Bone Healing

What is Bone?

- A mineralized organic matrix
- Mostly Calcium Phosphate
  - Calcium hydroxyapatite
- Osteoblasts – Make osteoid - which then mineralizes to bone
- Osteoclasts – Resorb bone
- Osteocytes – Control local homeostasis
- High compressive strength
- Low tensile and shear strength

Lamellar Bone - Haversian systems
A network of lacunae

What is Bone?

How does bone heal?
Bone Healing

• From a biologic perspective
• From a mechanical perspective
• From philosophical perspective

Bone Healing

INFLAMMATION
• Hematoma formation
  – Resorbing of necrotic tissue
  – Fibroblasts
  – Chondrocytes
  – Angiogenesis

REPAIR
• Soft Callus (3 weeks post fracture)
  • Intramembranous ossification begins
  • Replacement of the granulation tissue and cartilage
  • Osteoblasts from mesenchymal cells
  • Hard Callus (3-4 months)
  • Fracture now bridged by soft callus
  • Now endochondral ossification pred
  – woven unorganized bone

REMODELING (MONTHS-YEARS)
• The woven bone replaced by lamellar bone
• Resorption of unneeded callus
• Maturation along lines of stress
  – Wolff's law
• Restoration of medullary canal

But the biology is influenced by the mechanics of the fracture environment

Bone Healing

From a mechanical perspective:

• Absolute Stability
  – Direct Healing
  – Bone grows across the fracture site
  – No Callus

• Relative Stability
  – Indirect Healing
  – Callus forms and turns to bone in a series of biological steps
Primary Bone Healing

• “CUTTING CONES”
• Osteoclasts lead the way, followed by osteoblasts and blood vessels
• Requires anatomic reduction and rigid fixation
• ABSOLUTE STABILITY
• Lamellar bone grows directly across the fracture site

Secondary Bone Healing

The formation and maturation of Callus

• Under conditions of RELATIVE STABILITY
• With or without fixation

Bone Healing

• The pathway of which form of healing predominates is due to Stability combined with the biology.

Strain theory
Bone Healing

**STRAIN**
- Stability determines the strain at the fracture site(s)
- Strain defined as:
  - The change in fracture gap divided by the fracture gap
  - $\Delta L/L$

Too much strain is bad.....

Strain Theory of Healing

- Bridging will not occur when strain too high across a single fracture gap (too much motion)
- Body responds by forming more soft callus to try and decrease the strain

Strain Theory of Healing

- As described by Perren
- Interfragmentary movement stimulates soft callus
- As soft callus increases, less motion occurs
  - Less Strain!
- Allows bridging and transition from soft to hard callus
- This is not effective when the fracture gap has been considerably narrowed so that most of the interfragmentary movement occurs at the single gap, producing a (too) high-strain environment

Strain Theory of Healing

- Multi-fragmentary fractures can “spread out” the motion across multiple fracture sites
- Less strain at each individual fracture gap
- The soft callus bridges and matures

Failure of Healing

- Too much Strain:
  - Instability too great due to fracture gap or fixation characteristics
  - Hypertrophic nonunion occurs
  - Treat by increasing stability to decrease strain
  - The callus will bridge and mature

Failure of Healing

- Too Little Strain:
  - A large gap or too stiff fixation
  - No or little callus will appear
  - Atrophic nonunion
  - Treat by decreasing stability to allow callus
  - OR -Eliminate the fracture gap and allow minimal strain environment to allow primary healing
Strain Theory of Healing

- We will apply these concepts in case examples to reinforce them

Bone Healing – to review so far...

<table>
<thead>
<tr>
<th>Absolute Stability</th>
<th>Relative Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomic reduction</td>
<td>Micro-motion occurs at fracture</td>
</tr>
<tr>
<td>Rigid fixation</td>
<td>Strain is higher</td>
</tr>
<tr>
<td>No Motion at fracture</td>
<td>Secondary bone healing</td>
</tr>
<tr>
<td>Strain very low or zero</td>
<td>Callus is formed</td>
</tr>
<tr>
<td>Primary bone healing</td>
<td>No gap</td>
</tr>
<tr>
<td></td>
<td>No callus</td>
</tr>
</tbody>
</table>

Bone Healing

From a philosophical perspective:

- It is the interplay of biology and stability
- We can influence both, but not entirely control these factors
  - The injury – soft tissue, pattern
  - The patient – systemic and local biology

Bone Healing

From a philosophical perspective

Biology + Mechanical Environment = Bone Healing

Optimal Biology + Mechanical Environment = Bone Healing
Bone Healing
From a philosophical perspective

Case Examples
An isolated injury in an adult, bicycle crash
Treatment options?

Case Examples
Healing via callus formation – secondary bone healing

Case Examples
An adult, s/p MVC. Ipsilateral femur fracture. Has comminution and more displacement...
Treatment options and predict type of bone healing

Case Examples
What is technique of this fixation – the goal regarding type of healing?

Case Examples
No callus formation – primary bone healing
Absolute stability was achieved with this fixation technique
Case Examples

What is standard of care for this isolated, closed femur fracture? What do you predict healing will be?

The IM device allows micro-motion at the fracture
Relative stability
Healing by callus formation

Another femur fracture:
• 15 years old
• Treatment options?

What fixation strategy was used? What type of healing do you anticipate?

Dynamic Compression to achieve absolute stability
Primary bone healing
No callus formation
Case Examples

Another example of absolute stability by reduction and internal fixation with compression.
No Callus formation – Primary bone healing

Case Examples

- Multi-fragmentary humerus fracture, isolated injury. No nerve palsy
- Treatment options and type of healing?

Case Examples

A technique of relative stability – bridge plate. Allows micromotion and callus formation – secondary bone healing

Case Examples

Treated with SHS for neck and a relatively short retrograde nail – just past fracture. Was painful, hardware failing, and not united at 5 months. How does the strain theory apply to the problem? Too much or too little? How to correct?
Case Examples

• There was too much strain concentrated at the simple fracture gap
• Revision to longer and bigger reamed IM nail.
• Added stability and stimulated local biology
• Bridging completed and callus matured

Case Examples

• Treatment options?

Case Examples

What is goal of this technique of fixation?
What type of healing do you expect?

Case Examples

• 4 months
• IT fx healed
• Shaft fx without callus despite an attempt at bridging fixation
• Why not?
• What to do?

In summary - Bone Healing

• Primary or Secondary: Either is “good”
• The goal is to use your skill to create the proper environment for either type of healing
• ABSOLUTE STABILITY - SIMPLE PATTERNS (no Strain)
• RELATIVE STABILITY - COMMINUTED FRACTURES (some strain)
• Recreate anatomic length, alignment, and rotation of the limb
• Allow early motion and rehabilitation
• The ultimate goal of restoration of function

The construct was too stiff, not enough motion and likely compromised biology
Converted to a technique that more effectively created relative stability
Higher Strain over the comminuted area
Callus formed and matured – SECONDARY BONE HEALING