Pathophysiology of fracture healing

- Bone anatomy and biomechanics
- Fracture patterns
- Bone healing and blood supply
- Influence of implants
What is the structure of bone?
Bone structure

Four levels:

- Chemical – molecular
- Electron microscope – lamellae
- Microscopic – Haversian systems
- Macroscopic – compact and cancellous
Microscopy

Cortical bone
- also “compact” and “lamellar” bone

Cancellous bone
- spongy bone, woven bone.
Microscopy

Haversian systems:
10 Lamellae interleaved with osteocytes in lacunae
10 Central canal with Blood vessel and lymphatics
Bone dynamics

- Osteoblasts: mesenchymal, specialised adjacent to periosteum and endosteal areas
- Osteoclasts: multinucleated giant cells, from bone marrow
- Osteocytes: derived from osteoblasts, interlacunal connections, and entombed by their neighbours
Blood supply

- Blood vessels:
  - Nutrient artery
- Endosteal
- Periosteal
- Venous drainage
Bone Strength

Compression

Shear/tension

250 kg
How do bones fracture?
DESCRIBING THE FRACTURE

Mechanism of injury

- Traumatic
- Pathological
- Stress
- Pathological sieve
DESCRIBING THE FRACTURE

- Anatomical site (bone and location in bone)

- Configuration Displacement
  - three planes of angulation
  - translation
  - shortening

- Articular involvement/epiphyseal injuries
  - fracture involving joint
  - dislocation
  - ligamentous avulsion

- Soft tissue injury
MINIMALLY DISPLACED DISTAL RADIUS FRACTURE
MULTIFRAGMENTARY PROXIMAL-THIRD FEMORAL FRACTURE WITH SIGNIFICANT DISPLACEMENT

OPEN?
N/V INJURY?
Fracture mechanics

Spiral: Torsion Low energy
Fracture mechanics

Transverse: bending load

[Diagram of bone fractures with arrows indicating tension and compression forces.]
Fracture mechanics

Oblique or transverse with butterfly: Compression + bend
Fracture mechanics

Comminuted:

High energy: combination
- implosion
- compression,
- Bending
- Torsion
How do fractures heal?
Fracture healing

Why do fractures unite?

Because the bone is broken!
Healing cascade: indirect healing

**Inflammation 0 – 5 days**
- Haematoma
- Necrotic material
- Phagocytosis

**Repair: 5 – 42 days**
- Granulation tissue
- Acid environment
- Periosteum – osteogenic cells
- Cortical osteoclasis

**Remodelling**
- years
Cytokine release

- Inflammatory mediators
- Fibroblastic growth factor stimulates angiogenesis
- TGF β initiates chondroblast/osteoblast migration
- TGF β stimulates enchondral ossification
Healing cascade

Late repair:

1. Fibrous tissue replaced by cartilage
2. Endochondral ossification
3. Periosteal healing » membranous ossification
Healing cascade

Regeneration & remodelling

- Replacement of callus (woven bone with lamellar bone)
- Continued osteoclasia
- Mechanical strain

(Wolff 1892)
What is the difference between direct and indirect bone healing?
Indirect healing – healing by Callus

- Unstable
- Callus stabilises #
- Direct healing between cortices
Robert Danis 1880 - 1962

- Plaque co-aptateur, 1949
- Primary (direct) bone union “soudure autogène”
- No callus
Direct bone healing – the response to rigid fixation

- Temporary acceleration of Haversian remodelling
- Only occurs in absolute stability of the fracture
- Does not involve callus formation
- Requires good blood supply
Direct bone healing

Appositional healing

- No gap
- Osteons traverse #

Gap healing

- Accurate apposition impossible
- Vessels/mesenchymal cells
- Lamellar bone
Effect of implants on bone biology

**Absolute stability:**

- Plates
- Early reconstitution of macrocirculation
- Plate footprint
- Periosteal stripping
- Titanium vv SS.
Effect of implants on bone biology

Relative stability:
- IM nails
- Reaming & blood supply
- Periosteal reversal
- Thermal necrosis
Effect of implants on bone biology

Relative stability:

External fixation

- Pin configuration & rigidity of construct
- Bone and thermal necrosis
- Infection
Cartilage and Bone

- Cartilage -- function, types, location
- Bone Tissue -- structure, types
- Long Bone Structure and Development
- Most common bone problems
  - Fractures
  - Osteoporosis
What is cartilage?

- Skeletal tissue—maintains certain shape and form
- Very resilient (bouncy or rubbery), mostly water
- Grows fast—forms embryonic skeleton
Kinds of cartilage

- **Hyaline cartilage**—most common, found in joints
- **Elastic cartilage**—epiglottis, ear
- **Fibrocartilage**—annular fibrosis of intervertebral disk, menisci of knee
Bones provide:
- Support and movement (limbs, axial skeleton)
- Protection (skull bones)
- Mineral storage
- Blood cell development (long bone marrow)

Bone is made up of:
- 35% collagen, ground substance and cells
- 65% calcium (hydroxyapatite)
Bone is alive!! Bone cell types:

- **Osteoblasts**: Make and deposit components of bone extracellular matrix.
- **Osteoclasts**: Degrade and resorb bone for remodeling.
- **Osteocytes**: “watcher cells” Sit in bone and monitor its current status.
Types of bony tissue

- **Compact Bone**
  - Dense tissue at surface of bones
  - Haversian canals
  - Osteocytes in lacunae
  - Highly vascularized
  - Fig. 6.6, p. 138
Types of bony tissue

- Trabecular (“spongy”) bone
  - Trabeculae (oriented to give mechanical strength)
  - Interior of long bones, skull bones
  - Epiphyses of long bones
  - Intramembranous ossification (osteoblasts lay down bone around blood vessels in connective tissues of dermis (after 8 weeks of development)
Structure of a long bone

- Diaphysis (shaft)
- Epiphysis
  - Proximal
  - Distal
- Compact bone
- Spongy bone
- Periosteum
- Medullary cavity
- Articular/hyaline cartilage
- Epyphyseal (growth) plates

Fig. 6.3, p. 135
Bone Tissue within a Bone
Why do bones need to “remodel?”

**Growth**
- Bone grows in length because:

1. Cartilage grows here
2. Cartilage replaced by bone here
3. Cartilage grows here
4. Cartilage replaced by bone here

**Remodeling**
- Growing shaft is remodeled by:

1. Bone resorbed here
2. Bone added by appositional growth here
3. Bone resorbed here

Articular cartilage
Epiphyseal plate
Endochondral Ossification

1. Cartilage model

2. Bone collar forms in diaphysis (dense bone)
   - Cartilage chondrocytes in center of diaphysis die and cartilage disintegrates

3. Periosteal bud enters diaphysis
   - Makes spongy bone at ends of diaphysis (primary ossification center)

4. Epiphysis begins to ossify (secondary ossification center)

5. Hyaline cartilage remains only at
   - Epiphyseal surfaces (articular surfaces of joints)
   - Epiphyseal growth plates between diaphysis and epiphysis (primary and secondary ossification centers on either side)

Fig. 6.9, p. 141
Formation of bone collar around hyaline cartilage model.

Cavitation of the hyaline cartilage within the cartilage model.

Invasion of internal cavities by the periosteal bud and spongy bone formation.

Formation of the medullary cavity as ossification continues; appearance of secondary ossification centers in the epiphyses in preparation for stage 5.

Ossification of the epiphyses; when completed, hyaline cartilage remains only in the epiphyseal plates and articular cartilages.
Endochondral ossification centers—newly formed bone within cartilage shown is stained red.
Osteoclasts

- “Dig holes” with hydrochloric acid
- Degrades calcium
- Phagocytize collagen fibers and dead osteocytes

Osteoblasts

- Line tubes (Haversian canals) left by osteoclasts
- Lay down new bone in circular concentric lamellae
- Unique to warm-blooded animals---dinosaurs???
Bone Fractures

◆ Treatment is reduction
  ■ Closed--set in place by physical manipulation from outside body
  ■ Open--surgical placement of pins or screws

◆ Healing
  ■ Hematoma
  ■ Fibrocartilaginous callus
  ■ Bony callus
  ■ Remodeling by osteoclasts/osteoblasts

◆ Types of Fractures
Comminuted
Bone fragments into three or more pieces
Particularly common in the aged, whose bones are more brittle

Compression
Bone is crushed
Common in porous bones (i.e., osteoporotic bones) subjected to extreme trauma, as in a fall

Spiral
Ragged break occurs when excessive twisting forces are applied to a bone
Common sports fracture

Epiphyseal
Epiphysis separates from the diaphysis along the epiphyseal plate
Tends to occur where cartilage cells are dying and calcification of the matrix is occurring

Human Anatomy, Larry M. Frolich, Ph.D.
<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Description and Comments</th>
<th>Fracture Type</th>
<th>Description and Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depressed</td>
<td>Broken bone portion is pressed inward Typical of skull fracture</td>
<td>Greenstick</td>
<td>Bone breaks incompletely, much in the way a green twig breaks. Only one side of the shaft breaks; the other side bends Common in children, whose bones have relatively more organic matrix and are more flexible than those of adults</td>
</tr>
</tbody>
</table>
Fracture repair

1. Hematoma formation
2. Fibrocartilaginous callus formation
3. Bony callus formation
4. Bone remodeling

Hematoma
Internal callus (fibrous tissue and cartilage)
External callus
New blood vessels
Spongy bone trabeculae
Bony callus of spongy bone
Healed fracture

Copyright © 2004 Pearson Education, Inc., publishing as Benjamin Cummings.
Calcium regulation is negative feedback mechanism.
Osteoporosis

- Affects elderly, especially women
- Bone resorption proceeds faster than deposition
- Low estrogen levels implicated but estrogen replacement now considered risky
- Importance of calcium in diet???
- Leads to fractures
  - Compression fractures of vertebrae
  - Neck of femur
Bone grafts and artificial bone

- Widely used cutting-edge technologies
- Bone cells highly regenerative and move into any suitable matrix
  - Use bone pieces from same body—fibula
  - Use crushed bone from cadavers
  - Use bone substitutes—coral, synthetics—"nanotechnology"
- Applications are numerous
  - Jaw bone filler for dental work
  - Birth defects
  - Osteoporosis
  - Bone repair