

Chapter 1:

General Orthopedic

Dr Annie Sandhu and Dr Kuldip Singh

BONE: A primary structural element of musculoskeletal system and this must be mechanistically strong enough to support the daily living. Bone is an ANISOTROPIC i.e. fiber orientation deliver specific material properties along distinct loading directions means different material properties depending on loading direction. Bone should have sufficient strength, stiffness and durability to transmit forces /load and supports joint motion. Mechanical competency of bone and implant depends on their material and structural properties and these properties of bone and implant or Fixation construct accommodates mechanical function during fracture healing. Bone's mechanical properties characterize their deformation and failure of material under loading and these properties are measured by stress and strain, stress is measured in pascal (Pa) while strain has no units. Ultimate strength of cortical bone in compression is 50% greater than in tension.

So, bone is transversely anisotropic i.e. its stiffness is 50% higher when loaded in longitudinal direction i.e parallel to osteon orientation ($E=17$ GPa) than in transverse direction (12GPa). Transverse anisotropic behavior of cortical bone is also evident in greater ultimate strength in longitudinal direction (193MPa) than transverse direction (133MPa). Internal and external forces that are offset from fracture site generate Bending moments, further the Lever arm is Offset from fracture, the Larger will be bending moment around fracture. Short fixation construct with a small Lever arm require a proportionally greater load to counterbalance the destabilizing forces than construct with a Long lever arm.

Young's modulus of elasticity of bone(E) represents deformation in response to loading within LINEAR or Elastic working.

Material	Compression stress	Ultimate stress
SS	200GPa	900 GPa
Titanium	110 GPa	860 GPa

Materials like stainless steel (SS) and Titanium have same properties regardless of direction of loading and their strength is described by SINGLE E-modulus of elasticity value.

YIELD strength of bone is when permanent change begins in itself and Ultimate strength is when bone breaks. Complete elastic reversal of bone occurs if load is removed. Cortical bone is having 4 times less strength than stainless steel (SS). If repetitive loading below ultimate strength continues then it will lead to Micro cracks causing fatigue failure (important in femur Non-union).

A fractured bone should be bio mechanically fixed i.e. Biology (less invasive and promotes environment for healing) and mechanically (sufficient strength, durability and early mobilization).

In a Bio mechanically sound fixation construct, there is a race between bone healing and construct failure and both are mutually exclusive. An applied splint provides relative stability leading to natural bone healing and callous formation. However, if there is deficient mechanical stability will cause prolonged immobilization. In contrast compression plating is Invasive and provides absolute stability which suppresses natural bone healing.

A diaphyseal bone resembles principle structure of hollow cylinder. As individual ages, diameter of femoral diaphysis increases and thickness of cortex decreases. According to principal of second moment of Inertia:-the bending stiffness of Tubular bone increases as outer diameter increases even as cortical thickness and material property of bone decrease. Bone mineral density plays an important part in determining the structural properties of bone. This aggregate increase in

strength realized by increasing the diameter of shaft is enough to protect elderly from Osteoporotic diaphyseal femoral fractures. In contrast, Trabecular thinning in vertebrae can't be compensated by structural changes of vertebrae body resulting increased risk of fractures

The material property of single Trabecular bone spicule and similar sized cortical bone are comparable, with stiffness and strength measurements differing by less than 10-15%. The structural stiffness and strength of Trabecular bone is defined by its POROSITY which depends upon on individual and anatomic location, ranges from 30-90%. Clinically, density of Trabecular bone is measured radiographic densitometer and can vary by One order of magnitude, from about 0.1 to 1.0 g/cc.

The corresponding stiffness and strength of Trabecular bone vary upon to three orders of magnitude, means that Even a small decrease in density can significantly weaken structural properties of Trabecular bone.

BIOMECHANICS OF FRACTURES:

Fracture of a bone results when loads differ in both magnitude and direction than the loads normally experienced during locomotion or activities of daily living. Severity of fracture depends on magnitude of load, as tensile fracture requires lowest load, while compression requires greatest load. Transverse fracture occurs by loading bone in tension. Bone is strong in compression and weak in shear. The surrounding tissues also affects fracture pattern and severity by absorbing energy and changing the loading direction.

1) Types of fractures:

A) OBLIQUE FRACTURES: These are oriented diagonally to Long axis of bone and occurs due to three loading patterns: -

- Pure Axial compression- Oblique fracture because bone is strong in compression and weak in shear and axial compression bone fails in along plane of maximum shear i.e 45 deg like Tibial planfold

- Bending and axial forces causing Short oblique fractures
- Torsion and bending - also produced short oblique due to Bending component but due to torsional force dominant produced long oblique rather than short oblique

B) TRANSVERSE FRACTURES: Which are perpendicular to Long axis of bone. Bone is weak in tension and transverse fractures are typically LOW energy relative to complex fractures.

- Caused by Loading bone in tension
- If there is Internal loading, it will cause- avulsion fractures

May also occur due to Low energy Bending force in absence of compression force.

C) BUTTERFLY FRACTURES: these are produced by combined bending and compression forces:

- The Bending force creates a tension at far side of neutral axis and compression at nearside of neutral axis.
- The fracture begins as a Transverse tension on far cortex and compression in near cortex results in shear with typical 45 deg oblique fracture lines.
- The combination of oblique compression fracture line joining with Transverse tension fracture line produces butterfly Fragment.

D) SPIRAL FRACTURE: occurs as a result of Torsional force:

- The Fracture has long sharp ends with Vertical component and the resulting orientation depends on Direction of Torsional load.
- IF upper fragment is fixed and Clockwise Torsional load is applied to Lower segment then, resulting fracture will be Right Handed in direction.

E) COMMINUTED FRACTURE:

- High energy fracture with multiple fragments and having worst prognosis.
- The mechanical energy absorbed in producing a fracture is directly correlates to amount of Inter fragmentary surface area created during impact loading.

2) Load Transfer:

Joint motion is controlled by forces and moments acting across joints. Force represented by Vectors depicting Magnitude and Line of action of force. Joint forces and resulting moments are induced by External loads (held in hand) and Internal loads (muscle forces). Internal forces tend to be far greater than external forces due to small lever arm by which muscles act it and balance the external moments around joint. If a force of F is acting at distance of d from joint then it will create a Rotational Moment around joint. $M = F \cdot d$. A Fracture fixation construct must resist both these deforming loads to maintain alignment as fracture consolidates.

Internal and external forces that are offset from fracture site generate Bending moments. The further the Lever arm is offset from fracture, the Larger will be bending moment around fracture. Therefore, construct with a small lever arm or working length results in high loads at bone implant interface and increase the Risk of implant or fixation failure.

Conversely a Long Implant with a Long working Length has greater mechanical advantage than a shorter plate and will induce smaller stress riser at Implant- bone interface.