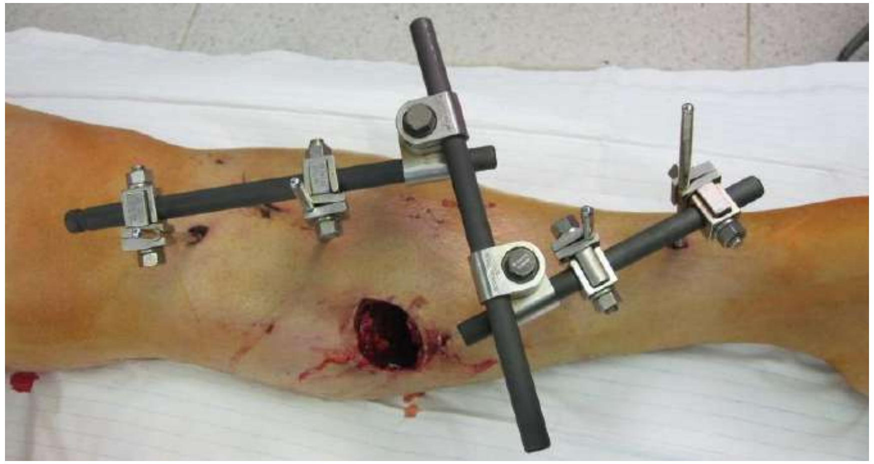


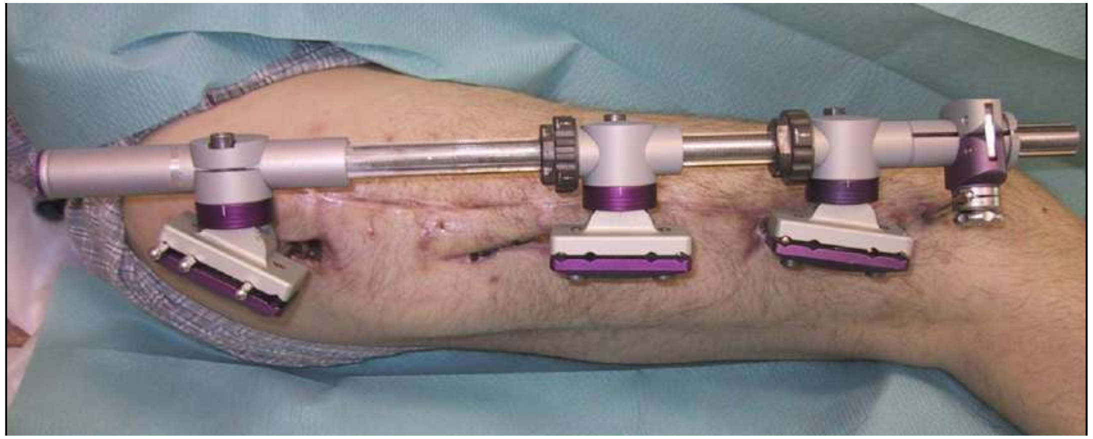
Caption

A Pin to centre of fracture
B Pin separation
C Bone–bar distance.

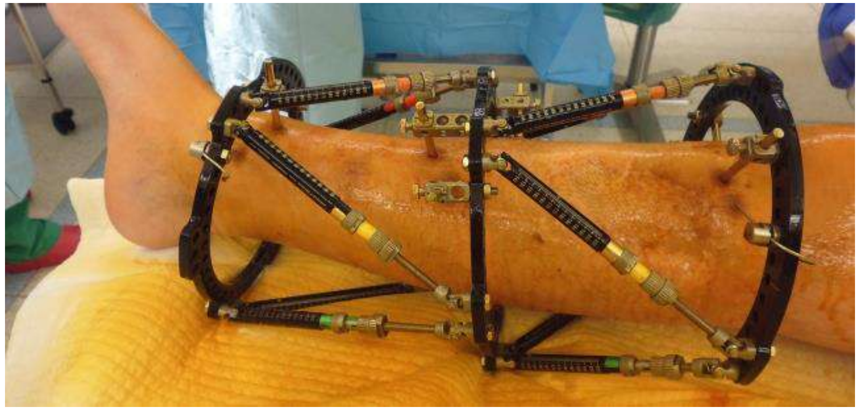
Types of external fixation

- Monolateral fixator





- Ring fixator



Types of external fixators :

1. Modular
2. Hybrid
3. Ring
4. Monotube
5. hexapod

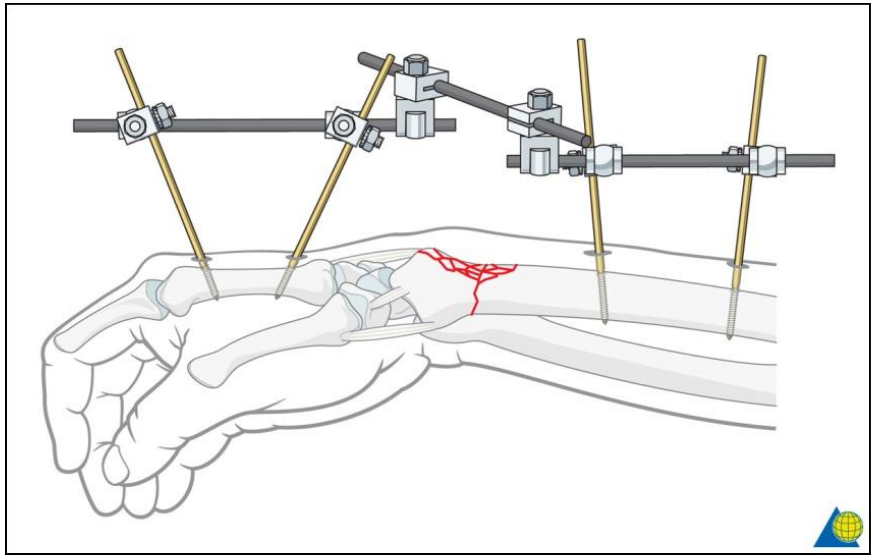
1. Modular system

Allows the external fixator to Become

a reduction tool .

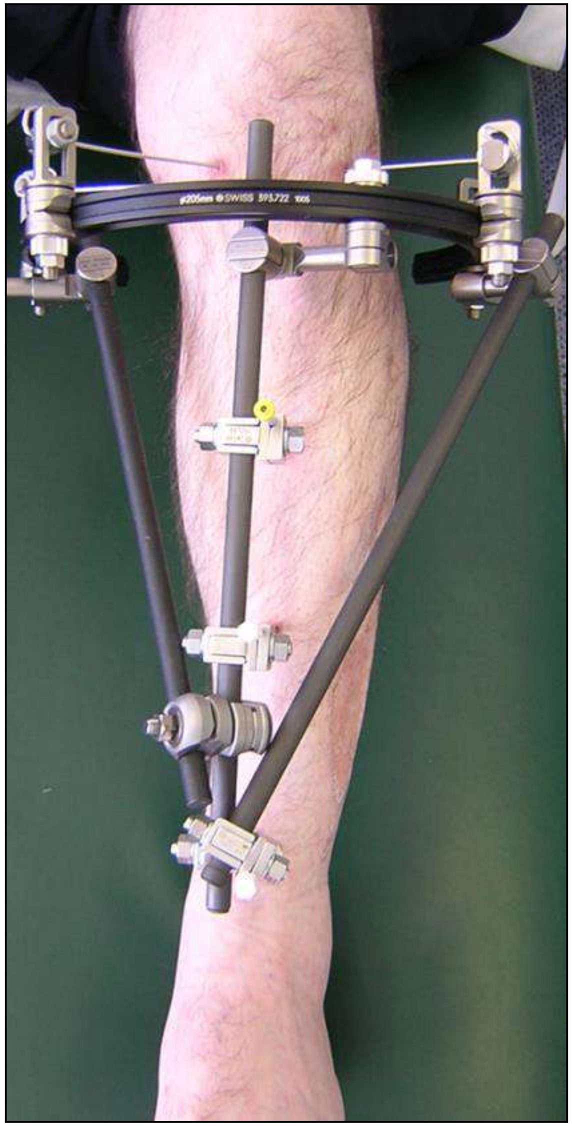
- Any limb

- Any joint



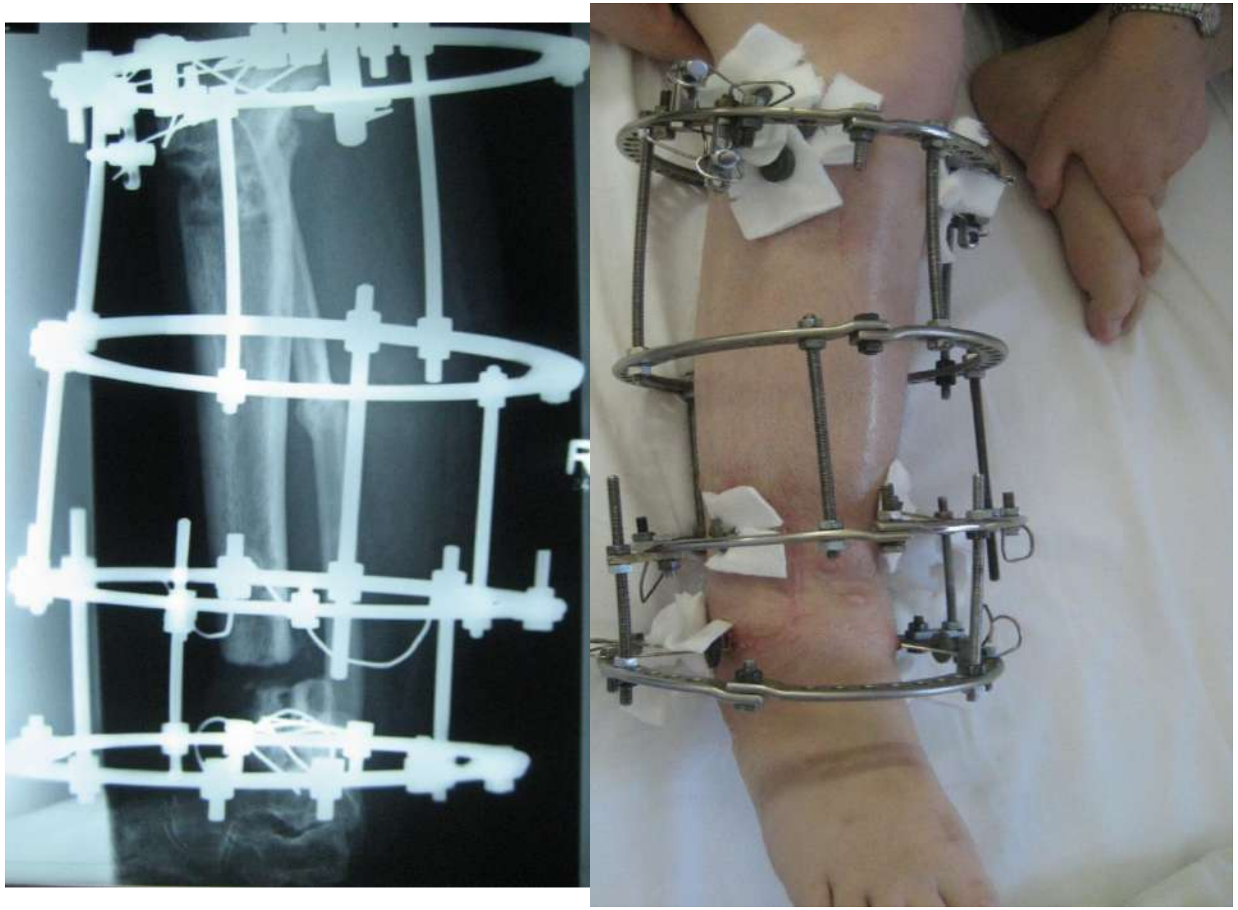
2. Hybrid system

- Combined use of
  - Partial ring or full ring with
  - Unilateral system
- Periarticular fractures
- Secondary procedures (eg, septic cases)
  - Alone
  - In combination with other implants

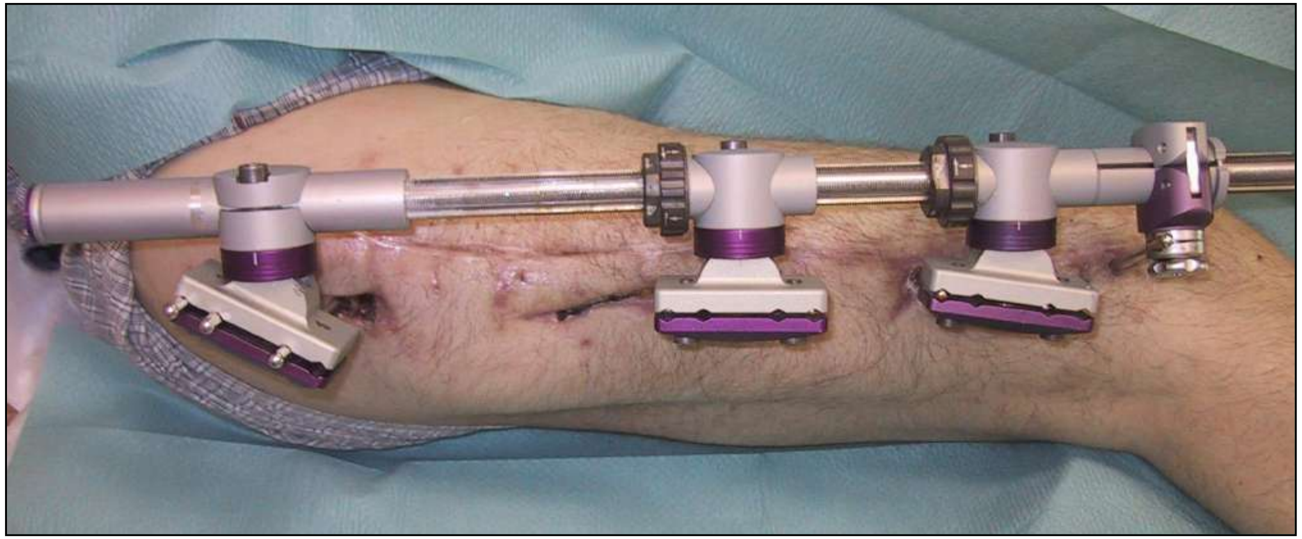


3. Ring/Ilizarov system

- Corrective procedures :
- Lengthening of shortened limbs
- Correction of rotational deformities
- Segmental bone transport



4. Monotube system



Corrective procedures

- Lengthening of shortened limbs
- Segmental bone transport
- Correction of simple deformities

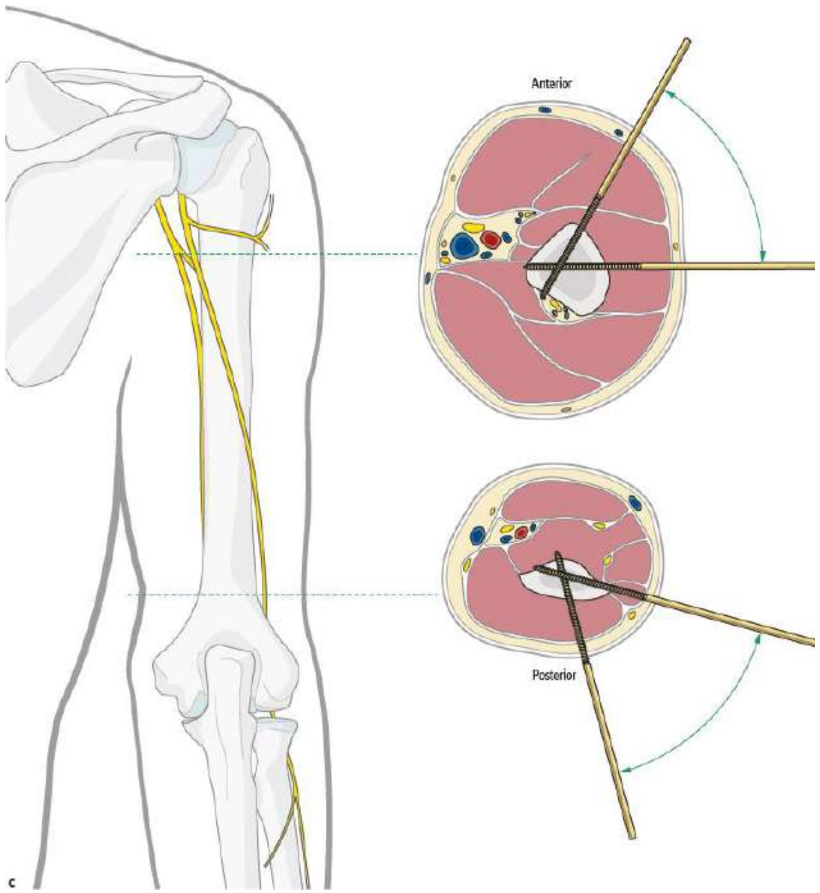
5. Hexapod system

- Ring fixation system that uses six angled struts to provide six axes of movement between bone segments
- Allows correction of complex deformity
- Requires computer assisted manipulations to guide strut adjustments

Safe zones ?

- Anatomy - Pin placement Upper Limbs

- Proximal Humerus - Anterolateral
  - Avoid damage to the axillary and radial n.
- Distal Humerus - Posterolateral
  - Avoid the olecranon fossa
- Forearm
  - Ulna - Subcutaneous border
  - Radius - Distally,Protect Superficial Radial n.



Anatomy - Pin placement Lower Limbs

- Femur - Anterolaterally or Direct lateral

- Tibia - Subcutaneous anteromedial surface of the tibia
    - Pins placed perpendicular to either the anteromedi or posterior tibial cortex

- Periarticular Ankle
    - Trans calcaneal pin
    - To prevent equinus & to provide more stability - additional pins into Talus neck, Cuneiforms, First metatarsal base medially or laterally Cuboid or Fifth metatarsal base laterally