

Bone anatomy and fracture healing

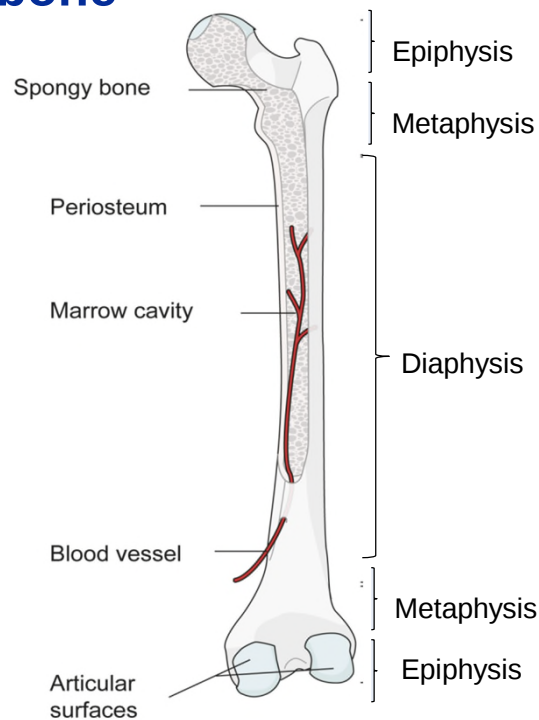
Klaus Dresing, Bianca Lumpp

Learning outcomes

At the end of this lecture you will be able to:

- Outline the anatomy of a bone
- Outline the phases of bone healing
- Explain direct and indirect fracture healing
- Identify factors that affect fracture healing

Anatomy of the bone



AO

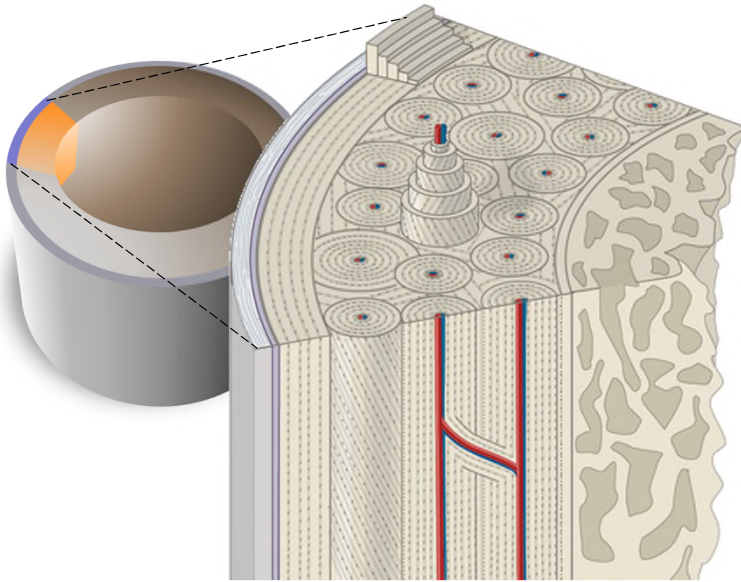
A long bone has a:

- Compact cortical shaft, or diaphysis, (comprising a cylinder of compact bone, its cavity (medulla) being filled with spongy cancellous bone containing bone marrow)
- The terminal portions of the bone have thinner cortices and consist largely of cancellous bone—these are the epiphyseal regions forming the articulating parts of the bone, and the metaphyseal areas which link the epiphyseal and diaphyseal parts of the bone

Diaphyseal bone is organized to create the best balance between weight and structural strength.

The nonarticular surface of the bone is covered by a tough membrane—the periosteum.

Anatomy of the bone

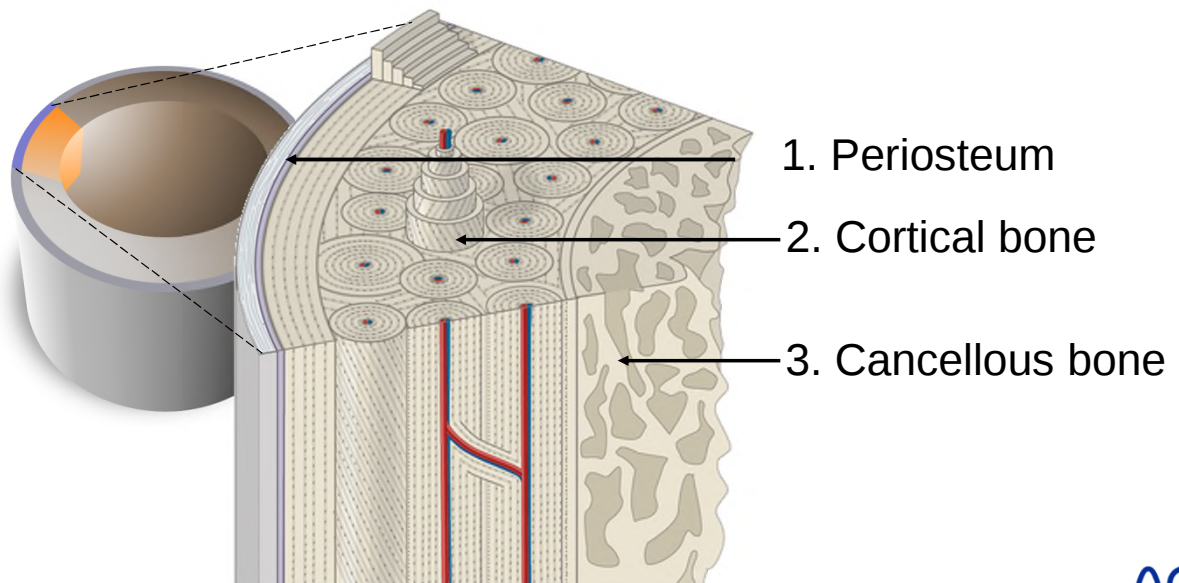


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The anatomy of the bone will now be considered from the point of view of:

continued on next slide

Anatomy of the bone

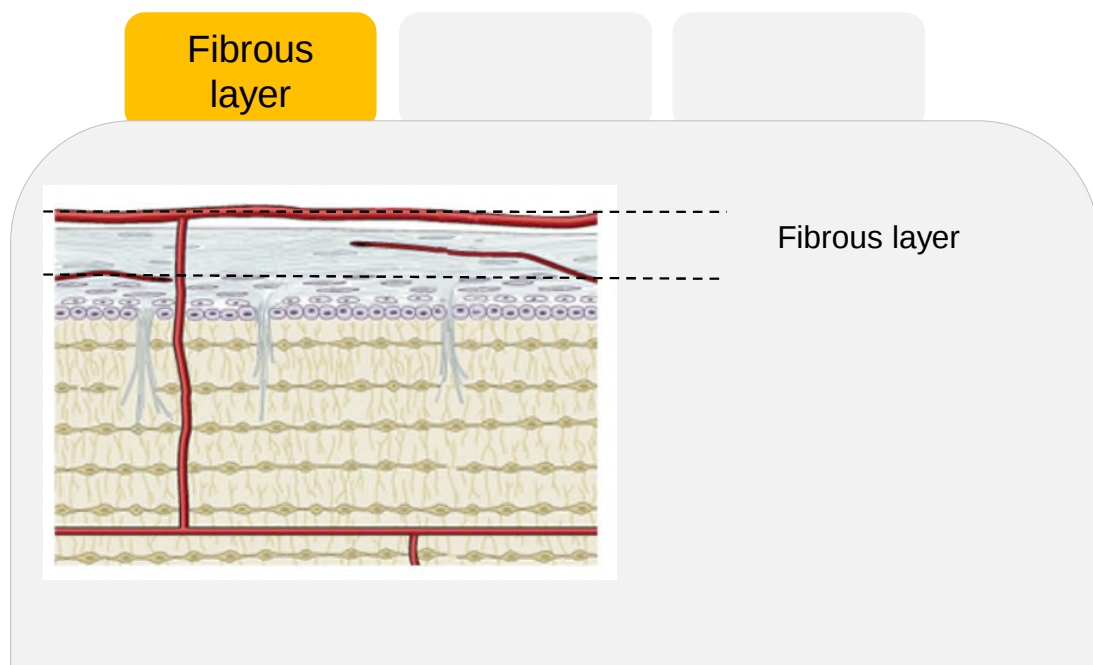


AO

The anatomy of the bone will now be considered from the point of view of:

1. The periosteum
2. The cortical bone
3. The cancellous bone

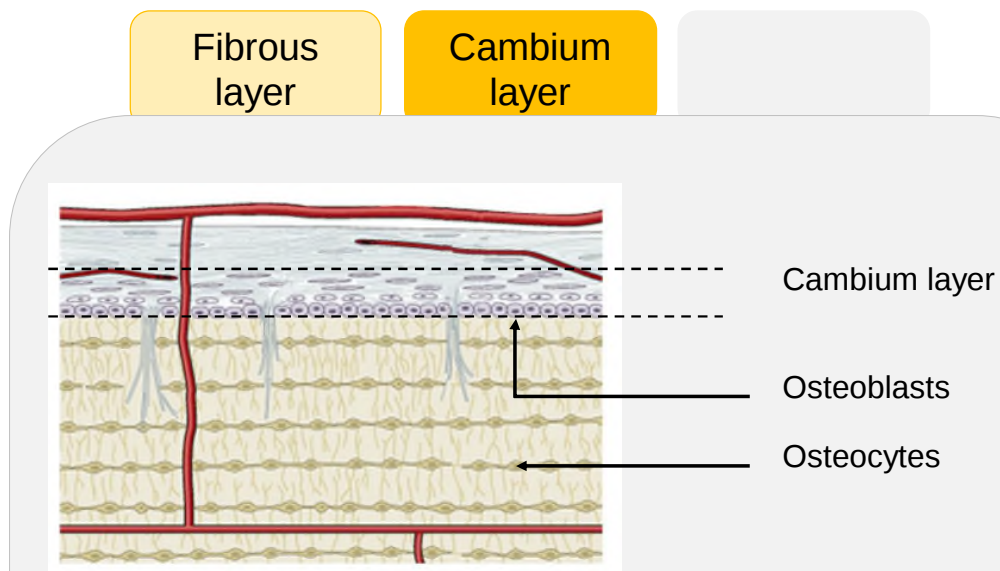
1. Periosteum



The periosteum envelopes the surfaces of diaphyseal bones, except where they are covered by articular cartilage and where tendons attach.

The periosteum comprises two layers: the fibrous layer...

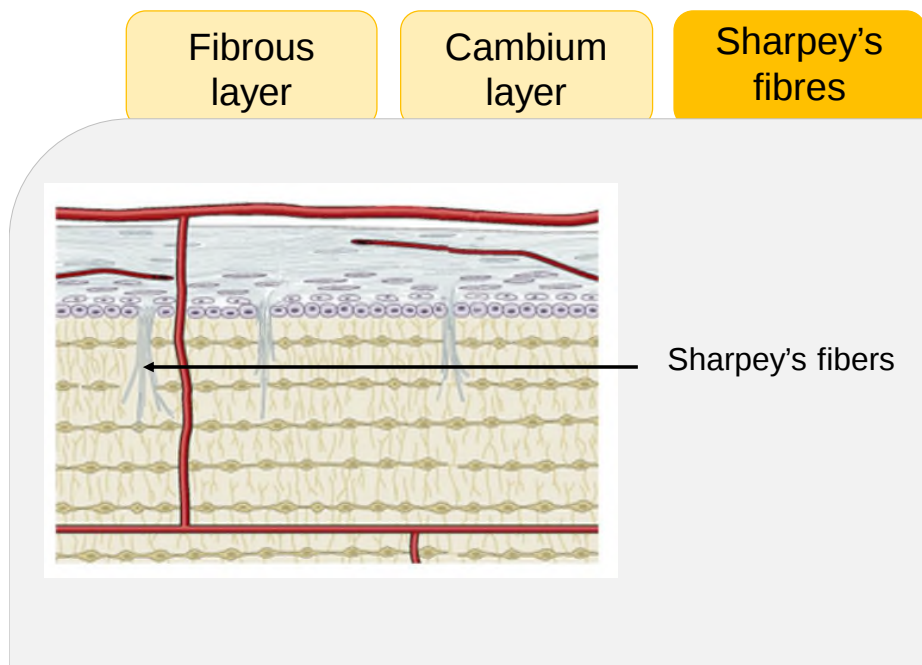
1. Periosteum



AO

...and the cambium layer...

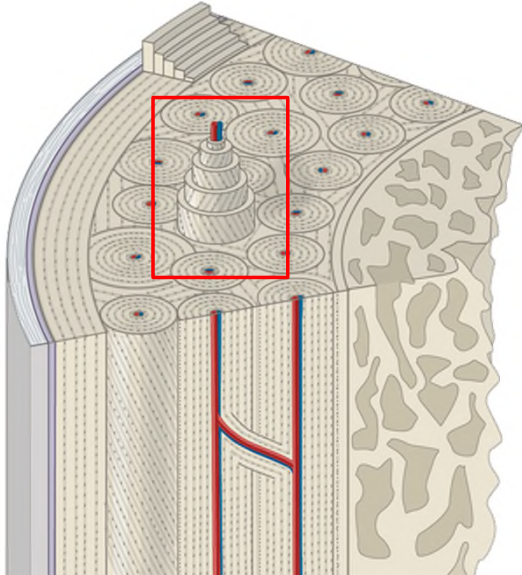
1. Periosteum



AO

...and is tightly bound to the bone by the Sharpey's fibers.

2. Cortical bone—osteon



- Osteon
 - Is a “unit” called haversian system
 - Has a central canal
 - Blood vessels
 - Concentric lamellae
 - Helical mode
 - Surrounded by connective tissues and interconnections
 - Runs longitudinal in the cortex

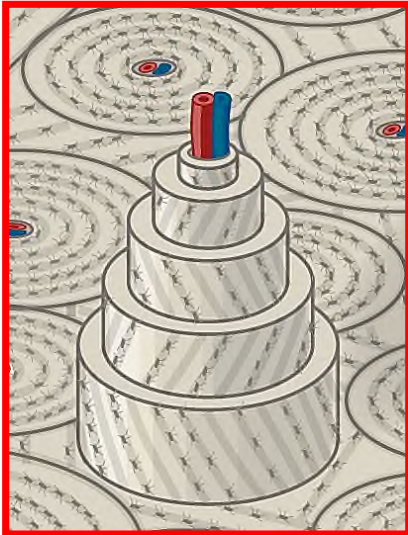
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An osteon is a basic construction unit also called haversian system. Each osteon has a central canal, containing blood vessels and a small amount of connective tissue with interconnecting channels surrounded by concentric layers of bone, the laminae.

The lamellae are orientated in a helical fashion, each twisting in the opposite direction to its neighbor.

Osteons (haversian systems) run longitudinally in the cortex. The osteons are bound to each other by cement lines. Each osteon is formed around a central vessel.

2. Cortical bone—osteon



- Osteon
 - Is a “unit” called haversian system
 - Has a central canal
 - Blood vessels
 - Concentric lamellae
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AO

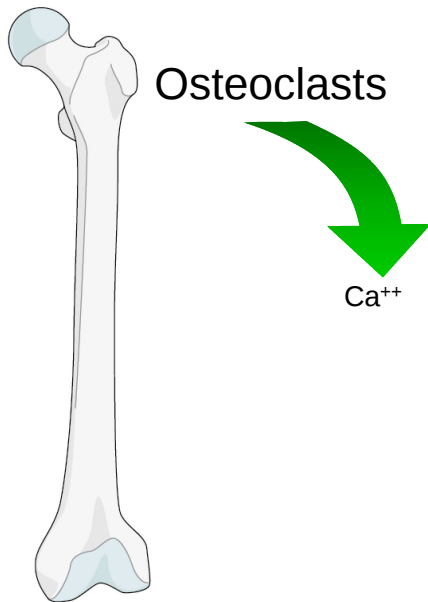
An osteon is a basic construction unit of cortical bone, also called a haversian system.

Each osteon has a central canal, containing blood vessels and a small amount of connective tissue, surrounded by concentric layers, or lamellae, of bone.

The lamellae are orientated in a helical fashion, each twisting in the opposite direction to its neighbor.

Osteons run longitudinally in the cortex. The osteons are bound to each other by cement lines.

Bone remodeling



- All bone is in a state of constant turnover
 - Bone is being removed
 - New bone laid down
 - At all times

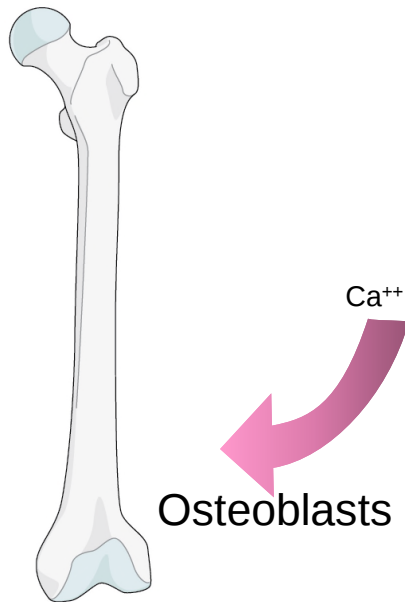
AO

Bone is constantly being removed and replaced. This process is called bone turnover and is an essential component of the body's calcium metabolism.

The removal of bone liberates calcium into the blood stream.

The cells that remove bone are called osteoclasts.

Bone remodeling



- All bone is in a state of constant turnover
 - Bone is being removed
 - New bone laid down
 - At all times

AO

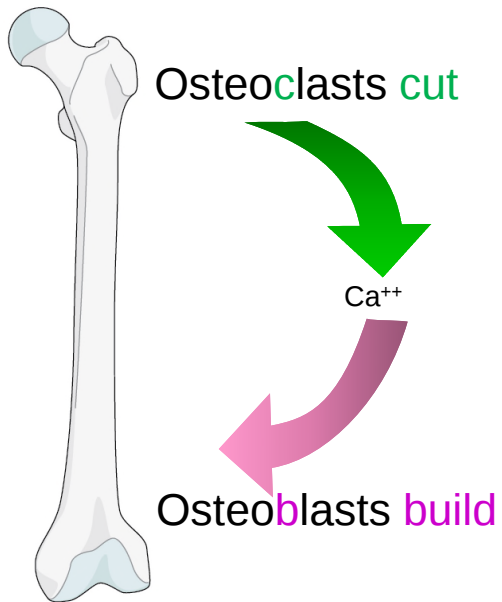
New bone is formed by specialized cells called osteoblasts.

Osteoblasts are derived from mesenchymal precursors, and have receptors for parathyroid hormone, prostaglandins, vitamin D, and certain cytokines. They synthesize bone matrix, and regulate its mineralization by capturing calcium ions from the blood stream.

They mature into osteocytes, which are the cells of mature bone tissue.

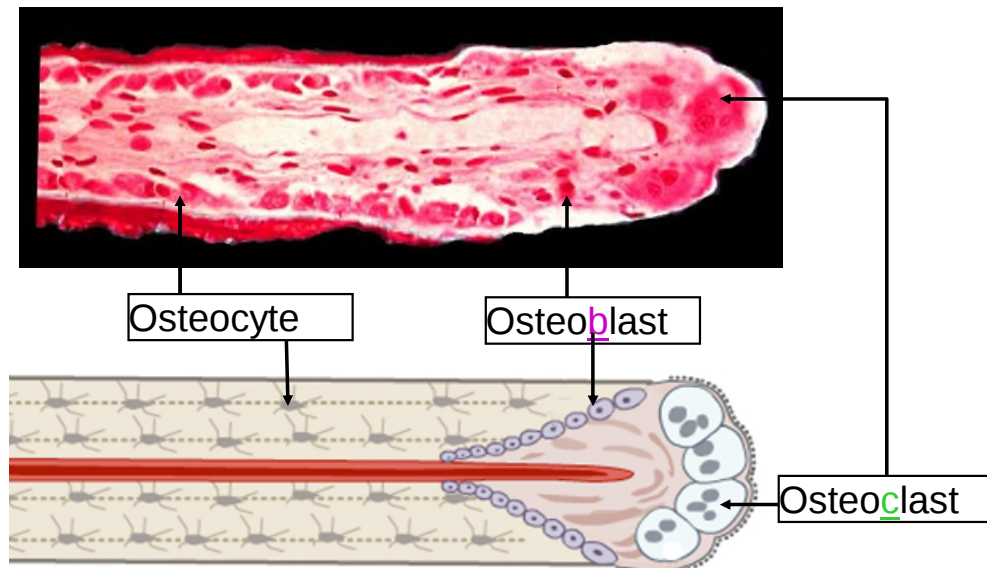
Osteocytes, surrounded by their secretions, each sit within a lacuna and its processes fill canaliculi. This equips them ideally to sense changes in strain distribution and magnitude, sending this information to bone cells at the surface. May influence modelling and remodeling. May sense microdamage.

Bone remodeling



- All bone is in a state of constant turnover
 - Bone is being removed
 - New bone laid down
 - At all times

Bone remodeling—cutter cone



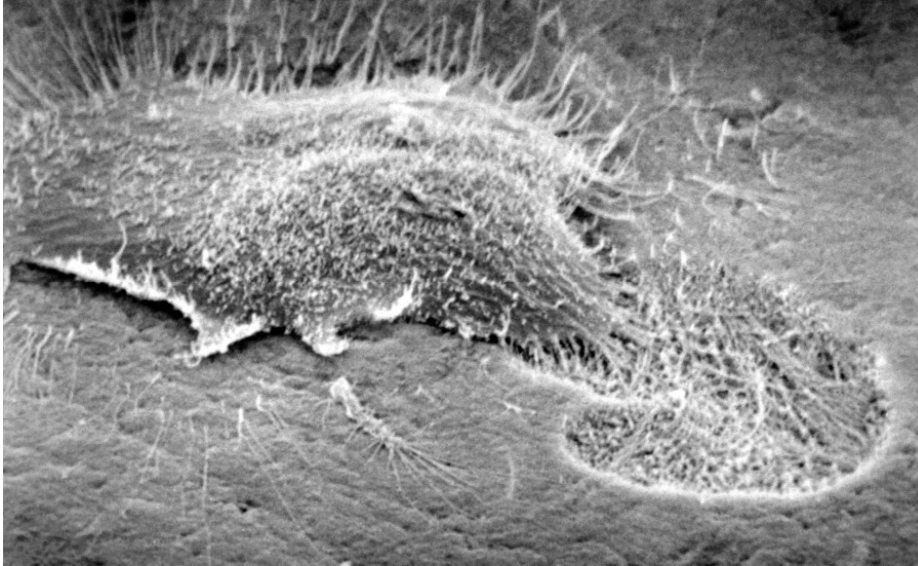
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The coordinated actions of the osteoclasts and osteoblasts takes place as cutter cones “drill” through old bone and lay down concentric lamellae of new bone to form new osteons.

This is considered in detail later on under direct bone healing.

Whether a cutter cone is taking part in the continuous process of bone turnover, or in bone healing, it functions similarly. Indeed, direct bone healing is accelerated bone remodeling.

Bone remodeling



Courtesy: Prof Tim Arnett, University College, London

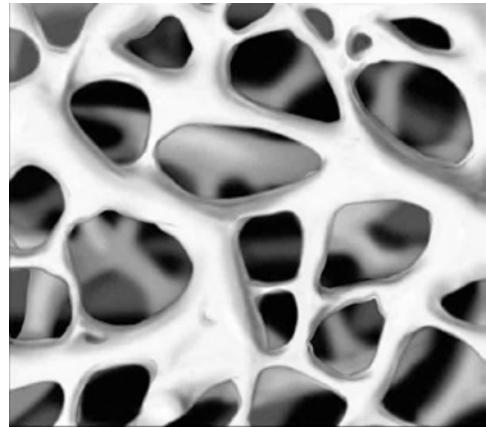
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Osteoclasts are located in scalloped concavities—Howship's lacunae. They are giant multinucleate cells, which seal to the bone surface. They release H^+ ions that maintain a pH of 3.5, so that bone mineral dissolves. They also secrete proteolytic enzymes to remove the proteins of the bone matrix.

This scanning electron microscope image shows an osteoclast dissolving a depression in the surface of bone.

3. Cancellous (trabecular) bone

- Less dense
- At the ends of a bone
- Remodeled by endosteum
- Heals faster than cortical bone (direct vascularization)



AO

Cancellous (trabecular/spongy) bone: 20% of its volume is bone mass, less dense, more elastic, and of higher porosity. It is the interior scaffolding of long bone ends and most short bones and helps maintain shape while resisting compressive forces.

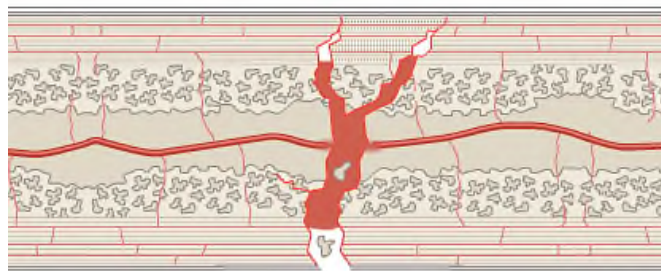
Cancellous bone: direct vascularization leads to fast healing.

Phases of bone healing (indirect)

- Inflammation
- Soft callus formation
- Hard callus formation
- Remodeling

1. Inflammation (1–7 days post fracture)

- The fracture results in:
 - Soft-tissue damage
 - Disruption of bone blood vessels
 - Separation of bony fragments



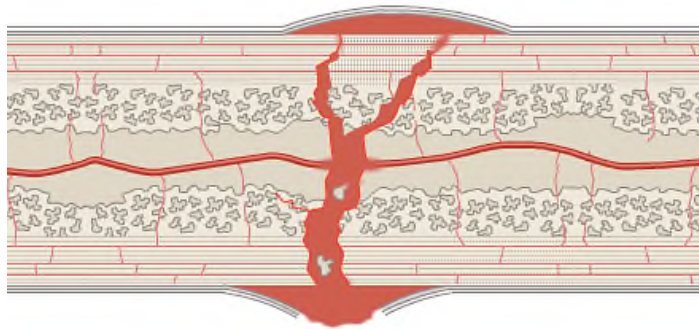
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The fracture results in:

- Soft-tissue damage
- Disruption of blood vessels in bone
- Separation of small bony fragments

1. Inflammation (1–7 days post fracture)

- Hematoma forms and the periosteum ruptures partly

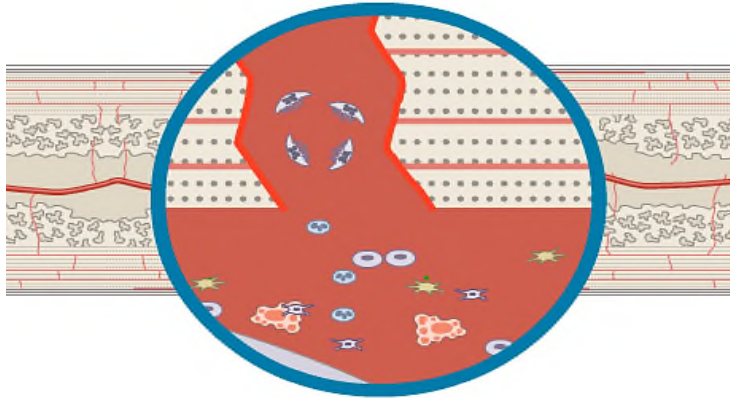


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Hematoma forms and the periosteum ruptures partly.

1. Inflammation (1–7 days post fracture)

- Cells migrate into fracture hematoma

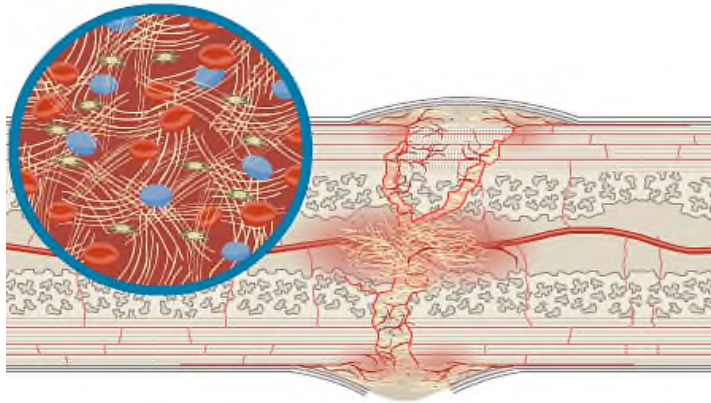


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Cells migrate into the fracture hematoma.

1. Inflammation (1–7 days post fracture)

- **Coagulation:**
 - Fibrin fibers stabilize the hematoma (hematoma callus)



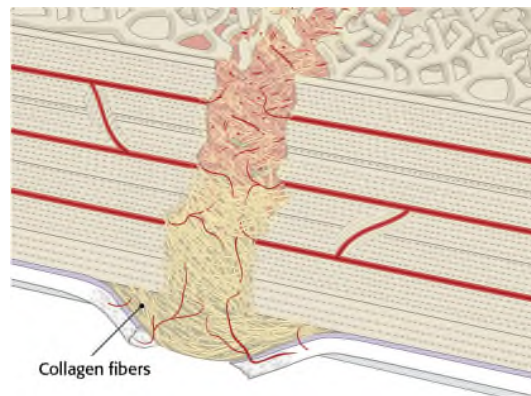
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Coagulation:

Fibrin fibers are formed and stabilize the hematoma (hematoma callus).

2. Soft callus formation (2–3 weeks post fracture)

- Phase 1:
 - New blood vessels invade the organizing hematoma
 - Decrease of pain and swelling



AO

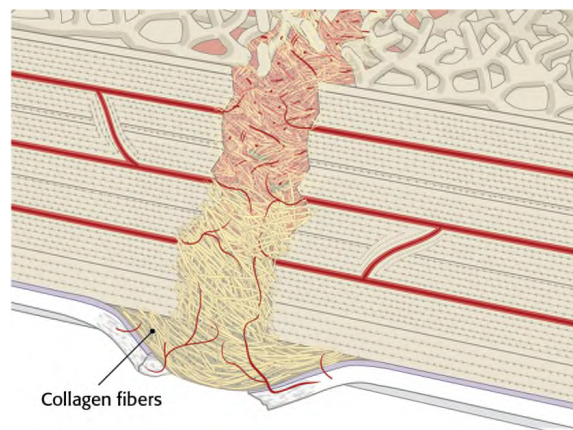
Once injury occurs, the natural process of bone healing begins with the creation of soft callus—a cascade of cellular differentiation occurs .

Phase 1:

- New blood vessels invade the organizing hematoma
- Decrease of pain and swelling

2. Soft callus formation (2–3 weeks post fracture)

- Phase 2:
 - Fibroblasts, derived from periosteum, invade and colonize the hematoma

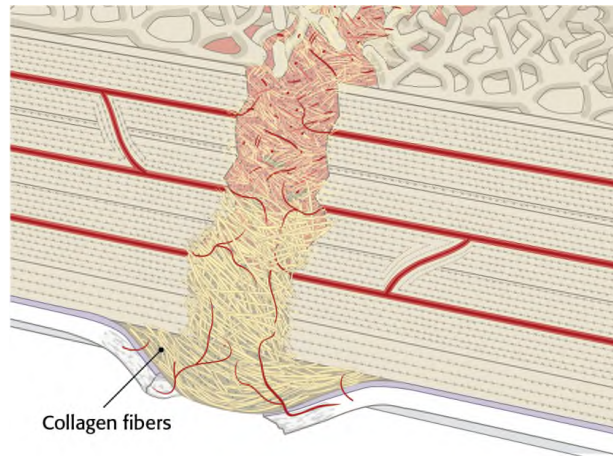


Phase 2:

- Fibroblasts, derived from periosteum, invade and colonize the hematoma.

2. Soft callus formation (2–3 weeks post fracture)

- Phase 3:
 - Fibroblasts produce collagen fibers (granulation tissue)



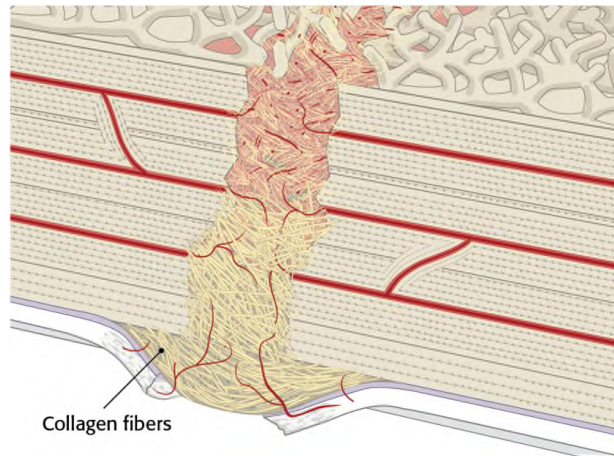
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Phase 3

- Fibroblasts produce collagen fibers (granulation tissue).

2. Soft callus formation (2–3 weeks post fracture)

- Phase 4:
 - Collagen fibers loosely linked to bone fragments



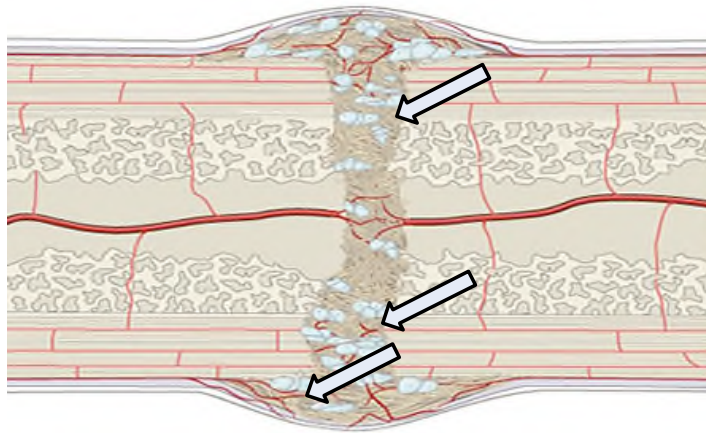
AO

Phase 4:

- Collagen fibers are loosely linked to the bone fragments.

2. Soft callus formation (2–3 weeks post fracture)

- Phase 5:
 - Cells of granulation tissue gradually differentiate to form fibrous tissue and subsequently fibrocartilage (replacing hematoma)



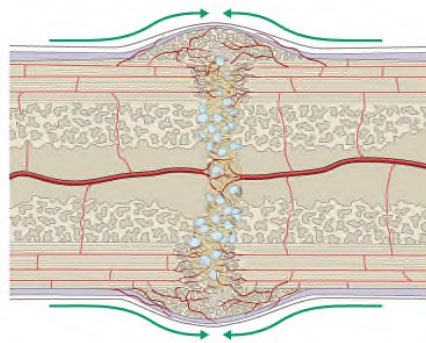
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Phase 5:

- The cells of the granulation tissue gradually differentiate to form fibrous tissue and subsequently fibrocartilage (replacing hematoma).

3. Hard callus formation (3–4/12 post fracture)

- Phases:
 - Soft callus lining of the fracture ends
 - Hard callus stage starts from peripheries towards center
 - Lasts until the fragments are firmly united by new bone and there is no more interfragmentary movement

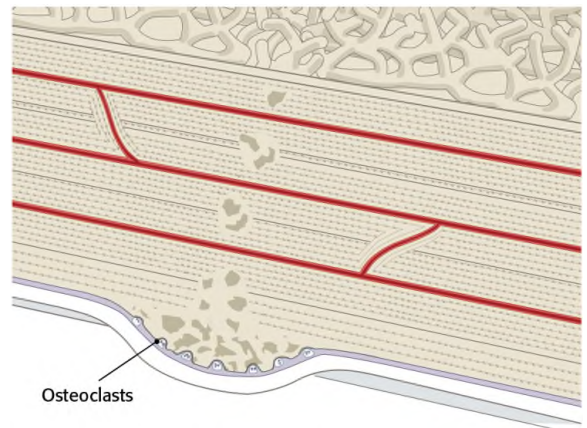


AO

Enchondral ossification converts the soft callus to woven bone starting at the periphery and moving towards the center, further stiffening the healing tissue. This continues until there is no more interfragmentary movement.

3. Hard callus formation (3–4/12 post fracture)

- Begins
 - Once interfragmentary motion stops
- Influenced by
 - Traction
 - Compression
- Occurs
 - By osteonal activity

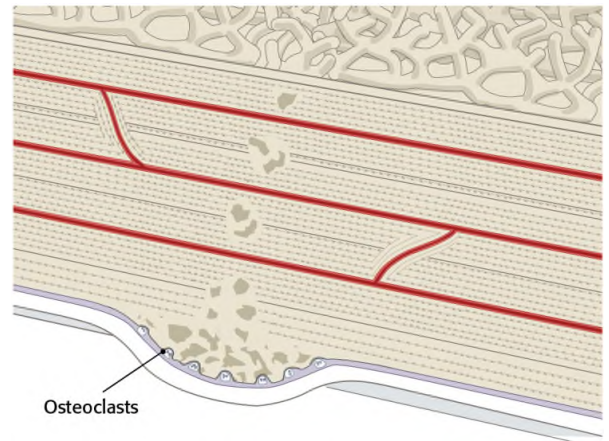


AO

The remodeling stage: conversion of woven bone into lamellar bone through surface erosion and osteonal remodeling once interfragmentary movement ceases.

4. Remodeling (process taking months to years)

- Healing completed
 - With remodeling of medullary canal
 - When bone has completely returned to original morphology

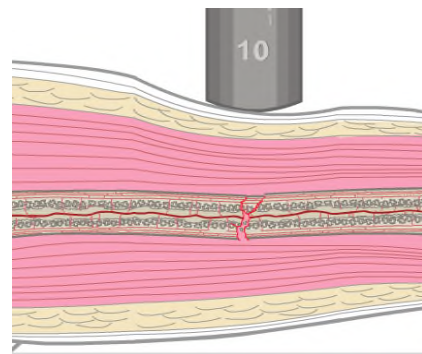


AO

Fracture healing becomes complete with remodeling of the medullary canal and removal of parts of the external callus.

Fracture healing

- Fracture healing is triggered by the breaking of the bone
- What is the “personality” of the injury problem?
 - Complexity of the fracture
 - Extent of the soft-tissue injury
 - Closed or open injury?
 - Periosteal stripping?
 - Status of the patient



AO

Bones heal because they are broken!

We often speak of the “personality” of the injury problem. This depends on the factors listed here:

- Complexity of the fracture
- Extent of the soft-tissue injury
- Closed or open injury?
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Types of fracture healing

- Indirect fracture healing
- Direct fracture healing

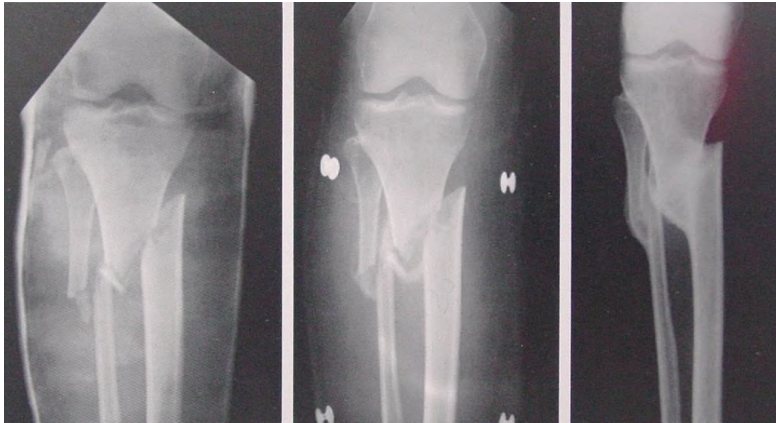
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In the next slides the types of fracture healing will be explained. There are:

- Indirect fracture healing
- Direct fracture healing

Indirect fracture healing

- Under conditions of relative fracture stability
- With callus formation



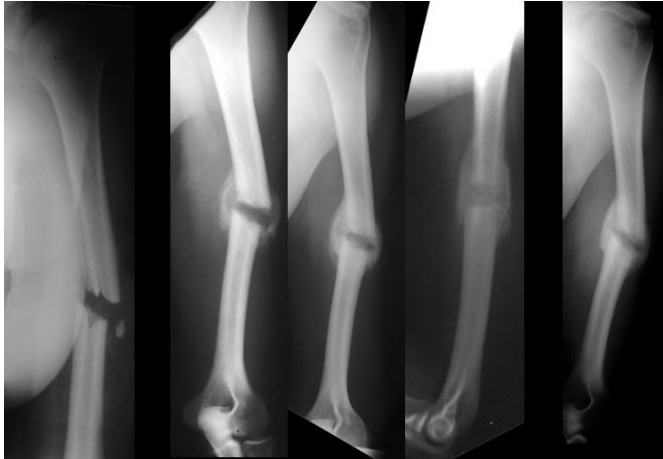
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Indirect healing occurs when there is still some small interfragmentary motion—a condition called “relative stability”. It is thought that the interfragmentary motion stimulates callus formation. However, too much interfragmentary motion can lead to failure of healing—nonunion.

Courtesy: Dr Kirit M Shah

Indirect fracture healing

- Hematoma changes to granulation tissue
 - Callus formation



AO

Course of healing: Initially hematoma (blood coagulation) formed between fragment ends—negligible mechanical properties.

During first few days hematoma changes to granulation tissue, which is a little stiffer.

As the tissue differentiates into more and more stiff forms, so the interfragmentary motion lessens, until it disappears when the hard bony callus bridges the fracture.

Relative stability

- Indirect fracture healing
 - Untreated fractures
 - Nonoperative treatment
 - Reduction
 - Cast, splint
 - Traction



AO

Bones heal because they are broken and the most wonderful thing is that they heal without scar formation.

Treatment is needed so that the bone unites in an acceptable position, which permits early mobilization and prevents joint stiffness and deformity.

Relative stability

- Indirect fracture healing
 - Untreated fractures
 - Nonoperative treatment
 - Reduction
 - Cast, splint
 - Traction



AO

Another example

Relative stability

- Indirect fracture healing
 - Untreated fractures
- Nonoperative treatment
 - Reduction
 - Cast, splint
 - Traction
- Operative surgical treatment
 - Intramedullary nailing
 - Bridge plating



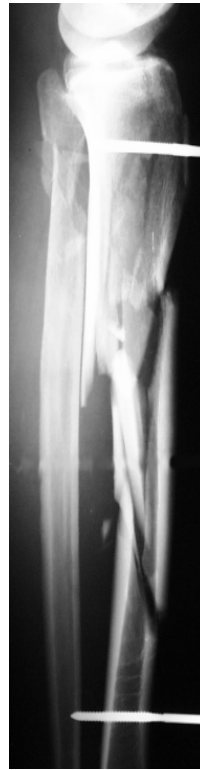
AO

Treatment options obtaining relative stability are

- Intramedullary nailing
- Bridge plating

Relative stability

- Indirect fracture healing
 - Untreated fractures
- Nonoperative treatment
 - Reduction
 - Cast, splint
 - Traction
- Operative surgical treatment
 - Intramedullary nailing
 - Bridge plating



AO

Treatment options obtaining relative stability are:

- Intramedullary nailing
- Bridge plating
- External fixation

Types of fracture healing

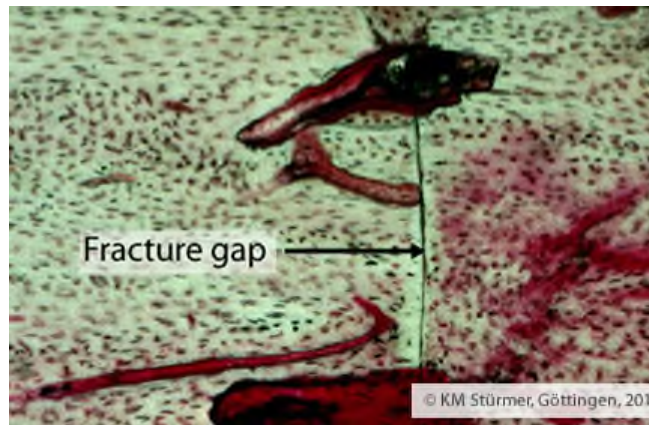
- Indirect fracture healing
 - Induces secondary healing
 - Always with callus formation
 - In conditions of relative stability
- Direct fracture healing

AO

Explain this slide as a summary.

Direct fracture healing

- Under conditions of absolute fracture stability
- By direct osteonal remodeling
- Without callus formation



AO

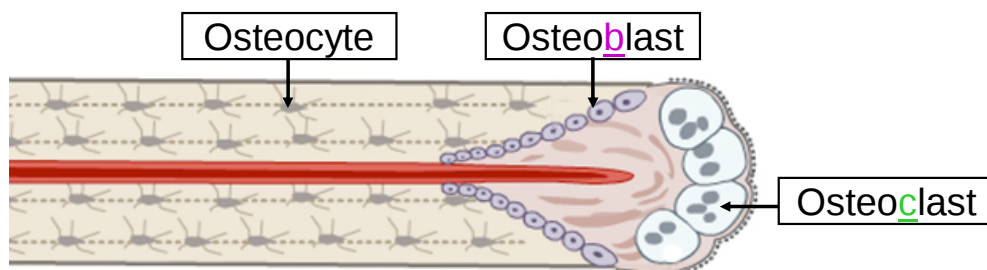
Occurs:

- Under conditions of absolute fracture stability
- By direct osteonal remodeling
- Without callus formation

Primary healing occurs even if there is a minimal gap. This is called gap healing.

Direct fracture healing

- Osteon formed by a cutter cone
- Osteoclasts (**cut**) at the front
- Osteoblasts produce (**build**) new bone and then become osteocytes



AO

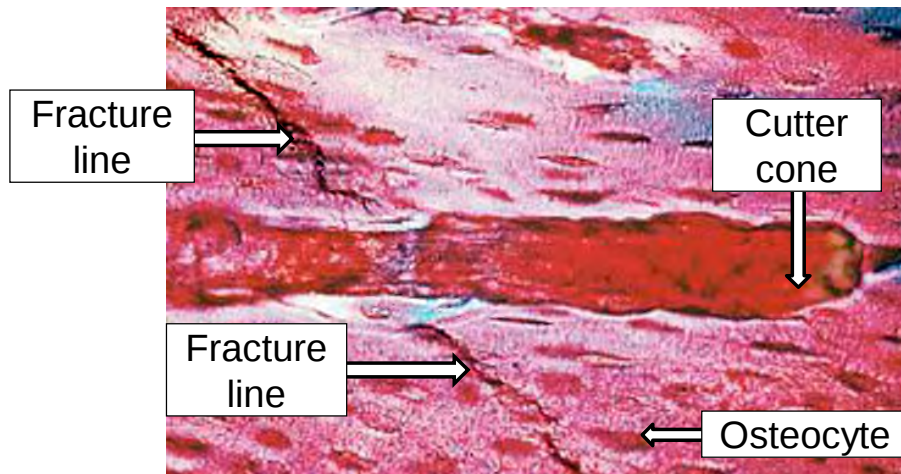
Continually remodeled by cutter cones.

- Osteon= basic construction unit also called haversian system. Each osteon has a central canal, containing blood vessels and a small amount of connective tissue with interconnecting channels surrounded by concentric layers of bone, the laminae.
- There are no osteons in cancellous bone.
- Osteoclasts are present where new bone is being resorbed.
- Osteoblasts participate in the ossification process, present when new bone is formed.
- Osteocytes are trapped within the bone lacunae, is active in the constant remodeling of bone. Lacunae communicate with each other and the canal of the osteons through canaliculae.

Reference:

Summerlee AJS. Bone formation and development. In: Geoff Sumner-Smith, ed. *Bone in Clinical Orthopedics*. 2nd ed. New York Stuttgart: Thieme; 2001:1–22.

Direct fracture healing

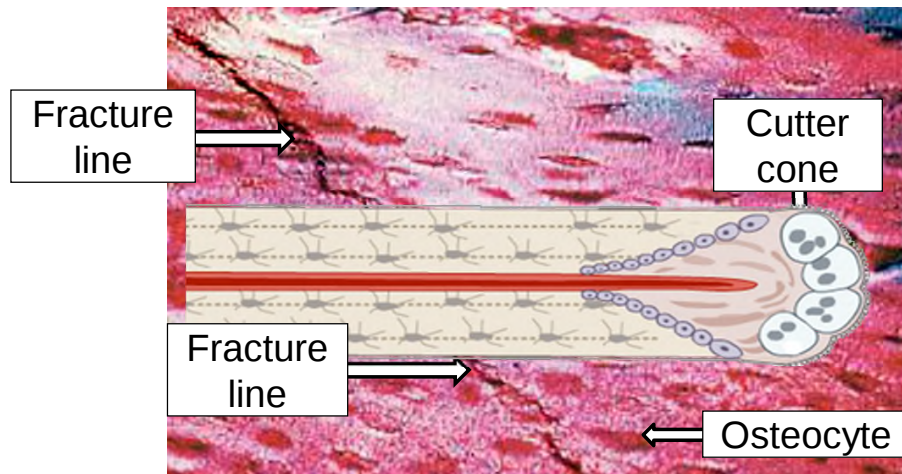


- Cutter cones
 - Cut through compact bone across fracture
 - Create new haversian osteons bridging fracture

AO

Due to the activity of cutter cones, tunnels are cut through the compact bone, resulting in the creation of new haversian osteons in their wake.

Direct fracture healing



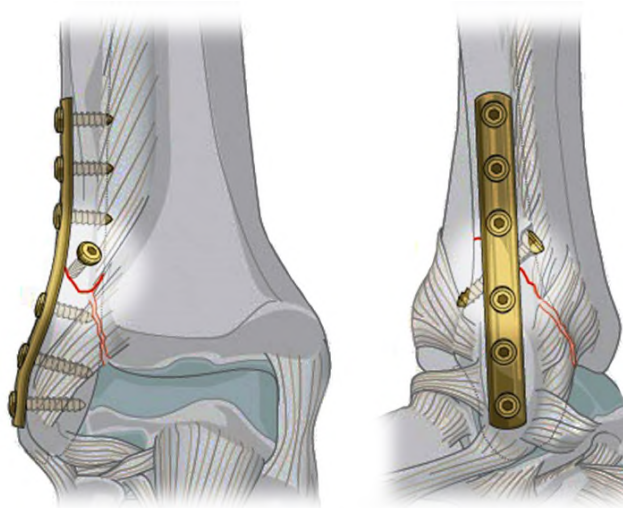
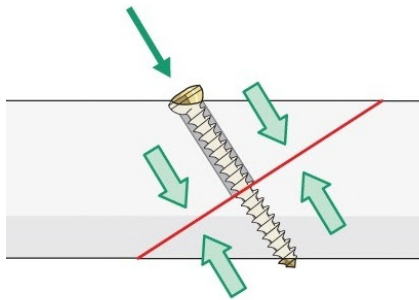
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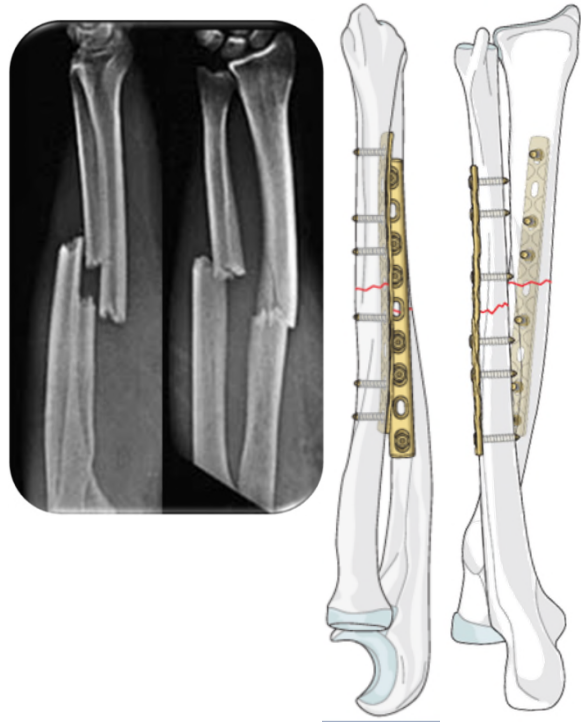
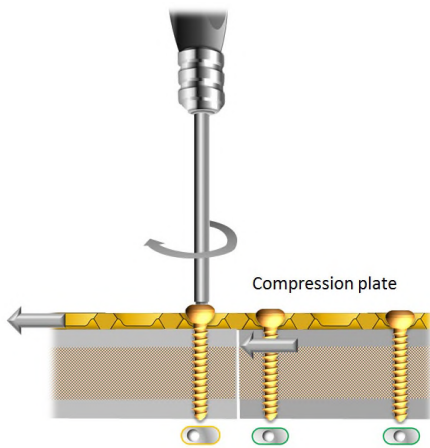
Absolute stability

- Direct fracture healing
 - Operative treatment
 - Lag screw



Absolute stability

- Direct fracture healing
 - Operative treatment
 - Compression plates



AO

Axial compression of transverse shaft fractures results in absolute stability—this is usually achieved by the use of selfcompressing plates, such as the DCP, LC-DCP , or LCP.

Types of fracture healing

- Indirect fracture healing
 - Induces secondary healing
 - Always with callus formation
 - In conditions of relative stability
- Direct fracture healing
 - Induces primary healing
 - Always without callus formation
 - In conditions of absolute stability

AO

Use this slide as an interim conclusion.

Factors influencing fracture healing

- Vascularization of bone fragments
 - Especially periosteum
- Soft-tissue conditions



AO

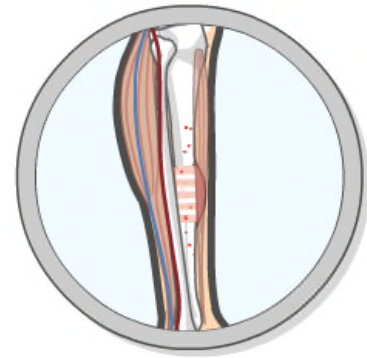
Factors that affect bone healing include:

- Vascularization of bone fragments, and especially the periosteum
- Soft-tissue conditions

Courtesy: Prof Chris Colton

Factors promoting fracture healing

- Movement of the limb
 - Increases muscle activity
 - Stimulates vascularity (venous and arterial flow)
 - Stimulates callus maturation
 - Prevents thromboembolic complications



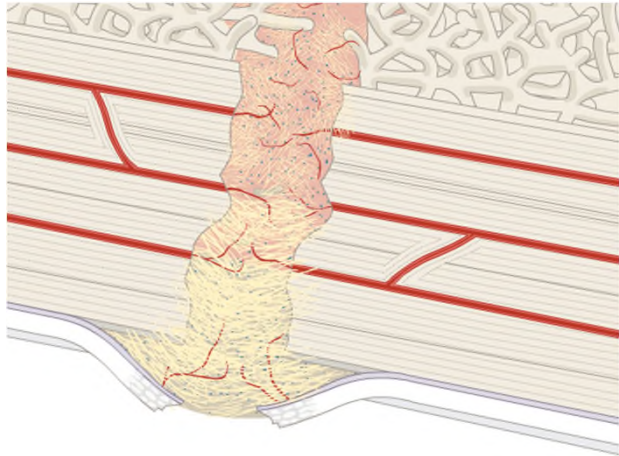
 Find balance for adequate movement

AO

Motion of the limb aids functional recovery, but if it causes strain at the healing fracture site, it increases the risk of tears in the repaired tissue and compromise of callus formation, which is a potential cause of delayed or nonunion.

Factors impeding fracture healing

- Strain
 - Too much movement results in strain
 - Risks tears in repaired tissue
 - Compromises callus formation
 - Causes delayed or nonunion



AO

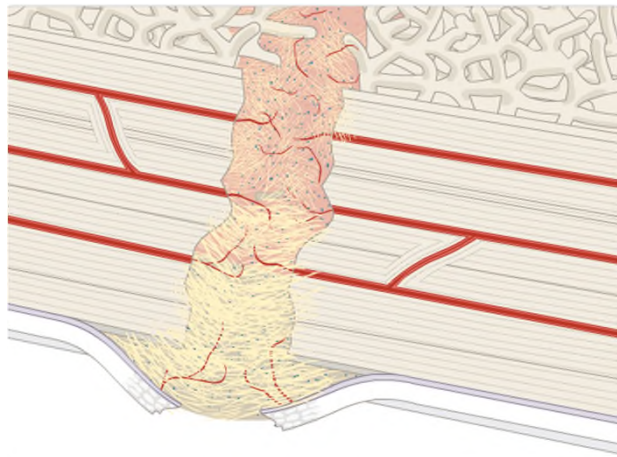
During the soft callus phase too much movement (excessive strain) risks tears in the repaired tissue and compromises callus formation, which is a potential cause for delayed or nonunion.

For faculty:

- *This and next 3 slides have the same content but the pictures change slightly. Focus on the changing pictures.*

Factors impeding fracture healing

- Strain
 - Too much movement results in strain
 - Risks tears in repaired tissue
 - Compromises callus formation
 - Causes delayed or nonunion

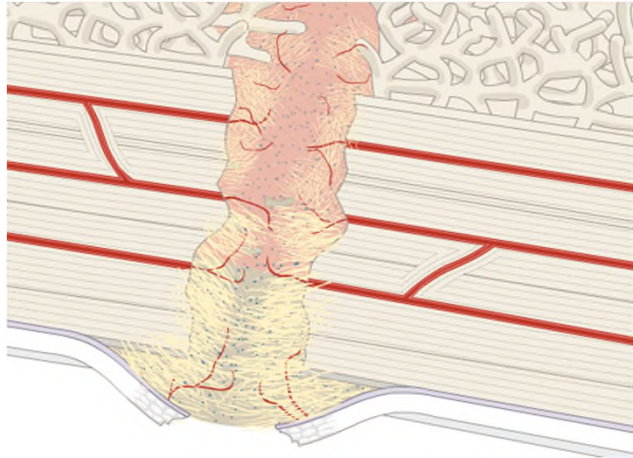


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Factors impeding fracture healing

- Strain
 - Too much movement results in strain
 - Risks tears in repaired tissue
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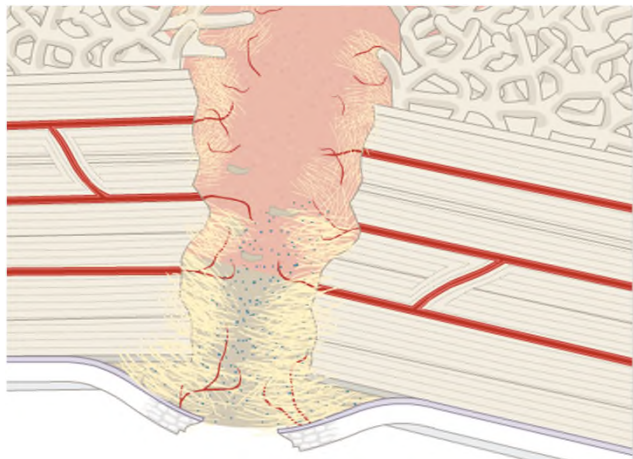


AO

During the soft callus phase too much movement (excessive strain) risks tears in the repaired tissue and compromises callus formation, which is a potential cause for delayed or nonunion.

Factors impeding fracture healing

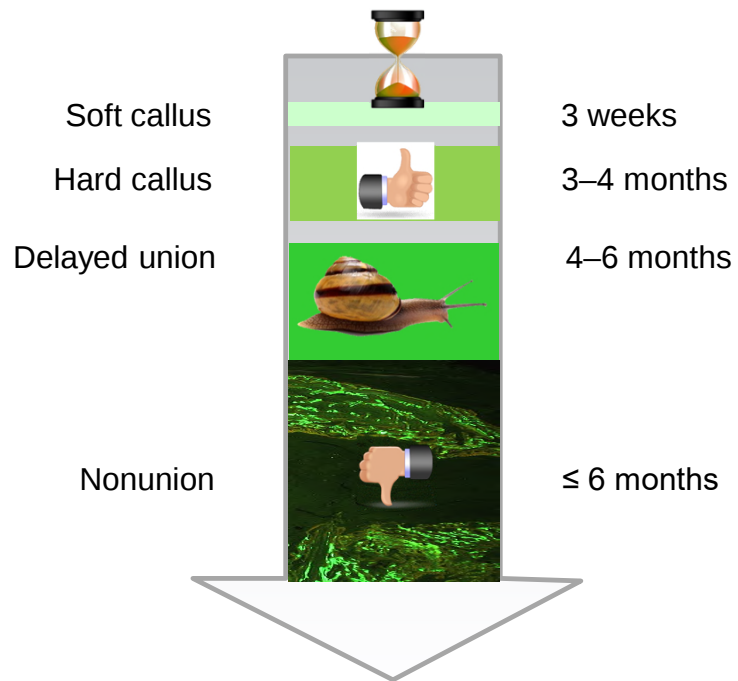
- Strain
 - Too much movement results in strain
 - Risks tears in repaired tissue
 - Compromises callus formation
 - Causes delayed or nonunion



AO

During the soft callus phase too much movement (excessive strain) risks tears in the repaired tissue and compromises callus formation, which is a potential cause for delayed or nonunion.

Normal and delayed fracture healing



What are osteoclasts?

1. Bone cells forming the haversian system

2. Bone cells to be found only in cancellous bone

3. Bone cells involved in resorption of bone

AO

*Optional:
Insert questions to check learning.*

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Negative factors influencing fracture healing

1. Severe damage of soft tissues and periosteum

2. Early weight bearing

3. Immobilization of limb

AO

*Optional:
Insert questions to check learning.*

Negative factors influencing fracture healing

1. Severe damage of soft tissues and periosteum



2. Early weight bearing

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Indirect fracture healing

1. Occurs when relative stability is applied to a fracture
2. Develops when a compression plate is applied to a fracture
3. Appears always in connection with direct osteonal remodeling

AO

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Summary

You should now be able to:

- Outline the anatomy of a bone
- Outline the phases of bone healing
- Explain direct and indirect fracture healing
- Identify factors that affect fracture healing