PLEASE CLICK ON THE FOLLOWING LINK TO WATCH THE LECTURE ONLINE:-

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Delayed healing—causes and treatment principles

AO Trauma Basic Principles Course

Learning objectives

- List factors leading to nonunion
- Understand the difference between delayed union and nonunion
- Discuss how these complications might be avoided in fracture management
- Outline the principles of treatment of nonunion

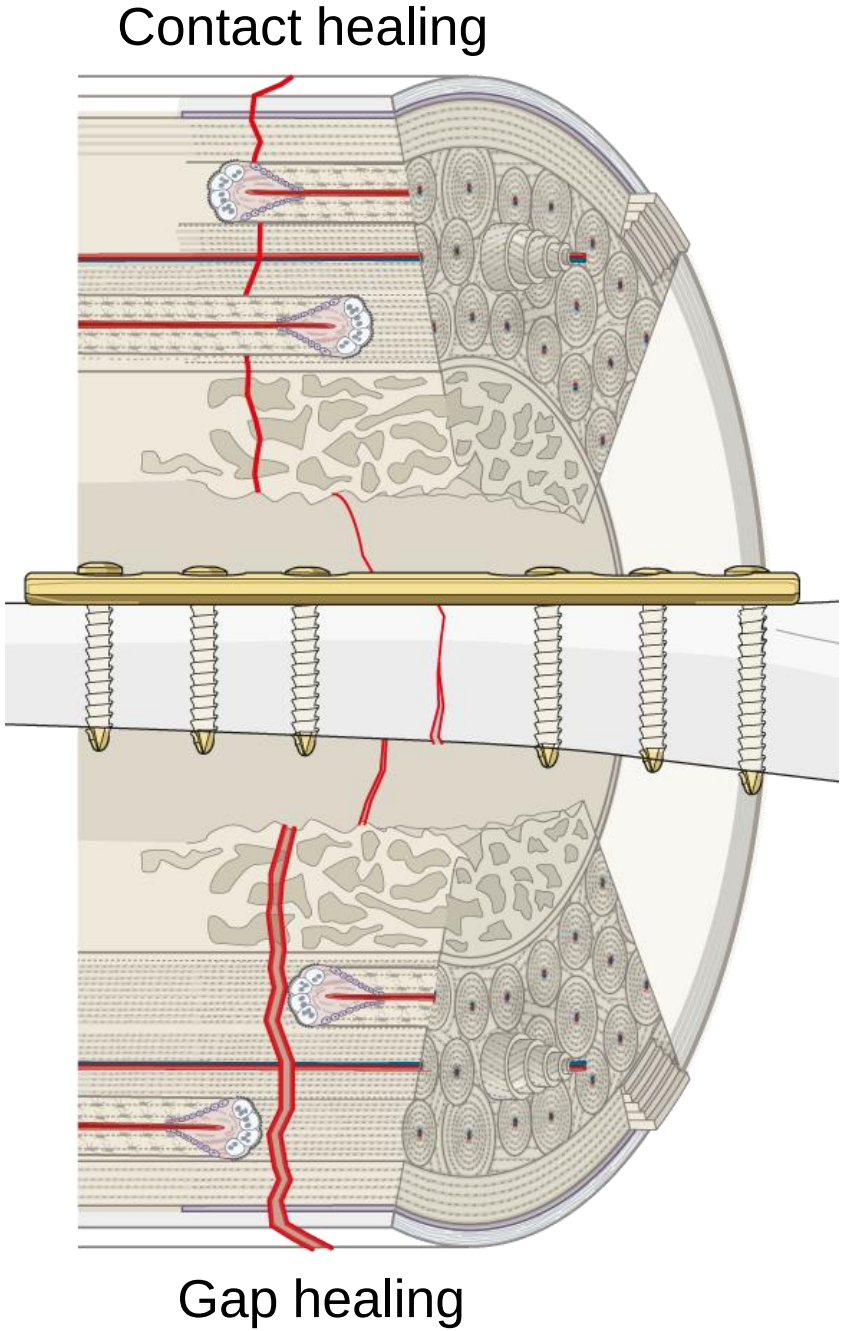
Definition of disturbed bone healing

- **Delayed union—**failure to consolidate within the normally expected time for fracture types and location
- **Nonunion—**the opinion of the treating surgeon is that healing will not occur without intervention
- **Pseudoarthrosis—**Formation of a false joint where a fibrocartilaginous cavity is lined with synovial membrane

Fracture healing

- Primary bone healing with osteonal reconstruction is not really healing

- It is the bone going about its usual business of remodelling



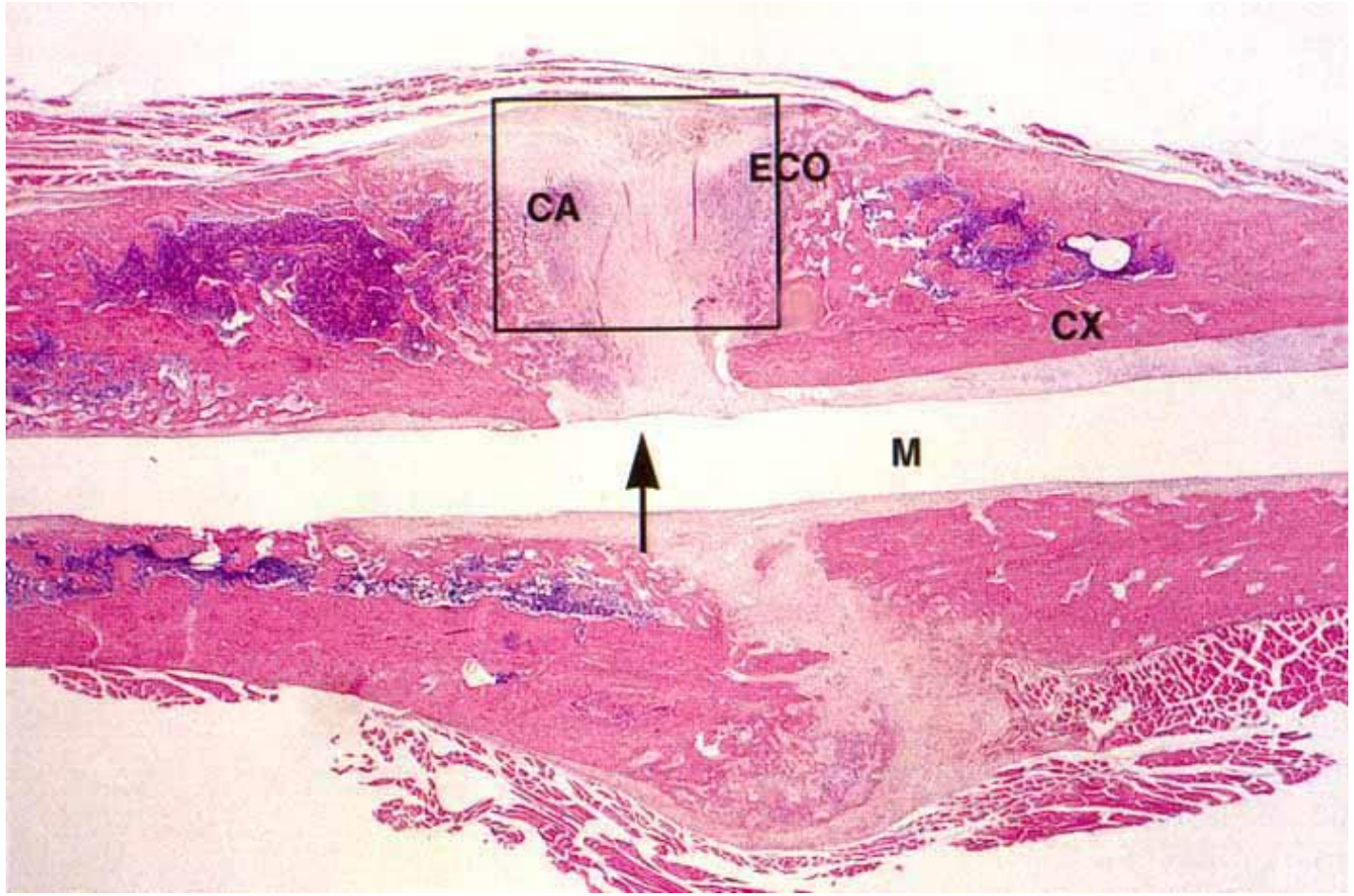
Secondary (indirect) bone healing

- True healing process is driven by inflammatory response to injury
- Described in four stages:
  - Inflammation
  - Soft callus
  - Hard callus
  - Remodelling

Requirements for bone healing

- Bone healing organ (BHO) is a hypothetical temporary structure
- Postulating its existence helps us understand the reasons for failure of bone healing
- BHO is derived from fracture hematoma and migrating pluripotential stem cells
- Appropriate mechanical environment

Bone healing organ (BHO)



Bone healing organ (BHO)

- Formation adversely affected by:
  - Open fracture
  - High energy (soft-tissue disruption)
  - Subcutaneous bone, intraarticular bone
  - Surgery?

Bone healing organ (BHO)

- Performance adversely affected by:
  - Presence of carbon monoxide (smoking)
  - Poor blood supply (microvascular disease)
  - Infection
  - High strain environment (instability)

Bone healing organ (BHO)

- Type of tissue formed is dependent on the mechanical environment

- Interfragmentary Strain Theory of Fracture Healing—Stephan Perren (1975)

Interfragmentary Strain Theory

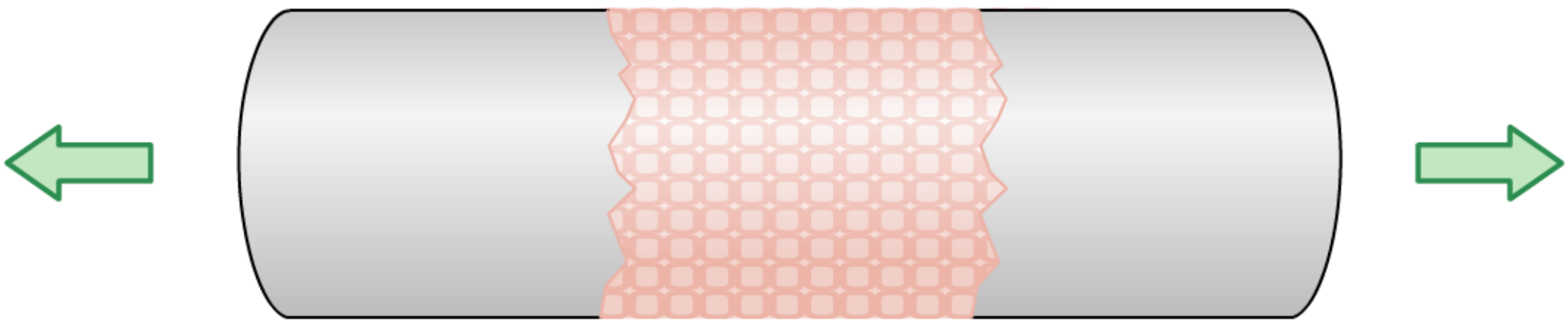
- Strain: $\varepsilon = \Delta L/L$ (measured in %)

- Tissue cannot be formed by the BHO if the interfragmentary strain is greater than the yield tolerance of the tissue concerned

Yield tolerances

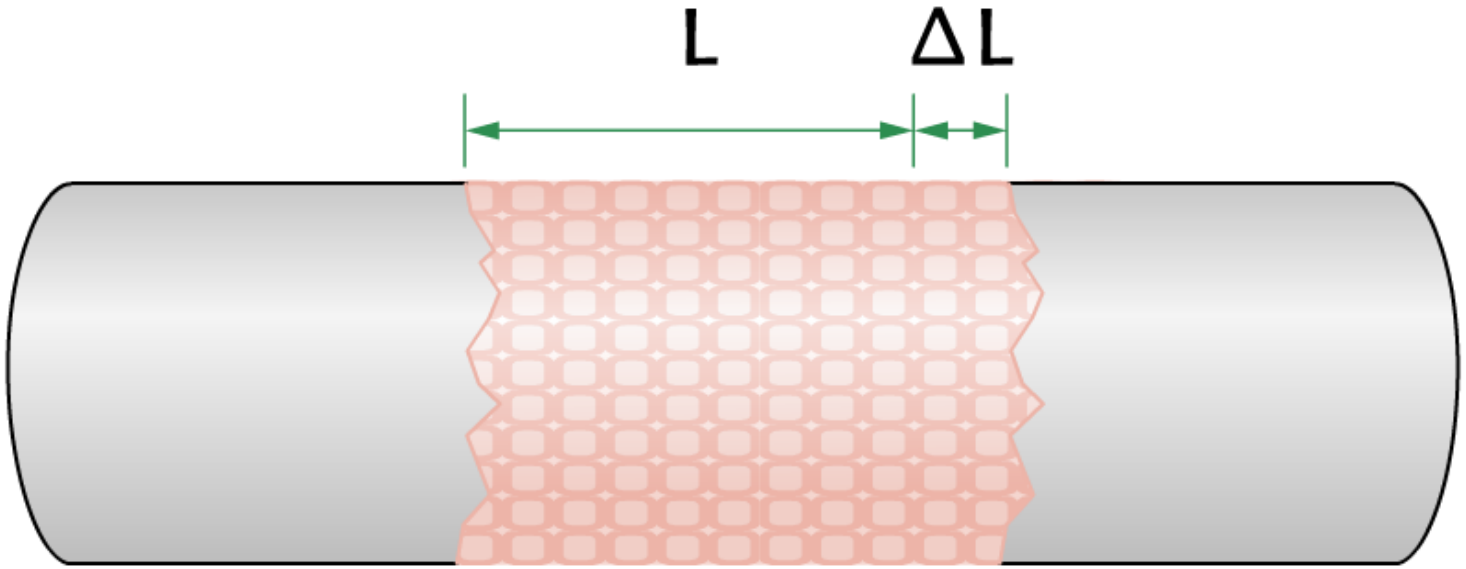
- Bone = 2%
- Cartilage = 10%
- Granulation tissue = 100%

Thinking in terms of the individual cells of the BHO



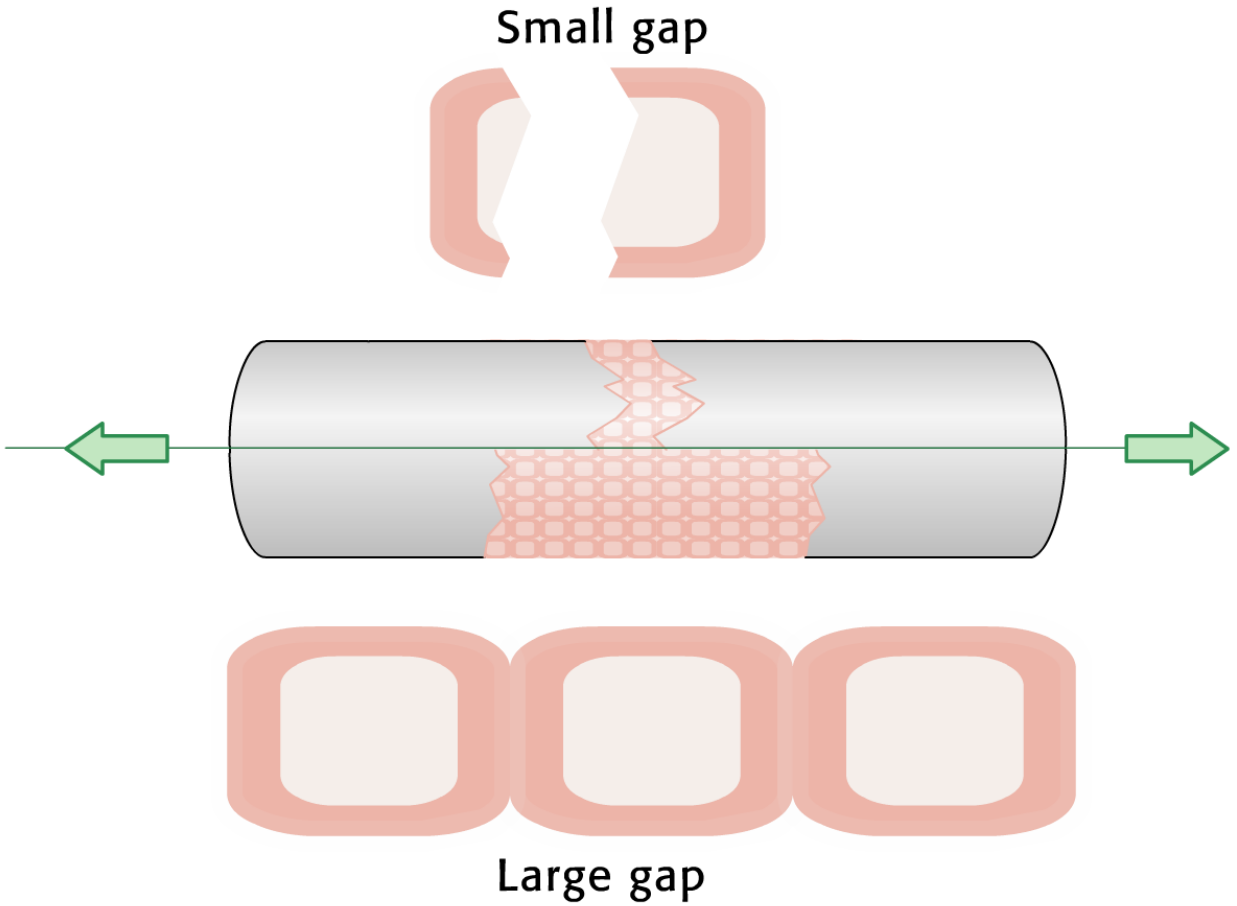
Strain = deformation of tissue in gap

Thinking in terms of the individual cells of the BHO

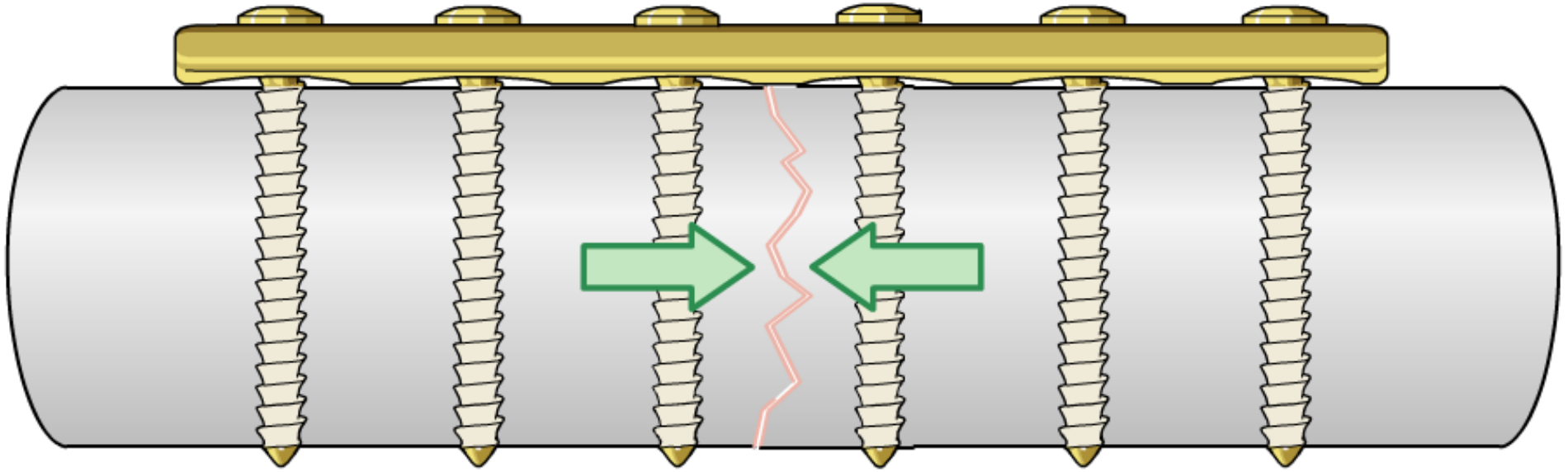


$$\text{Strain} = \frac{\Delta L}{L} \times 100\,\%$$

Thinking in terms of the individual cells of the BHO

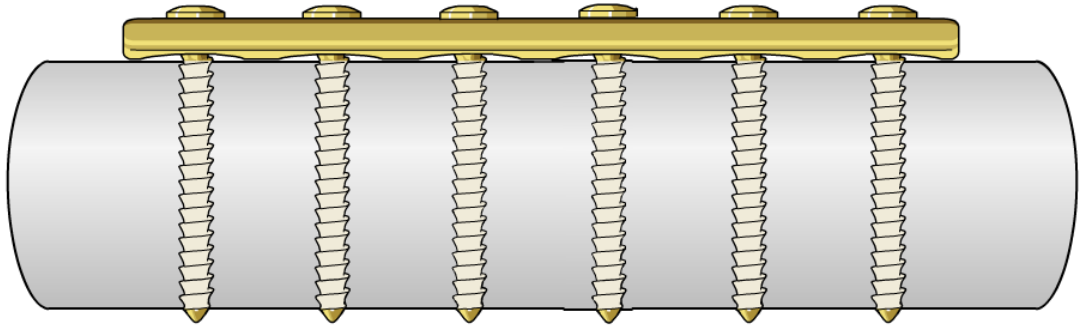


Clinical relevance



Small gap + compression → absolute stability

Clinical relevance



Small gap + compression → absolute stability

↓

No movement
low strain

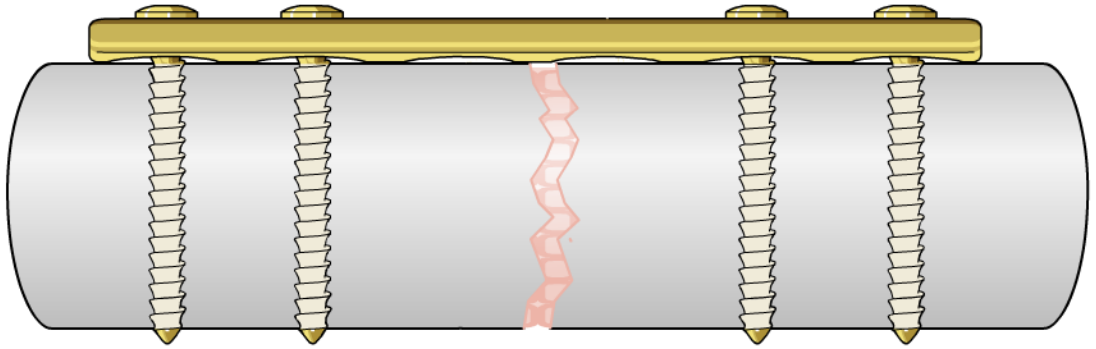
↓

Direct healing

↓

No callus

Clinical relevance



Small gap—no compression → relative stability

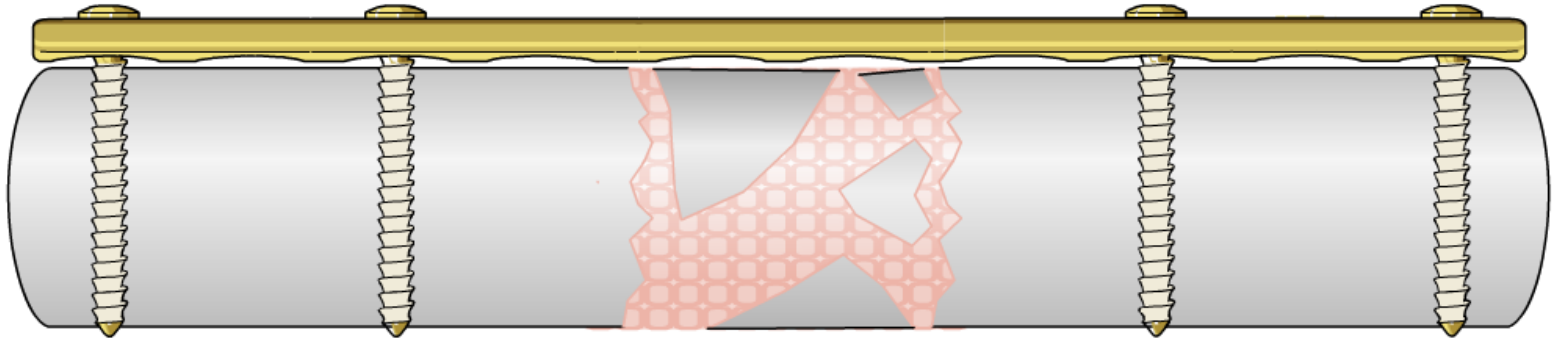
↓

Movement
high strain

↓

Poor healing

Clinical relevance

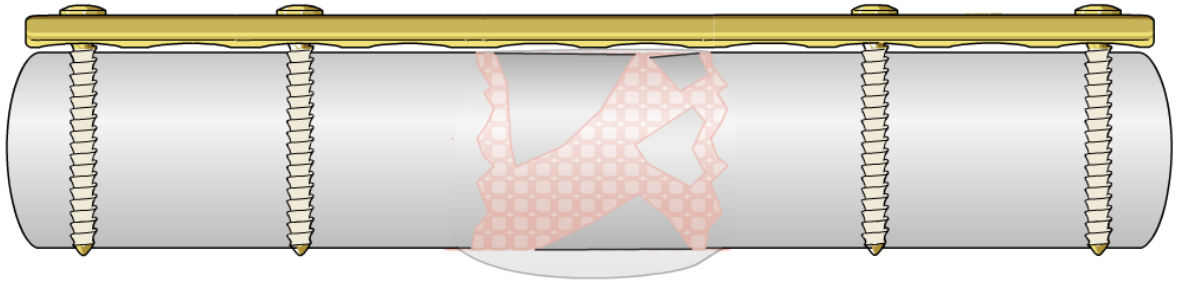


Large gap—bridging → relative stability

↓

Movement
low strain

Clinical relevance



Large gap–bridging → relative stability

↓

Movement
low strain

↓

Indirect healing

↓

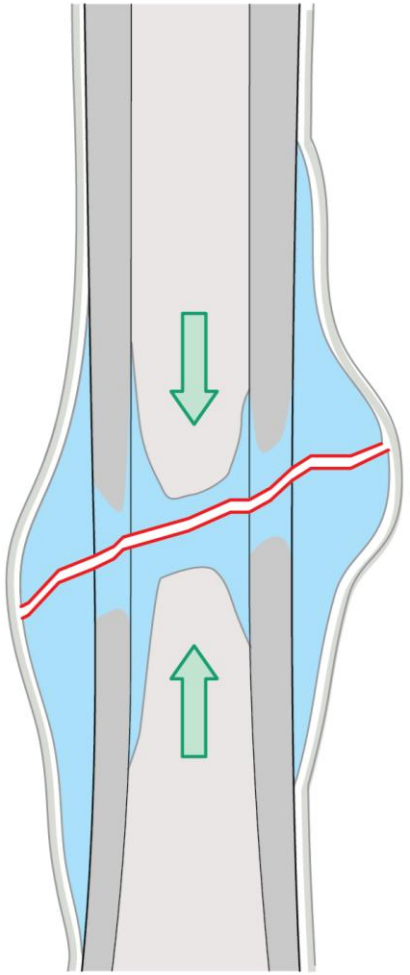
Callus formation

Radiology of nonunion

- X-rays are blocked by the dense nuclei of metallic atoms
- In bony tissue, these are calcium ions
- Callus is not radio-opaque until mineralization occurs
- Mineralization cannot occur in any zone of a fracture gap until the local strain is 2% or less
- Amount and distribution of callus is a radiological marker of the strain environment at the fracture

Vascular (hypertrophic)

- Major displacement of fracture
- Distraction of fragment
- Without accurate apposition of the fragment



Adequate vascularity

/ Lack of mechanical stability

Treatment of nonunion

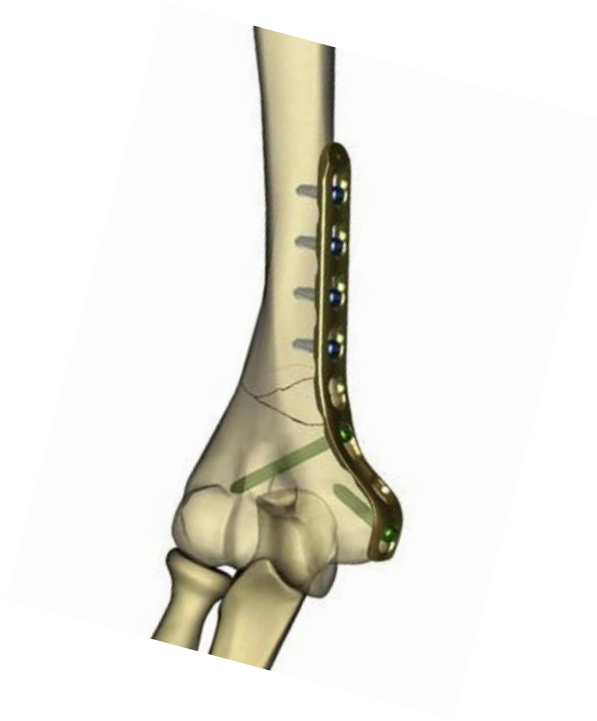
- Restore alignment
- Stabilize with durable implant
- Prevention

Alignment

- Essential to equalize the strain across the fracture gap
- Osteotomy may be needed to move the plane of the fracture line closer to perpendicular to the mechanical axis (anti-shear)

Stability

- Essential to achieve low interfragmentary strain in order to permit bone formation
- Default options
  - Reamed IM nail for lower limb diaphyseal nonunion
  - Compression plates for upper limb and metaphysis

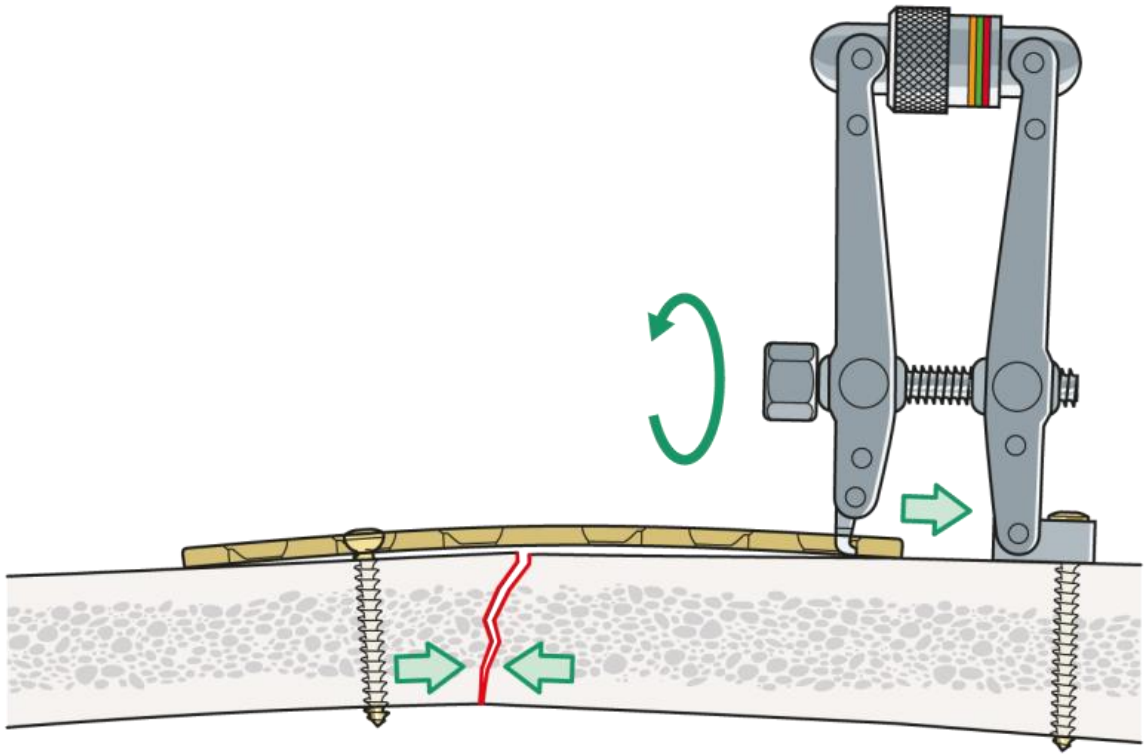


Exchange nailing

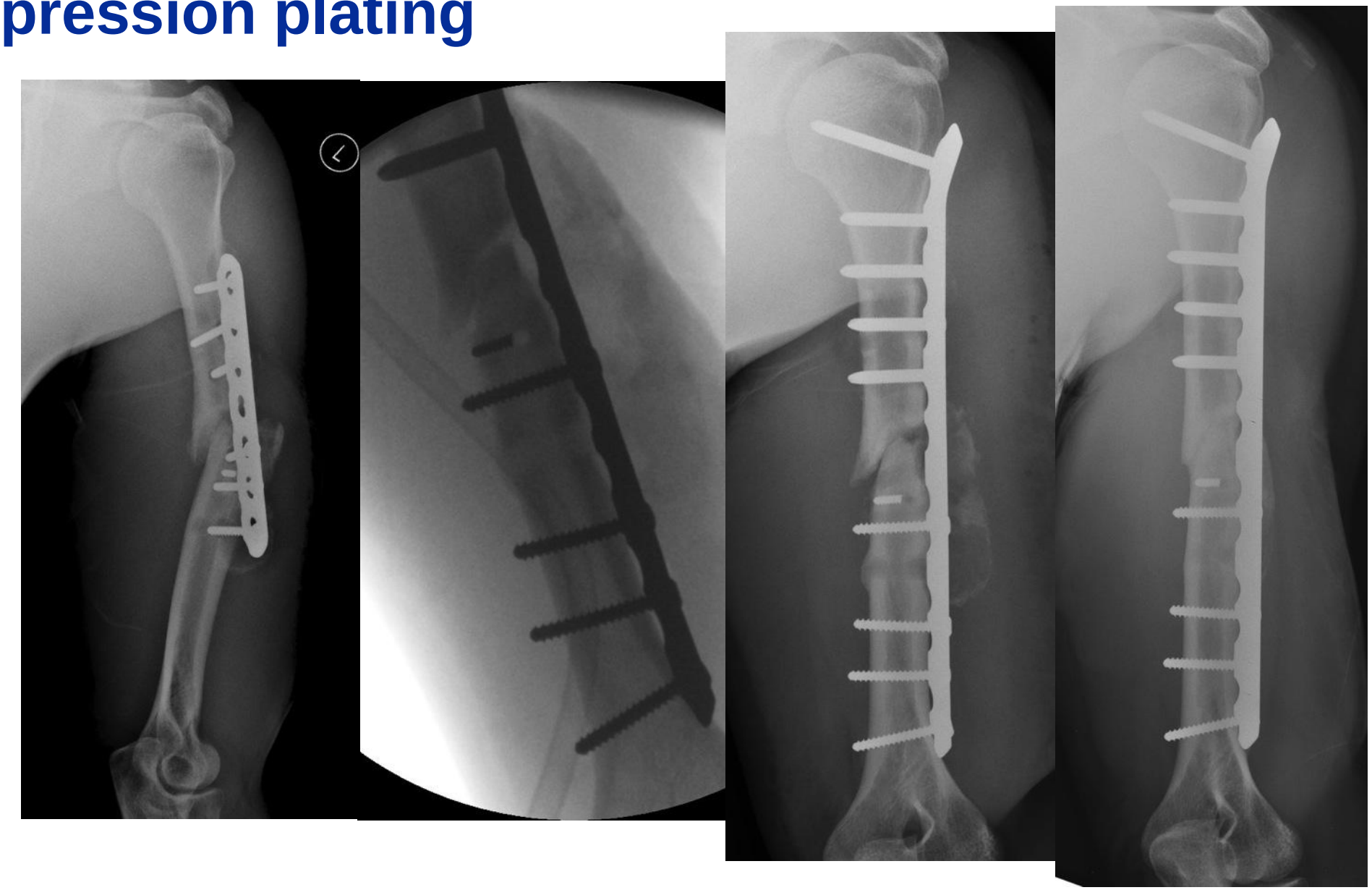
- First option in diaphyseal femoral and tibial nonunion
- Nonunion occurs because of instability or malreduction
- Both must be addressed to heal the fracture

Compression plating

- Implants must be preloaded to achieve a stabilizing compressive force
- Prebending the plate and using load screws in the elliptical hole of an LCP may have to be supplemented with a tension or compression device
- Lag screws are unlikely to generate sufficient compressive force to adequately stabilize the nonunion



Compression plating



Circular fixators

- Advantage of transferring force along the mechanical axis of the bone
- Can store large amounts of energy = large preload = stability at nonunion site

Avascular

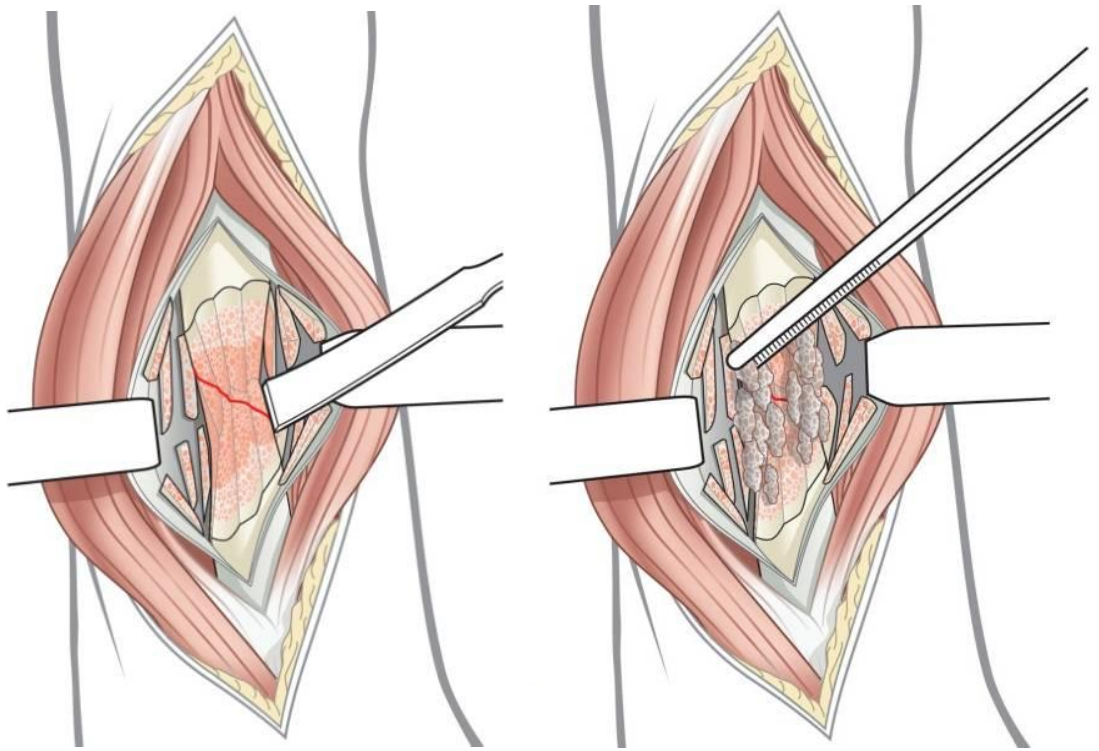
Results from

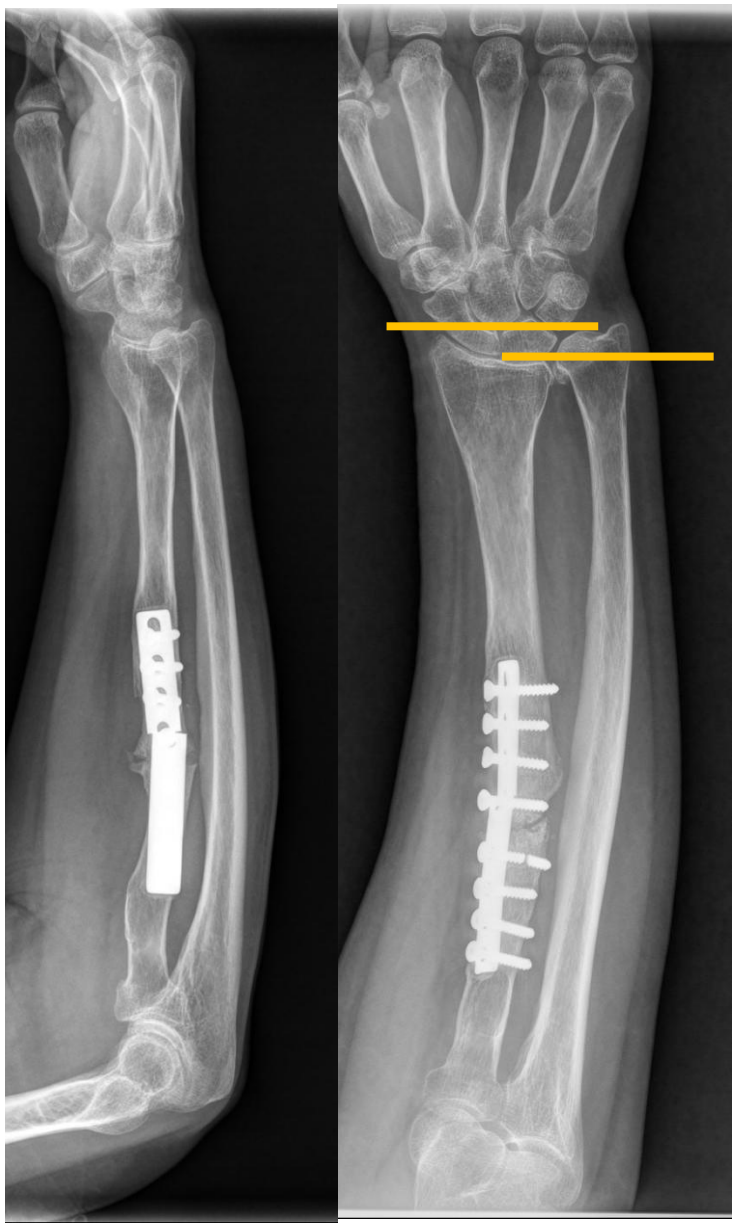
Poor vascularity

(+/- instability)

- Open plating
- Open fracture
- Careless handling of fracture site

Solution ➔ bone graft





- 2 year after ORIF
- Instability
  - Loosening of screws
- Radial shortening
- Little callus formation
  - Atrophic after ORIF
- Strategy
  - Need stability
  - Lengthening of radius
  - Biological stability

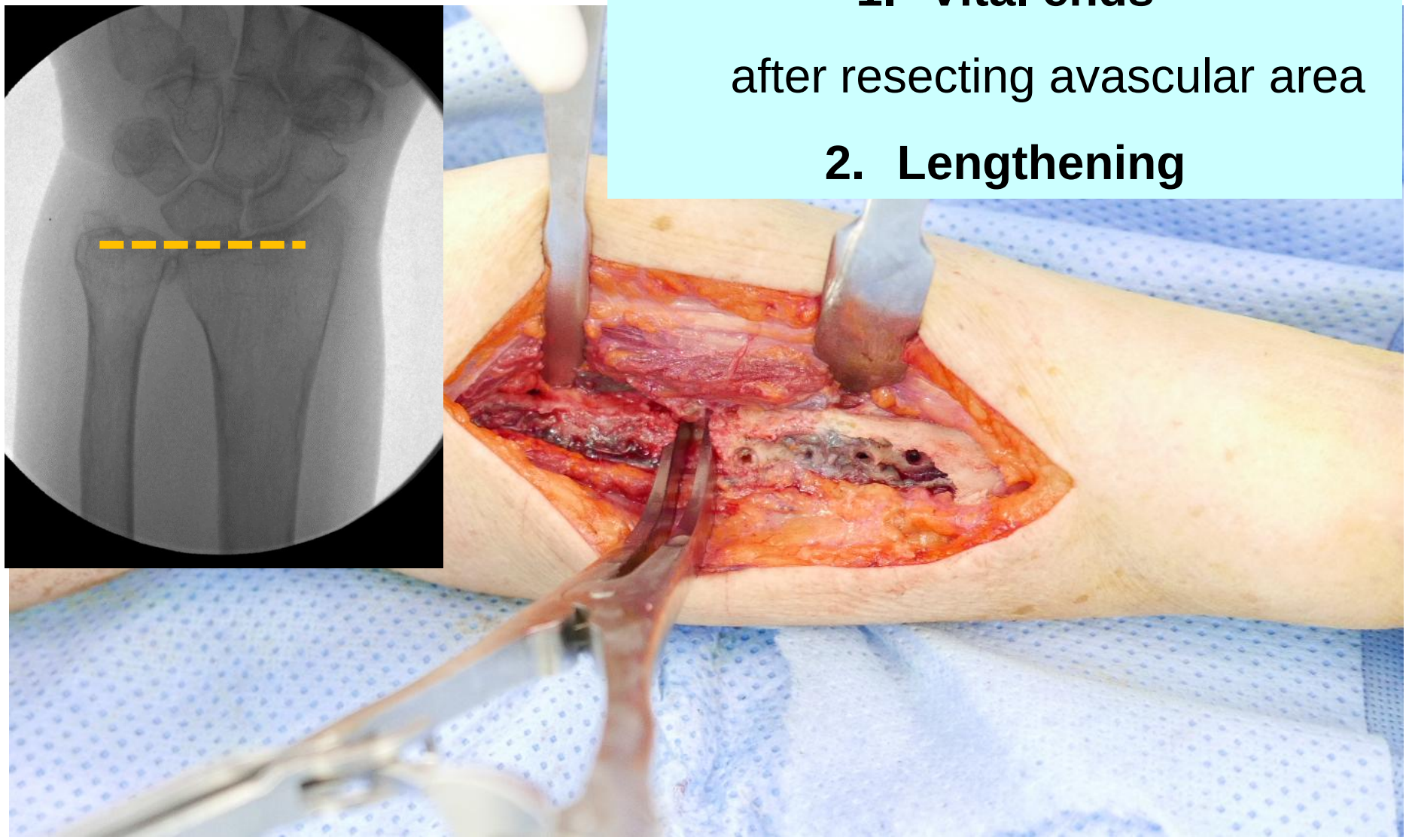
1. **Vital ends**

after resecting avascular area

1. **Vital ends**

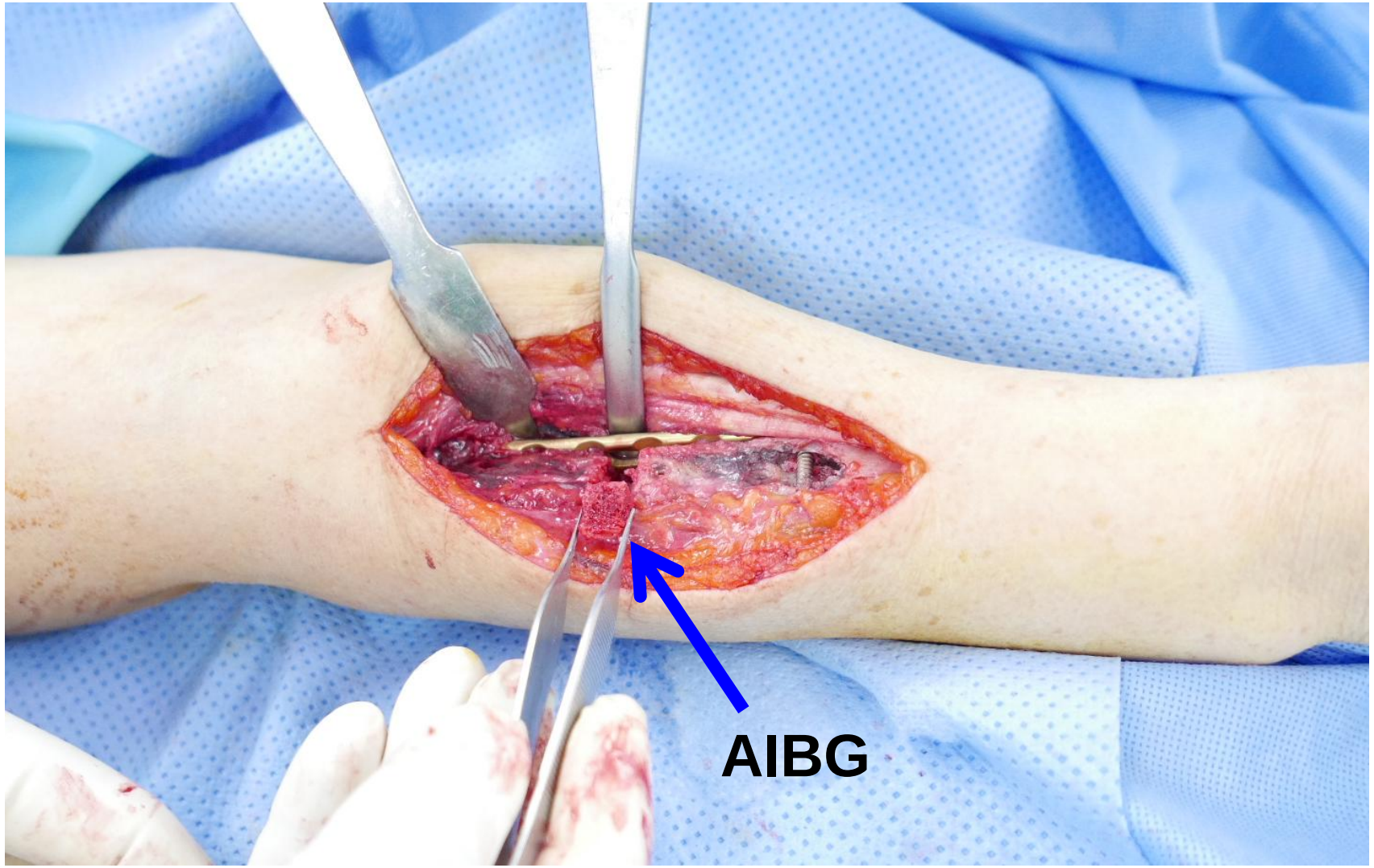
after resecting avascular area

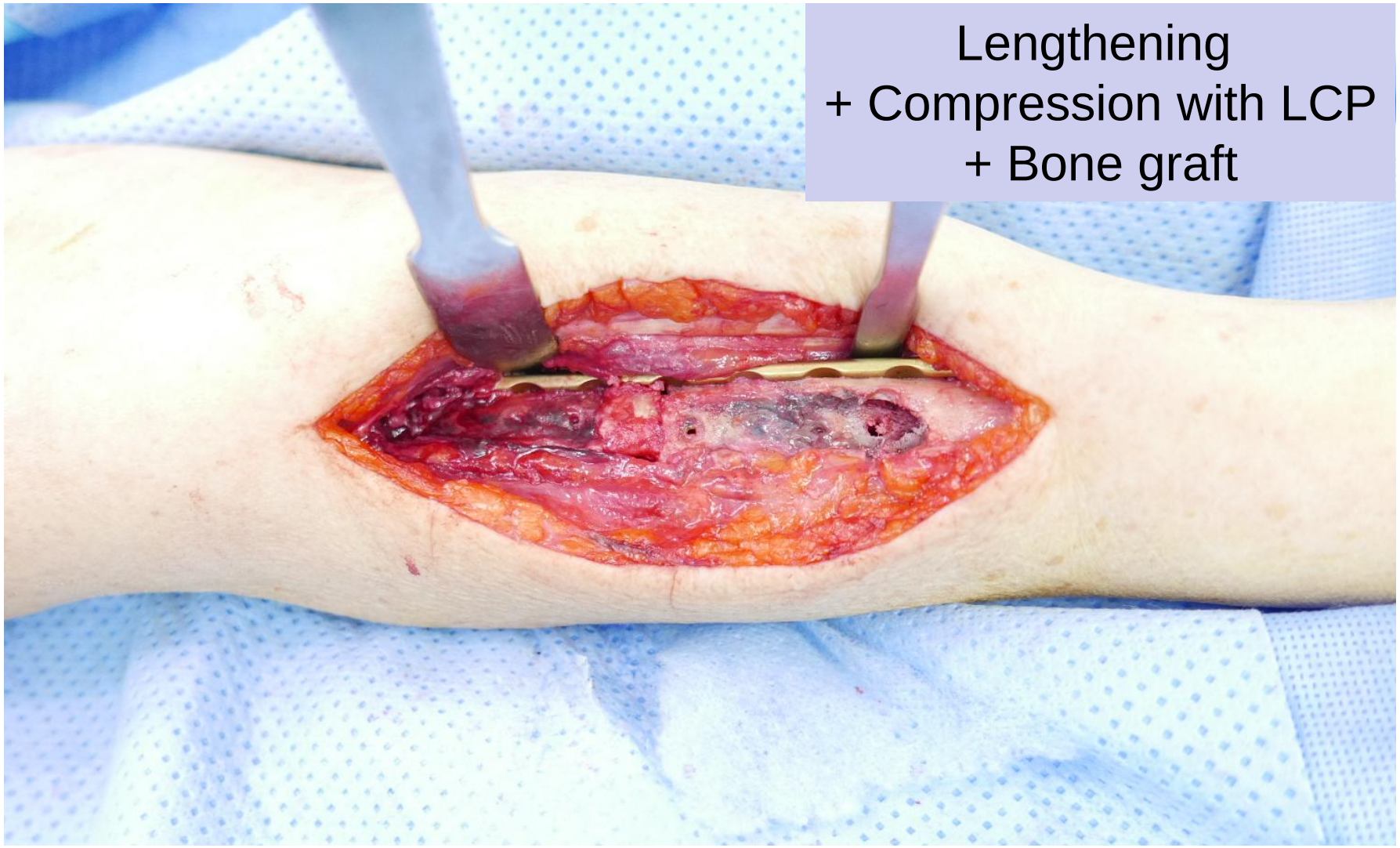
2. **Lengthening**



3. Stability

Osteoporosis ➔ Locking plate


AIBG


Lengthening
+ Compression with LCP
+ Bone graft

After correction

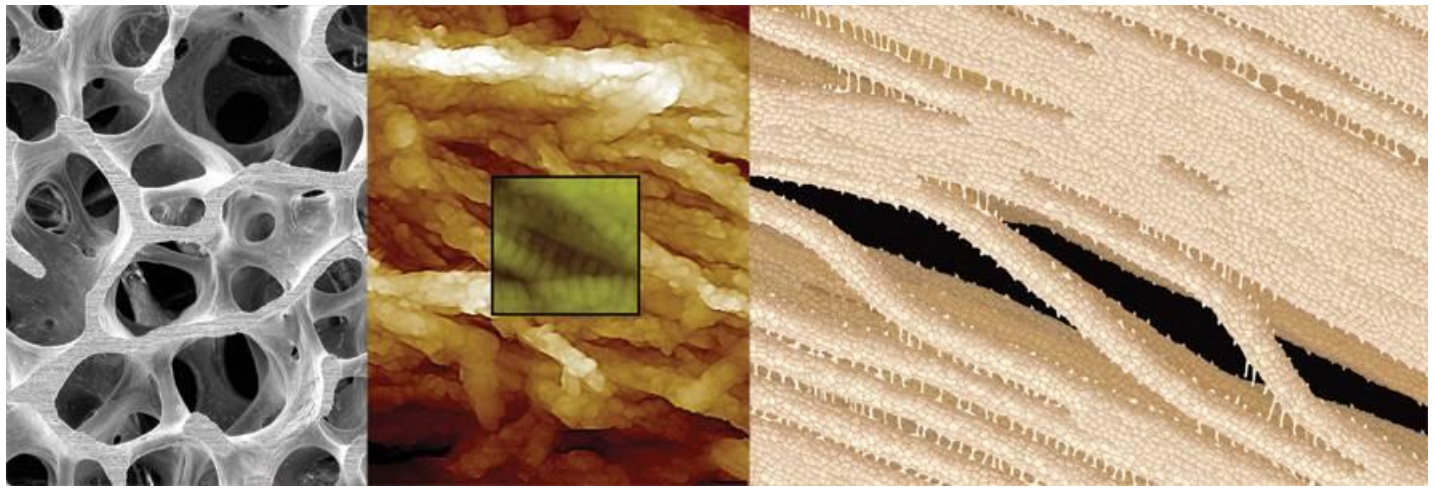
Postop 6 months

What about bone grafting?

- Many surgeons no longer use cancellous autograft as an adjunct to surgery
- Removing existing implants and restoring alignment lead to the formation of a fresh BHO
- Considerable doubt as to whether the benefits outweigh the extra morbidity

What about nonsurgical treatments?

- Structure of bone is known and understood right down to an atomic level
- It must be possible to influence the chemical reactions or manipulate the microscopic physical/electrical environment
- However, clinically relevant experimental data is extremely difficult to produce



Prevention of nonunion

- Attend AO course and faithfully follow the principles learned
- Embrace the concept of the BHO
  - Understand why some fractures heal faster than others and some not at all
  - Importance of soft-tissue handling
  - Advantages of indirect reduction and minimal access techniques
- Use large diameter IM nails where possible
- Do not use an all-locked LCP in simple fracture patterns without a tension or compression device

Take-home messages

- Understanding how the local strain environment influences bone formation is crucial
- Restoration of alignment and stable fixation with a durable implant
- In plate fixation, some energy must be stored (preload) in the construct to confer sufficient stability to allow healing
- More research is needed on nonsurgical treatment
- Prevention is better than cure