(Hierarchical) Bone Structure
Basic Multicellular Unit (BMU)
<table>
<thead>
<tr>
<th>Type of force</th>
<th>Description of the force</th>
<th>Fracture characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tapping force</td>
<td>Small force acting on a small area</td>
<td>Nightstick fracture of ulna</td>
</tr>
<tr>
<td>Crushing force</td>
<td>High force acting on a large area</td>
<td>Crush fracture with comminution and severe soft tissue injury</td>
</tr>
<tr>
<td>Penetrating force</td>
<td>High force acting on a small area</td>
<td>“Open” fracture and minimal to moderate soft tissue disruption</td>
</tr>
<tr>
<td>Penetrating-explosive force</td>
<td>High force acting on a small area at a high or extremely high</td>
<td>“Open” fracture with severe soft tissue disruption and devitalized bone fragments</td>
</tr>
<tr>
<td></td>
<td>loading rate</td>
<td></td>
</tr>
<tr>
<td>Fracture type</td>
<td>Example fractures</td>
<td>Injury force</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Transverse</td>
<td>Some transverse patella fractures</td>
<td>Tension force</td>
</tr>
<tr>
<td>Oblique</td>
<td>Oblique or Y-fractures of the distal femur/humerus</td>
<td>Axial compressive force</td>
</tr>
<tr>
<td>Spiral</td>
<td>Spiral fracture of the tibia/humerus with intermittent longitudinal crack lines</td>
<td>Torsional force</td>
</tr>
<tr>
<td>Transverse</td>
<td>Transverse shaft fracture of the humerus/tibia, with small butterfly fragment</td>
<td>Bending force</td>
</tr>
<tr>
<td>Transverse oblique</td>
<td>Transverse shaft fractures of the tibia with large butterfly fragment</td>
<td>Axial compression and bending</td>
</tr>
</tbody>
</table>

Fracture Morphology (Mechanistic)
Fracture Morphology
Flexure vs. Torsional Load Uptake
Fracture Healing Parameters
Callus Maturation
<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I</td>
<td>The bone fails through the original fracture site with a low stiffness, rubbery pattern.</td>
</tr>
<tr>
<td>Stage II</td>
<td>The bone fails through the original fracture site with a high stiffness, hard tissue pattern.</td>
</tr>
<tr>
<td>Stage III</td>
<td>The bone fails partially through the original fracture site and partially through the previously intact bone with a high stiffness, hard tissue pattern.</td>
</tr>
<tr>
<td>Stage IV</td>
<td>The site of failure is not related to the original fracture site and occurs with a high stiffness pattern.</td>
</tr>
</tbody>
</table>

Classic Four Stages of Fracture Healing
Periosteal vs. Endosteal Callus
Interfragmentary Strain Theory
External Fixation
Interfragmentary Strain

(d>d'>d" Gap motion decreases due to tissue transformation)
Strain in Large Fracture Gaps

$d > G$
$\varepsilon = \frac{d}{G} > 100\%$
No tissue formation

$G' \gg G$
$\varepsilon = \frac{d}{G'} \leq 100\%$
Fracture healing and tissue formation will begin
$G' =$ new gap with after bone resorption

Area of bone resorption
Healing with Stiff External Fixation
Primary vs. Secondary Healing
Secondary Contact Healing
Loading Modes

Axial stiffness = $F/\Delta = (AE)$

Bending stiffness = $F/\Delta, F/\theta = (EI)$
(Flexural modulus)

Torsional stiffness = $T/\theta = (GJ)$
Fixation Mode Rigidities
External Fixator Arrangements
External Fixator Arrangements
Frame Stiffness Comparisons
Increased pin diameter
Increased pin number
Decreased side-bar separation
Decreased pin separation
Increased pin group separation

Rigidity-Increasing Parameters
Pin Tract Biomechanics

Pin geometry and thread design
Bone thread preparation
Pin insertion technique
Pin-bone stress
Plate positioning: Plate should be applied such that acting forces tend to close the fracture site (applying the plate to the convex or tensile surface of the bone).

Interfragmentary compression: Fixation should produce a sufficiently high amount of compression to increase rigidity and to counteract tension and shear forces under functional load.

Prebending of plate: Use of prebent plates results in more uniform compressive contact stresses across the fracture site, initially to prevent opposite cortex opening.

Plate screws: To allow screws engaging the full cortex. It is important to use screws close to the fracture site to reduce unsupported length.

Lag screw compression fixation: A screw may also be used to compress fracture surfaces as a "lag screw." Lag screw compression fixation, protected by a neutralization plate, reduces fracture gap displacement and thus promotes primary or osteonal bone fracture healing.
Intramedullary Nails
Subtrochanteric Fracture Fixation
Comparative Fixation Stiffness
Response to Nail vs. Plate
Response to Ex-Fix vs. Plate
Response to Number of Pins
Effects of Static Compression
Unilateral vs. Bilateral Frames
Effects of Dynamization
Evaluation of fracture mechanism and trauma energy by studying the injury history and the radiographic appearance of the fracture.
Attention to possible local stress riser that may predispose the bone or the device to fracture.
Recognition of possible systemic factors or underlying diseases that could affect the quality (material properties) of the fractured long bone.
Selection of the fixation method to achieve the preferred fracture stability and the associated bone healing mechanism.
Following the established operative technique according to the biomechanical principles upon which the fixation device was designed.
Staged hardware removal and loading protection in order to allow bone defect repair and remodeling.

Biomechanical Considerations in Fracture Treatment
Normal vs. Shear Stress

Normal stress:
\[ \sigma = \frac{F}{A} \]

Shear stress:
\[ \tau = \frac{S}{A} \]
Stress-Strain Curve