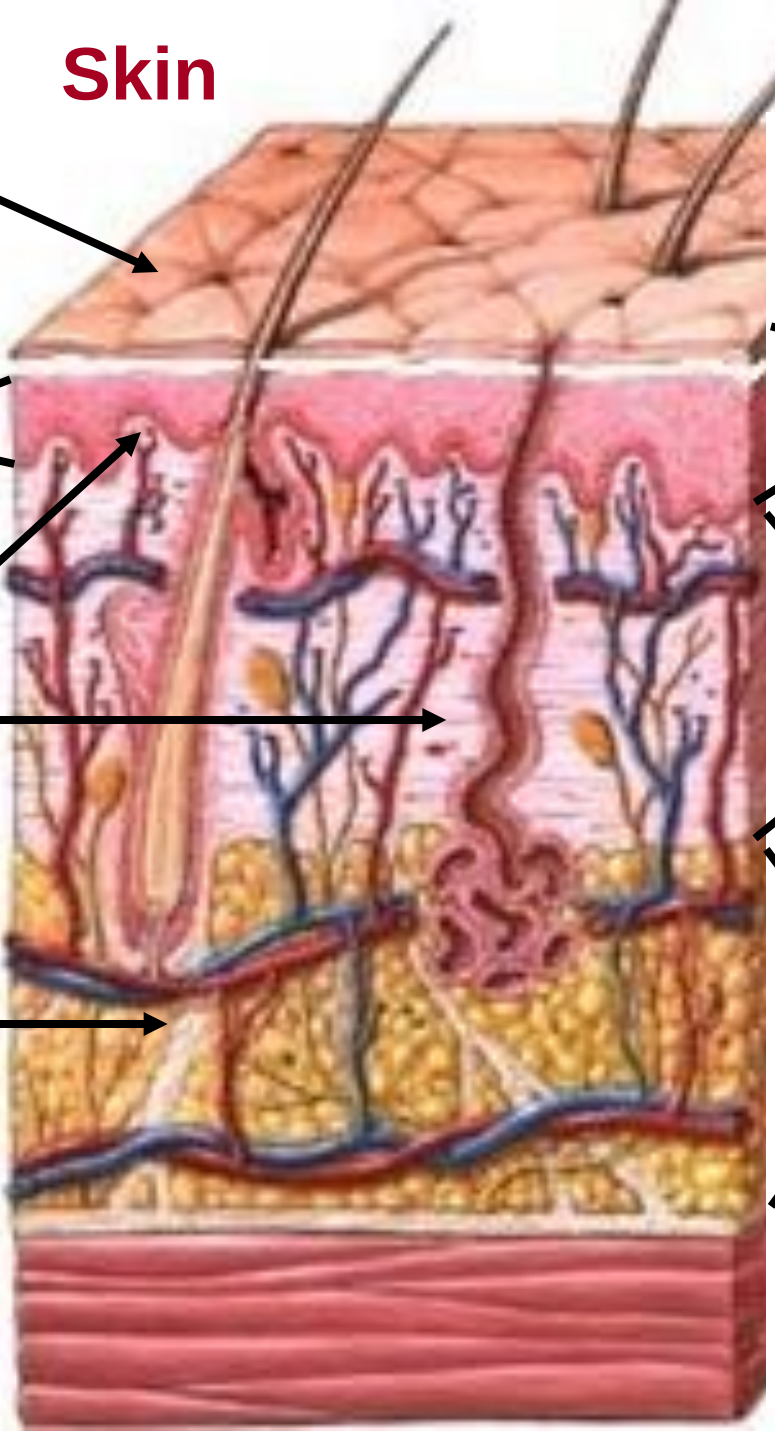
General Notes on Tissue Healing

- **Tissue classified according to regeneration potential**
  - **Labile** - continues to regenerate throughout life ("continuous replicators")
    - Note: any type of tissue regeneration requires basement membrane
    - **Examples: Skin, GI tract, vaginal wall, endometrium, bone marrow**
  - **Stable** - can regenerate if "framework" is intact ("discontinuous replicators")
    - Includes all glandular functional tissue & tissue from many organs
    - Cells in these tissues stop dividing when organism growth ceases
    - **Examples: liver (hepatitis vs. cirrhosis), kidneys**
  - **Permanent** - cannot regenerate ("non replicators")
    - **Examples: Spinal nerves, cardiac muscle**
      - Note: skeletal muscle can partially regenerate
- **Contusions, lacerations, & punctures all heal similarly**
- **Repair quality depends on:**
  - Degree to which parenchymal (functional) tissue is replaced
    - Regeneration potential ↓ from womb (no scarring) to old age (much scarring)
  - Degree to which replacement (scar) tissue is correctly organized
  - * Quality & quantity of re-vascularization (angiogenesis) ie. **O_2 supply**

Skin



Stratum corneum
(horny layer)
(keritinized cells)

Stratum granulosum
(granular layer)

Stratum
germinativum
(basil layer)

Dermal papillae (form ridges)

Elastic Fibers
Collegen Fibers
Reticular Fibers
Fibrocytes
Blood Vessels
Sensory organs
Sweat Glands

Adipose tissue
Areolar fibers

Epidermis

Dermis

(Dense Irregular Tissue)

Hypodermis
(Subcutaneous)

Surface Area:
1.8 to 2.0 square meters
⬆ 7 X from birth to adult

Thickness:
.5 to 3.0 mm
average 1 to 2 mm

Skin Micrograph

Stratum corneum
(horny layer)
(keritinized cells)

Stratum granulosum
(granular layer)

Stratum
germinativum
(basil layer)

Dermal papillae (form ridges)

Elastic Fibers
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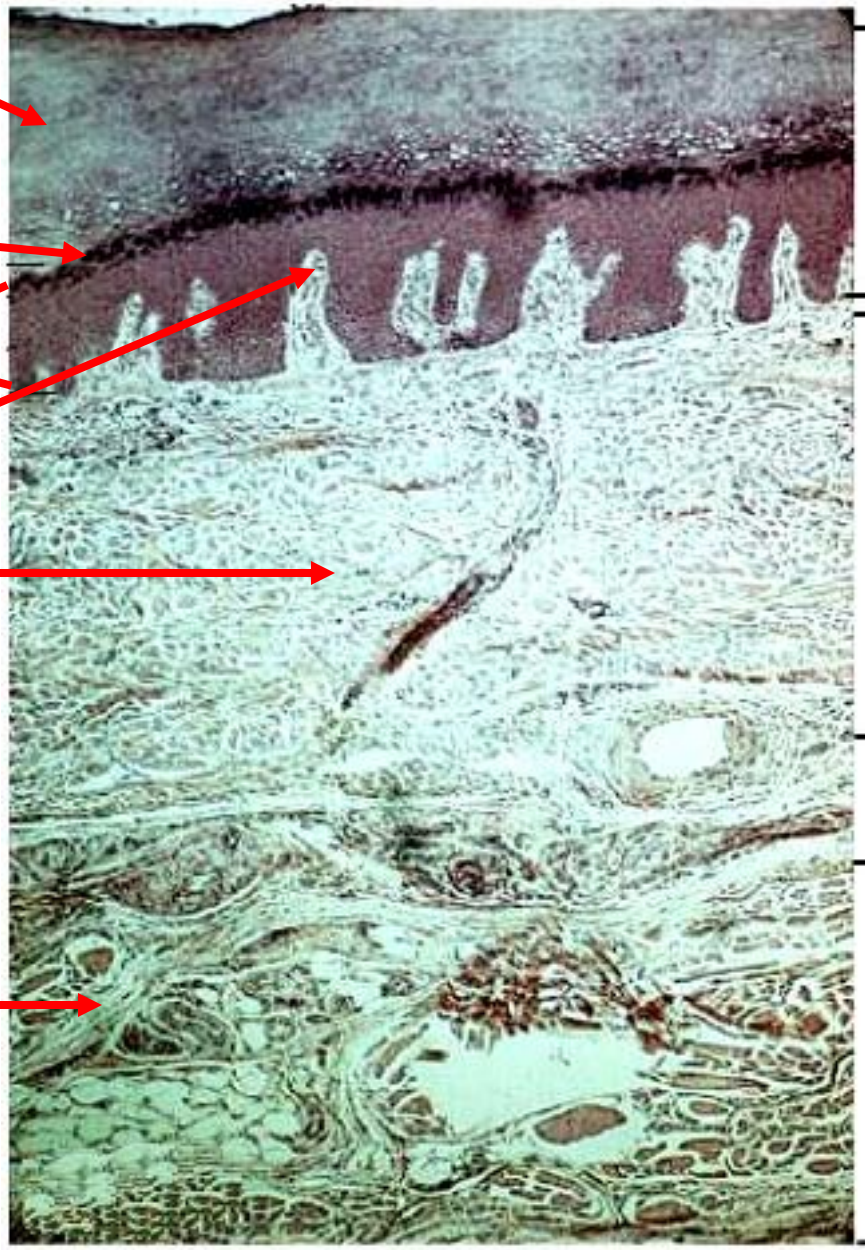
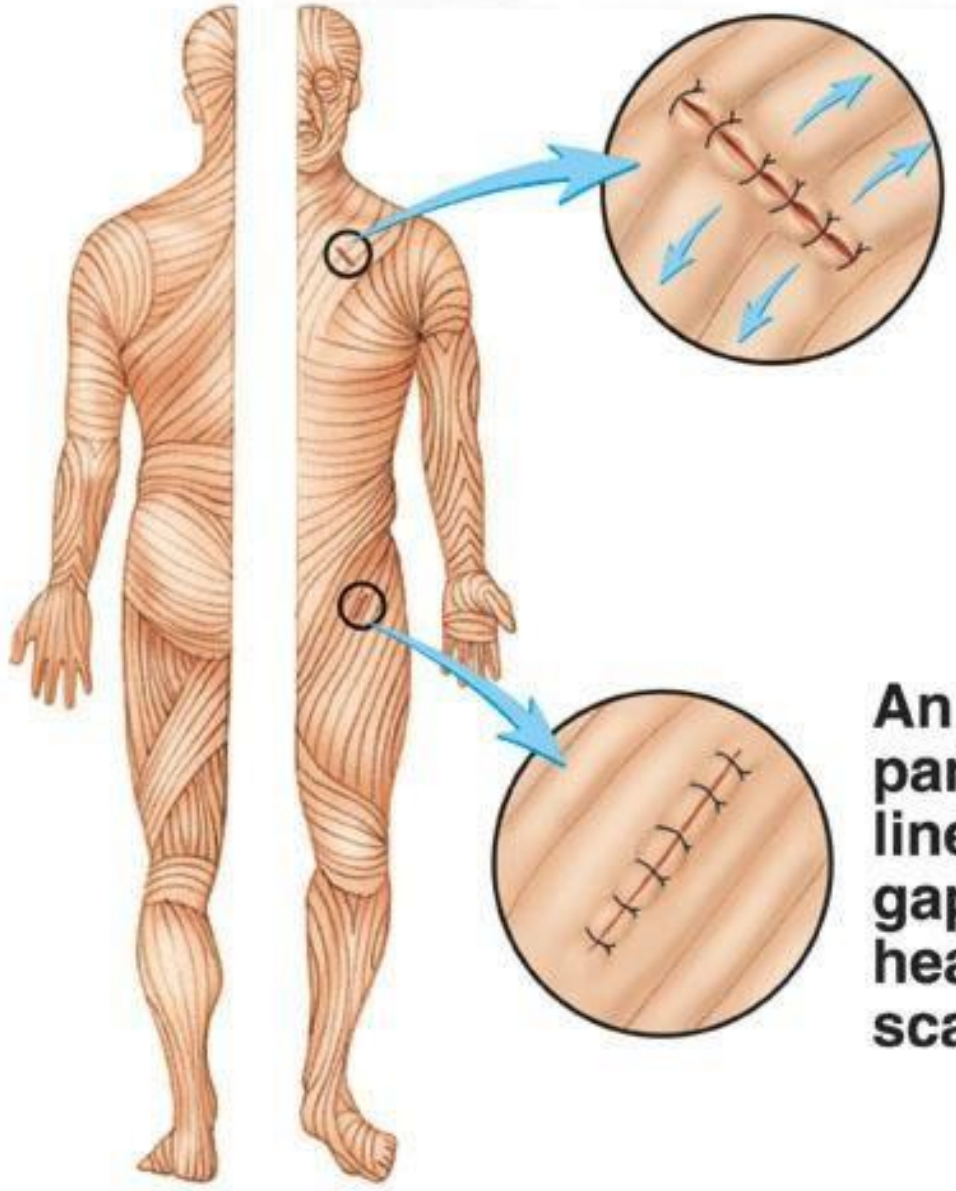
Adipose tissue
Areolar fibers



Skin

- **Epidermis - avascular but well innervated - .3mm to 1mm thick**
  - Regenerated in normal healing
  - Composed of stratified squamous epithelium
  - Deeper cells (stratum germinativum) are the only “living” cells
    - Deeper cells become increasingly keratinized as they are pushed to surface
  - Epidermal mitosis (cell reproduction) is stimulated by the loss of horny layer cells
    - The mitotic process is more active at night
- **Dermis - .5mm to 3 mm thick**
  - Regenerated in normal healing
  - Dermal papillae (ridges that compose finger prints) helps hold epidermis in place
  - Dermis has smooth muscle tissue (pilo-erector) bundled with hair follicles
    - Prominent examples (scrotum, areola)
  - Langer’s lines - lines formed at right angles to direction of natural stretch
    - Caused by gravity & activity
    - Incisions along these lines tend to form less scar tissue
      - Substantial plastic surgery implications
- **Hypodermis - Subcutaneous tissue**
  - Density & cellular arrangement of this tissue determines skin “mobility”
  - Composed mostly of fat cells and areolar tissue

Langers Lines (Cleavage Lines)



An incision made across cleavage lines can gap, increasing the time needed for healing, and result in increased scar tissue formation.

An incision made parallel to cleavage lines results in less gapping, faster healing, and less scar tissue.

Healing of Lacerations, Abrasions & Punctures

1. Inflammatory Phase: inflammation, bleeding / clotting (1 - 48 hours)

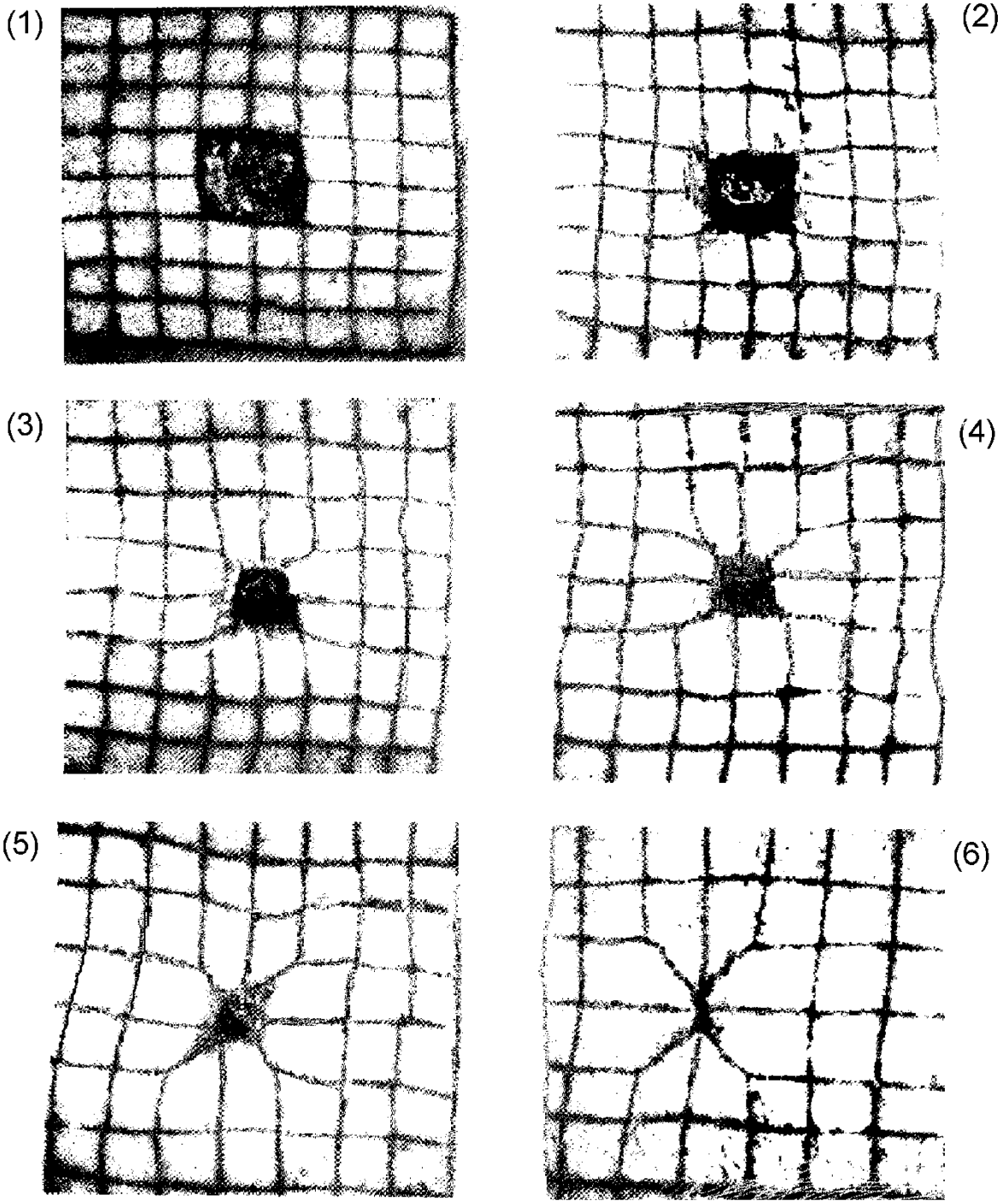
- Reflexes via ruptured cell membranes, thromboxanes & prostaglanidins cause a brief vasoconstriction before bleeding begins
- Thromboplastin & Hageman factor contribute to platelet aggregation & scab:
  - Activation of compliment system:
    - Attraction of neutrophils & inflammatory mediators (chemotaxis begins)
    - Arachadonic acid cascade → ↑ prostaglandins, thromboxanes, & leukotrienes
    - Mast cells & basophils release histamine → ↑ vascular permeability
  - Blood touches collagen → platelet activation - coagulation process begins
    - Platelets aggregate, coagulation is begun, platelets release cytokines & growth factors
    - Platelets cause release of serotonin, histamine, prostaglandins → ↑ vascular permeability
    - PDGF & cytokines begin attracting fibroblasts
    - Cytokines orchestrate inflammation and the cellular activity involved in healing
  - Activation of kalikrein → ↑ bradykinin → **PAIN** & vasodilation
  - Fibrin & Fibronectin form protective scab
- Surface Coagulation completed - Granulation tissue forms
  - Neutrophils begins to arrive within an hour after wounding
  - Macrophages release angiogenic growth factors that stimulate re-vascularization
  - **GRANULATION TISSUE**: **capillary buds**, **fibroblasts**, **macrophages**
    - Scar forming tissue

Healing of Lacerations, Abrasions & Punctures

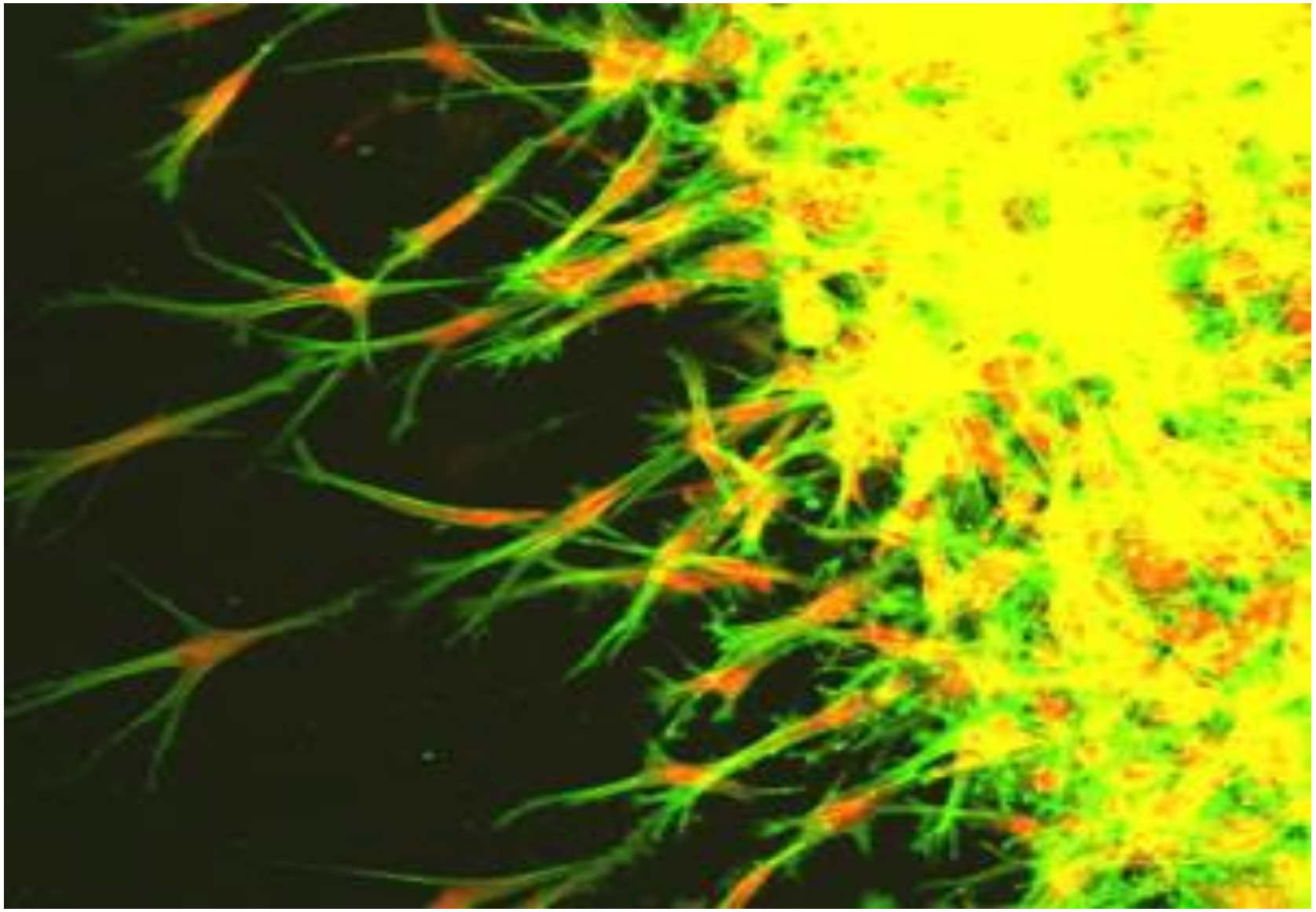
2. Fibroplastic (proliferatory) phase - begins during inflammatory phase !!!

- Tissue hypoxia + macrophage GF produce capillary "extensions" or "buds"
  - Usually happens within 24 to 72 hours after injury
  - Termed **"angiogenesis"**
  - Buds proliferate & grow new circuits & also connect with existing capillaries
    - Capillary – Venule loops are formed
- Fibroblasts produce additional extracellular matrix components
  - Proteoglycans, collagen fibers, reticular fibers, elastic fibers, glycoproteins
  - Vitamin C & oxygen needed for collagen synthesis
- In extracellular matrix (ECM), hyaluronic acid + fibronectin form Scaffold
  - Fibronectin + hyalruonic acid form a "scaffold" or "framework" for cell migration
    - Fibronectin - adhesive glycoprotein located in blood & cell membranes
  - Initial wound tensile strength (day 4 or 5) provided by:
    - Fibronectin & cross-linking of fibronectin & collagen
- Keratinocytes regenerate epithelium and it proliferates beneath the clot
- Wound contraction occurs
  - Myofibroblasts located in wound margins have high actin content
  - Myofibroblasts move toward the center of the wound & contract
  - Ends of damaged tissue are pulled closer together

Wound Contraction



Fibroblast Cell Secreting Collagen

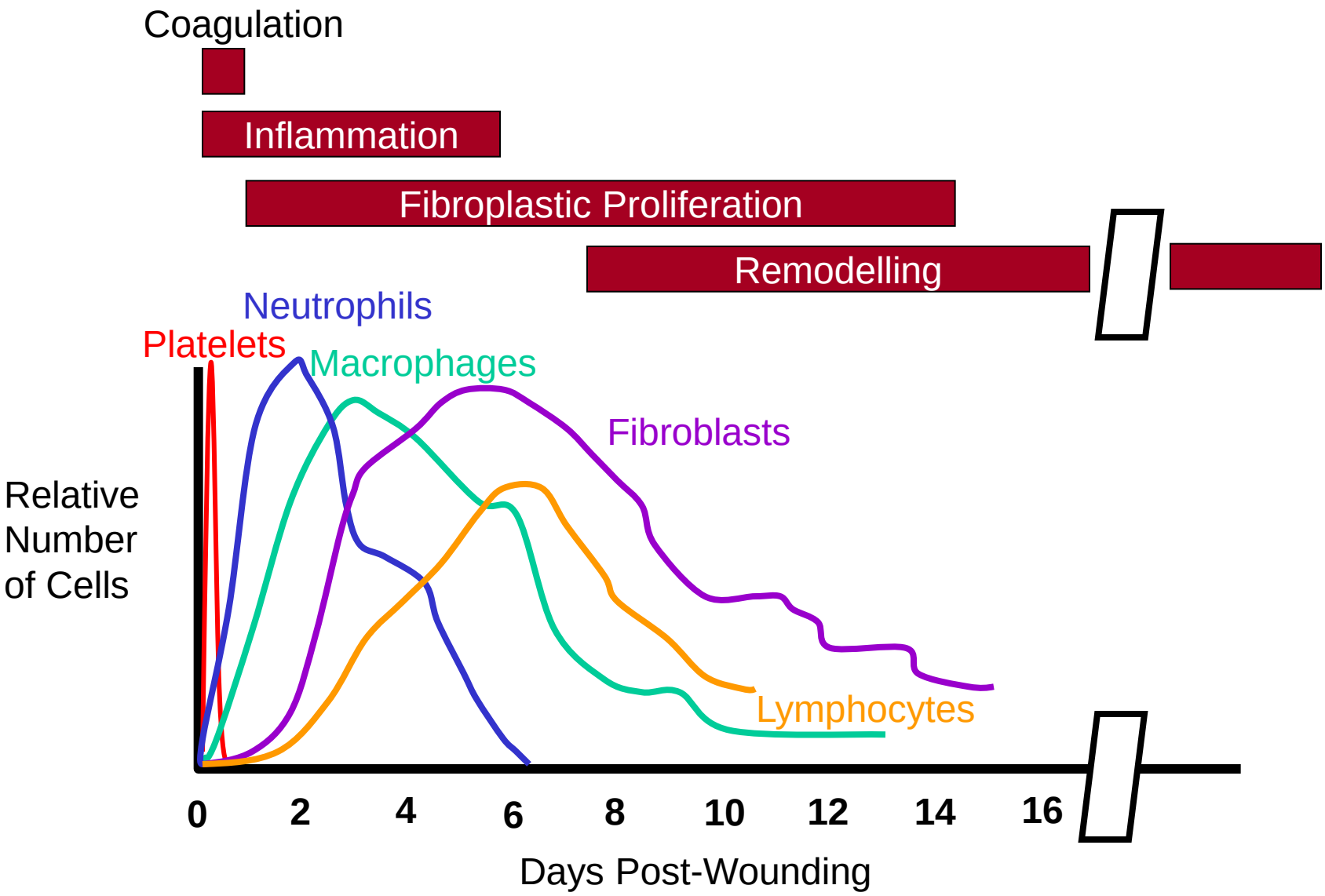


Healing of Lacerations, Abrasions & Punctures

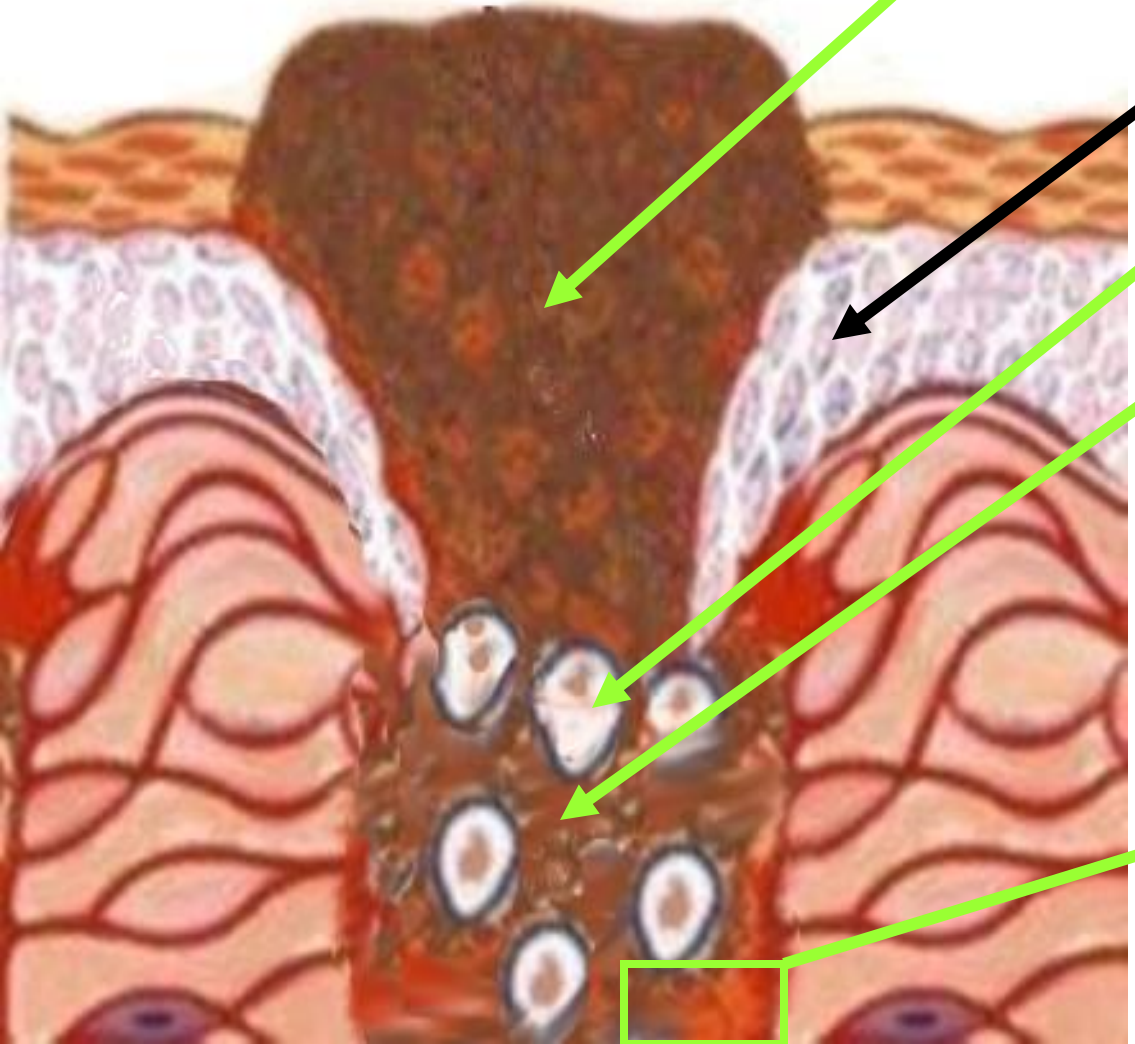
3. Maturation phase - mostly complete in 3 weeks to 6 months

- Clot lysis (early in the phase)
- Breakdown & re-synthesis of collagen fibers in direction of tensile forces
  - May continue for years
- Elevated pink scar eventually replaced by a soft flat white scar
- Embryonic Type III collagen (inferior) is replaced by normal Type I collagen

Cell Recruitment in the Wound



Wound Healing: Inflammatory Phase

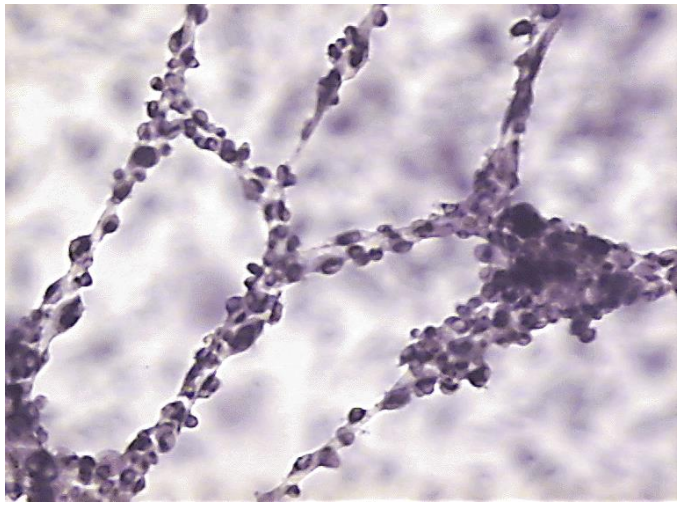


Clot

Keratinocytes produce New Epithelial Tissue

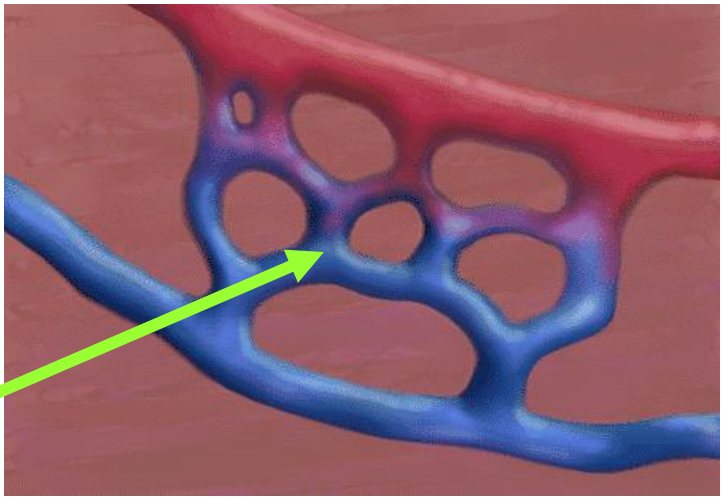
Granulocytes (neutrophils macrophages)

Early Granulation Tissue



Capillary Bud Formation (Angiogenesis)

Wound Healing: Fibroblastic Phase



Capillary Buds Finally Form
Capillary-Venule Loop

Collagen Bundles in Dermis

Mitosis of Epithelial Tissue

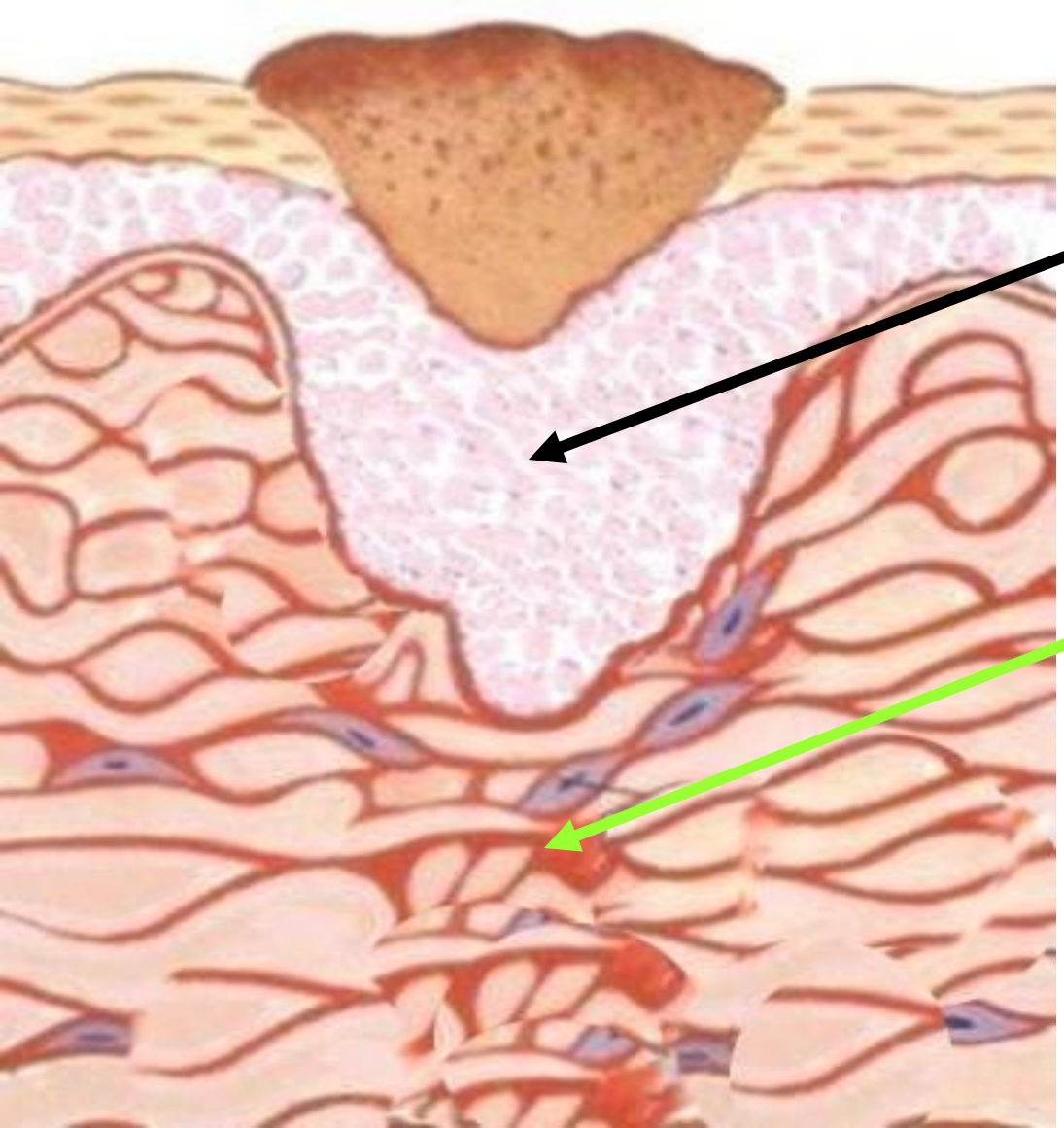
Fibroblasts
(migrating along “scaffold”)

New Collagen Fibers

Fibronectin ECM “Scaffold”

Granulocytes

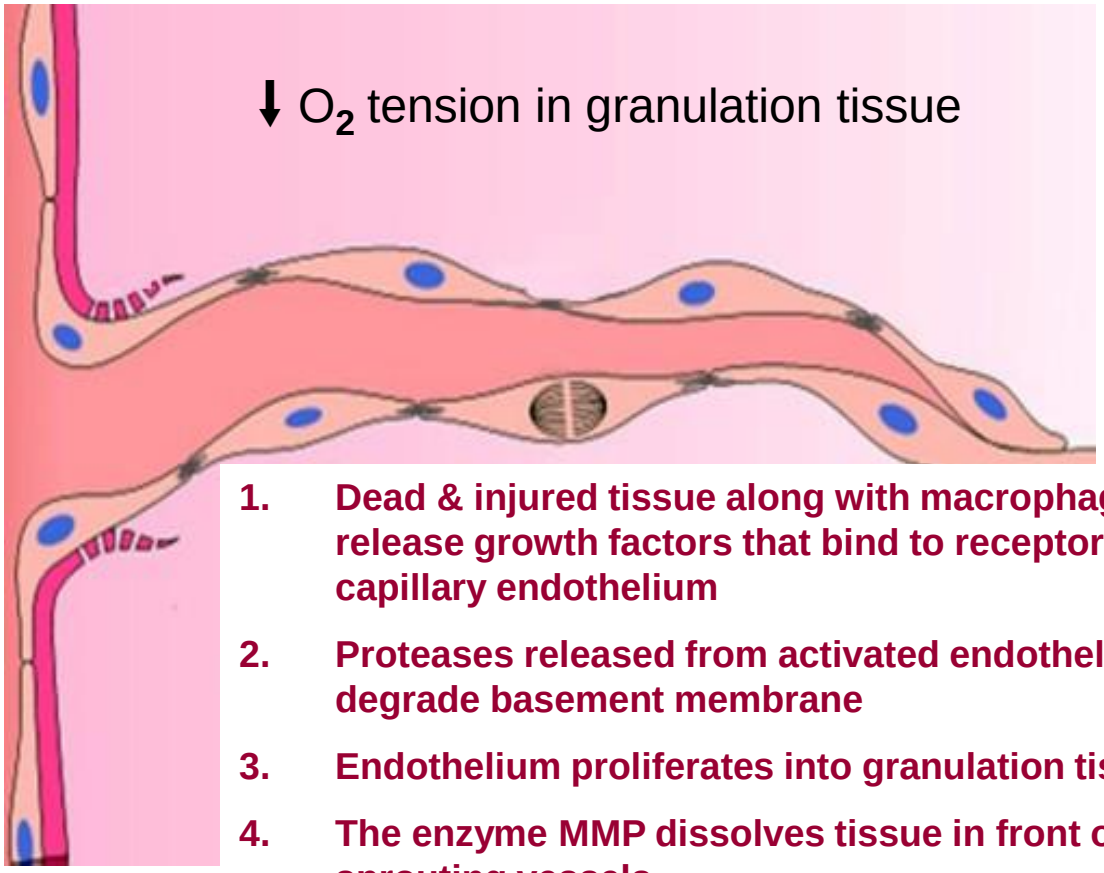
Wound Healing: Early Maturation Phase



Epithelial Migration Complete

New Collagen Fibers
(Type III Collagen - Scar Tissue)
Note tissue disorganization

Capillary Angiogenesis



1. **Dead & injured tissue along with macrophages release growth factors that bind to receptors on capillary endothelium**
2. **Proteases released from activated endothelial cells degrade basement membrane**
3. **Endothelium proliferates into granulation tissue**
4. **The enzyme MMP dissolves tissue in front of the sprouting vessels**
5. **Integrins (proteins) "grapple" the granulation tissue and pull the capillary buds forward**
6. **Sprouting endothelial buds roll up and form a blood vessel tube which is covered with fibronectin and proteogylcans**
7. **Tube connects to form loops with other neo-vascular tissue and existing capillaries**

Excessive angiogenesis occurs in diseases such as:

- **Cancer**
- **Diabetic blindness**
- **Age-related macular degeneration**
- **Rheumatoid arthritis and**
- **Psoriasis**

Insufficient angiogenesis occurs in conditions such as:

- **Coronary artery disease**
- **Stroke**
- **Delayed wound healing**

Note: control of angiogenesis is through the balance of angiogenic growth factors and angiogenic inhibitors. Normally, the balance favors the production of inhibitors

Healing by First & Second Intention

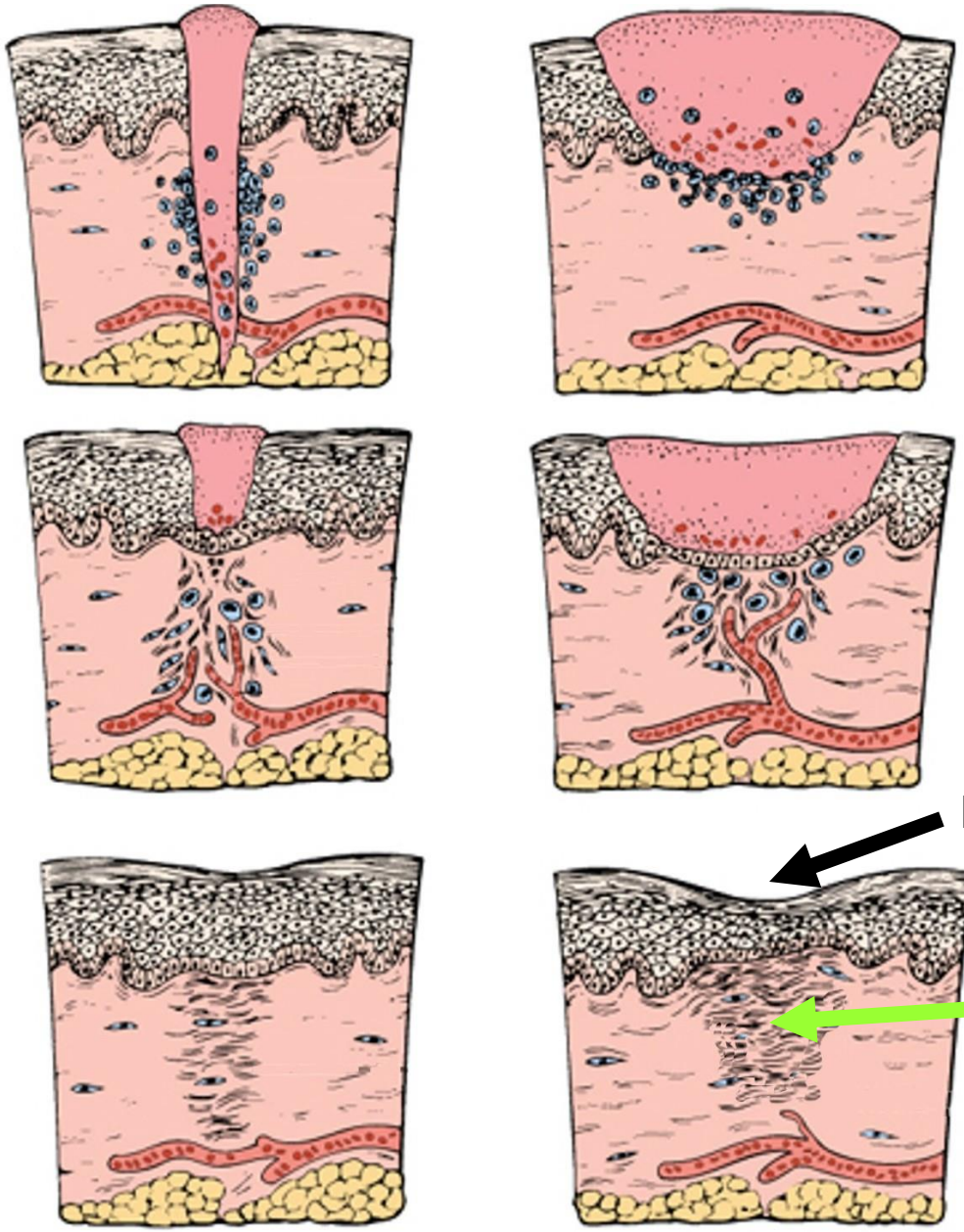
- **Healing by first intention** - wound edges brought together by sutures
  - ↓ loss of parenchymal tissue → ↓ amount of scar tissue
  - Healing occurs faster
  - Less chance of infection

- **Healing by second intention** - wound not closed / unable to be closed
  - Examples: decubitus ulcers (bed sores), burns
  - Significant loss of parenchymal tissue → ↑ amount of scar tissue
  - Healing occurs slower
  - Greater chance of infection

Wound Healing

First Intention (sutures)

Second Intention (no sutures)



Things that Inhibit Healing

- **Ischemia** (lack of oxygen to the wound)
  - Poor blood supply
- **Dry Wound Environment**
  - Cover wounds & keep them moist with antibiotic ointment
- **Infection**
  - Make sure wound is thoroughly cleaned before bandaging
- **Foreign Bodies or Material Left in Wound**
  - Change bandage often and look for foreign material
- **NSAID Anti-inflammatory Medications**
- **Nutritional deficiency**

Scar Tissue

- Scar tissues is not as vascularized, flexible, elastic, or strong as original tissue
- Scar tissue formed in a muscular organ may inhibit function
  - Examples: heart, bladder
- Scar tissue may form **Adhesions** which connect serous surfaces and organs
  - **Adhesions:** inflammatory fibrous bands connecting serous surfaces
    - Most often found in pleural cavity and peritoneal cavities
  - May cause loss of function
- Scar tissue may form **Contractures**
  - **Contractures:** Fibrotic tissue laid down in connective tissue, skin, fascia, muscle, or joint capsule that prevents normal range of motion
  - May form within a joint ➞ loss of mobility & range of motion
  - May form in skin or muscle fascia ➞ loss of mobility & elasticity
- **Stretch Marks** (striae distensae) – results from tearing of the dermis
  - Fibroblasts cannot secrete enough fibers to keep skin growing fast enough
  - A genetic component may exist that predisposes one to stretch marks.
  - Usually appears where large amounts of fat are stored
    - Abdomen, breasts, thighs, hips, butt, upper arms, under arms
    - Approximately 90% of pregnant women, 70% of adolescent females, and 40% of adolescent males have stretch marks.

Classification of Muscle Injury

- **Muscle Strain - tension exceeds the weakest structural element in the muscle causing a partial or complete tear**
  - Injury usually located 0.1 to 3 mm from the muscle-tendon junction
  - Caused by: sudden over-stretch or contraction and limb deceleration
    - Failure of GTO may play a significant role in muscle strain
    - Insufficient warm-up may contribute to muscle strain
  - Other contributory causes: corticosteroid injections & previous injury

  - First degree (mild)
    - Minimal structural damage and minimal hemorrhage
  - Second degree (moderate)
    - Partial tissue tear, significant loss of function, significant hemorrhage
  - Third degree (severe)
    - Complete tear, total loss of function, extensive hemorrhage, possible muscle (myofibrillar) retraction

http://www.emedicinehealth.com/muscle_strain/article_em.htm

http://www.sportsinjuryclinic.net/cybertherapist/back/hamstrings/hamstringstrain.htm

Classification of Muscle Injury

- **Muscle Contusion: blow to muscle → fiber tearing → hematoma**
  - Severe contusions sometimes difficult to distinguish from complete tear
    - **Intermuscular hematoma** - bleeding between muscle fascia
      - Characterized by early migration of echymosis to distal part of limb
      - Heals more quickly than intramuscular hematomas
    - **Intramuscular hematoma** - bleeding within a fascia enclosed muscle bundle
      - Hemorrhage is more confined and localized
      - Inflammatory response is exaggerated
      - ↑ risk of myositis ossificans, scarring, & **compartment syndrome**
- **Compartment syndrome: hemorrhage → ↑ pressure in muscle unit**
  - ↑ pressure → ↓ blood flow → ischemia → necrosis → gangrene
  - Most often result from severe contusions
  - Can be caused by excessive exercise induced muscle damage
  - Causes severe pain, palpable tightness, “shiny” skin appearance
  - Fascia release (surgery) is done within 12 hrs to minimize damage

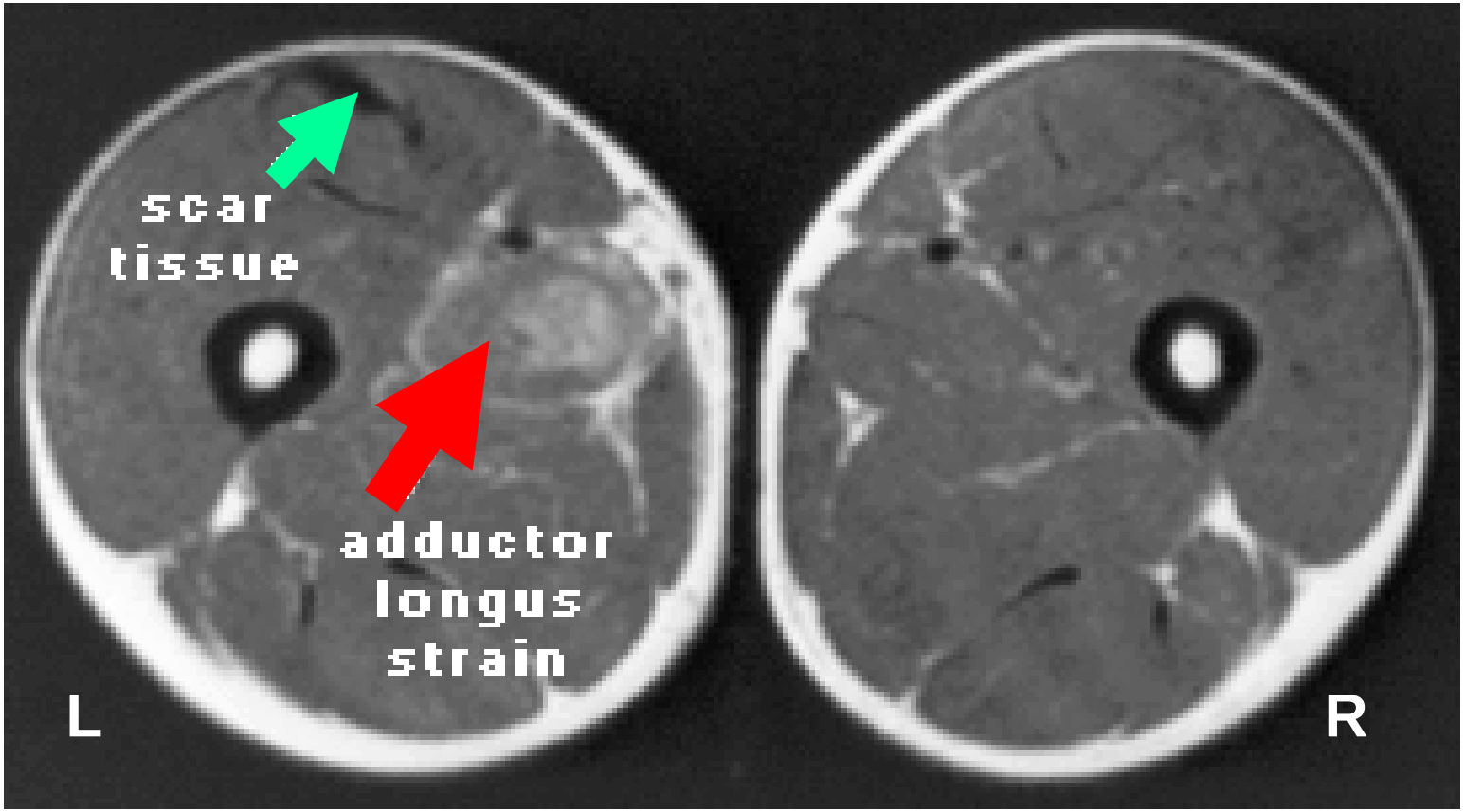
General Steps in the Healing of Muscle Trauma

Stage	Pathology - Healing	Treatment Implications
Inflammatory (days 1 - 2)	- Cell disruption → hemorrhage & edema formation - Myofibrillar retraction + possible nerve damage - Macrophage and neutrophil invasion (inflammation) - Phagocytosis	- RICE - Immobilization & Protection - NSAID drugs
Fibroplastic Proliferation (days 3 - 6)	- ↑ rate of collagen synthesis by fibroblasts - Muscle regeneration from 2 types of **"Satellite" cells** **(Satellite cells are "stem cells" activated by injury)** - Neovascularization (angiogenesis)	- Partial ROM exercises - Gentle resistance work - Directionalize collagen & muscle - **Protect neovascularization** - Pulsed ultrasound
Fibroplastic Proliferation (days 7 - 14)	- Muscle fiber & satellite cell fusing & bridging begins - Tensile strength approximately 50% of normal - Contraction still inhibited by edema & pain - Tendency to return to activity → ↑ chance of re-injury	- ↑ resistance work - Progress to full ROM exercises - Ultrasound & heat modalities
Remodeling Maturation (days 15 - 60)	- ↑ maturation of collagen → ↑ tensile strength - Replacement of initial or inferior tissues **- Permanent loss of tissue tensile strength in severe injury: 7%**	- Progression of activity - ↑ intensity & duration

MRI of Adductor Longus Muscle Strain

- Note ↓ signal intensity (very dark) around old scar & cortical bone of femur

- Note ↑ signal intensity around the strain indicating fluid buildup



MRI of Muscle Strain

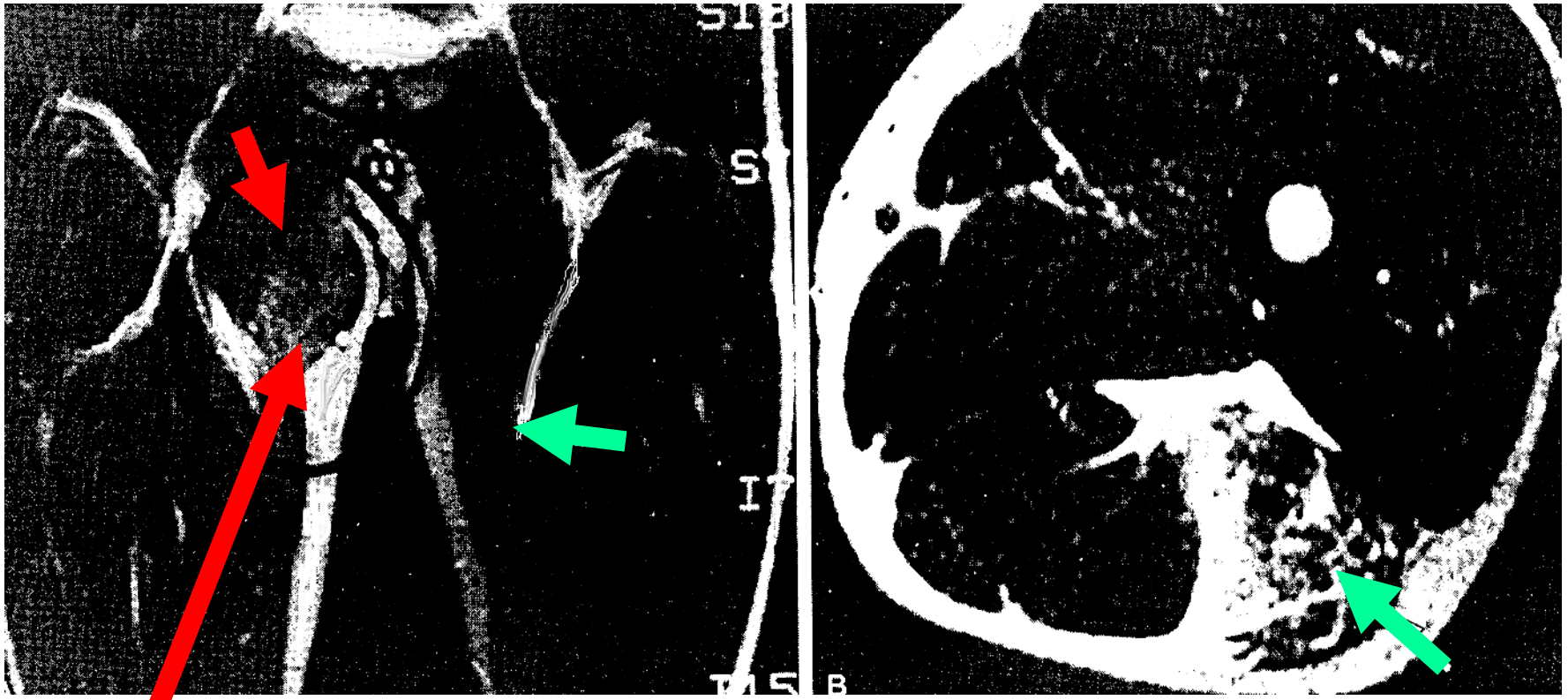
MRI of adductor longus strain (sagital)

Note retraction of muscle (red arrows)

Normal contralateral muscle (green arrow)

MRI of biceps femoris (hamstring) strain

Note ↑ signal intensity → edema (green arrow)



Myofibrillar Retraction

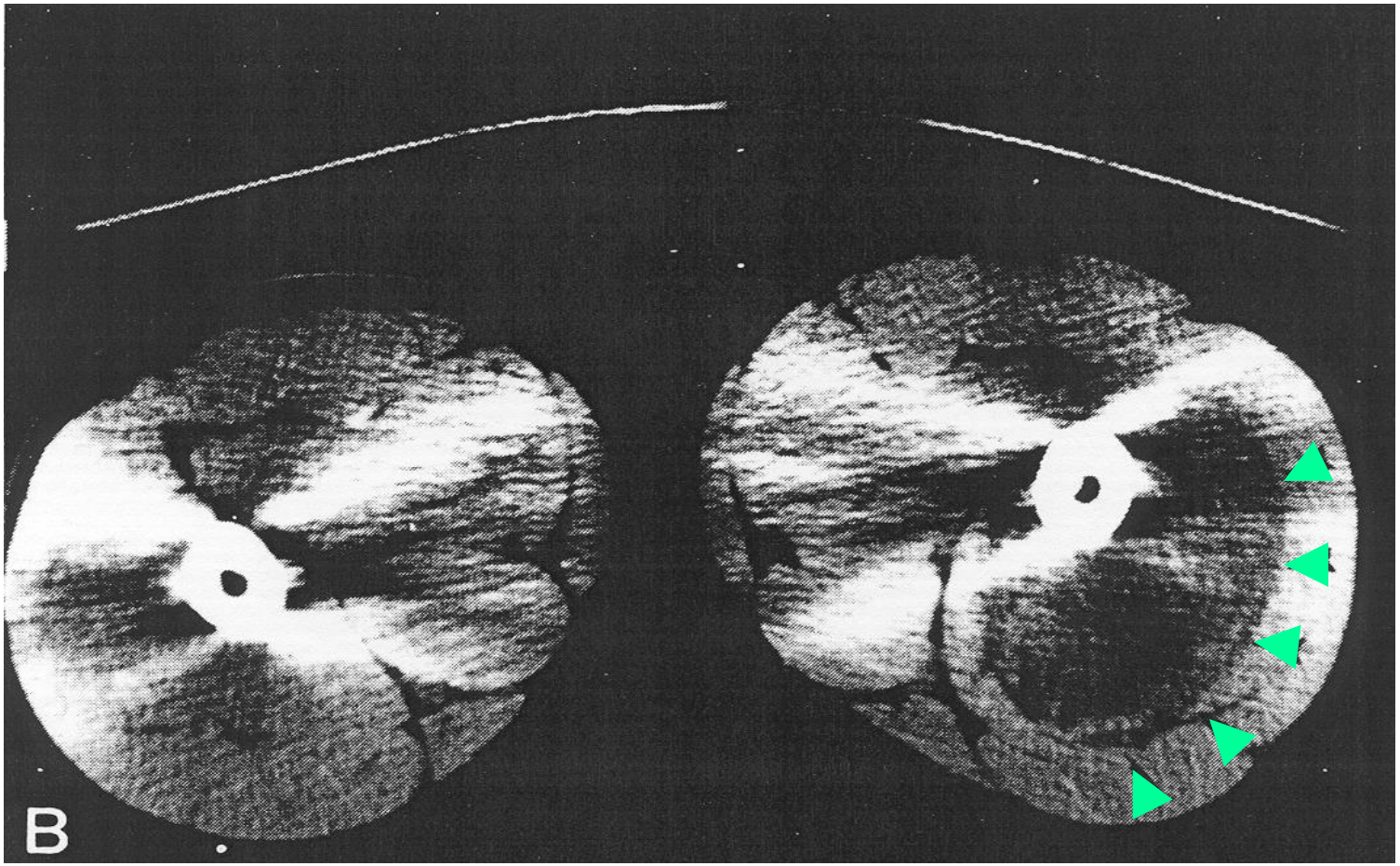
CT-scan of Intramuscular Hematoma

CT Scan of intramuscular hematoma from a direct blow to the quadricep.

Note the decreased signal intensity (green arrows) indicating fluid buildup.

This particular person applied heat to the injury, exacerbating it.

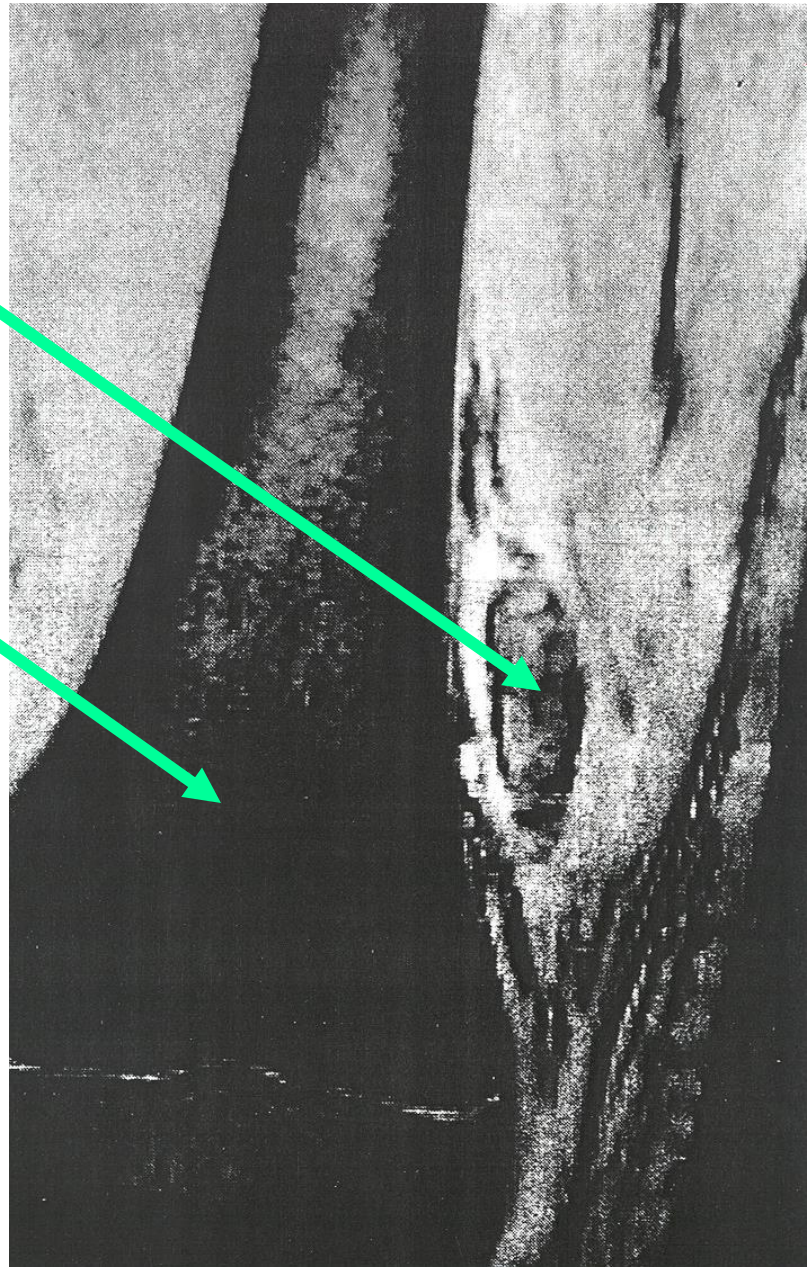
An emergency fasciotomy had to be performed.



MRI of Myositis Ossificans

Myositis Ossificans in Vastus Lateralis

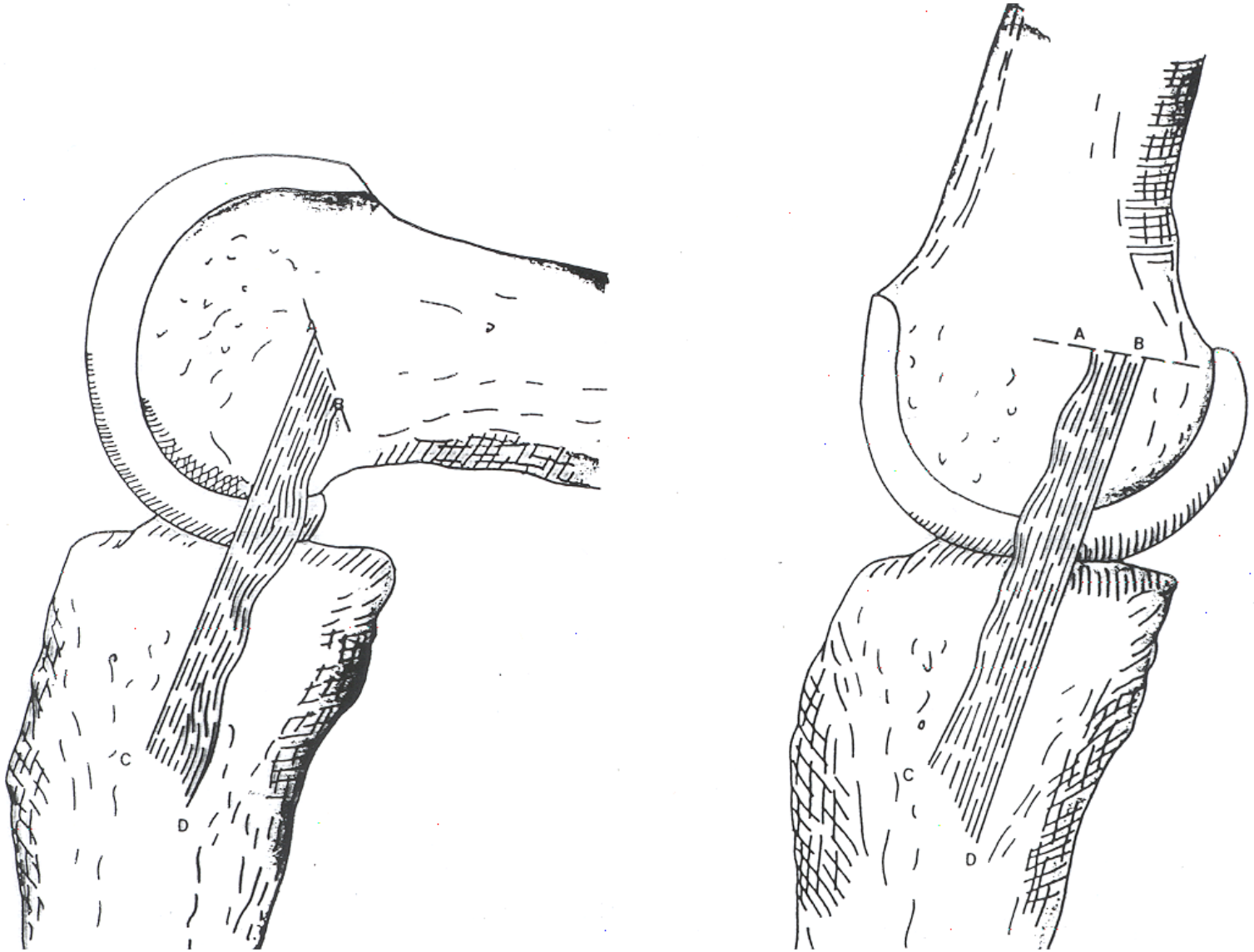
Femur



Ligament Injury

- **Ligament** - fibrous dense connective tissue - binds bones
  - Injuries to these structures are associated with the future development of OA
  - Ligaments have subunits that tighten or loosen depending on joint position
  - Ligaments are not densely innervated or densely vascularized
    - Do contain some blood vessels and nerves in outer covering (called the epiligament)
    - Do contain **proprioceptors**
    - Do transmit pain signals via type C fibers
  - In bone-ligament-bone structures, ligament is the weakest link
    - Adolescent & osteoperotic exceptions
    - Weakest point is near the site of ligament insertion
  - Ligaments are not readily weakened by physical inactivity
    - Several weeks of inactivity are required to weaken a ligament
  - Ligaments show only a 10% - 20% ↑ in tensile strength with exercise training
  - Surgical repair of ligament injuries is not done unless ends are far apart
    - Length of repair scar does not affect tensile strength
    - Long repair scar → ↓ joint stability & ↑ joint laxity
    - ACL tears most often result in ends unopposed → surgery required
  - Surgical repair restores only about 80% - 90% of original tensile strength

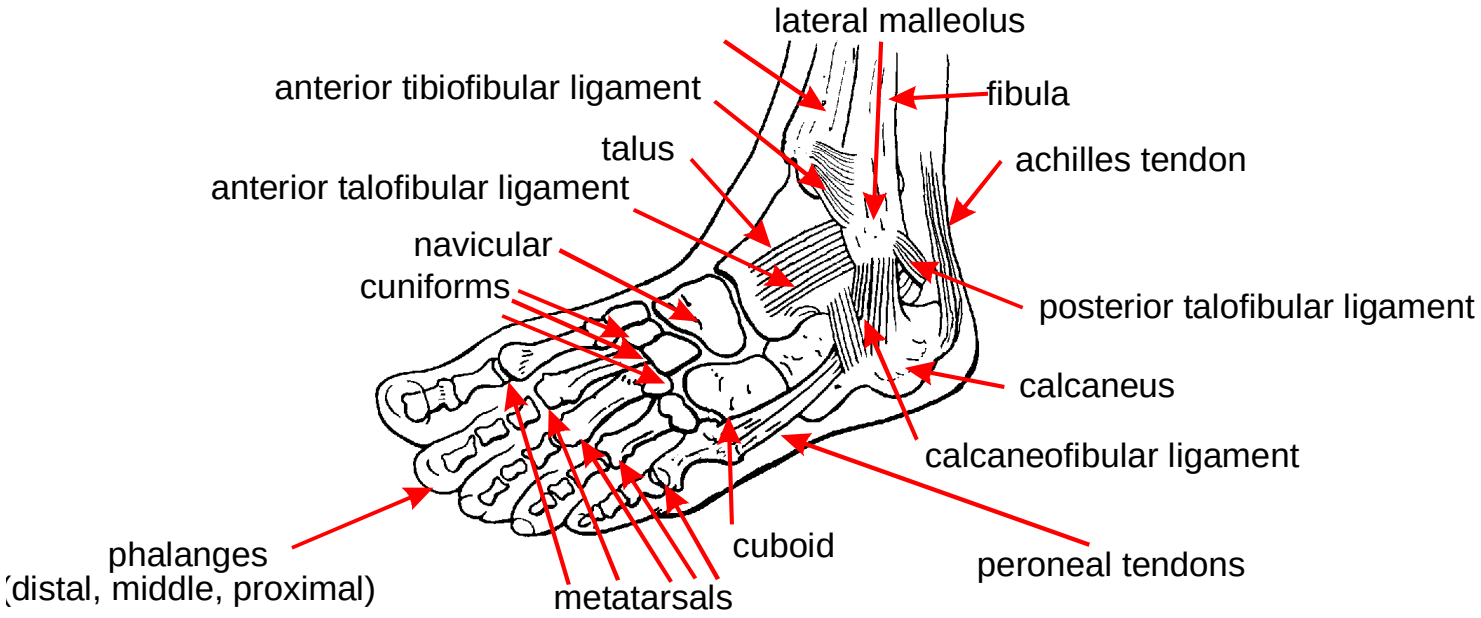
Functional Sub-units of the Lateral Collateral Ligament - Left Knee

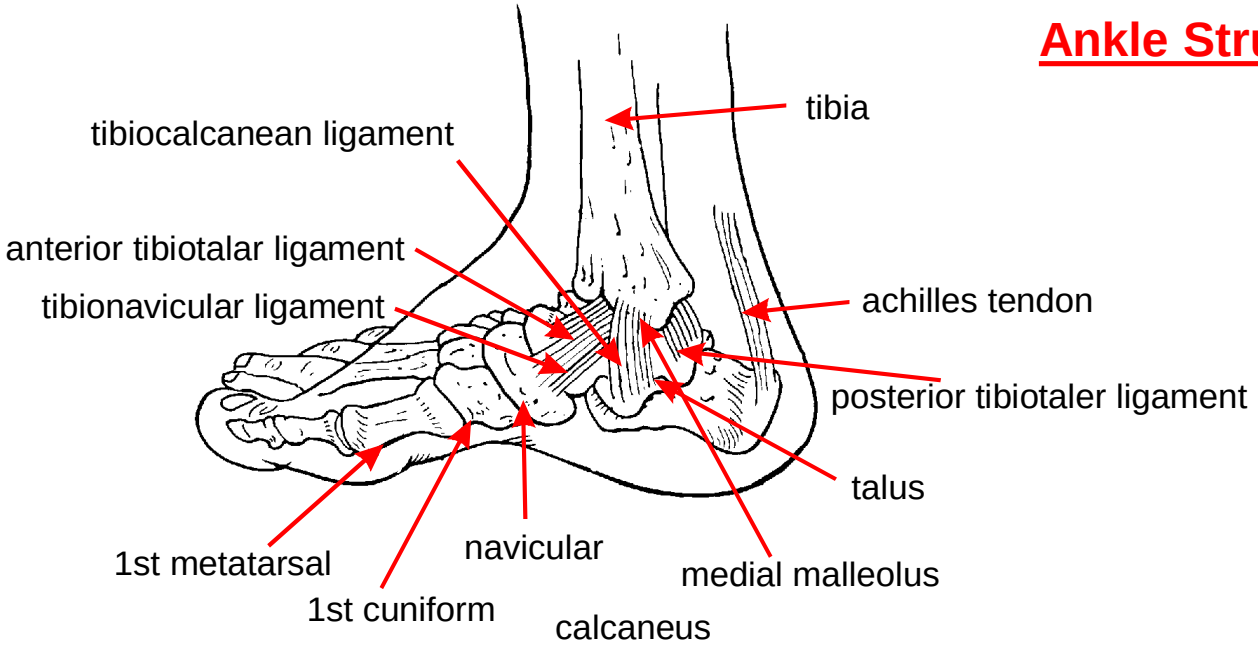


Ligament Sprain

- **In most cases, more than 1 ligament share loads around a joint**
  - Most sprains involve more than one ligament - example: ankle
    - Most common sprain: ankle inversion accompanied by plantar flexion
      - Primary ligaments: anterior talofibular ligament and calcaneofibular ligament
    - If sprain is severe, "backup" structures may sometimes be involved
      - Backup structures: posterior talofibular ligament & peroneal tendon
  - Repeat injuries not only tear healed areas but backup structures as well
    - Prevention of re-injury is of critical importance
  - Most common knee sprain: valgus force to knee ➞ medial collateral tear
    - Backup structure: anterior cruciate
  - Joint instability in knee sprain likely to be evident only in injury position
- **Ligament sprain classifications**
  - **Grade I** - Slight incomplete tear - no notable joint instability
  - **Grade II** - Moderate / severe incomplete tear - some joint instability
    - One ligament may be completely torn
  - **Grade III** - Complete tearing of 1 or more ligaments - obvious instability
    - Surgery usually required http://catalog.nucleusinc.com/displaymonograph.php?MID=7

Ankle Structures

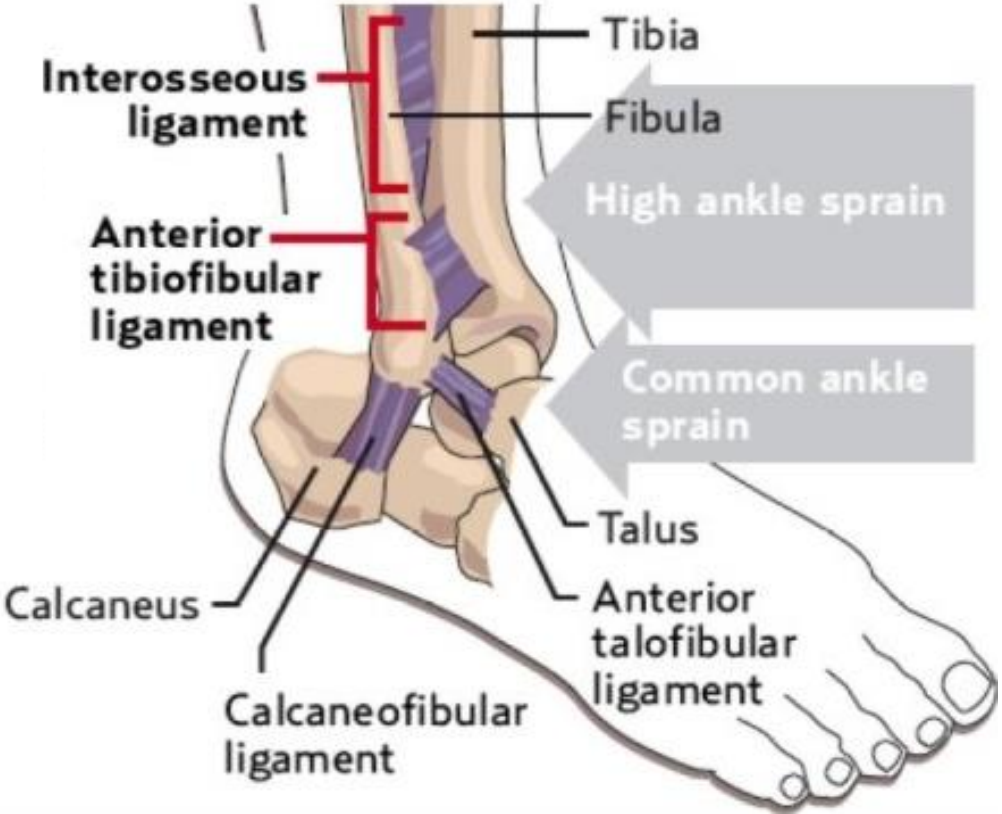




High Ankle Sprain

A **"high ankle sprain"**, also known as **"syndesmotic sprain"**, is an inury to the syndesmotic and / or "Interosseous ligaments" that joins the tibia and fibula bones of the lower leg. The distinction exists because a "high" ankle sprain occurs above the ankle joint and is **more severe than a sprain of the joint ligaments.**

A high ankle sprain results from an outward twisting of the ankle



Ligament Healing

Stage	Pathology - Healing	Treatment Implications
Inflammatory (days 1 - 4)	**Intra-articular injury (ACL & PCL)** - ↑ intra-articular pressure & hemarthrosis **Extra-articualr injury (LCL & MCL)** - Subcutaneous hematoma	- RICE (Protect & Immobilize <48 hrs) - Immobilize (→ ↓ chance osteoarthritis) - NSAID drugs - Light passive ROM exercise machines - Exercises that "cross" the joint (straight leg raises for ACL injury) - Weight bearing exercise & mobilization begun as soon as possible
Fibroplastic Proliferation (day 4 - weeks)	- Fibroblasts & angiogenic cells form scar matrix - Phagocytes remove damaged ligament debris - "Decent" tensile strength within 3 weeks	- Progress to full active ROM exercise - Resistance exercise - ↑ intensity of all types of exercises - Biomechanical evals begun at 3 wks
Remodeling Maturation (weeks to years)	- ↑ density of scar matrix - Replacement of initial or inferior collagen tissues - ↑ strength of molecular bonds of scar matrix - Near maximum tensile strength reached within 1 year **** but not back to 100% of original**	- Progression of activity (↑ intensity & duration)

Healed Ligament never attains pre-injury tensile strength due to:

↓ Number of hydroxypyridinium crosslinkages in collagen

↑ Quantity of type V (inferior) collagen vs. Type I → ↓ collagen fibril diameter

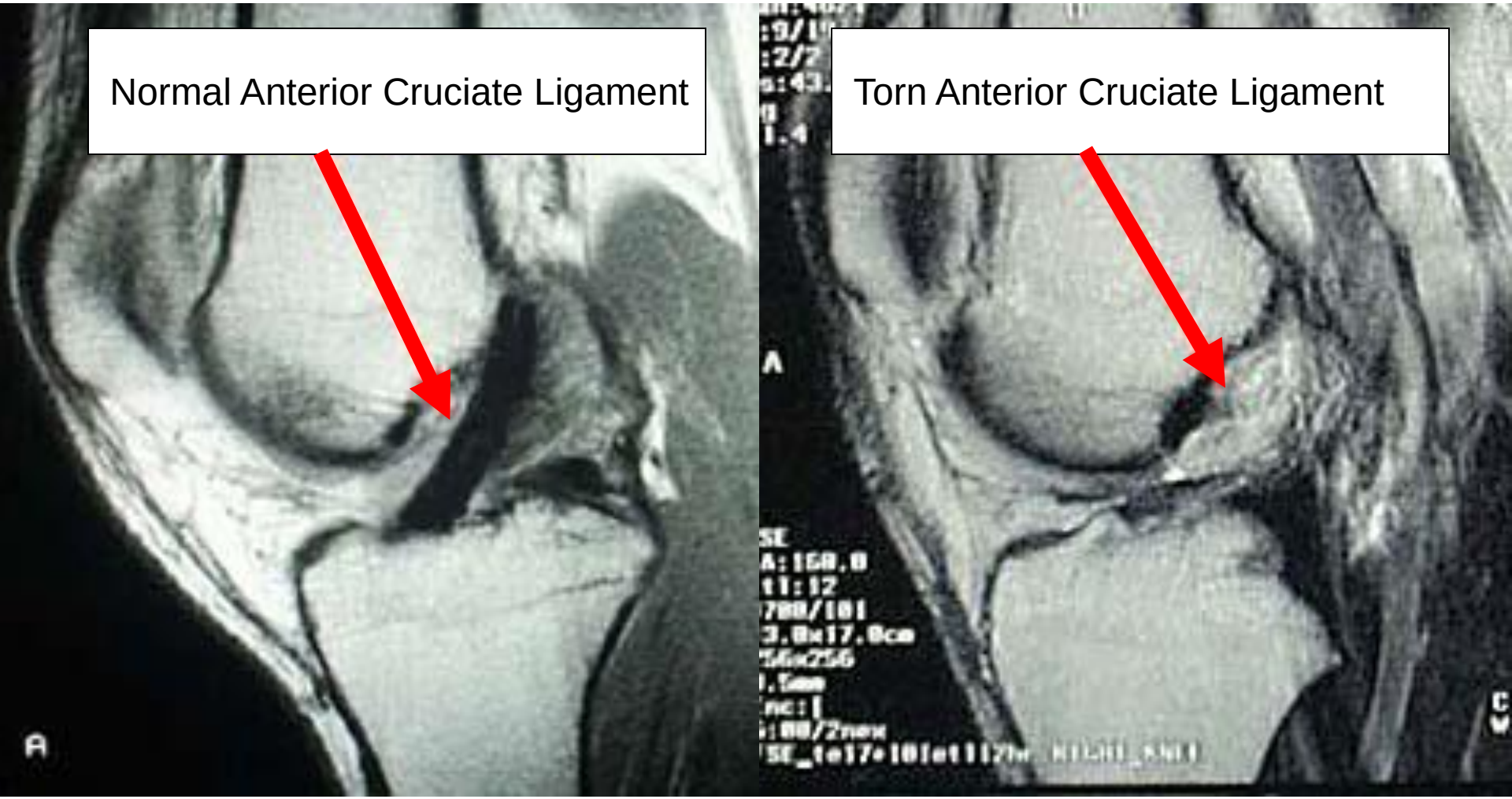
↑ Amount of fat cells, blood vessels and loose disorganized collagen in the scar

Immobilization vs. Mobilization: A Fine Line

- **Effects of immobilization on injured ligamentous tissue**
  - **GOOD**
    - Less ligament laxity (lengthening)
    - ↓ risk of osteoarthritis
  - **BAD (immobilized too long)**
    - Less overall strength of ligament repair scar
    - Protein degradation exceeds protein synthesis → net ↓ in collagen quantity
    - Production of inferior collagen types by blast cells
    - Resorption of bone occurs at site of ligament insertion
    - ↓ tissue tensile strength (50% in 6 - 9 weeks)

- **Benefits of mobilization (movement) on injured ligamentous tissue**
  - Ligament scars are wider, stronger, and are more elastic
    - In general, weight bearing & mobilization are encouraged ASAP

MRI of ACL Rupture



ACL Surgeries

Should Surgery or Surgical Reconstruction be Done?

- Yes if activities requiring lateral pivoting of the knee are to be undertaken
- Yes if knee is significantly unstable

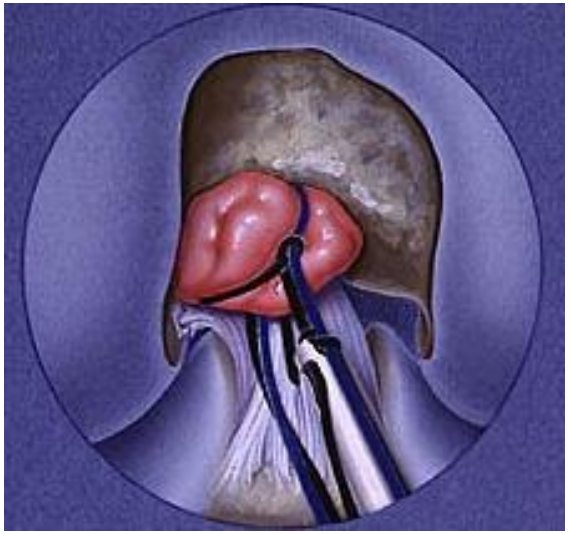
http://www.sportsinjuryclinic.net/cybertherapist/front/knee/anteriorcruciate.htm

(ACL) Ligament Repair Surgery- not done as often as in the past

Suture anchor placed in condyle of femur in and through the site of normal ACL origin

Ends of ACL approximated using the sutures from the anchor

A clot of the patients own blood is formed and attached to the suture site



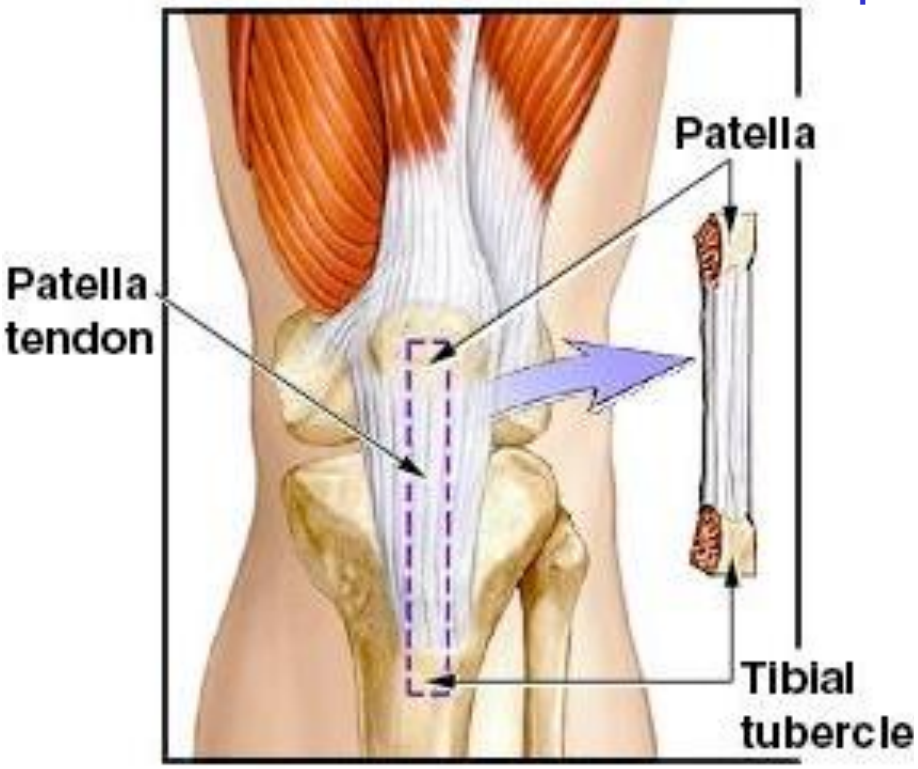
ACL Re-construction Surgery (100,000 per year in US)

Harvest of Ligament Replacements

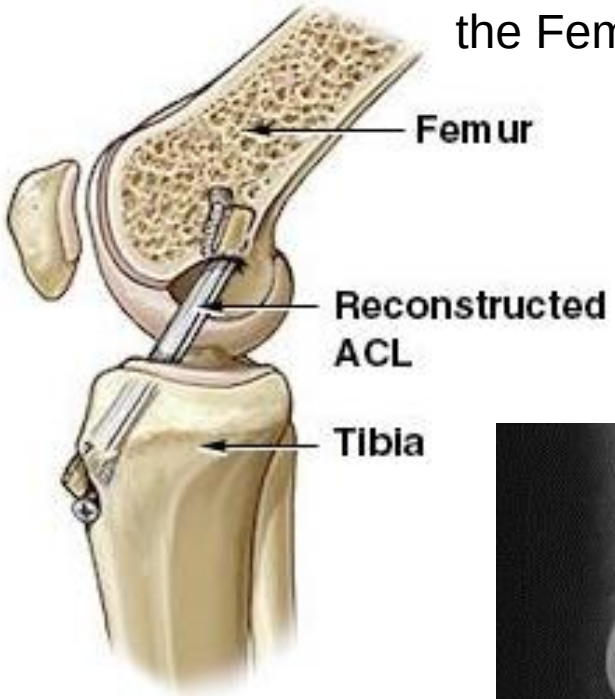
http://www.ehealthmd.com/library/acltears/ACL_surgery.html

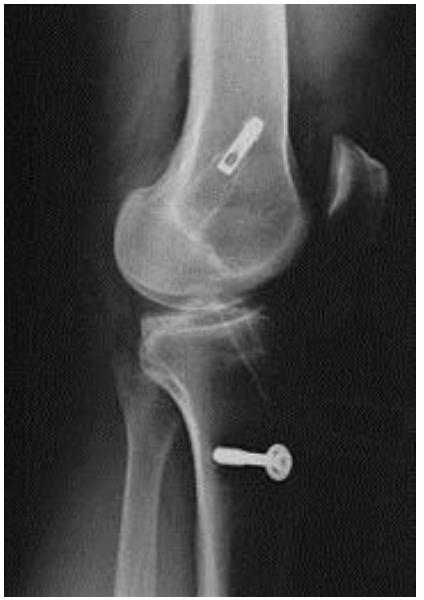
http://orthopedics.about.com/od/aclinjury/p/rehab.htm

- **Patient's Patellar Tendon - Hamstring Tendon ("Autografts")**
- **Cadaver ACL's & achilles that are frozen and preserved ("Allografts")**



Grafting of Replacement Into Holes Drilled into the Femur & Tibia





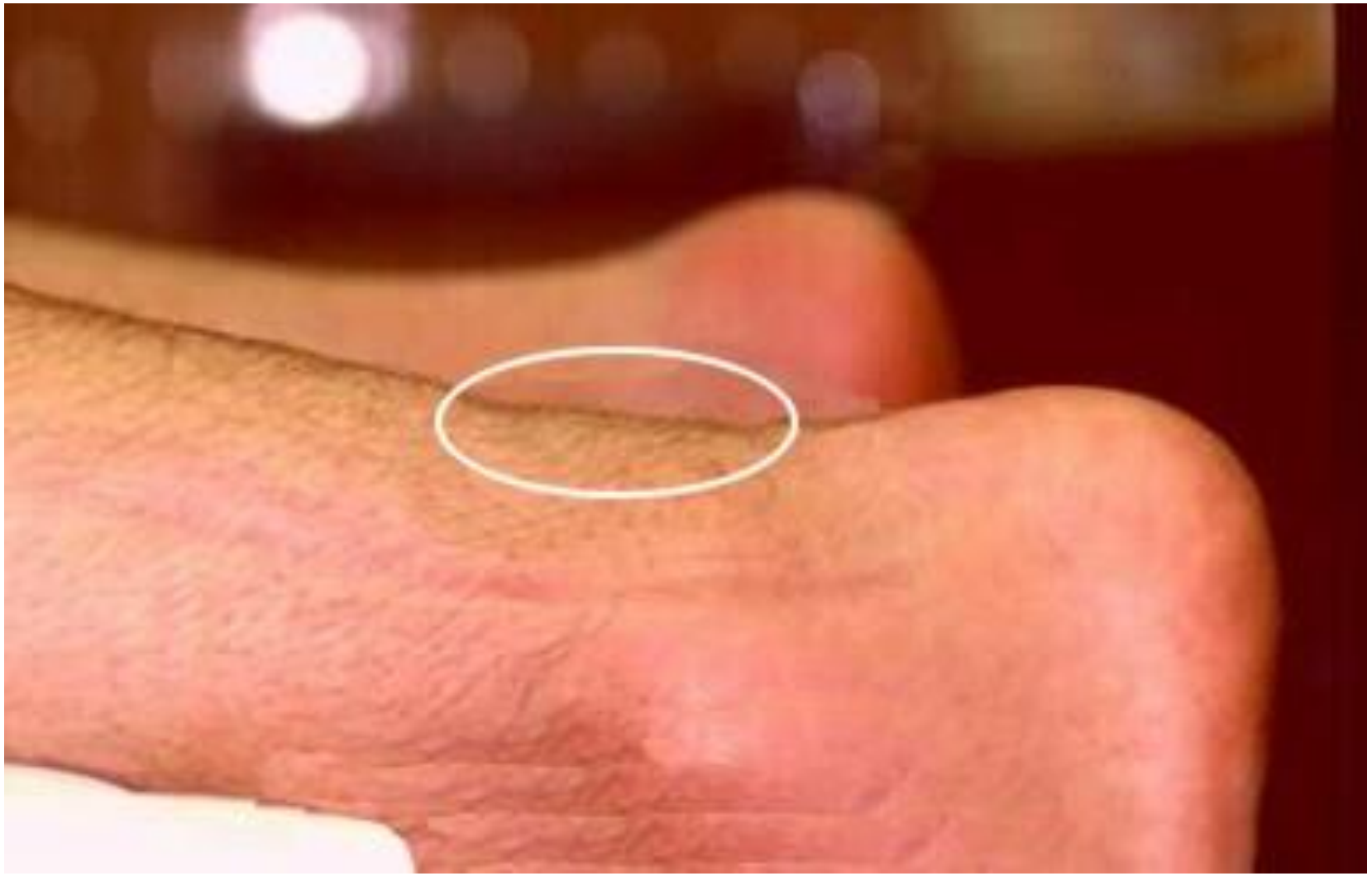
- **Kneeling on the donor knee may be problem for a while after surgery**
- **<u>Rehab</u>: mobilize and bare weight ASAP; at 4wks-walking & light exercise; 12 wks-test bench marks; move on to more aggressive rehab based on test bench marks.**
- **<u>Concerns</u>: infection, bone bruises in the femur condyle may ↓ effectivness of surgery, simultaneous meniscal injuries may have to be addressed, intra-articular fibrosis, future OA**

Tendon Rupture

- **Tendon** - dense regular tissue attaching muscle to bone
  - Forces of 2000 psi have been recorded in the human Achilles (running)
  - Max tensile strength is 4X as strong as max force production in muscle
- **Tendon Rupture** - most often seen in Achilles tendon
  - After age 30, blood flow ↓ in an area 4-6 cm above calcaneal insertion
    - Most tears occur in this area (men - 6:1 gender ratio) 30 – 50 years of age
  - Tendon can still function with as little as 25% of the fibers intact
  - Complete tendon rupture diagnosed from the following symptoms:
    - Patient cannot stand in a plantar flexed position
    - Palpable & sometime visible gap above calcaneous is present
    - Excessive passive dorsiflexion exists
    - Absence of plantar flexion when calf muscle is squeezed (Thompson test)
- **Contributing factors to Tendon Rupture**
  - Diabetes
  - Age
  - Disuse (immobilization)
  - Corticosteroid injections
  - Use of certain Antibiotics

Tendon Rupture

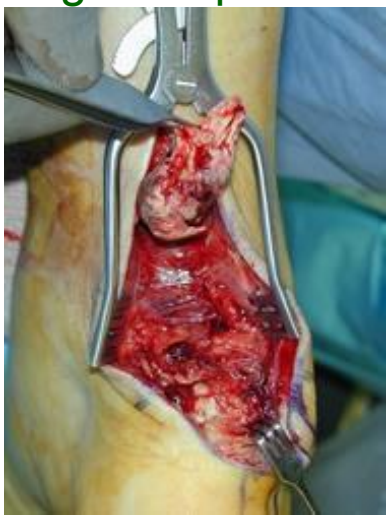
Note circled area outlining the rupture gap

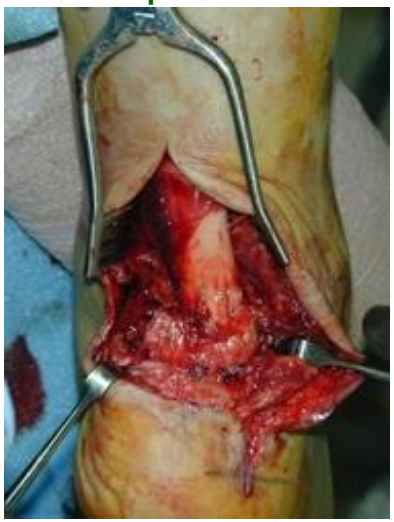


Tendon Rupture

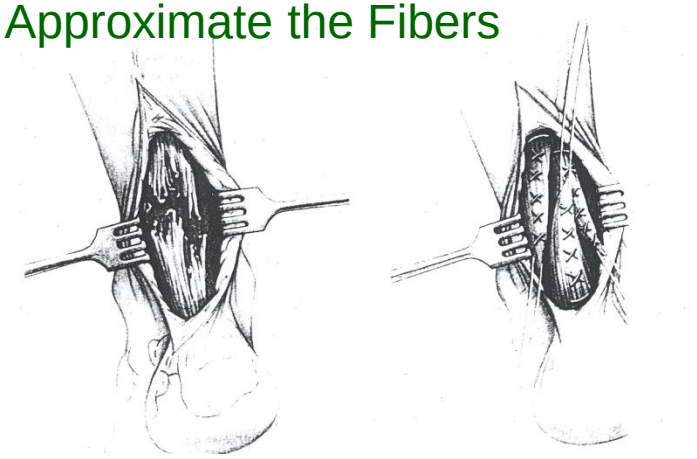
- Tendon rupture treated with casting or surgery
  - Usually surgery is best, especially when tear is complete
    - Results in maximal restoration of both optimal length and tensile strength
    - Surgeon removes all necrotic and inflammatory tissue then sutures ends together
      - This may require an incision into the tendon
    - After surgery, foot is immobilized in plantar flexed position and casted
    - At 4 weeks, foot is brought to neutral position & re-casted
    - At 6-8 weeks, cast is removed & weight bearing, stretching & ROM exercises begin
      - Aggressive stretching begun to allow for proper collagen fiber alignment
    - Bounding type exercises begin no earlier than 12 weeks post surgery
  - Casting alone may be done in partial tears

Surgical repair done with “Whip Stitch” sutures





Surgical Repair of Achilles Tendon Using Bunnell Cross-stitch Sutures to Approximate the Fibers



Fracture Types

Simple (closed) - little or no bone displacement

Compound - fracture ruptures the skin & bone protrudes

Green stick - occurs mostly in children whose bones have not calcified or hardened

Transverse - crack perpendicular to long axis of the bone - displacement may occur

Oblique - diagonal crack across the long axis of the bone - ↑ chance of displacement

Spiral - diagonal crack involving a "twisting" of the bone about the longitudinal axis (occurs in skiing when bindings are too tight)

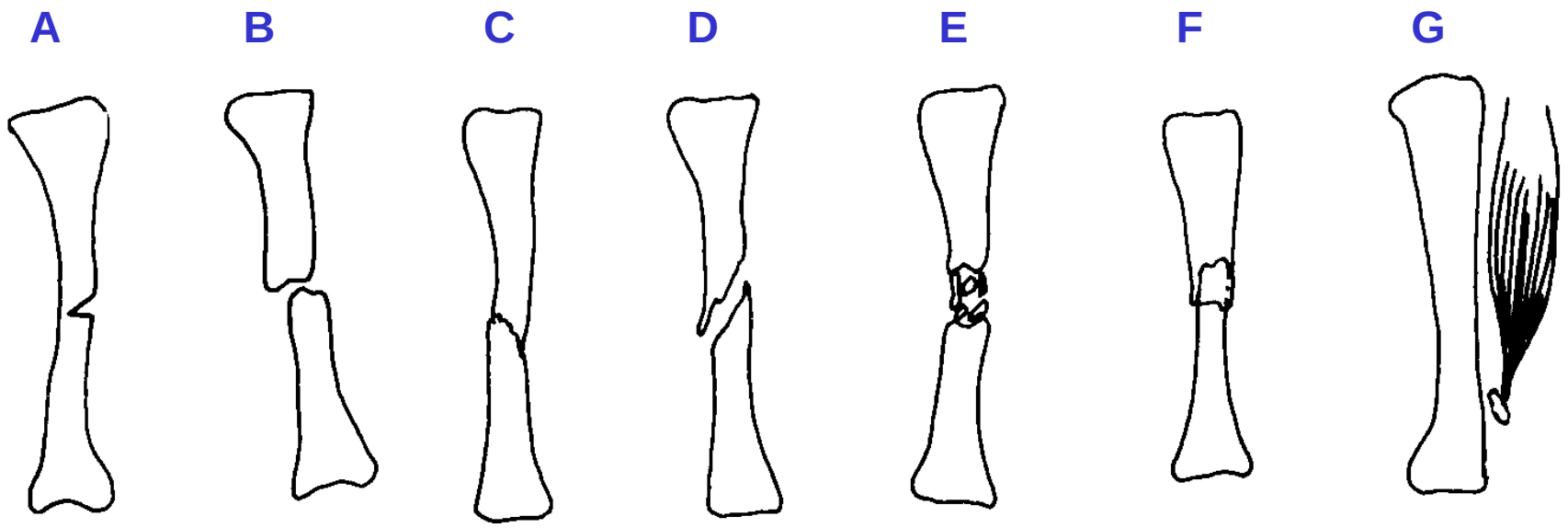
Comminuted (blowout - explosive) - "crushing" fracture - more common in elderly – may require screws, rods, & wires - may cause permanent discrepancy in leg length

Impacted - one end of bone is driven up into the other - may result in length discrepancy

Depressed - broken bone is pressed inward (skull fracture)

Avulsion - fragment of bone is pulled away at origin or insertion point

Fracture Types



A. Greenstick

B. Transverse

C. Oblique

D. Spiral

E. Comminuted

F. Impacted

G. Avulsion

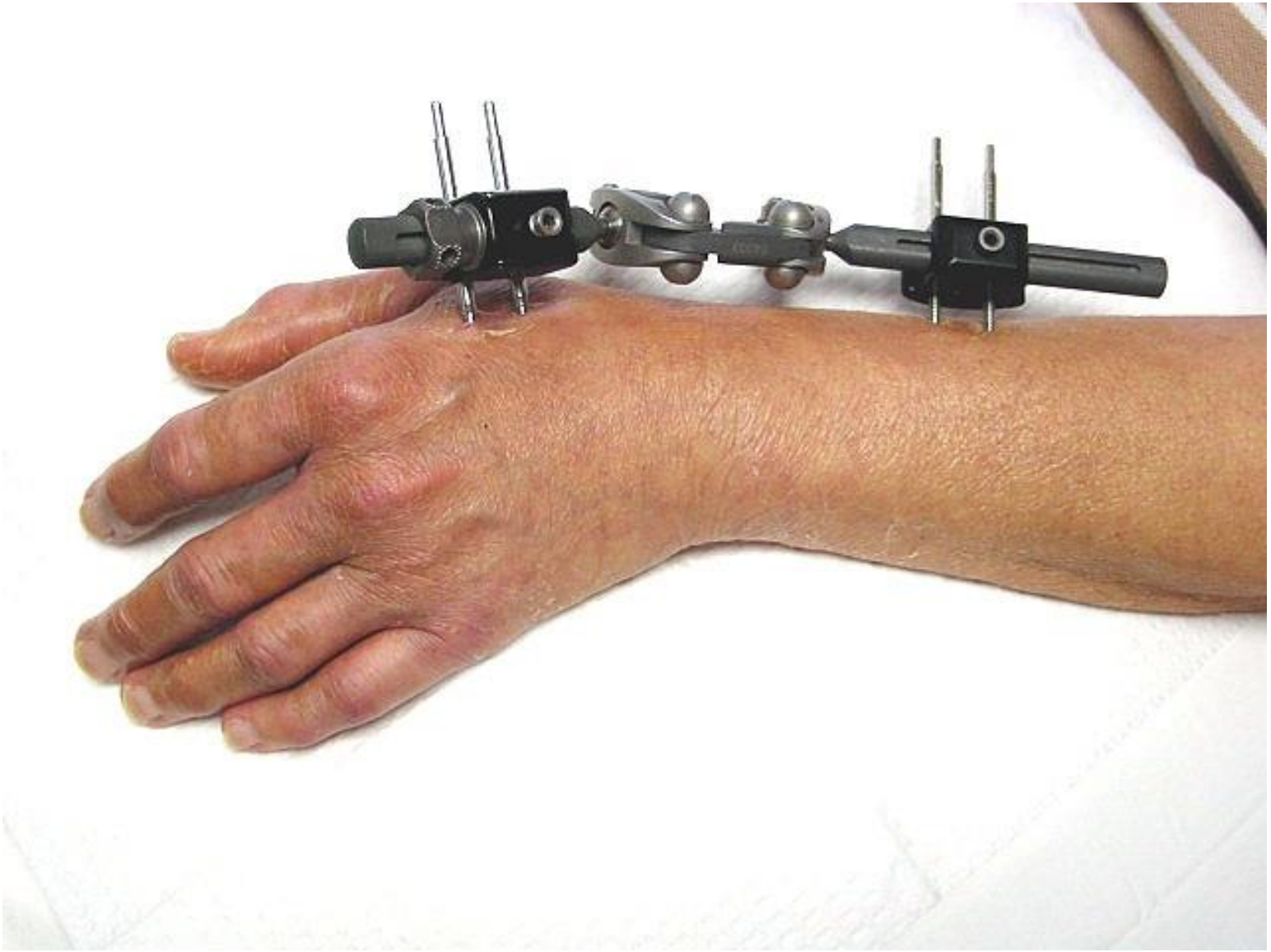
Points to Remember with Regard to Fracture Healing

- Fractures are treated by reduction (realignment) & immobilization
- In most cases, simple fractures heal in approximately 6 - 8 weeks
  - Bones of elderly heal slower because of poor circulation
- Two types of bone healing: Primary & Secondary

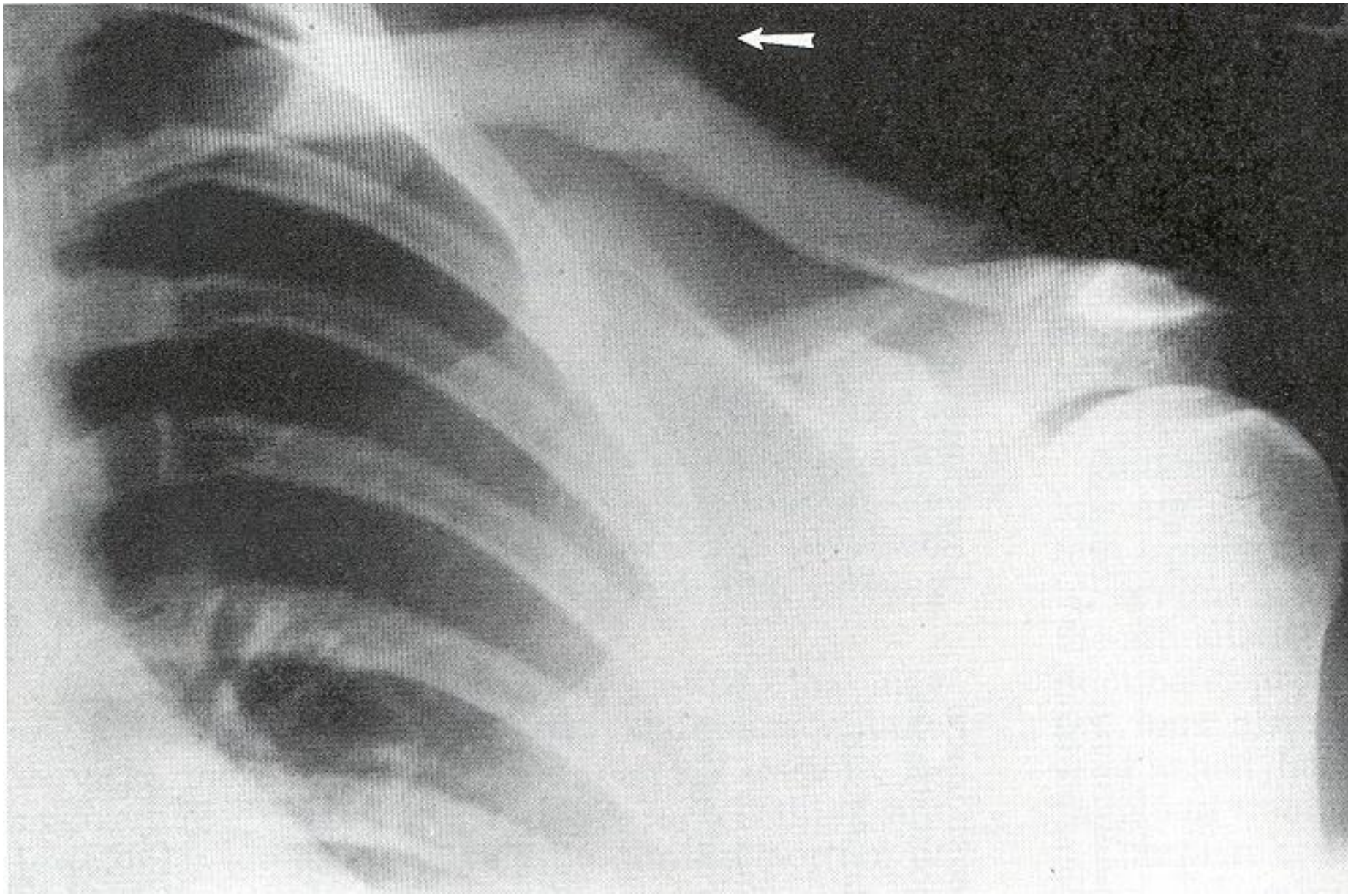
  - **Primary** - healing without external fibrocartilagenous callus formation
    - Seen with rigid (exact) internally or externally fixated reductions
    - Similar to Haversion Remodeling (normal homeostatic bone metabolism)
    - Rate of healing the same as secondary bone healing

  - **Secondary** - healing with a small gap between bone ends
    - External fibrocartilagenous callus forms leaving area of ↑ girth upon healing

External Fixator Device Facilitating Primary Bone Healing



Fracture of Clavicle with Beginnings of External Fibrocartilagenous Callus Formation Easily Seen (arrow)



Steps in Secondary Fracture Healing

1. Hematoma Formation & Inflammatory Phase (Reactive Phase)

- **Bleeding from bone, bone periosteum, & tissues surrounding the bone**
  - Formation of fracture hematoma & initiation of inflammatory response
- **Induction (stimulus for bone regeneration) - caused by**:
  - ⬇ Oxygen ➡ bone necrosis (fractured bone becomes anoxic immediately)
  - Disruption of & creation of new bioelectrical potentials
- **Inflammatory response - lasts between days 2- 9 following injury:**
  - Cytokines, prostaglandins & other agents summon & mediate inflammation
  - Neutrophils, macrophages, & lysosomes clear necrosed bone and other debris
  - A fibrin mesh forms and “walls off” the fracture site
    - This fibrin mesh serves as “scaffold” for fibroblasts and capillary buds
  - Capillaries grow into the hematoma from periosteum & bring fibroblasts
  - Granulation Tissue formation completed

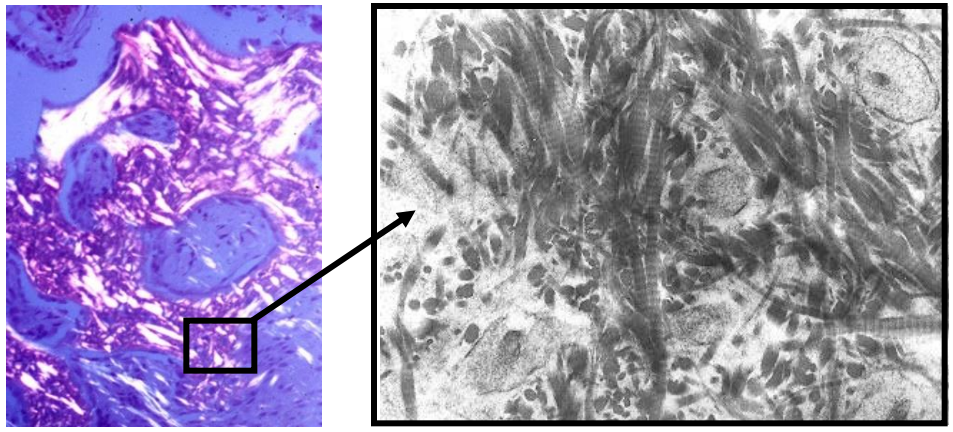
    - Note: In a fracture at any age, the new blood supply arises from periosteum
      - Normally 3/4 of healthy bone blood flow in adult bone arises from endosteum
        - Blood flow in an adult much switch to the periosteum.
      - In children, normal blood flow already comes from periosteum ➡ ⬇ healing time

Steps in Secondary Fracture Healing

2. Firbrocartilagenous callus formation – last an average of 3 weeks (Referred to as the "Reparative Phase")

- Chondroblasts & osteoblasts arrive from periosteum (some from endosteum)
  - Distal to the fracture gap, **osteoblasts** secrete **Woven Bone**
    - Woven Bone - Immature bone with collagen arranged in random arrays
  - Proximal to the fracture gap, **chondroblasts** secrete **Hyaline Cartilage**
  - Within the hematoma **fibroblasts** secrete **Collagen**
- Within 2-3 days, these tissues span the break
  - This tissue is called **F**ibro - **C**artilagenous **C**allus and serves to "splint" the bone
  - FCC is formed both in and around the fracture site
  - Osteoblasts in outer layer of FCC begin to lay down new hard bone
  - In a **Non-Immobilized Fracture**, the FCC has poor vascularization
    - Poor vascularization → ↓ bone production → incomplete periosteum at repair site

Woven Bone



Steps in Secondary Fracture Healing

3. Hard Bony Callus Formation & Ossification - weeks to months (still in "Reparative Phase")

- By now, fracture fragments are joined by collagen, cartilage, & woven bone
  - These temporary tissues begin to be replaced
    - Osteoblasts form trabecular bone along fracture periphery (external callus)
    - Trabecular bone is then laid down in the fracture interior (internal callus)
- Ossification (mineralization) starts by 2-3 weeks & continues for 3-4 months
  - Callus is replaced by Lamellar (Cancellous) bone, this is called boney substitution
  - Alkaline phosphatase is secreted by osteoblasts
    - Blood serum alkaline phosphatase levels indicate rate of bone formation
- In a **Non Immobilized Fracture**, more "cartilage" than bone is laid down
  - This must later be replaced by normal cancellous bone
    - Results in a longer healing time and fractured area remains weak for a longer period
- ➡ Fractures should be reduced (immobilized) within 3-5 days

4. Bone Remodeling - months to years ("Remodeling Phase")

Fracture is mechanically stable at 40 days – adequate strength in 3-6 months

- Excess material inside bone shaft is replaced by more compact bone
  - Final remodeled structure is influenced by optimal bone stress

Bioelectric Factors in Bone Repair & Nonunion Fractures

- Areas of growth & repair in fractures have shown to be **Electronegative**
  - This electronegativity is thought to:
    - Play a major role in induction
    - Stimulate osteoblast activity
  - Compression of fractured bone ends seems to ↑ electronegativity
    - ↑ electronegativity → ↑ rate of hard bone deposition
    - This presents a strong case for using internal or external fixation
- Non-union fractures (fractures that fail to heal within 5 months)
  - Caused by excessive age, infection, motion at fracture site
  - **Treatment 1. Electrical Stimulation (20 amps for 12 weeks)**
    - Electrodes are implanted in the fibrous tissue at fracture site
  - **Treatment 2. Bone Grafting**
    - Small quantities of bone from a non-critical area (ex: pelvis) are harvested
    - The harvested bone is then implanted at the non-union fracture site

Adverse Effects of Immobilization (Cast Disease)
(most changes are reversible)

- Muscle Atrophy
- ⬇ calcium content in surrounding bone area
- Resorption and weakening of tissues at sites of ligament attachments
- No stress forces on an immobilized joint ➞ thinning of articular cartilage
- Intra- and extra-articular adhesions may form and cause joint stiffness
- Sensory dissociation (light touches interpreted as painful)

Therapeutic Implications for Treating Fractures

- Do active ROM exercises to joints above and below immobilized region
- Do resistive ROM exercises to muscle groups that are not immobilized
- Once the cast or immobilization device has been removed:
  - Do gentle but progressive resistance exercises of all immobilized joints
  - Evaluate strength of joint(s) and compare to non-injured counterparts
    - Return to vigorous activity only after strength discrepancy $\leq$ 15%

Factors Enhancing Bone Healing

- Youth
- Early Immobilization of fracture fragments
- Maximum bone fragment contact
- Adequate blood supply
- Proper Nutrition
  - Vitamines A&D
- Weight bearing exercise for long bones in the late stages of healing
- Adequate hormones:
  - Growth hormone
  - Thyroxine
  - Calcitonin

Factors Inhibiting Bone Healing

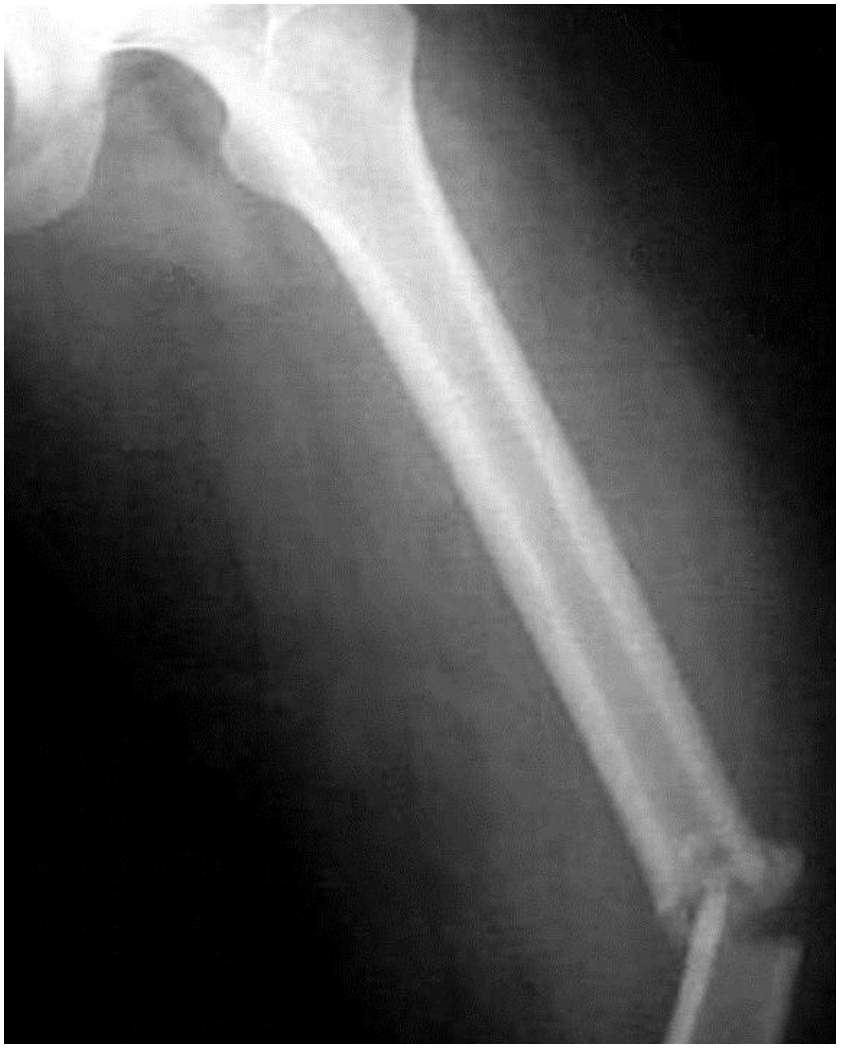
- Age: Fractured Femur Healing Time:
  - infant: 4 weeks
  - teenager: 12 to 16 weeks
  - 60 year old adult: 18 to 20 weeks
- Extensive local soft tissue trauma and excess bone loss
- Inadequate immobilization (motion at the fracture site)
- Infection
- Use of NSAIDS or steroids during inflammatory phase
- Use of tobacco during callus formation

Factors Inhibiting Bone Healing

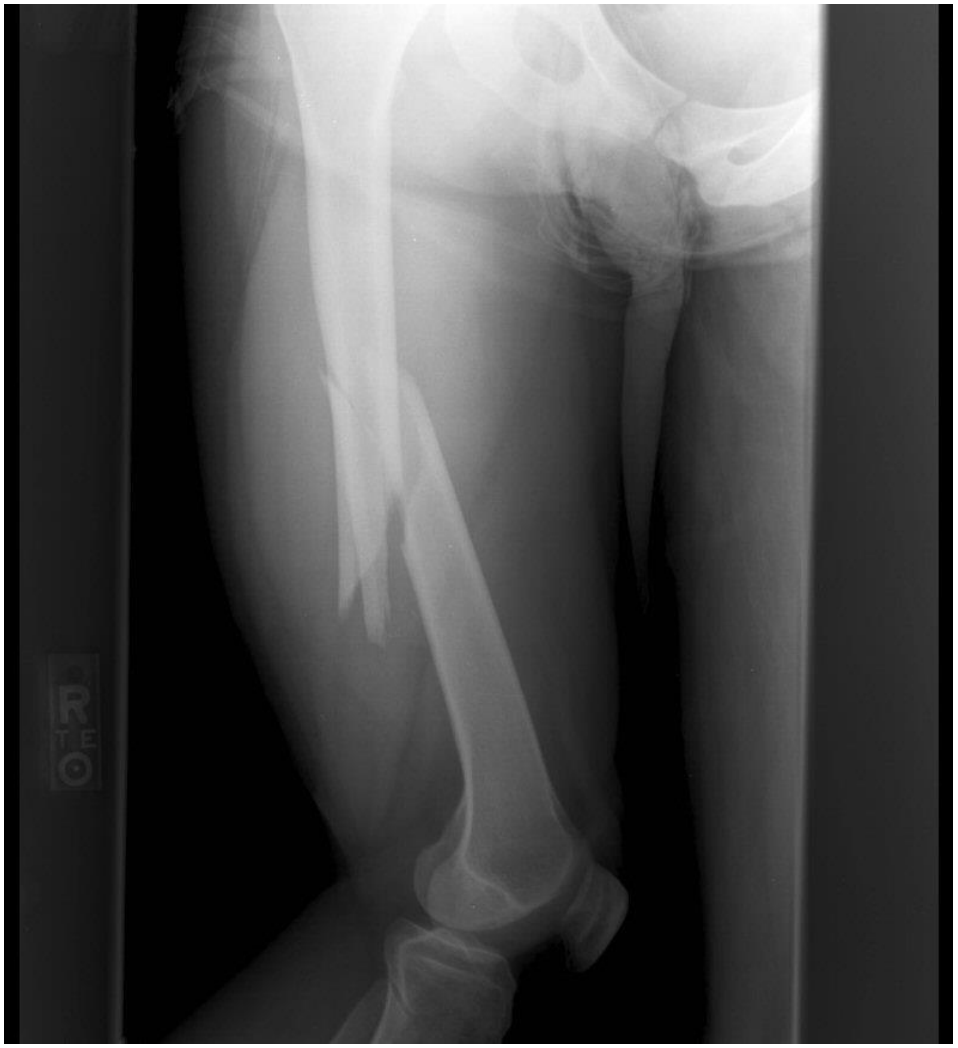
- **Smoking – Delays both bone and ligament healing**
  - Reduces chondrogenesis (laying down of collagen by osteocytes)
    - Reduced Collagen type II protein expression during initial healing
    - Reduced cartilaginous callus formation and total callus area
    - Replacement of callus with hard bone is delayed in smokers
    - The start of the remodeling phase is delayed in smokers
    - Smokers showed a lower overall Type I collagen protein expression

Animal Study, Journal of Orthopedic Research, 24; 2006

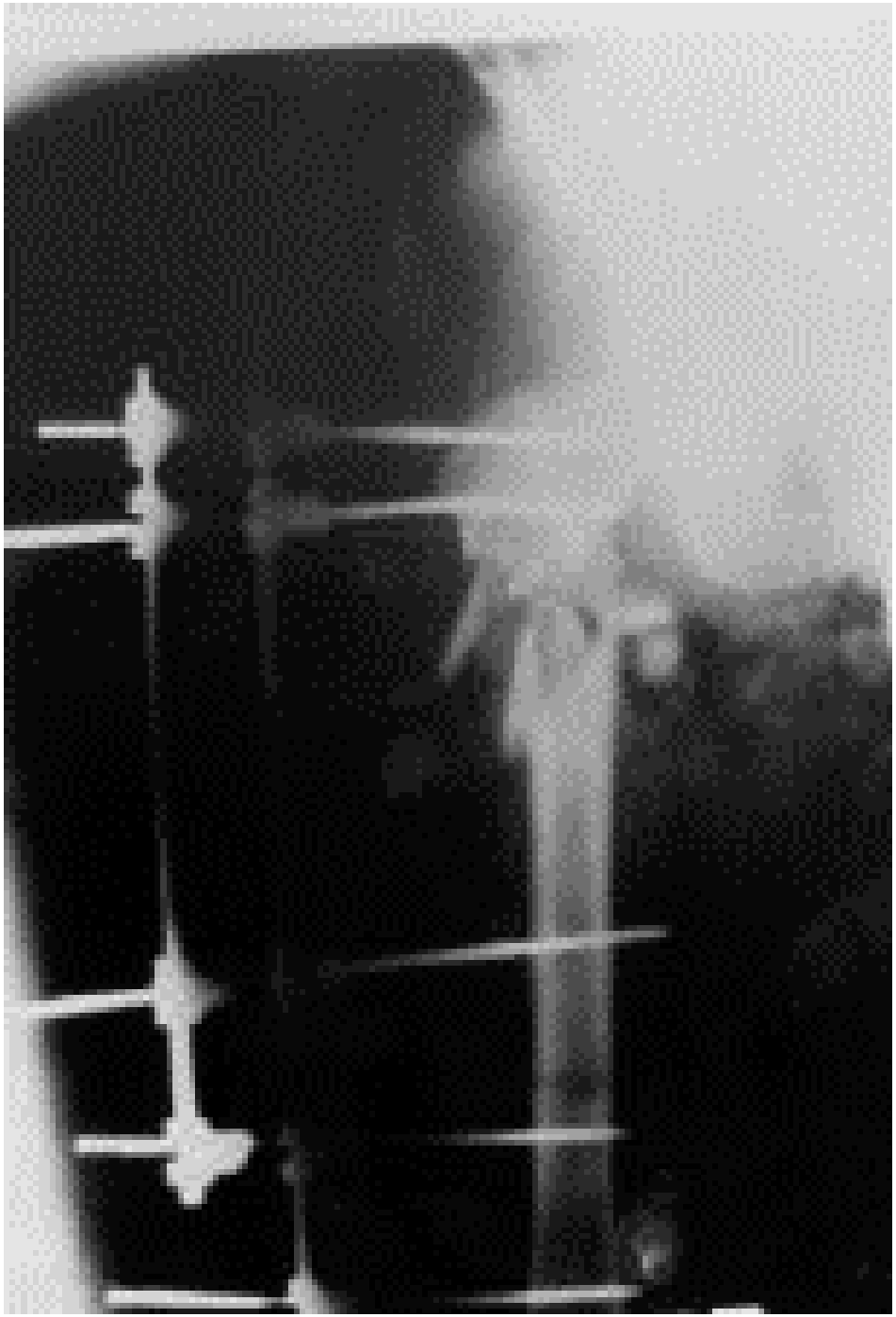
Compound Femur Fracture from Fall from Height



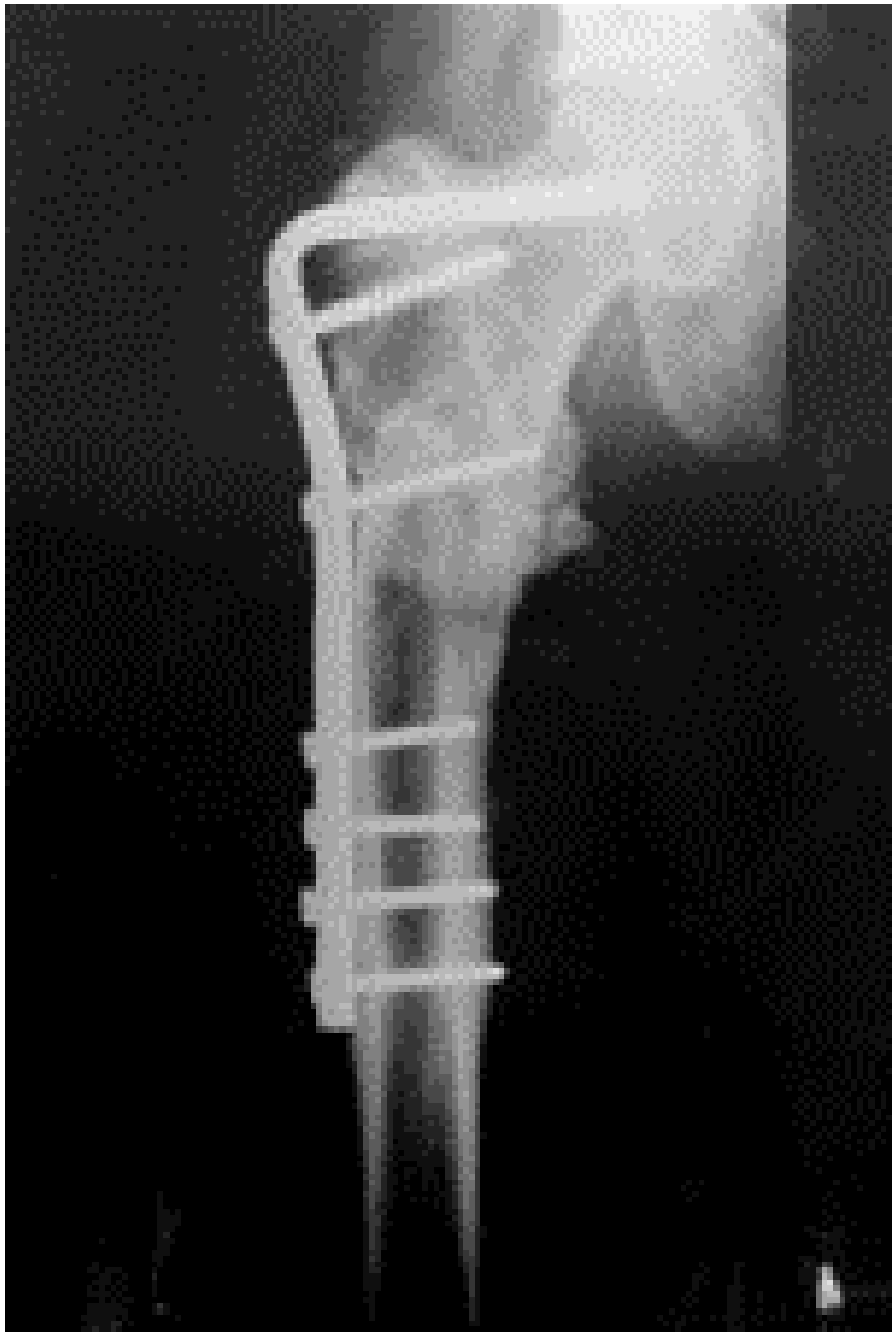
Cominuted Femur Fracture in 25 year old “Pudding Wrestler”



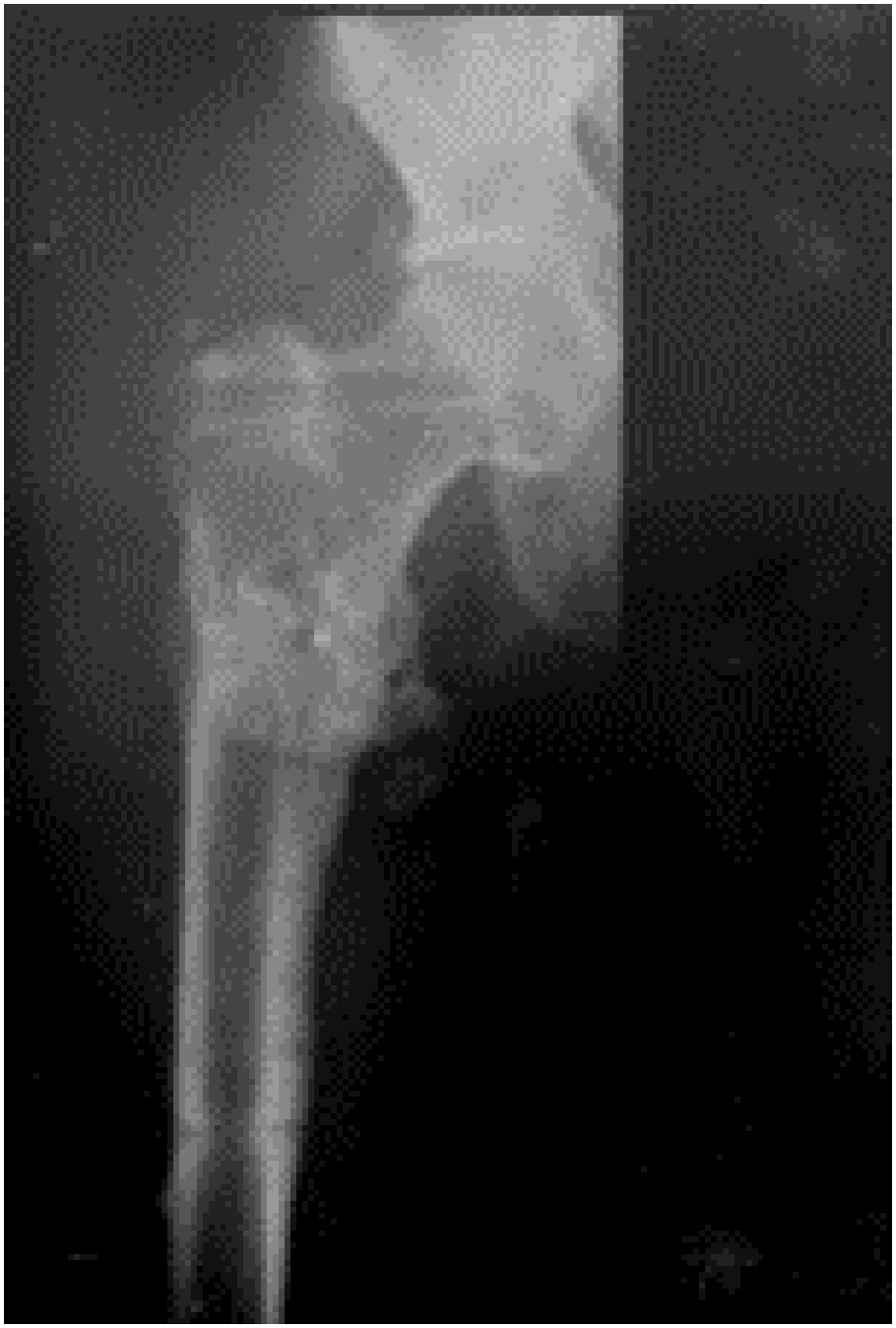
Hip Fracture First Reduced with External Fixation



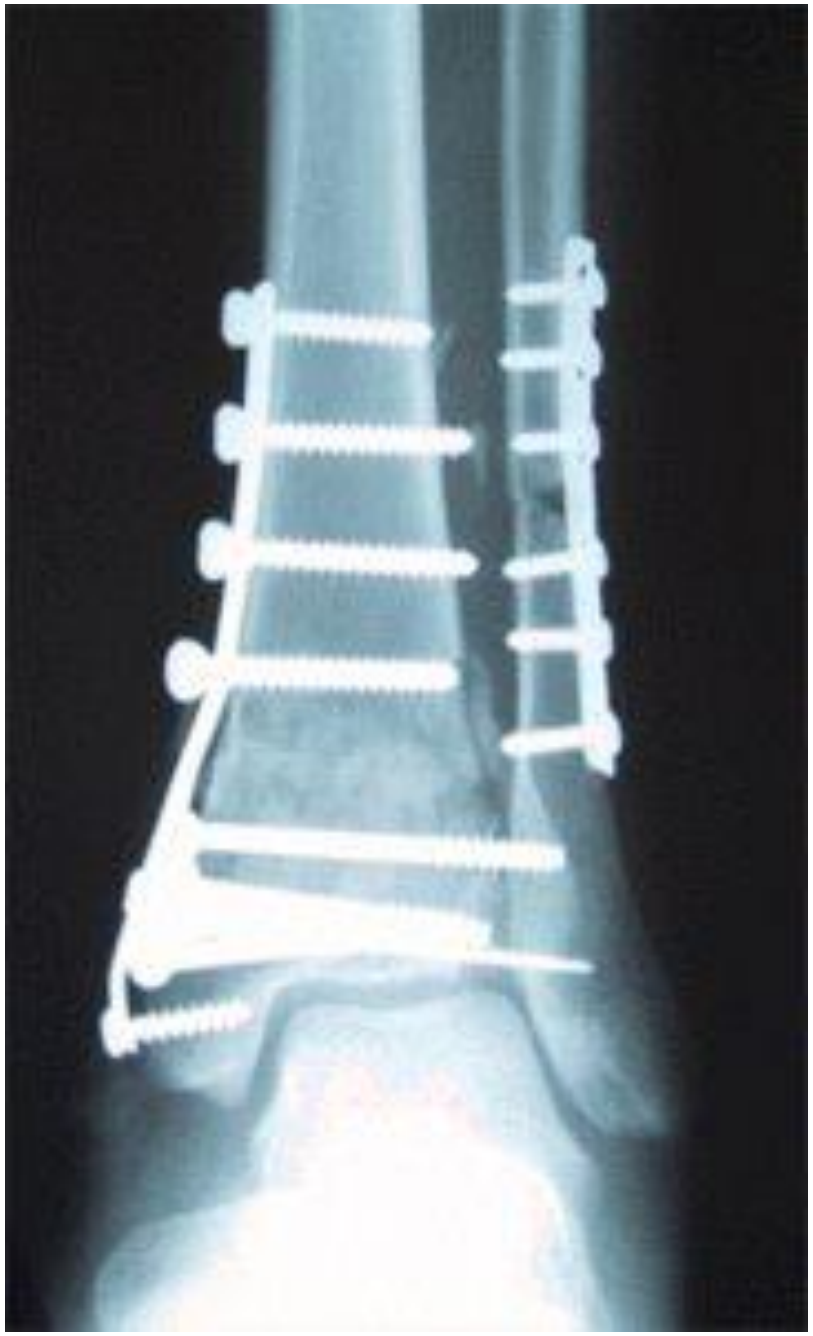
Hip Fracture:
2nd Surgery:
External Fixation
Now Replaced with
Internal Fixation
(Plate & Screws)



Hip Fracture:
3rd Surgery:
Pins Removed

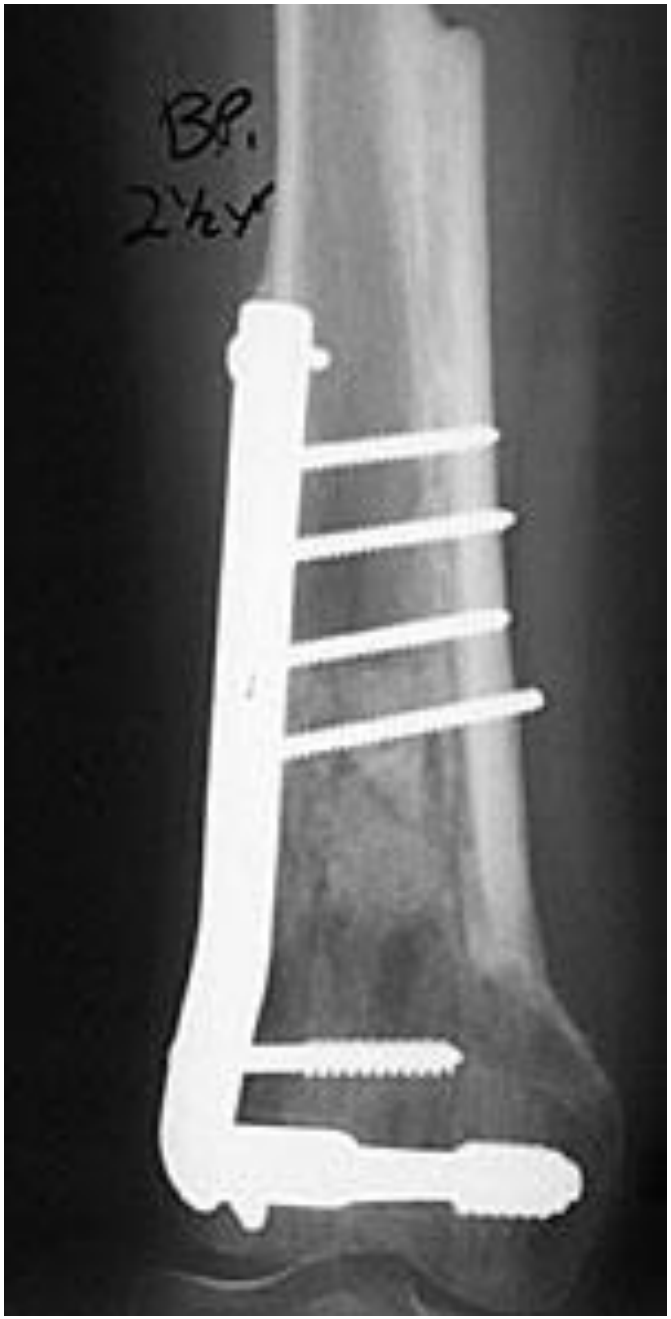


Fracture of Lower Tibia & Fibula with Plates and Screws

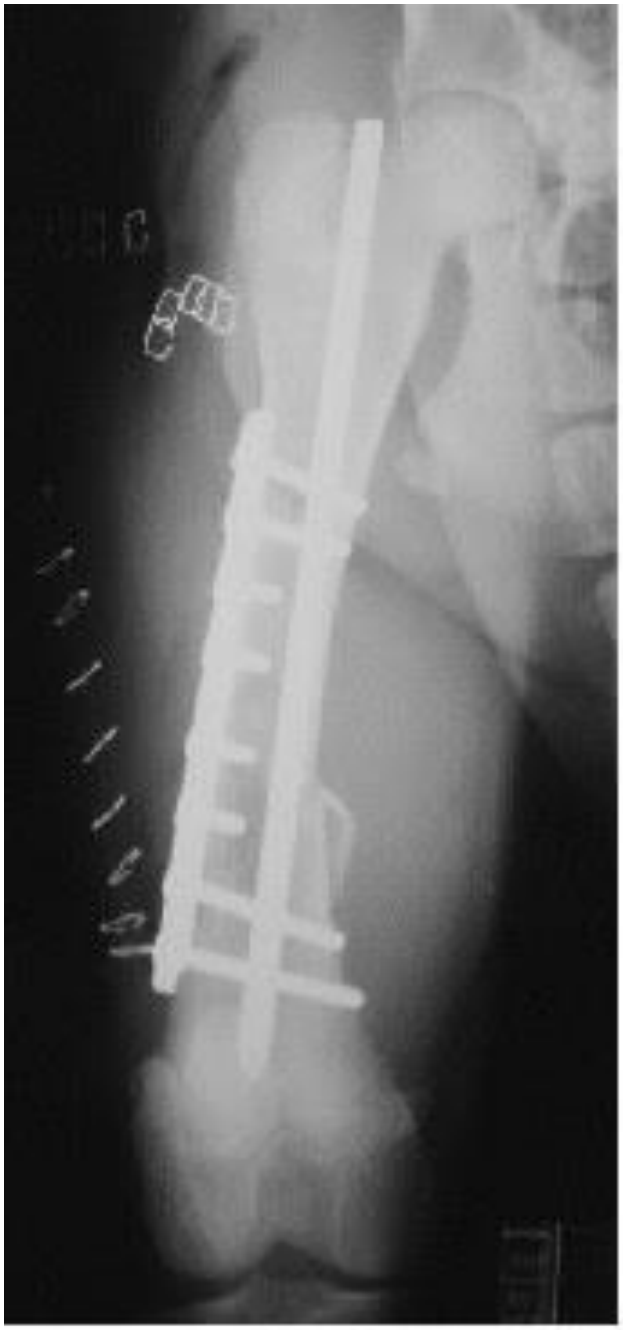


Comminuted Femur Fracture Reduced with Compression Plate & Screws + Bone Graft

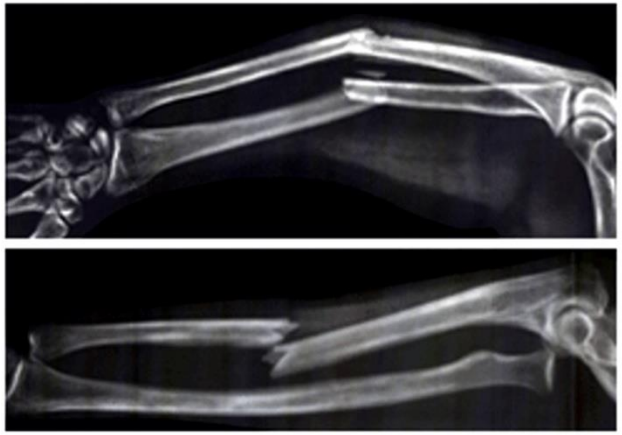
Note: bone is the second most transplanted tissue after blood.

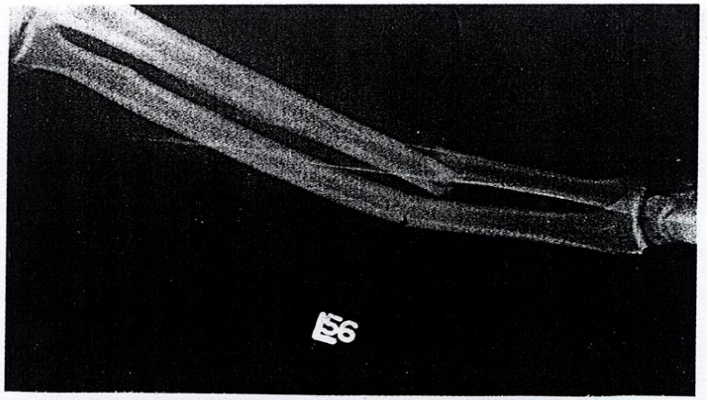


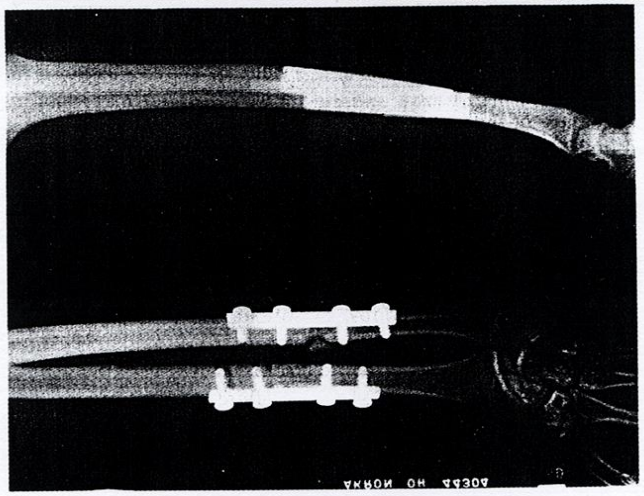
Comminuted Femur Fracture Reduced by Intramedullary Rod, Plates & Screws in a Dog



The Common “Broken Arm”

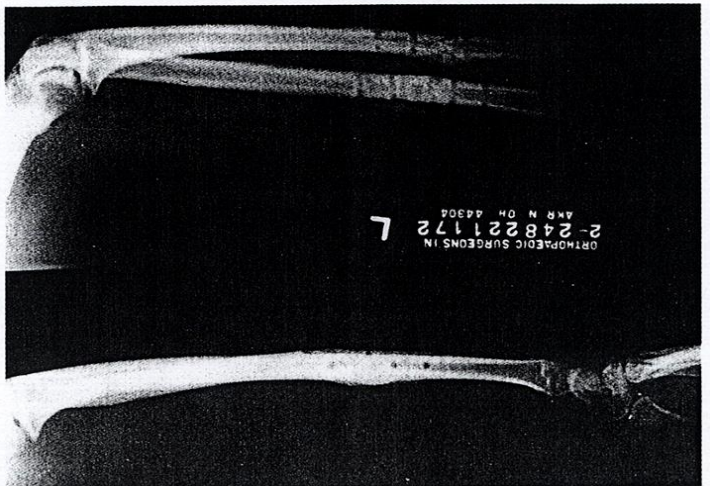






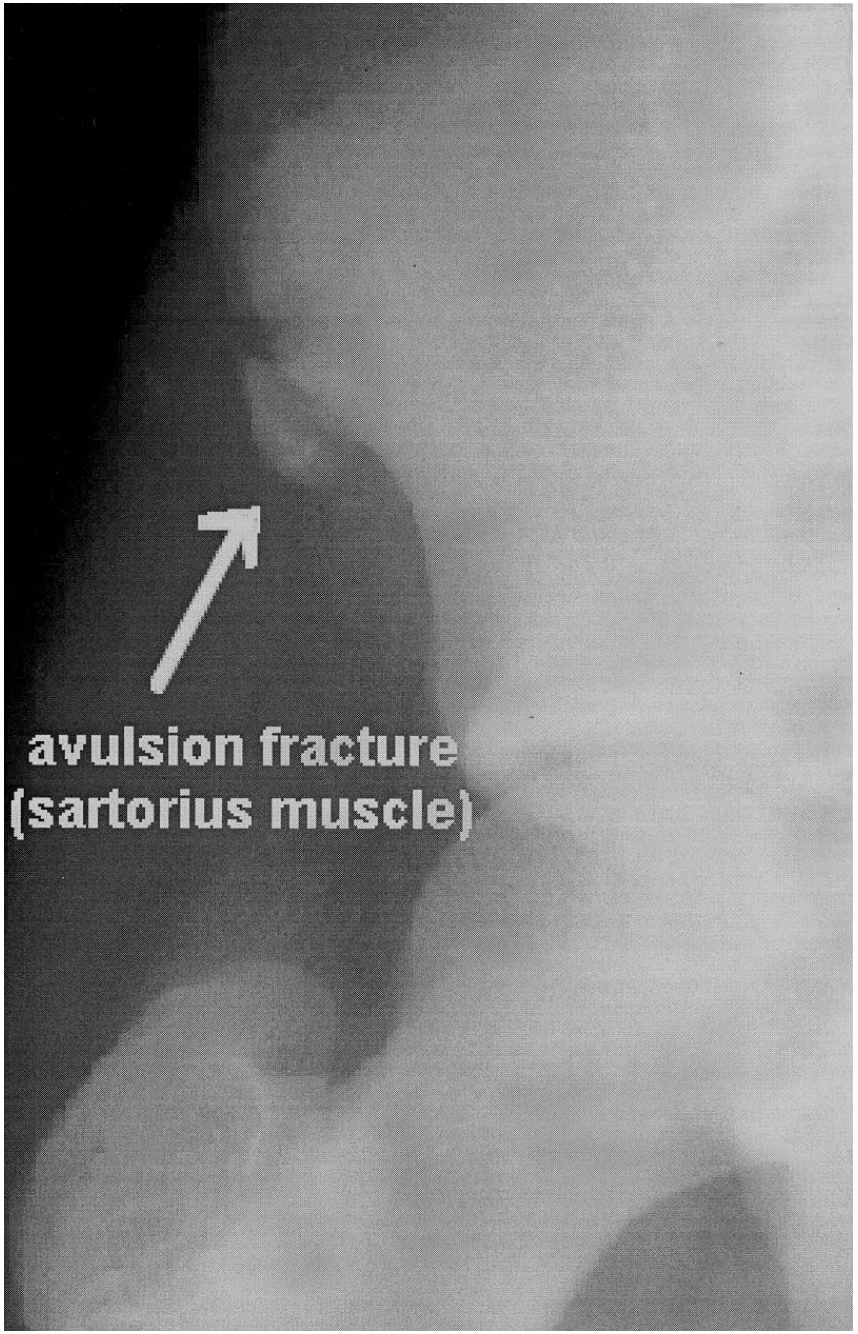
Fracture of Radius & Ulna Reduced with Pressure Plates and Screws

Note Bottom Picture Showing Remnant Signs of Fracture Repair 1 year later



Avulsion Fracture:

Sartorius Muscle Attachment Area is Pulled Away From Ilium



Falls & Hip Fractures – the Scourge of the Elderly

- Falls are the leading cause of accidental death in persons > 65 yrs
- 9,500 older Americans die of falls each year
- 5% of falls result in fractures, 1% result in hip fractures

http://www.aafp.org/afp/20000401/2159.html

- Hip fractures - second most common cause for entry in nursing home
- One in six women will have a hip fracture in her lifetime
  - 90% are in women ages 65 and older
- Over 300,000 people are hospitalized with a hip fracture every year
- 30% of those entering a hospital with a hip fracture never come out !
  - Blood clots (DVT from immobility), Pneumonia, CHF, heart attack
- 20% of people with hip fractures die within a year
- 50% of hip fracture patients cannot return home or live independently
- 65,000 women die each year from complications of a hip fracture
  - Compare this with 43,000 who die from breast cancer

http://my.clevelandclinic.org/disorders/osteoporosis/hic_hip_fractures_in_the_elderly.aspx

Avascular Necrosis

- **Avascular Necrosis** – Disturbance in blood supply ➞ bone cell death
  - 4.5 : 1 male : female ratio
  - Most often seen in the femoral head and femur (hip)
  - Causesd by: http://www.mayoclinic.com/health/avascular-necrosis/DS00650
    - Fractures and dislocations (20% of dislocations develop AN)
    - Overuse of corticosteroids
    - Excessive alcohol produces fatty blockages in blood vessels that feed bone
    - ⬆ intracapsular pressure ➞ ⬇ blood supply to bones
  - Treatment: NSAID's for pain + range of motion exercises
    - Drugs to block fatty deposition in the blood vessels supplying the joint
    - Surgery: ⬇ intracapsular pressure or, more commonly, **joint replacement**