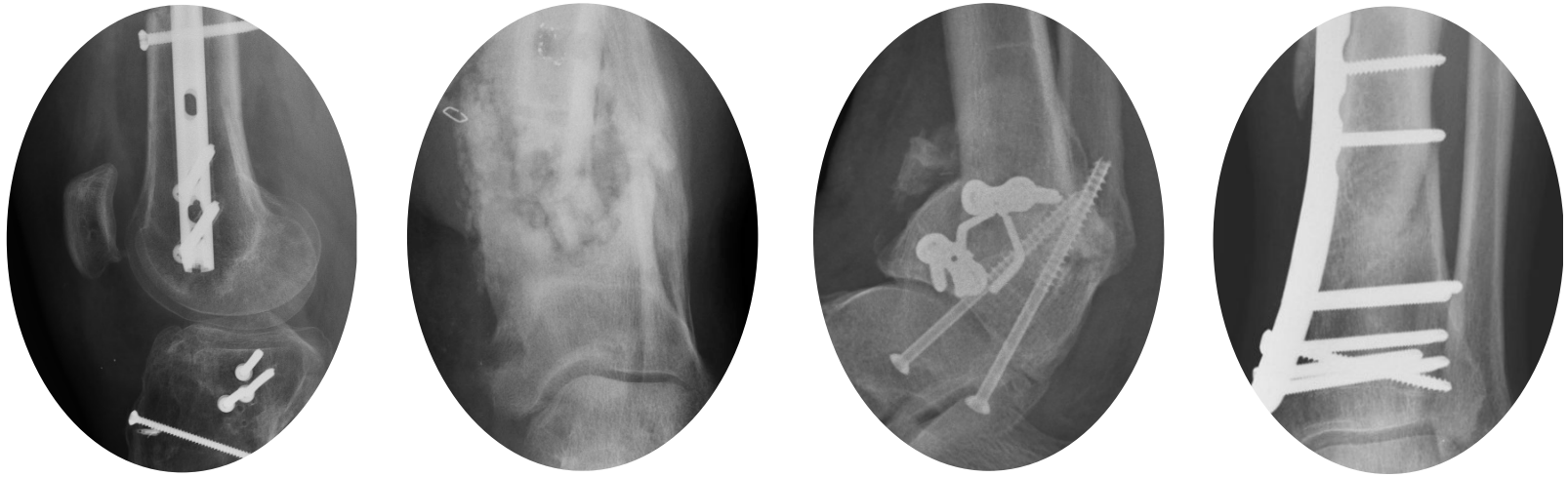
Principles of Nonunion Management

- J. Spence Reid MD
- Penn State University College of Medicine
- Milton S. Hershey Medical Center
- Hershey, PA

- Editor: Henry Boateng M.D.



- Nonunions present in a wide spectrum – we will seek to find the principles of treatment for these cases

- Incidence and impact of nonunions
- Factors predisposing to nonunion

  Systemic:

  Endocrine

  Smoking

  medications (NSAIDS etc)

  Local:

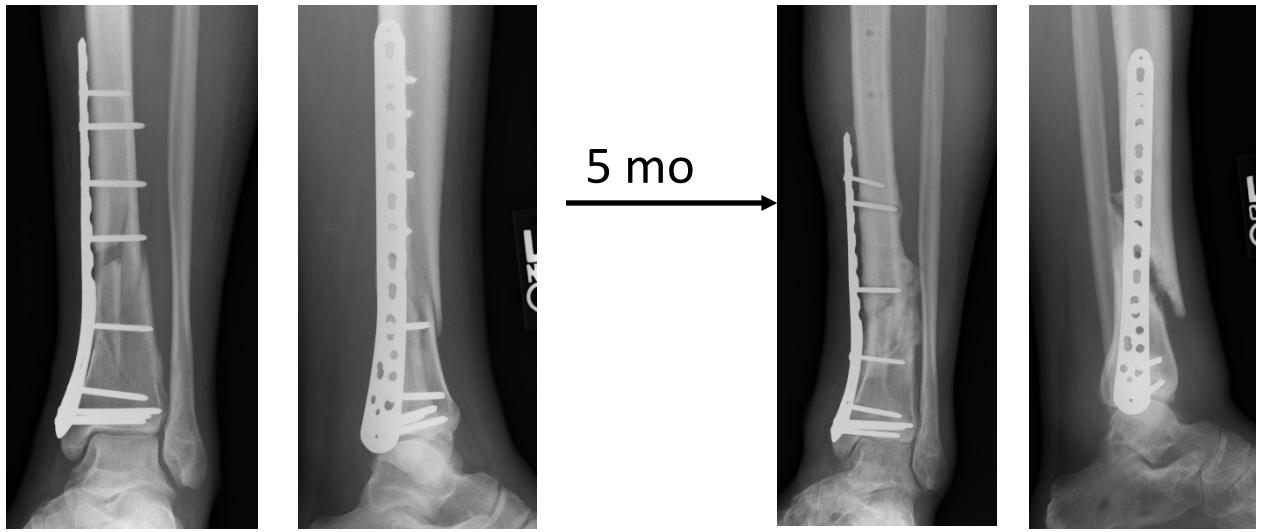
  Infection/vascular

- Mechanical factors – strain theory
- Deformity and bone loss
- Approaches to management

When is it a nonunion?

Radiographic and clinical diagnosis

- Non-progression towards radiographic union over multiple points of evaluation.
- Usually accompanied by non-improving clinical progression.
- Broken/failing hardware – common finding



Incidence & cost of tibial nonunions

- Large series (853 patients) ~ 12% nonunion
- 87% likelihood of an open fracture
- All categories of care – more expensive in patients with nonunions vs healed fractures
- Outpatient physical therapy (60% vs 42%) p<0.001
- Median total cost ($25,556 vs 11,686) p<0.001
- Opioid pain medication (90% vs 76%) p=0.002
- Duration of opiods (5.4 vs 2.8 mo) p<0.001

Antonova, E., et al., *Tibia shaft fractures: costly burden of nonunions.* BMC Musculoskeletal Disorders, 2013. 14: p. 42.

Quality of Life Impact

- 237 tibial nonunions over a 10-year period
- Distal third 49% Infection 18%
- SF-12 physical component score 24.7

  extremely disabling
- AAOS Lower limb Core score 52.0

  high level of physical disability
- SF-12 Mental Component Summary 42.3

  substantial effect on mental health

Brinker, M.R., et al., *The devastating effects of tibial nonunion on health-related quality of life.* Journal of Bone & Joint Surgery - American Volume, 2013. 95(24): p. 2170-6.

Quality of Life Impact

Brinker, M.R., et al., *The devastating effects of tibial nonunion on health-related quality of life.* Journal of Bone & Joint Surgery - American Volume, 2013. 95(24): p. 2170-6.

Nonunion Workup

Radiographs +/- CT scan – can be very surprising!

Good history and exam:

Focus on correctable co-morbidities and ask the question “could this be infected?”

Nonunion Workup

Laboratory evaluation:

consider on all patients:

- CBC/ESR/CRP
- TSH/PTH
- Vitamin D
- Albumin/prealbumin
- HgB A1C
- Testosterone

Brinker, M.R., et al., *Metabolic and endocrine abnormalities in patients with nonunions.* Journal of Orthopaedic Trauma, 2007. 21(8): p. 557-70.

Endocrine Evaluation

Unexplained nonunion

- 83% one or more new diagnosis
- New metabolic or endocrine abnormalities
- 67% Vitamin D deficiency
- 24% thyroid abnormality
- 13% central hypogonadism

- 25% healed with medical treatment only
- Workup every patient with a nonunion

Brinker, M.R., et al., *Metabolic and endocrine abnormalities in patients with nonunions.* Journal of Orthopaedic Trauma, 2007. 21(8): p. 557-70.

Hyperparathyroidism

An unexplained nonunion can be the presenting feature of primary hyperparathyroidism.

Prevelence: Elevated PTH

tibial nonunion	33%
normal union	9%

Severe Vitamin D deficiency can present as secondary hyperparathyroidism

Sauve, P.S., I.G.I. Suliman, and J.D. Calder, *Primary hyperparathyroidism presenting as delayed fracture union.* Knee Surgery, Sports Traumatology, Arthroscopy, 2009. 17(5): p. 551-4.

NSAIDS

- Use of NSAIDs in the early post-operative period may double the chance of fracture healing problems.
- Multiple studies suggest that use of NSAID's for HO prophylaxis will increase the rate of nonunions in patients with long bone fractures
- Controversial topic at present – NSAID's now being used more often in early fracture care to avoid opiod issues. This may increase rate of nonunions.
- Avoid NSAID's when treating a nonunion.

Jeffcoach, D.R., et al., *Nonsteroidal anti-inflammatory drugs' impact on nonunion and infection rates in long-bone fractures.* The Journal of Trauma and Acute Care Surgery, 2014. 76(3): p. 779-83.

Smoking / Nicotine

- 2 to 3 x increased risk of nonunion
- May also be true for marijuana smoke(THC?)
- Ask about tobacco chewing

- Smoking - treatment of a tibia fracture

  increased time to union: 17 vs 12 wks

  time out of work: 21 vs 16 wks

  3-18 x risk of impaired bone healing

- Open fracture: Flap failure, infection

Moghaddam, A., et al., *Cigarette smoking influences the clinical and occupational outcome of patients with tibial shaft fractures.* Injury, 2011. 42(12): p. 1435-42.

Tobacco Cessation

- Smoking and chewing (marijuana-ask)
- Consider Varenicline (Chantix) – FDA approved for smoking cessation
  - overall very good efficacy
  - neuropsychiatric side effects
  - cardiovascular side effects

Discuss risk with smoking patients!

Wong, J., et al., *A perioperative smoking cessation intervention with varenicline: a double-blind, randomized, placebo-controlled trial.* Anesthesiology, 2012. 117(4): p. 755-64.

Overall Nonunion Strategy

Correct as many factors as possible prior to additional surgery

- correct Vit D levels
- smoking cessation
- glucose control
- plastic surgery eval for coverage issues
- optimize medications (NSAID cessation)

Work on the rest – during treatment

Create a plan with a high likelihood of success

Refer patients that exceed your skill set!

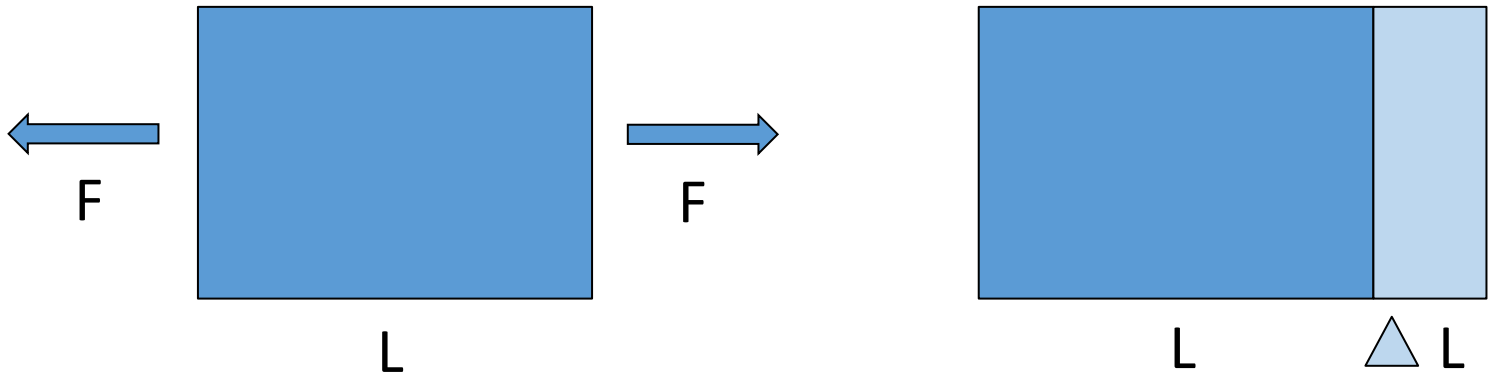
Nonunion - Checklist for Treatment

- Mal-alignment
- Hardware (± broken) present
- Biology-systemic
- Biology-local
- Mechanical stability
- Infection
- Bone loss
- Soft tissue loss/Coverage needs

To understand these nonunions,
You need to understand "strain"

What is Strain?

How a material responds to loading by deforming

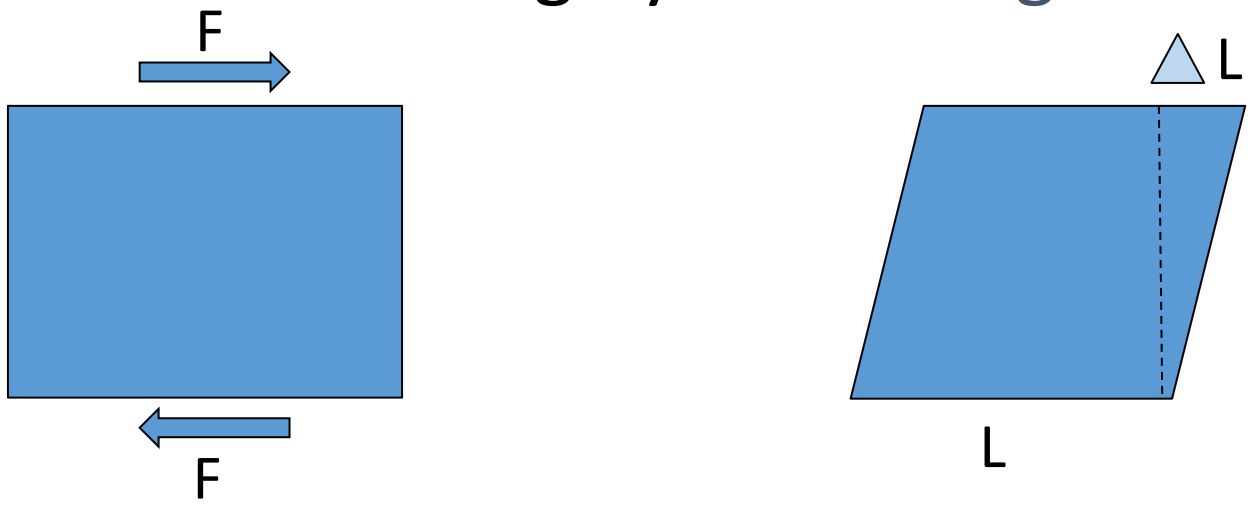


$$\text{Strain} = \frac{\Delta L}{L}$$

AXIAL Strain

What is Strain?

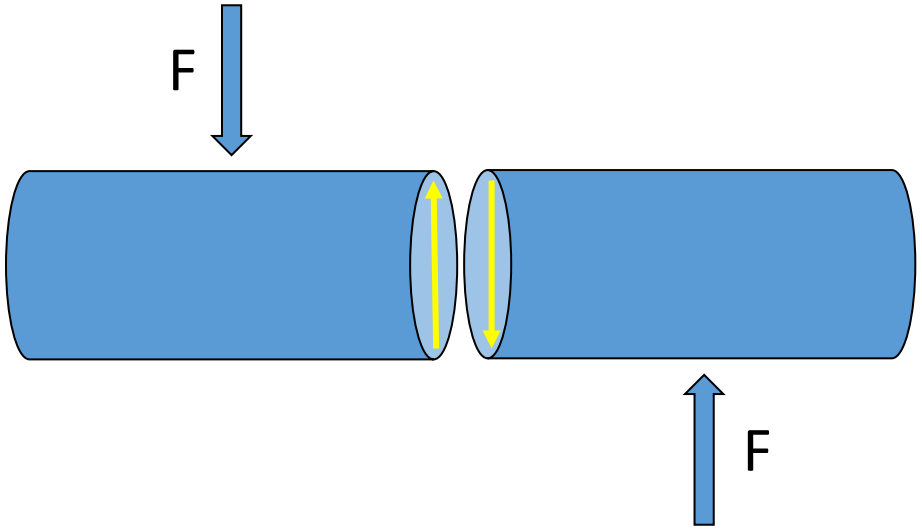
How a material responds to loading by deforming



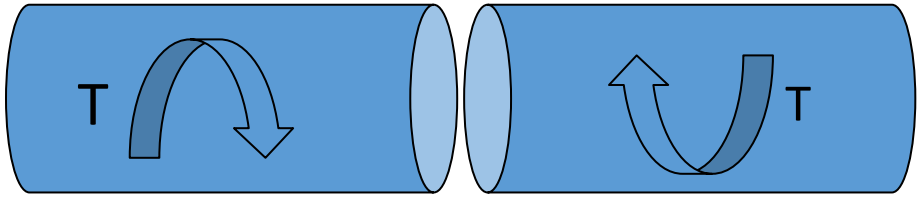
$$\text{Strain} = \frac{\Delta L}{L}$$

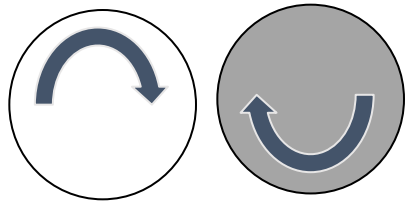
SHEAR Strain

Shear Strain – Two Sources



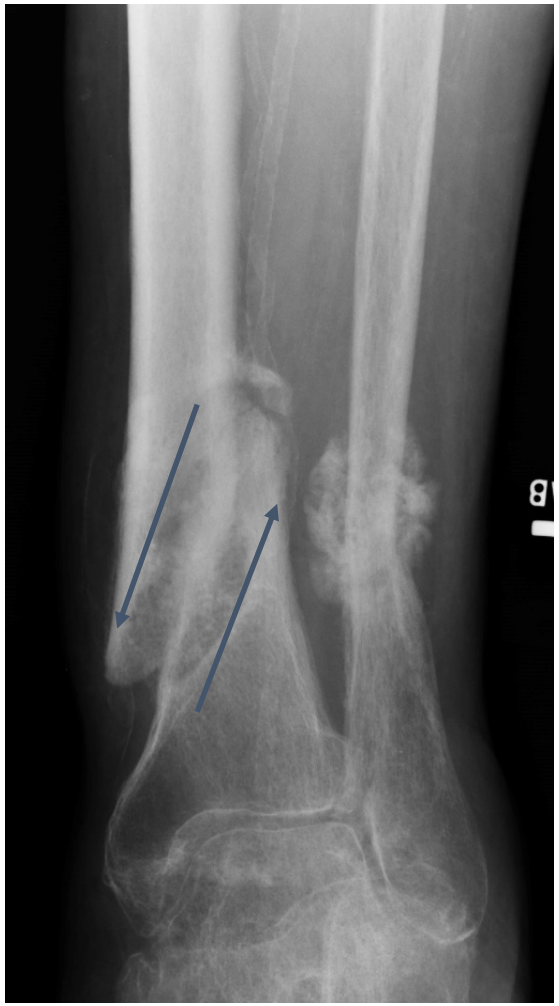
Translational shear

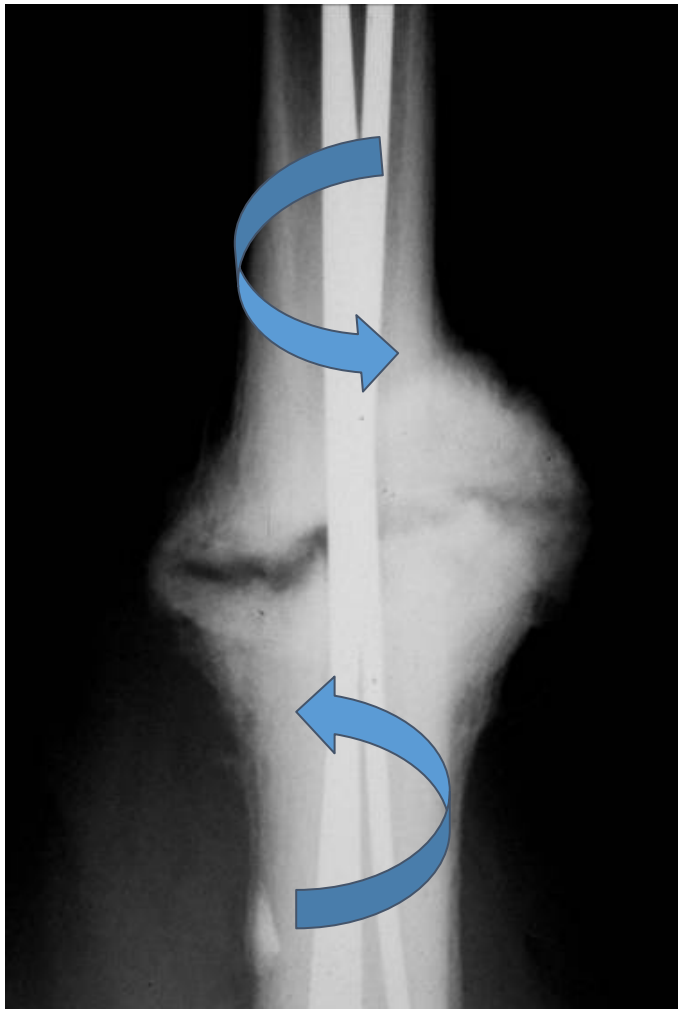


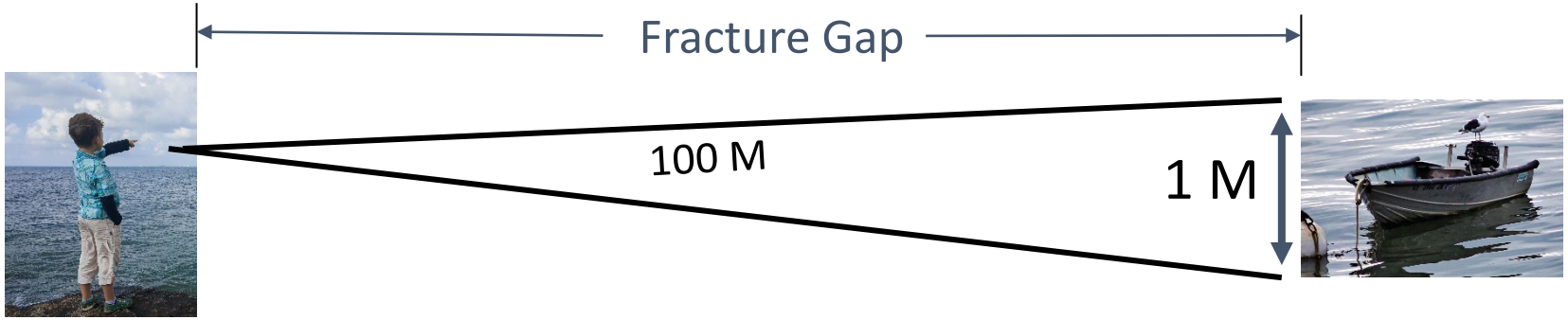


Torsional shear

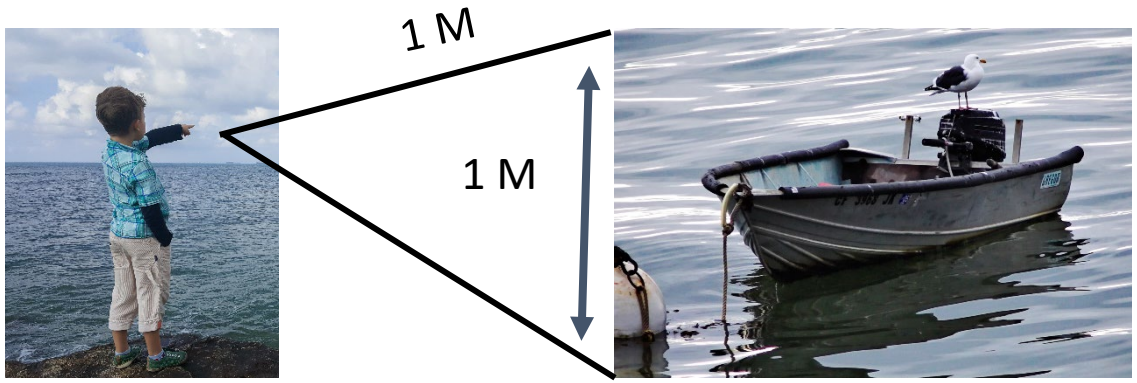
Shear Strain – Why is it a problem?



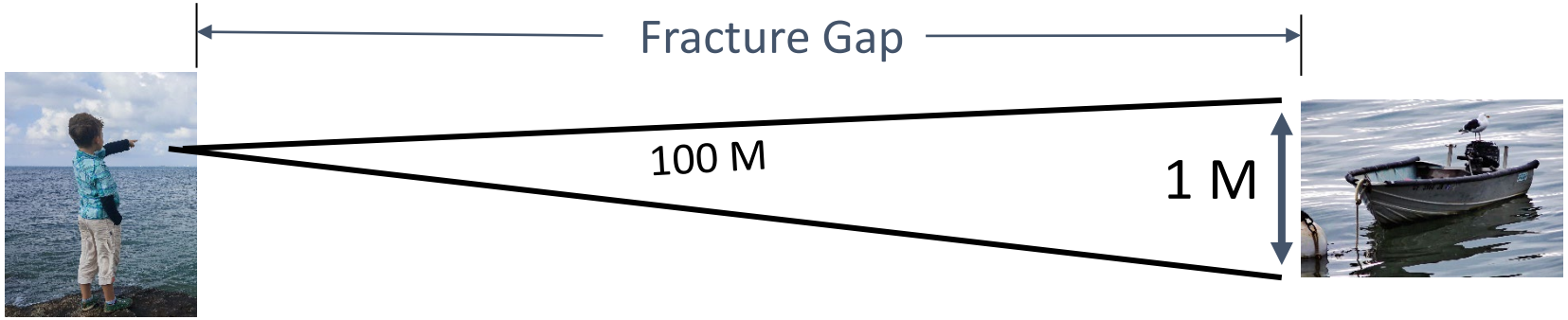




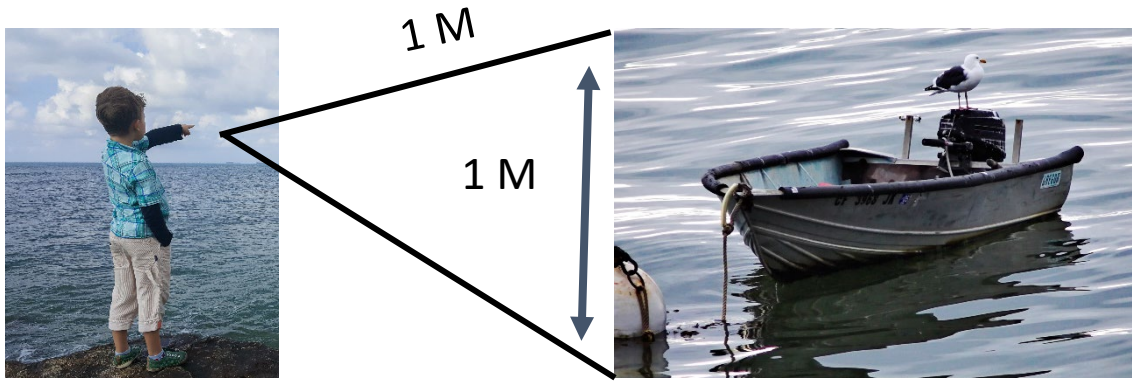
$$\text{Shear Strain} = \frac{\triangle L}{L} = 1/100 = 1\%$$



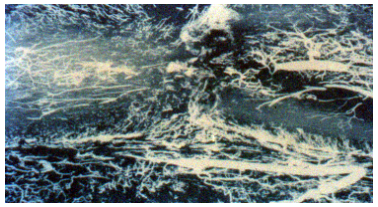
$$\text{Shear Strain} = \frac{\triangle L}{L} = 1/1 = 100\%$$



$$\text{Shear Strain} = \frac{\triangle L}{L} = 1/100 = 1\%$$



Imagine that the rope is a fragile capillary



Interfragmentary Strain Theory

Stephan Perren Ph.D

CORR 1979 138

"A tissue cannot survive in an environment that exceeds its strain tolerance"

	Strain tolerance
• Granulation tissue	100%
• Cartilage	10%
• Bone	2%

Strain theory

Each tissue prepares the local environment biologically and mechanically for the next tissue

Callus Stiffens

Interfragmentary motion decreases

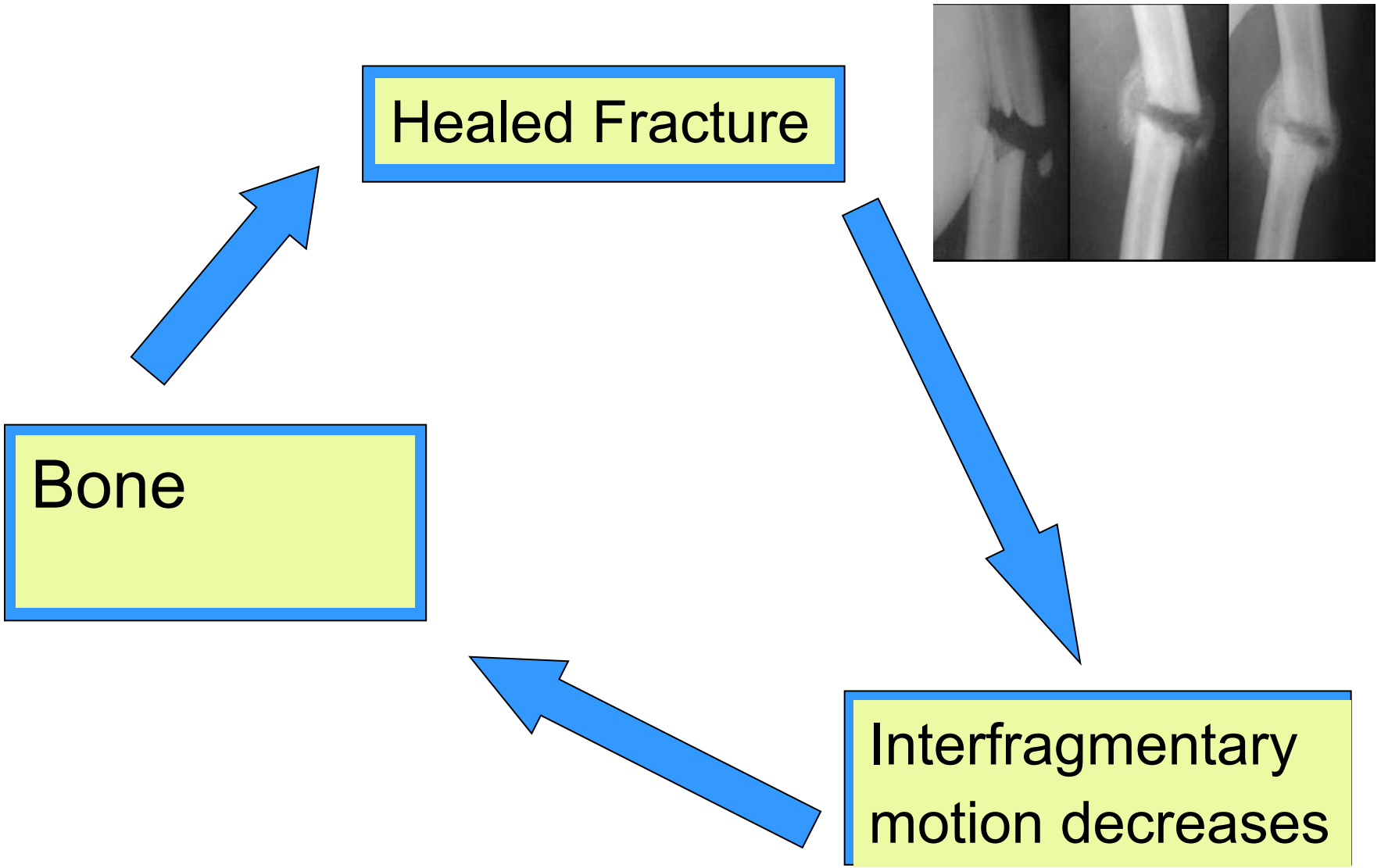
Granulation

Initially:
Strain 10% – 50%
Optimal callus

Callus Stiffens

Interfragmentary motion decreases

Cartilage


Healed Fracture
Bone
Interfragmentary motion decreases

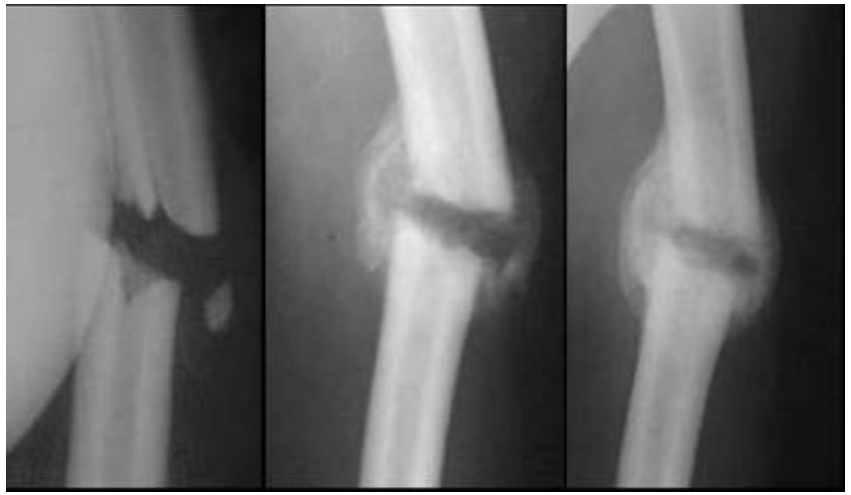
What is the oxygen tension in an osteocyte in the middle of your tibia?

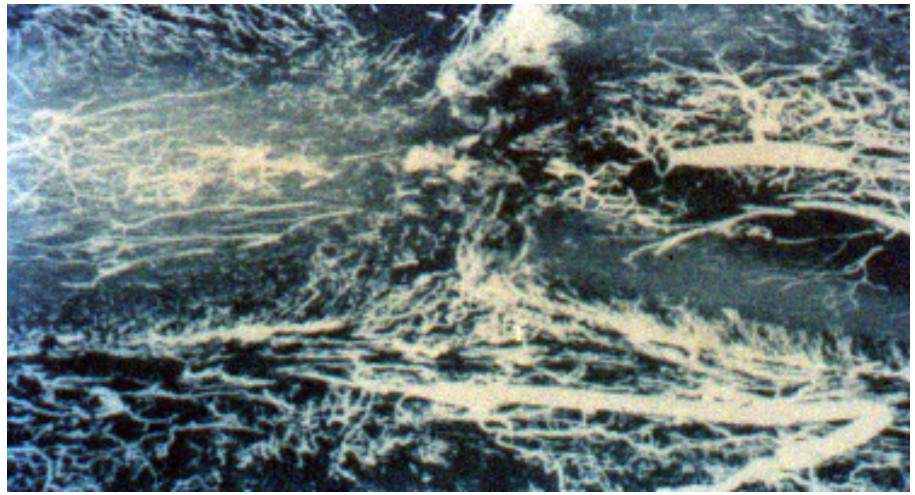
~ 100 mm Hg

same as arterial blood

Bone is a very aerobic tissue and requires an intact capillary network to survive

Strain theory

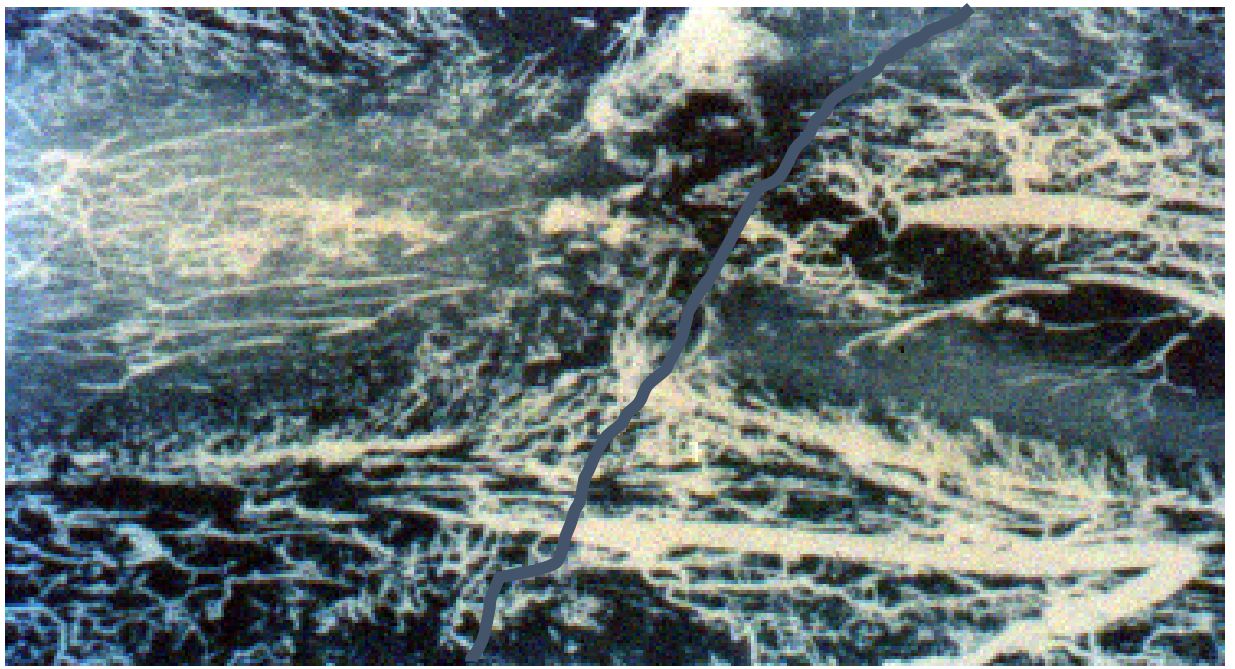




- Bone cannot exist in a region of high strain because the capillary network to support bone cannot survive

- Precursor tissues create an environment stable enough for a capillary network to form

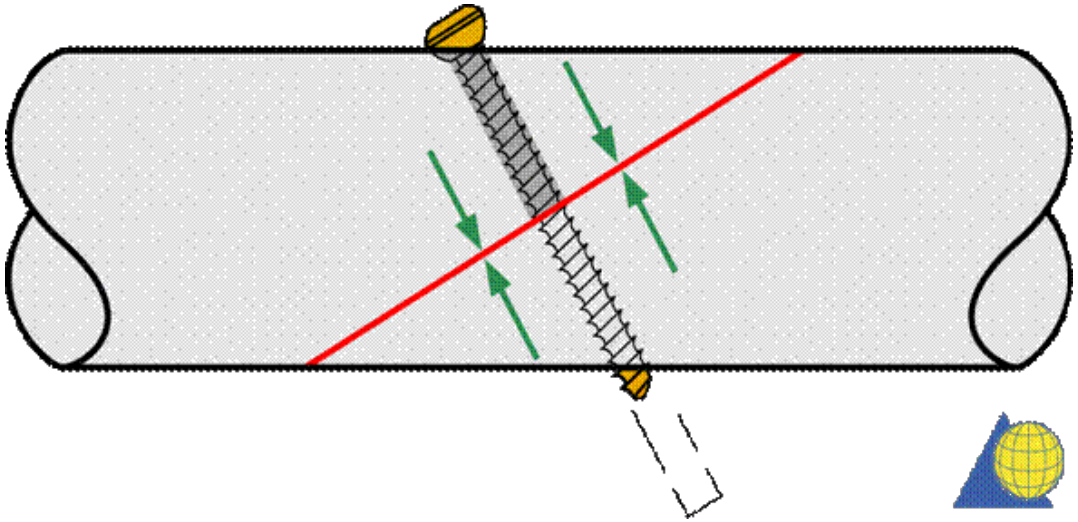
Bone needs a capillary network
Capillaries needs low strain

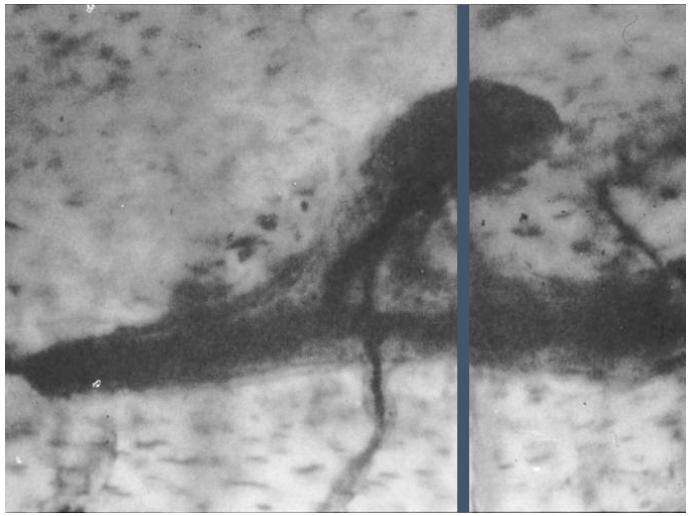


bridging capillary = fracture union

Compression – indirectly useful

Very efficient way to control shear strain through friction and interdigitation



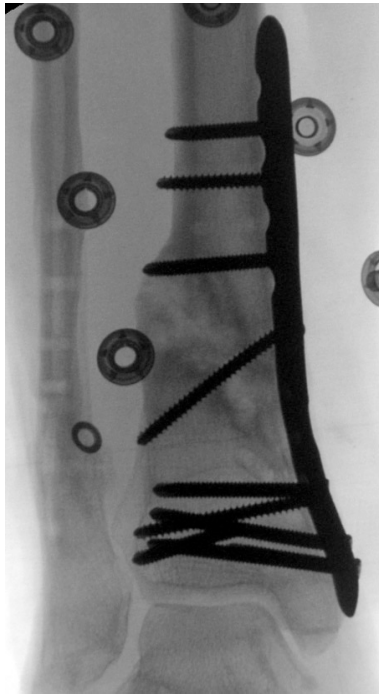


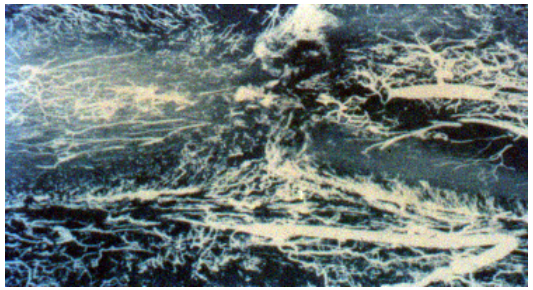
No need for intermediate tissues

To Obtain Union

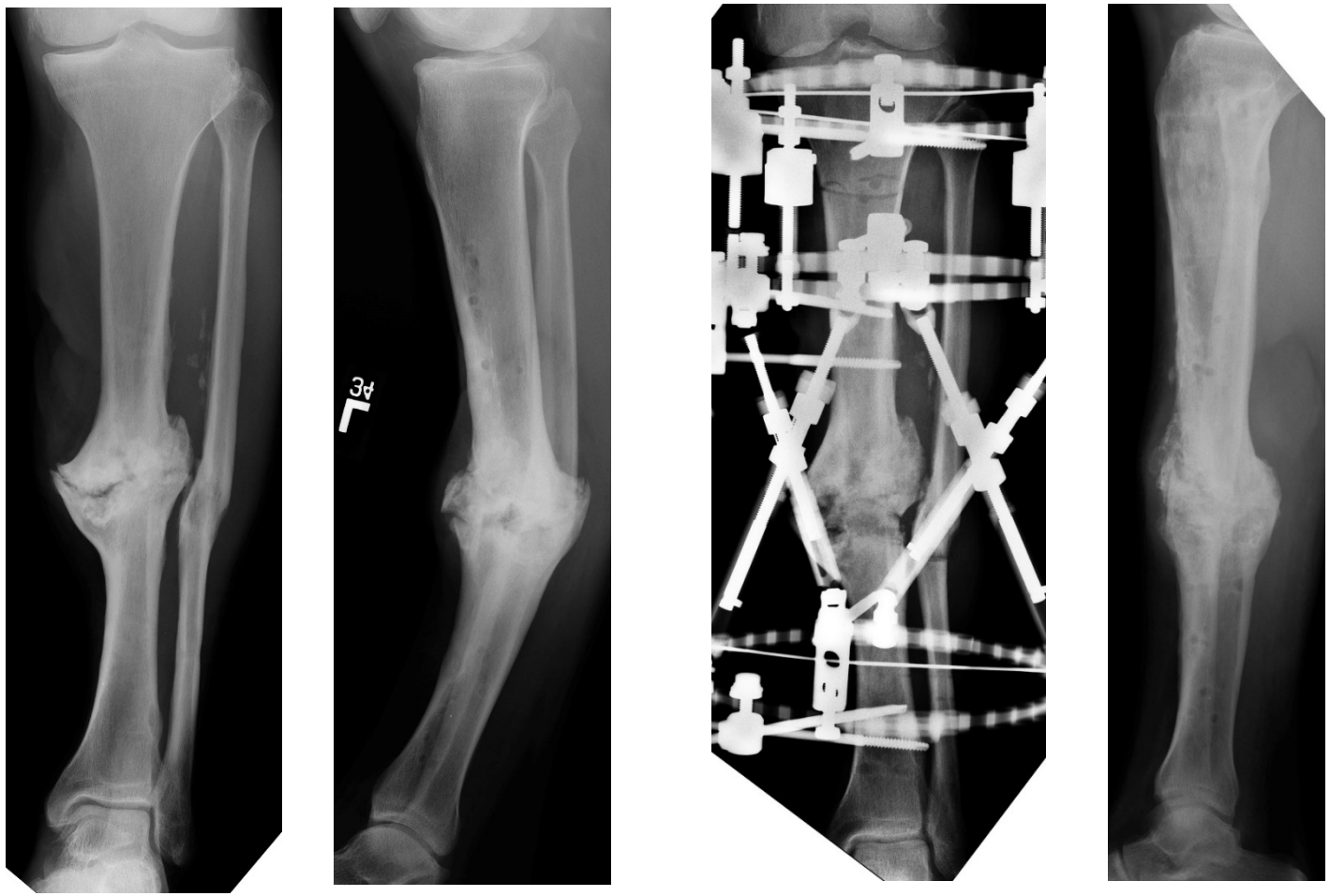
Implant and the callus together must control motion at the fracture gap such that capillaries can begin to cross.

Control of torsional and translational shear strain is most difficult





How does distraction and re-alignment affect shear strain?



Alignment normalizes forces and reduces strain
Distraction actually widens the gap and can decrease strain in that way

Analyze your Nonunion

- What tissues are in the fracture gap?
- What is the strain in the fracture gap?
- Can the local tissue undergo metaplasia if strain is controlled?
- If not – biologic augmentation is needed to allow the creation of callus.
- Restore axial alignment
- Control translational and torsional strain
- Create stability and protect the capillary bed!

Case:
32 yo healthy male – closed fracture

8 days in ex-Fix

Placed using an MIPPO technique with a 4 cm distal incision

Not exposed or compressed
What is the strain here?

Is this a bridge plate??
What do you think will happen here?

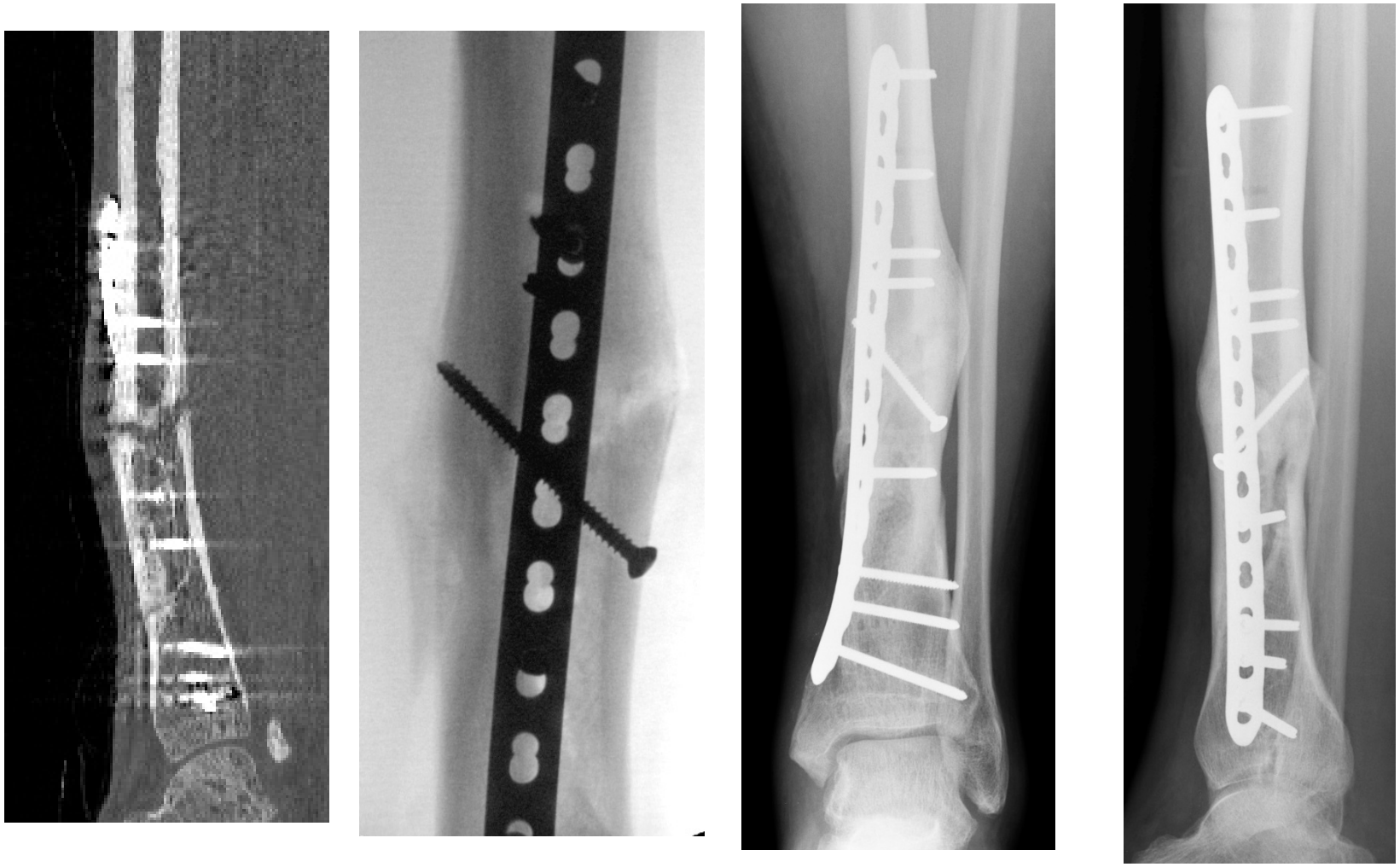
3 mo 5 mo 8 mo

Why did it fail?

Strain was very high because of small gap and no compression.

Callus attempted to control motion/strain

Fatigue life of plate was exceeded

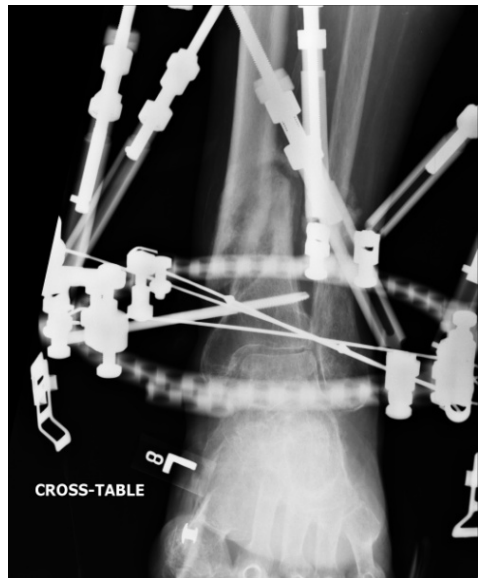


Shear strain controlled with lag screw/compression

Case: 71 yo male – IDDM
severe venous stasis disease
6 mo in a cast

High angle nonunion:
difficult to plate – bad soft tissue – options?

Case: 71 yo male – IDDM
severe venous stasis disease
6 mo in a cast



High angle nonunion:
difficult to plate – soft tissue

Case: 71 yo male – IDDM severe venous stasis disease 6 mo in a cast

Prescription

Date	Day	Strut 1 ● (Red)	Strut 2 ● (Orange)	Strut 3 ● (Yellow)	Strut 4 ● (Green)	Strut 5 ● (Blue)	Strut 6 ● (Violet)	View
4/19/09	0	180	199	166	192	143	205	View
4/20/09	1	179	199	167	194	145	204	View
4/21/09	2	179	199	169	196 a	147	204	View
4/22/09	3	178	199	170	197 a	148	203	View
4/23/09	4	177	199	172	199 a	150	203	View
4/24/09	5	177	199	173	201 a	152	202	View
4/25/09	6	176	198	175	203 a	154	202	View
4/26/09	7	175	198	176	205 a	155	201	View
4/27/09	8	174	198	178	206	157	201	View
4/28/09	9	174	198	179	208	159	200	View
4/29/09	10	173	198	180	210	161	199	View
4/30/09	11	172	198	182	212	162	199	View
5/1/09	12	172	198	183	214	164	198	View
5/2/09	13	171	198	185	215	166	198	View
5/3/09	14	170	198	186	217	168	197	View
5/4/09	15	170	198	188	219	169	197	View
5/5/09	16	169	197	189	221	171	196	View
5/6/09	17	168	197	191	223	173	196	View
5/7/09	18	167	197	192	224	175	195	View
5/8/09	19	167	197	194	226	176	195	View
5/9/09	20	166	197	195	228	178	194	View

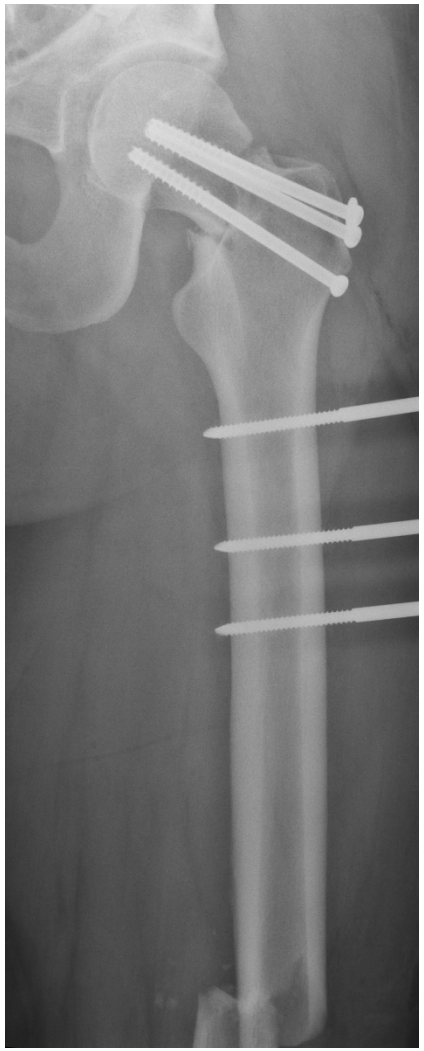
Frame controlled shear – very slow correction

21 days……then compressed

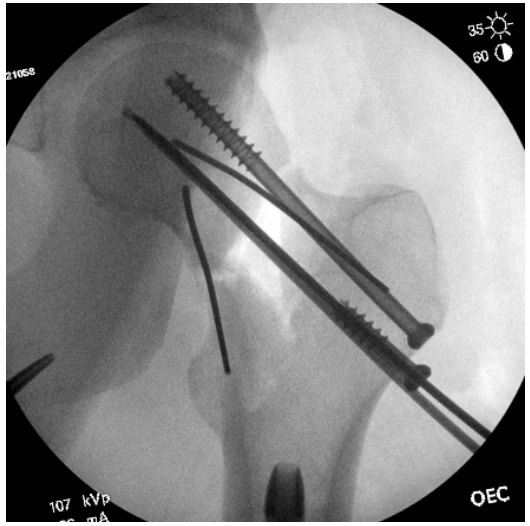
SL waking cast x 6 weeks

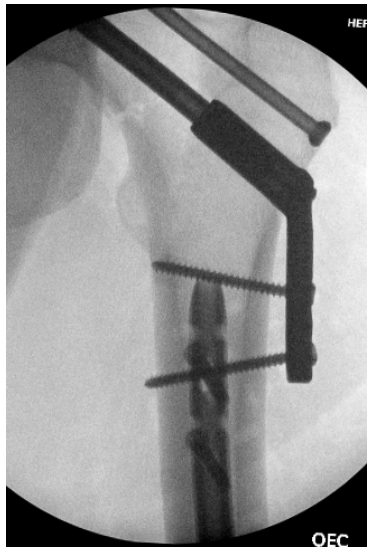
Time in frame 5 mo

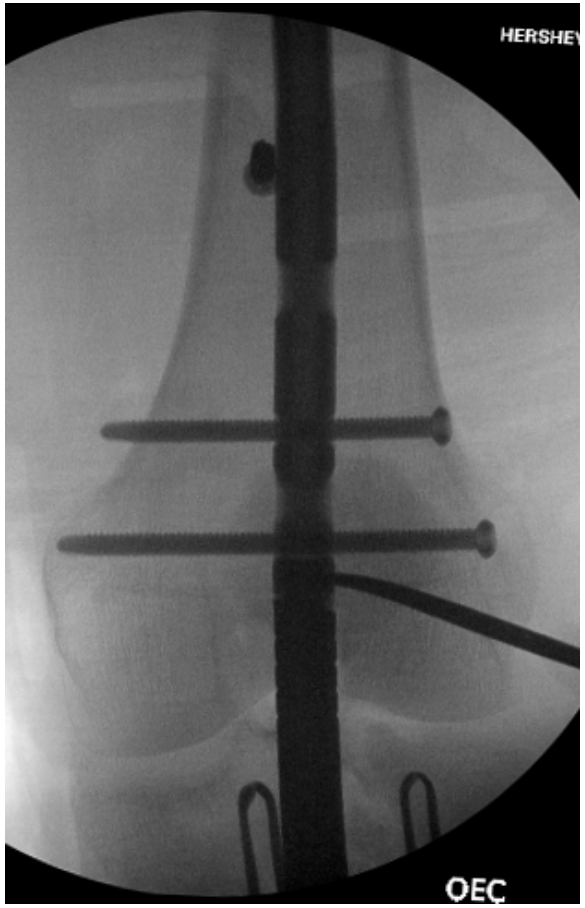
Case: 35 yo male healthy MCA
Type IIIA open femur, proximal tibia with extensor mechanism injury, open pilon

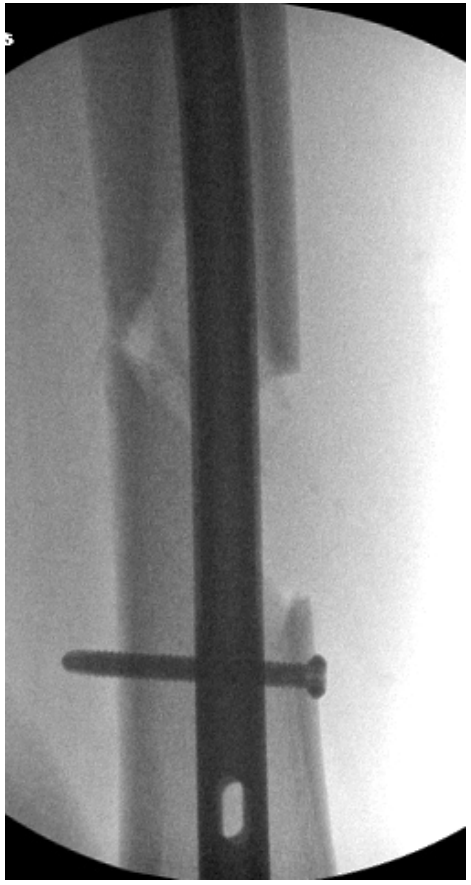


ORIF femoral neck
Retrograde femoral nailing

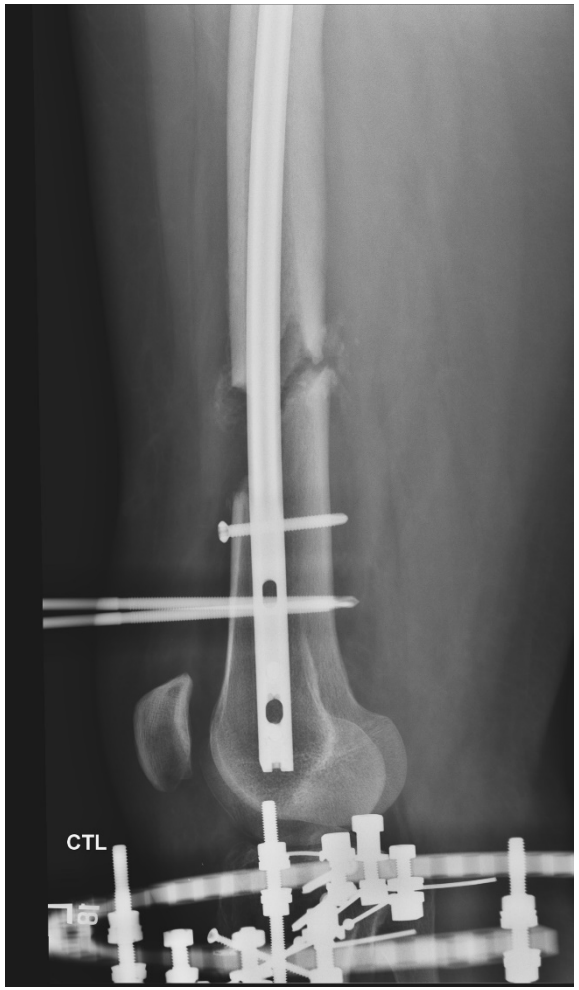




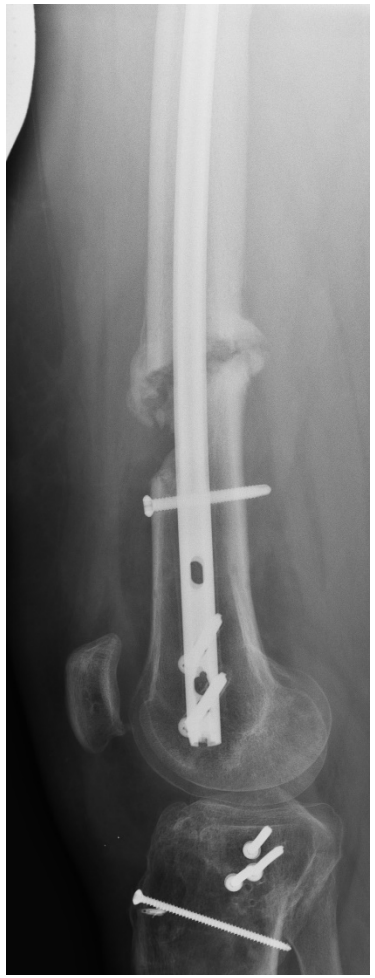


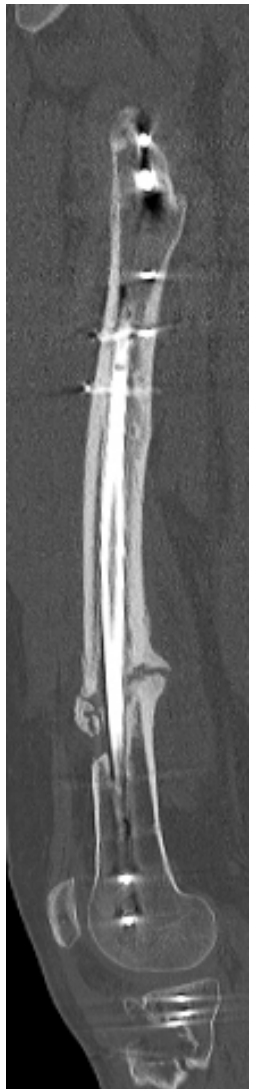


Extension of ring fixator across the knee to protect extensor mechanism repair



18 mo later: pain with ambulation
0 -110 ROM knee: no infection
femoral neck has healed

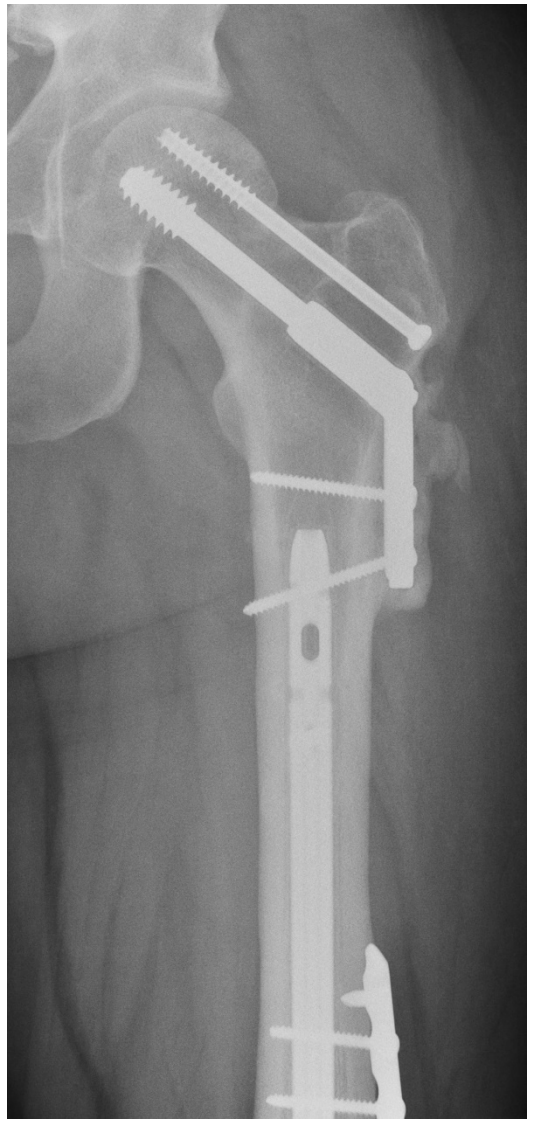




What to do now?

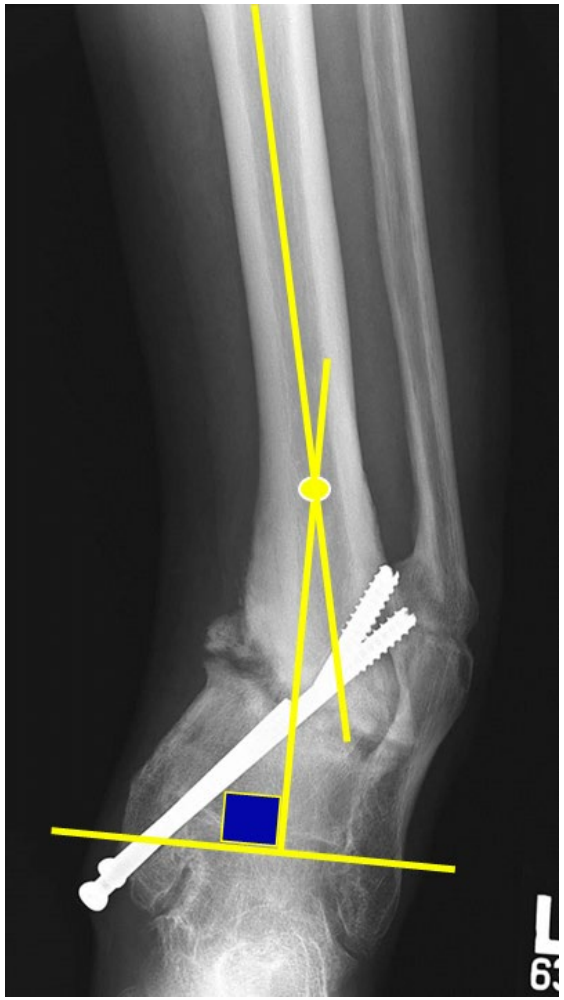
reamed exchange nailing
compression plating of nonunion
no bone grafting – DBX putty

4 mo later

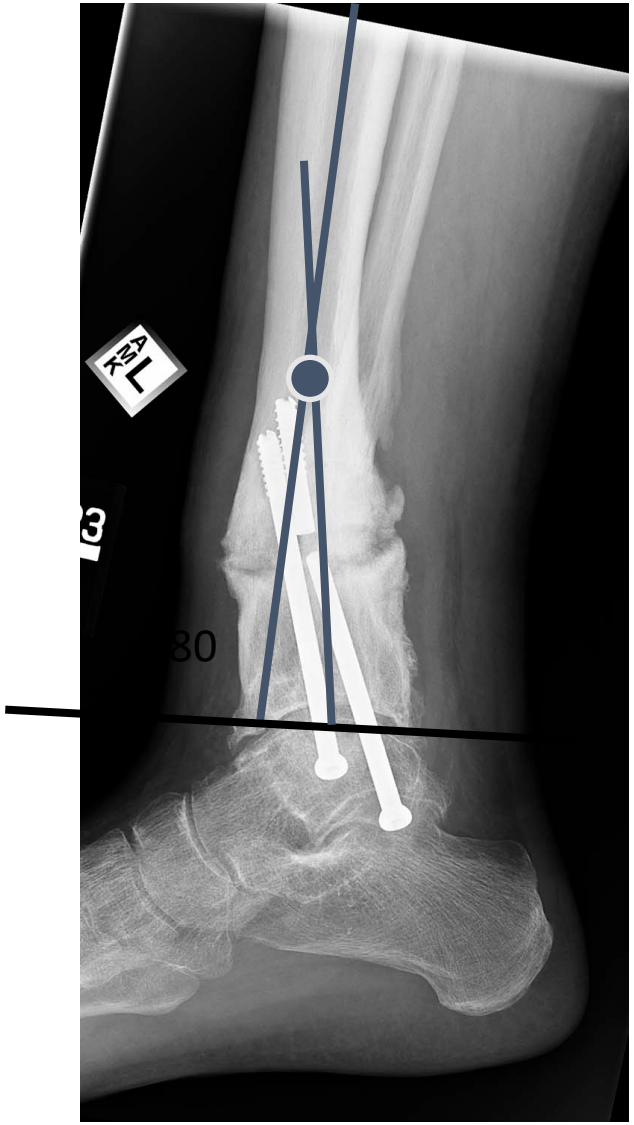


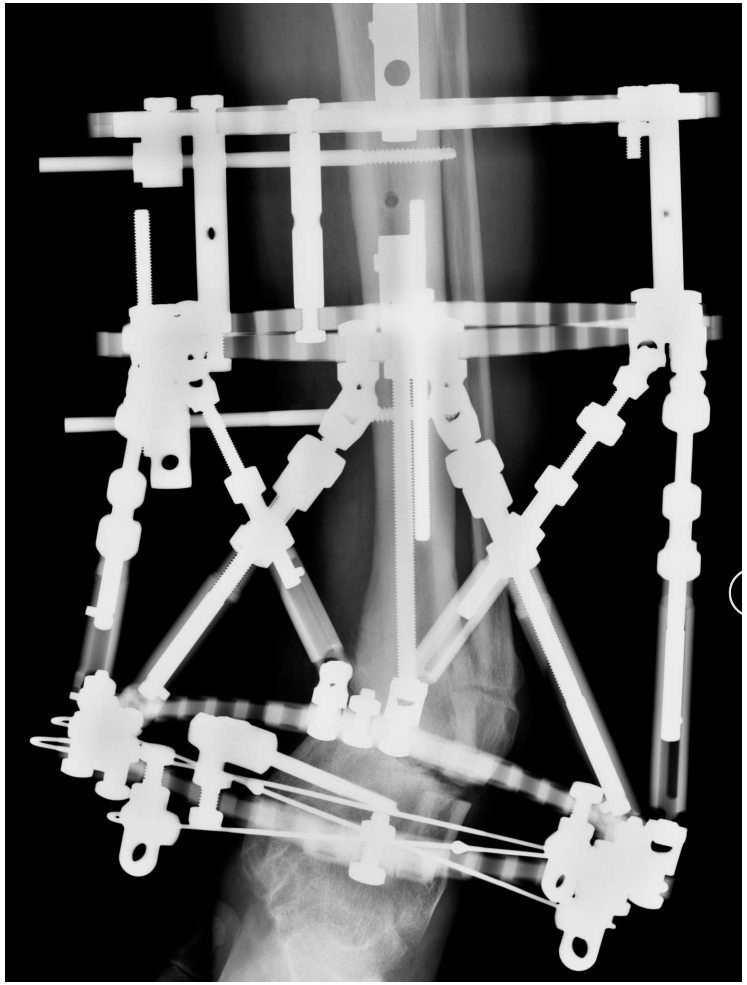
55 yo nonunion after osteotomy

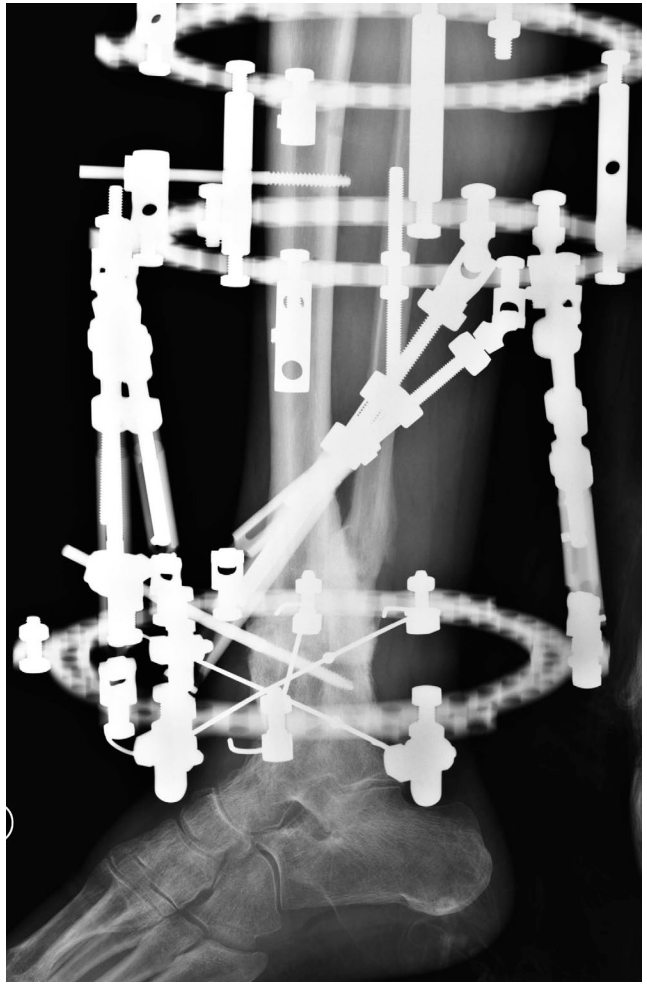
Deformity analysis



In the Sagittal Plane

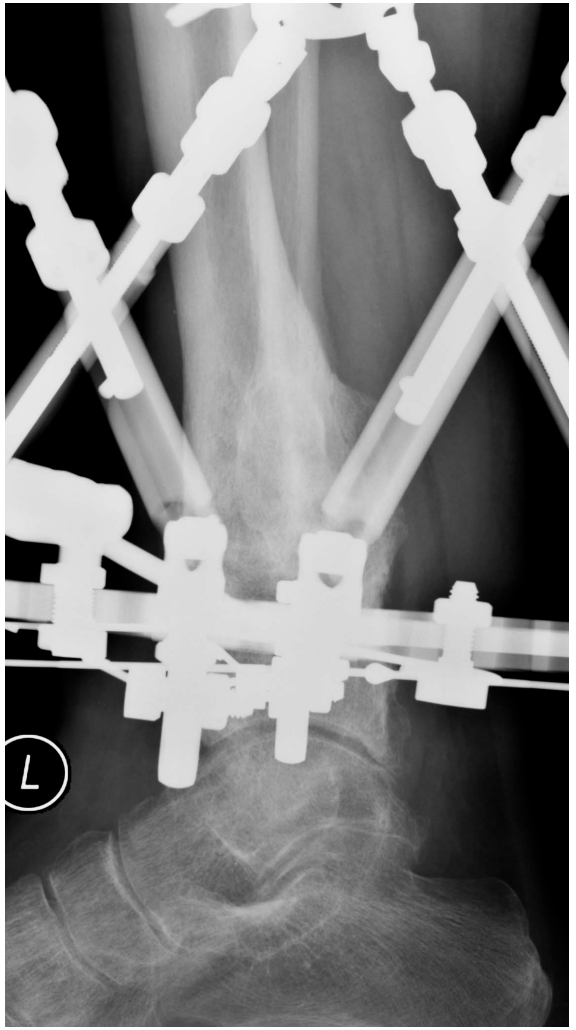






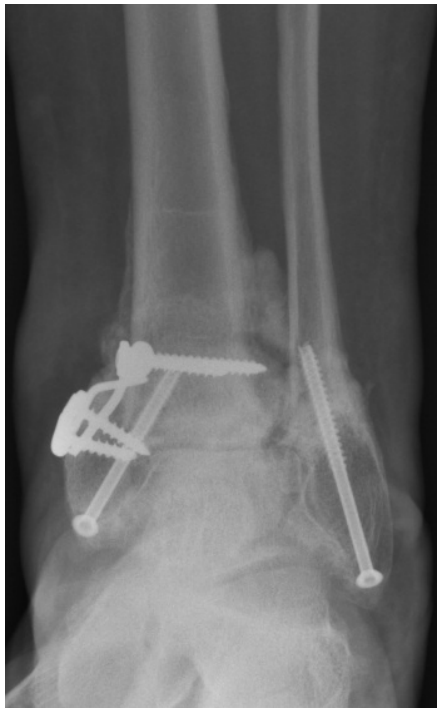
Fracture not opened : distraction and deformity correction

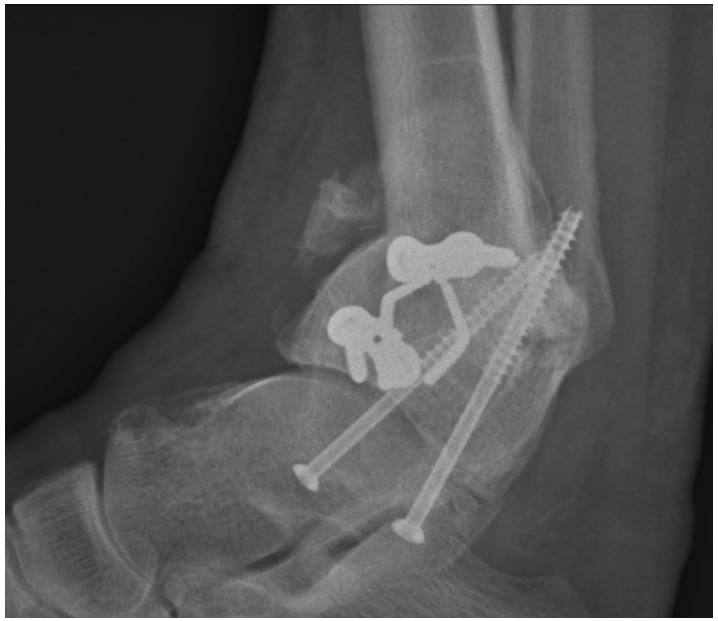
Slow


L

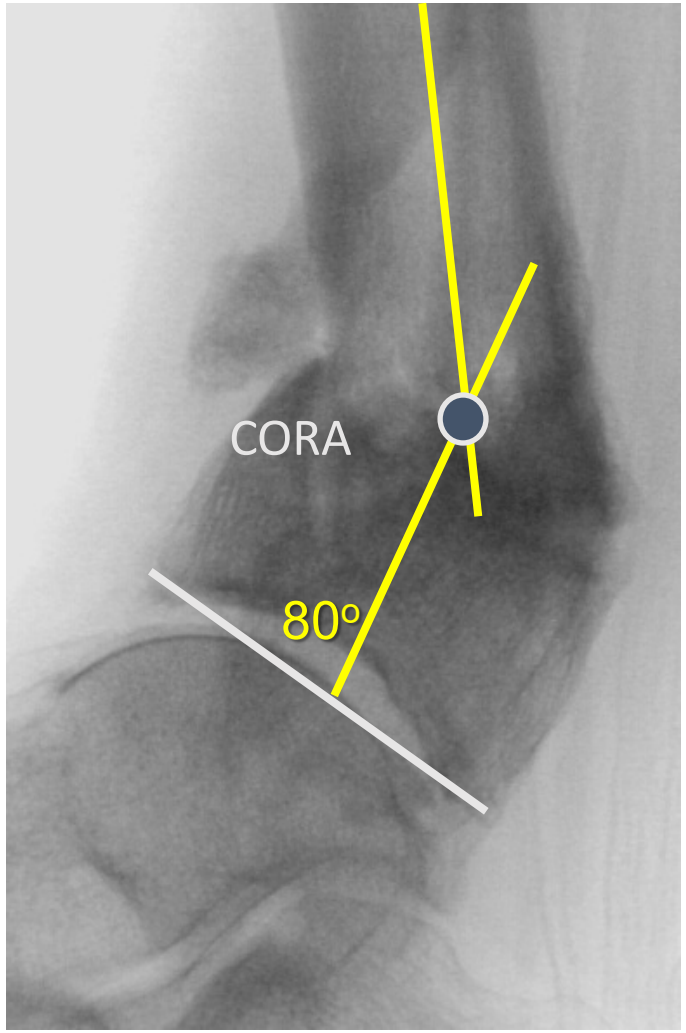
Bone in fracture gap undergoes metaplasia into bone when alignment is corrected and strain is controlled by frame

44 yo woman – 18 mo s/p a closed pilon fracture. Infection w/u negative

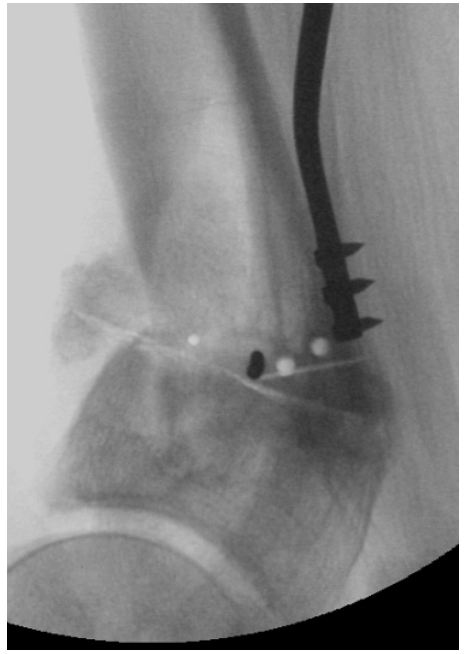




Goals:
Correct Deformity
Create Stability
Restore Biology


CORA
80º

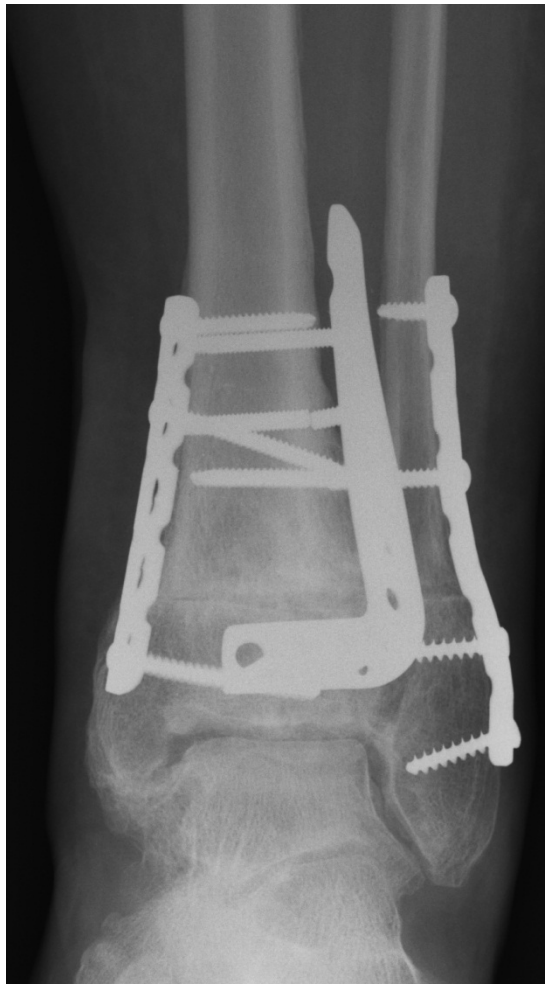
Pivot around CORA

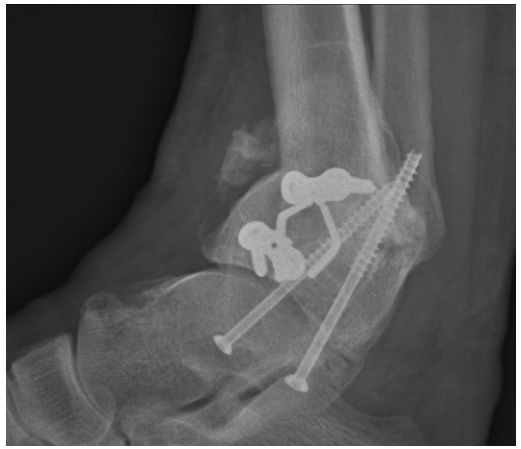


Opening/closing wedge

Iliac crest autograft

2 years later – some pain





Fracture Gaps/Bone Loss

- Fractures with critical bone loss are the subject of another lecture
- Fracture gaps (including distraction) are an issue and effect on healing very dependent on the bone.
- Femur gaps may spontaneously heal without grafting.
- Tibia is much less forgiving

Fracture gaps / bone loss

- Tibia healing much more impaired by a gap compared to femur
- Tibia fractures with < 25% cortical contact highly predictive of nonunion (OR 4.72 p=0.02)
- Highlights the need for early bone grafting in situations with significant bone loss

Fong, K., et al., *Predictors of nonunion and reoperation in patients with fractures of the tibia: an observational study.* BMC Musculoskeletal Disorders, 2013. 14: p. 103.

Case: 45 yo male – non smoker
closed fracture – 9 mo

Reamed exchange nailing

Partial fibulectomy

Open bone grafting from prox. tibia

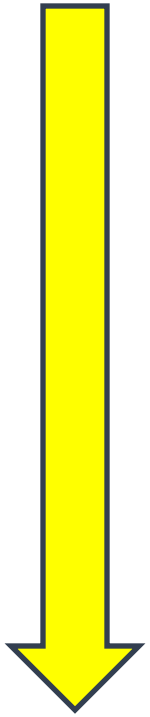
Healed 4 mo later

The Infection Problem

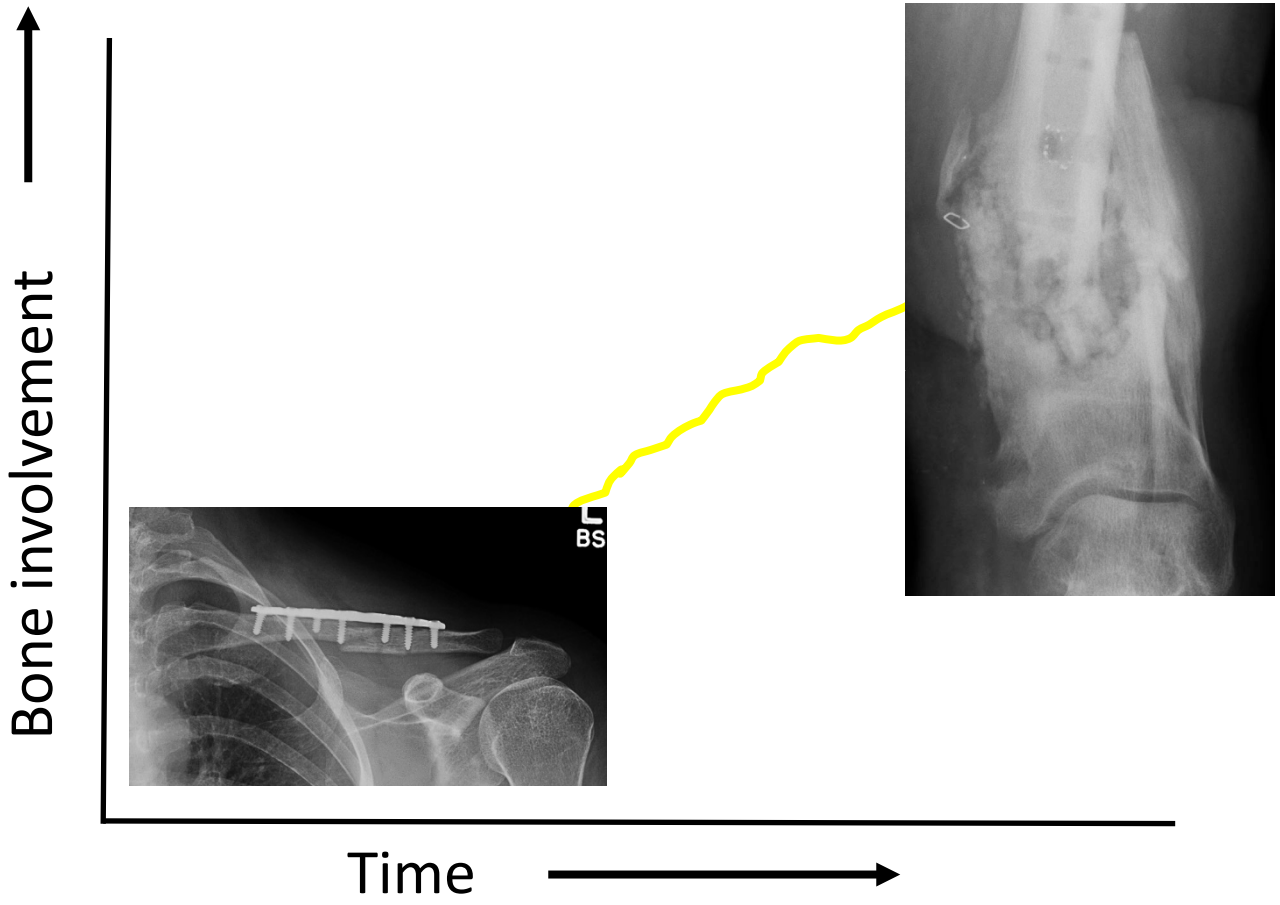
- Consider every nonunion that was open or has had surgery as potentially infected
- Preop w/u to include WBC, CRP, ESR
- If all are negative, high likelihood not infected
- However… could still be infected with a quiescent organism (p. acnes, staph epi.)
- Always culture and *include fungus and AFB*
- Have the lab hold for slow growing organisms
- Consider two stage if obviously infected

Exists on a time spectrum….

- Acute infection with hardware
- Late infection with hardware
- Chronic osteomyelitis



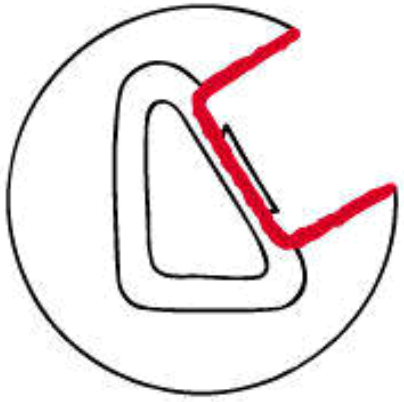
Infected Nonunion - spectrum



Osteomyelitis

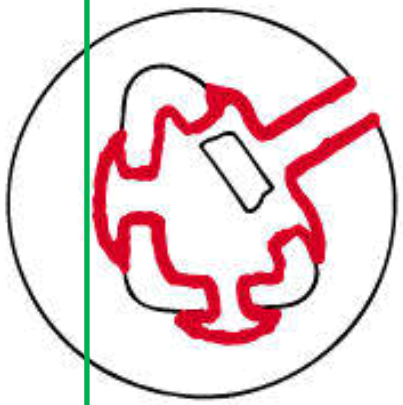
Cierny – Mader classification

Medullary



Superficial

Localized



Diffuse

Infected nonunion

Infected nonunion

How does it happen?

- Inadequate debridement of an open fracture
- Bacterial contamination at the time of surgery
- Failure of primary wound healing

Inadequate Debridement

injury

After first

After second

That intramedullary cortical fragment will become a sequestrum!

Poor surgical timing

- 

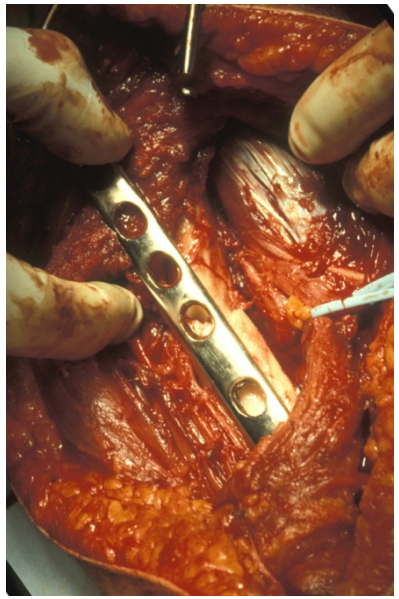
Case: 57 yo nonsmoker – healthy male
6 months s/p grade II open fracture 2 incision
technique

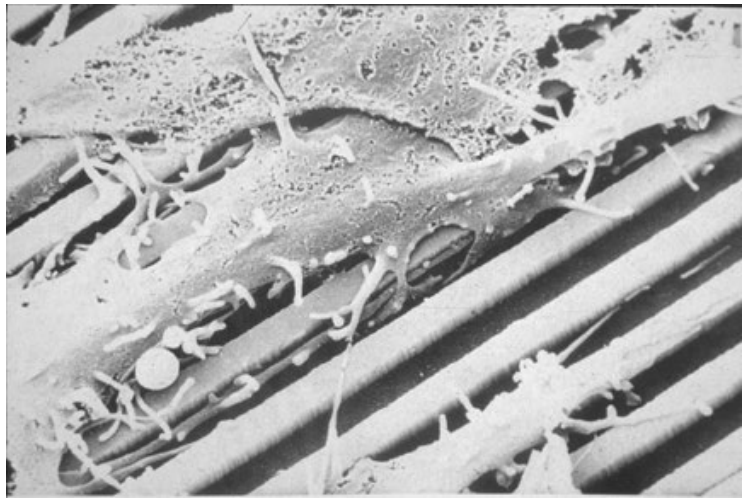
draining

What is happening on the surface of the plate and bone?

The race for the surface!

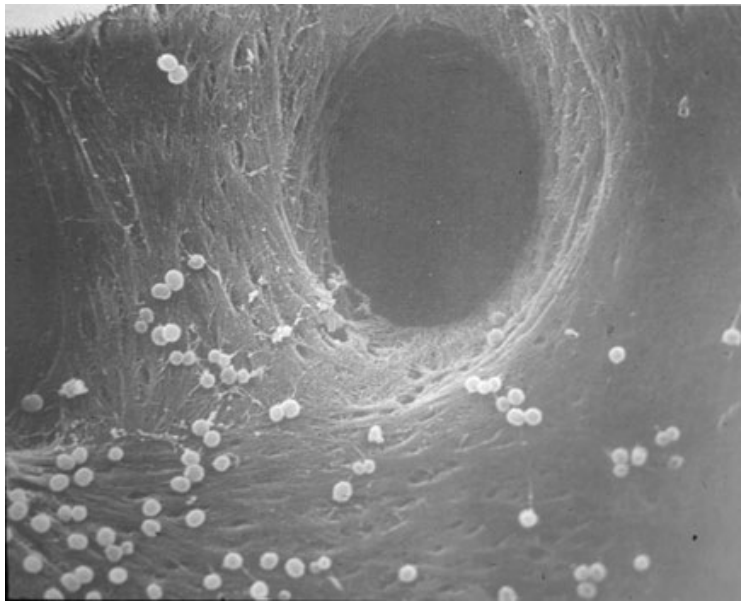
- surfaces colonized by healthy tissue are rarely colonized by bacteria
- surface bacterial colonies are rarely replaced by healthy tissue





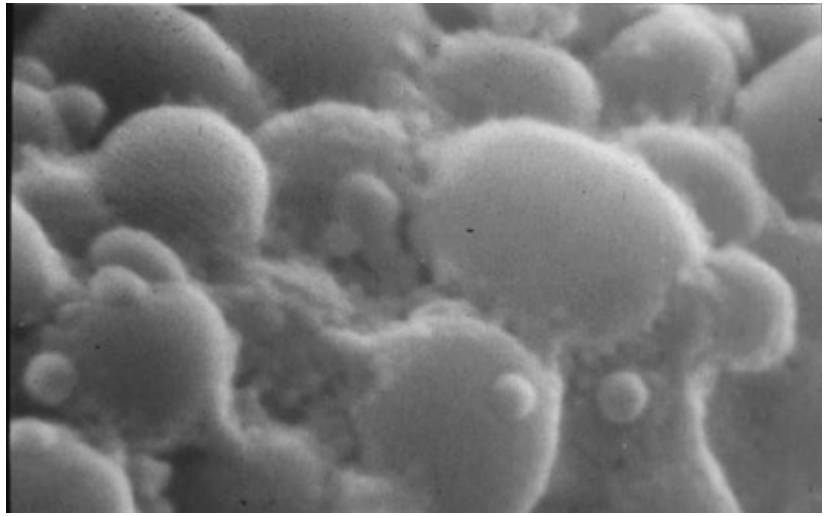
Bacterial adherence

Gristina AG Science 1987



Reversible - early

6 - 8 hours



Irreversible - late

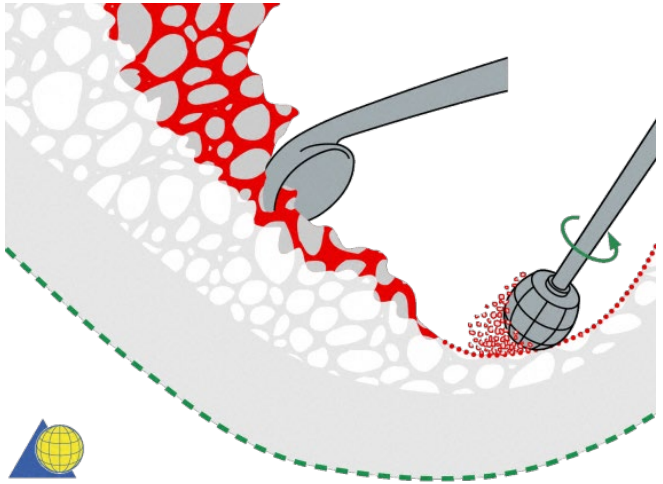
Antibiotic Resistance

- Biofilm layer dramatically reduces the metabolic rate of the bacteria.
- MIC 50-100 times higher in biofilm colonies than swarmer cells

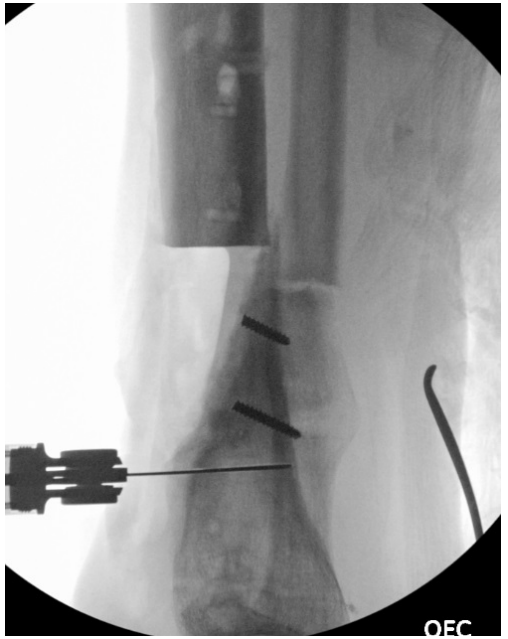
- "You can't kill me, I'm sleeping"

- surface specific:

  titanium<stainless steel<PMMA<BONE



After the biofilm is well established,
The surface has to be debrided or removed to resolve the infection



Debridement - bone

Get it done in 2 visits to OR

Consider a CT scan after hardware out

Based on the location of dead bone

- External: *burr / curette*
- Medullary diaphysis: *ream / RIA*
- Metaphyseal: *slot the cortex to gain access*

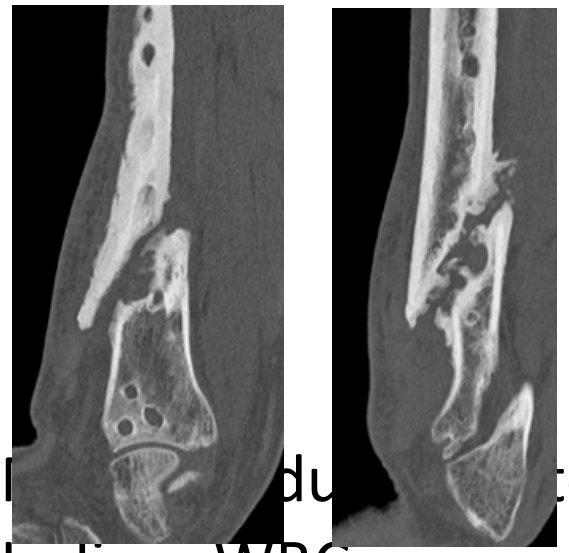
Debridement

create a LIVE contaminated wound

- 2 debridements to clean (maybe more)
- plan approach to remove all necrotic tissue (bone/muscle/skin)
- Send everything for culture (+fungus)
- Consider fastidious organisms
- excise sinus tracts present >1 year - *send to path (squamous cell carcinoma)*
- do not elevate flaps (make a canyon)
- use a burr with constant cooling

Imaging – infected nonunion

- Plane radiographs
- CT scan – very useful after hardware out



- I du tent of
- Indium WBC scans – beware false negative

Debridement - hardware

Hardware / Tracts are contaminated

- Plates: curette/burr under surface
- Screws: overdrill – remove broken
- IM nail: ream and flush canal
  antegrade and retrograde

Dead space management

Temporary:

- antibiotic beads (pouch)
- +/-VAC sponges

Permanent:

- muscle grafts
- resorbable antibiotic delivery
- bone graft or transport / shorten

Systemic Antibiotics

- Generally 4-6 weeks IV
- Consider short IV (2 weeks) then PO (A host)
- Oral Rifampin in Gm+ if hardware retained – penetrates biofilm
- Don't use: bacteriostatic antibiotic *with* bacteriocidal antibiotic
- ID consult

  -manage antibiotic levels

  -monitor toxicity

  -good medicolegal sense

Definitive Reconstruction

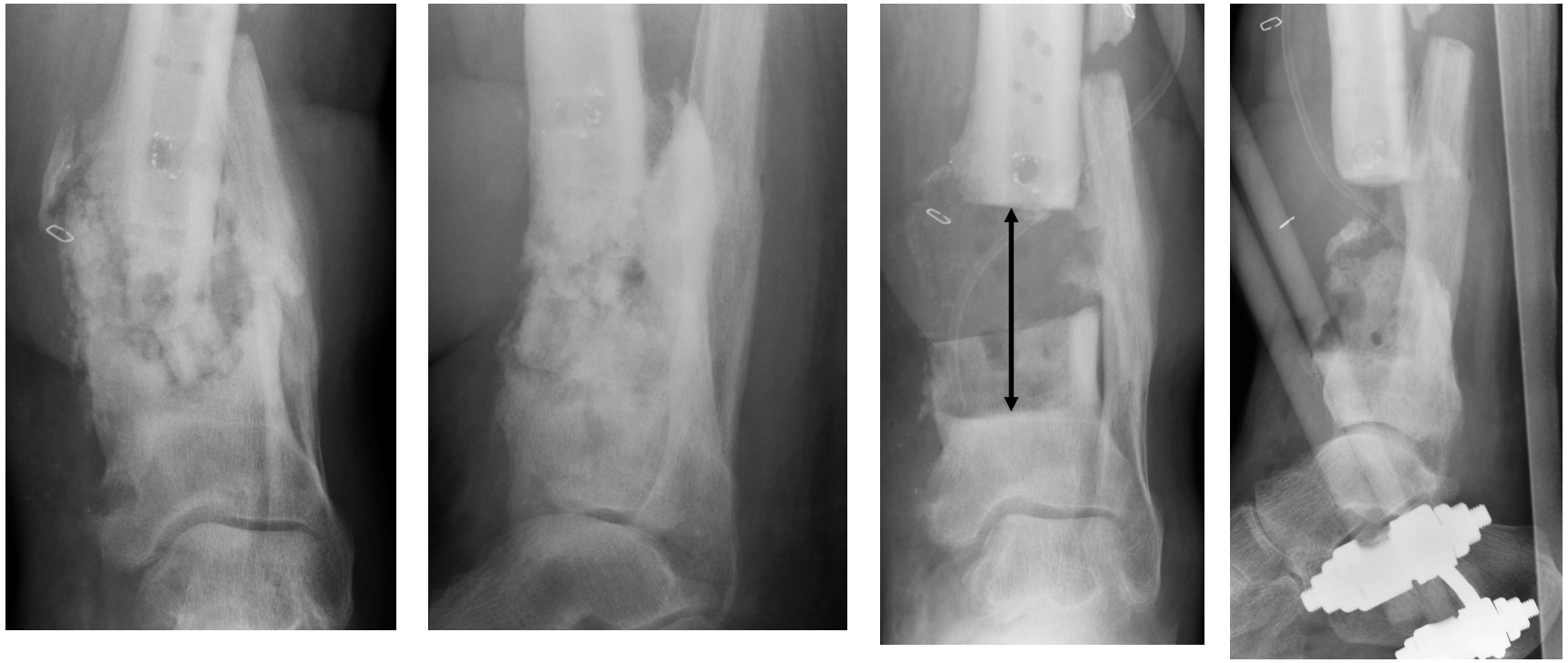
All methods viable if the debridement was done well.

- Plate
- IM nail
- Ring Fixator

Consider adding specific antibiotic to bone graft.

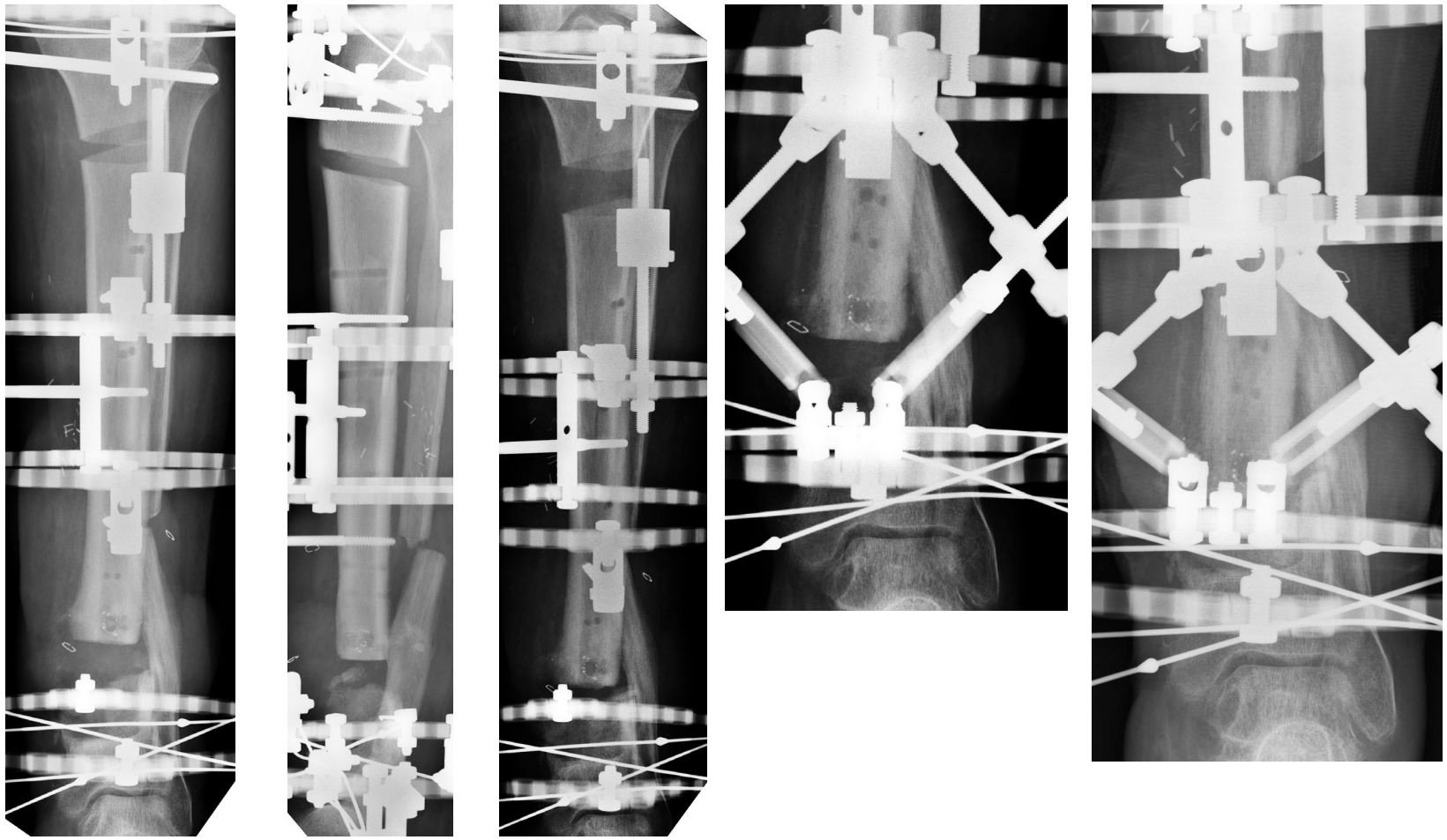
1 gm Vanco powder well tolerated

Case: 32 yo male 1 ppd smoker
IIIA open fracture
ESR 85 – CRP 4.3 – previous plating



Staged resection (6 cm)– MRSA & serratia

Quit smoking – vitamin D level very low -



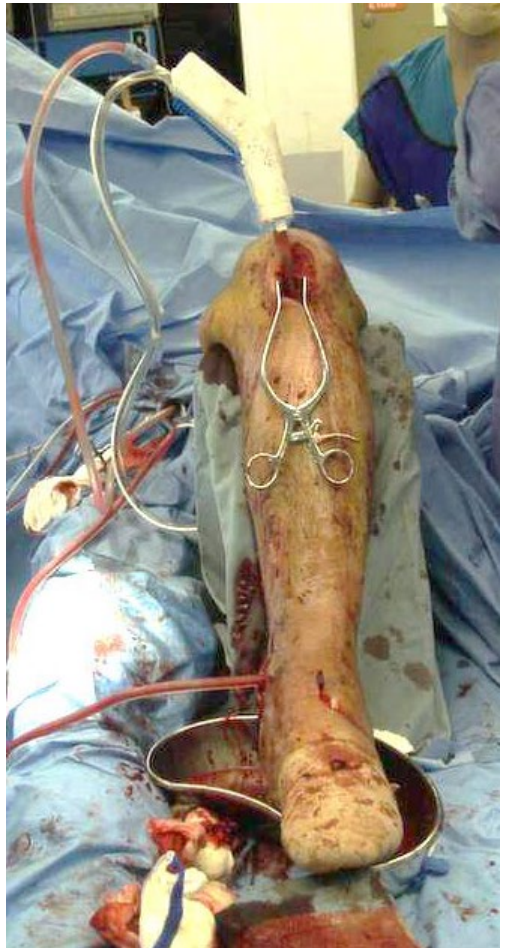
Bone transport

Bone grafting at distal site:
12 mo in frame

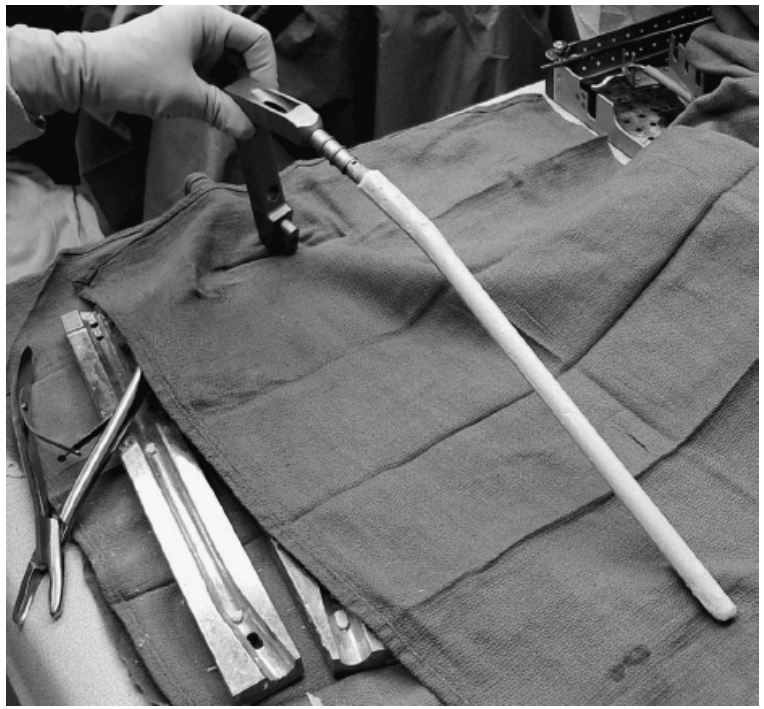
Case: 54 yo local attorney
10 weeks after IM nailing grade 1 open fracture - MVA

WBC 15.5
ESR 95
CRP 6.3

Same day



After 7 days – Redebride
Antibiotic coated IM nail + IV Vanco



Infection cleared

re-nailed
standard IM nail
iliac crest BG
vanco added
cultures negative

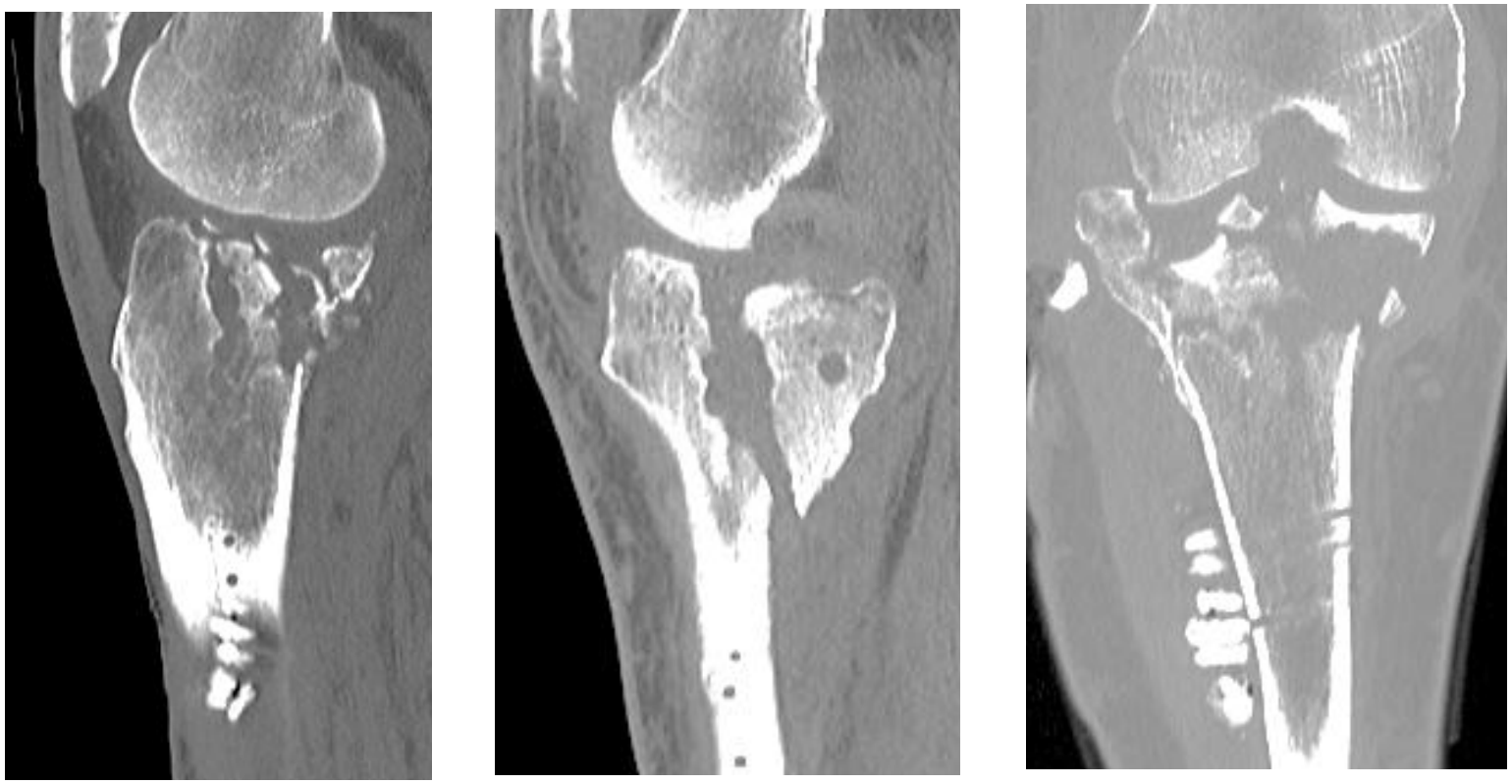
What to do?

dehisence of lateral wound – corner of plate exposed – growing MRSA

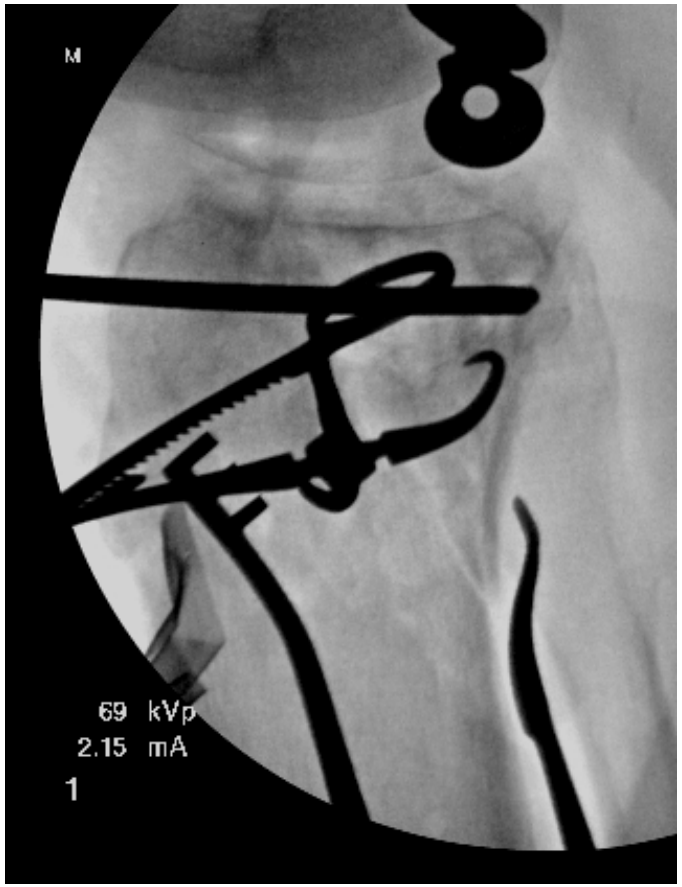
Staged Treatment

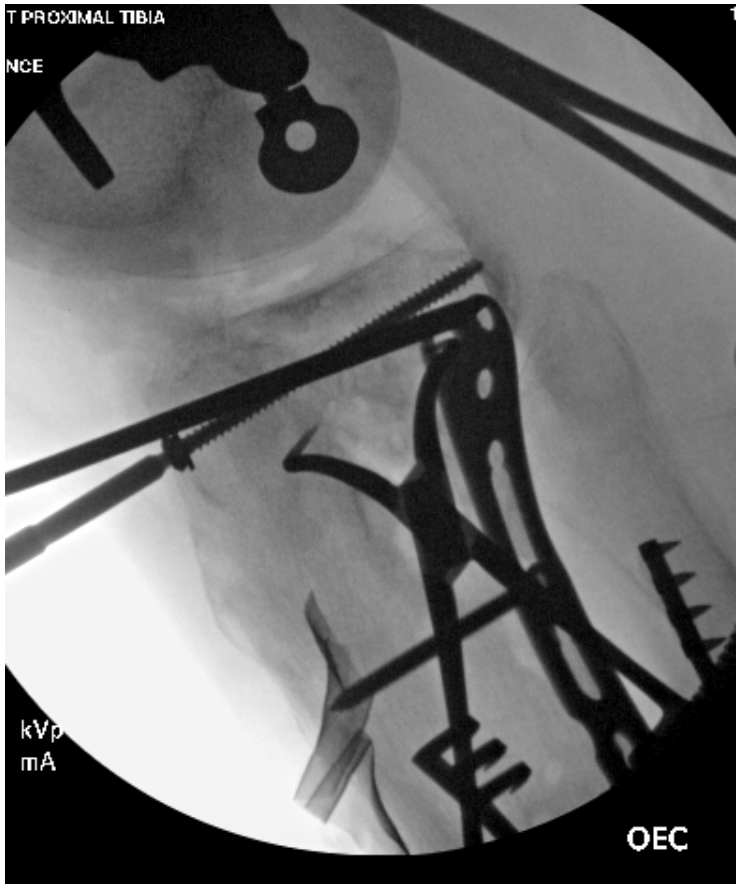
Part one:

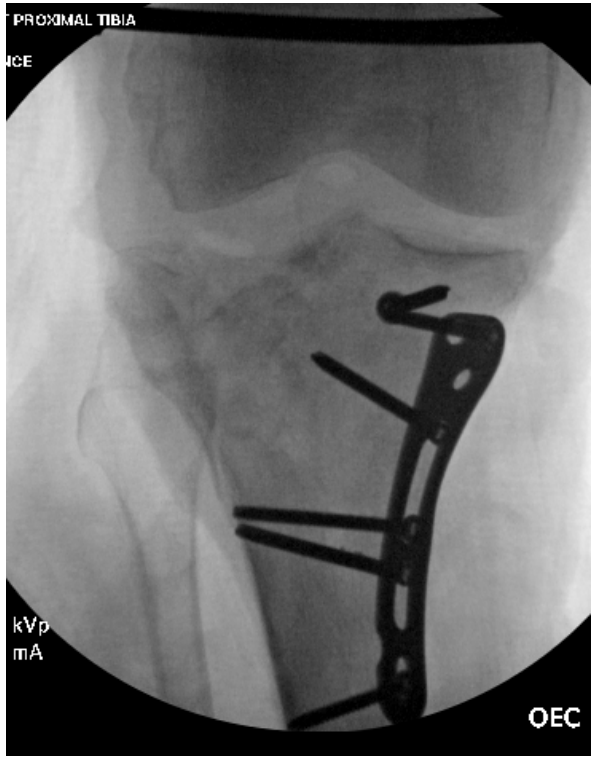
- Hardware removal
- Debridement
- Antibiotic Bead placement
- Gastroc Flap – IV antibiotics
- CT scan

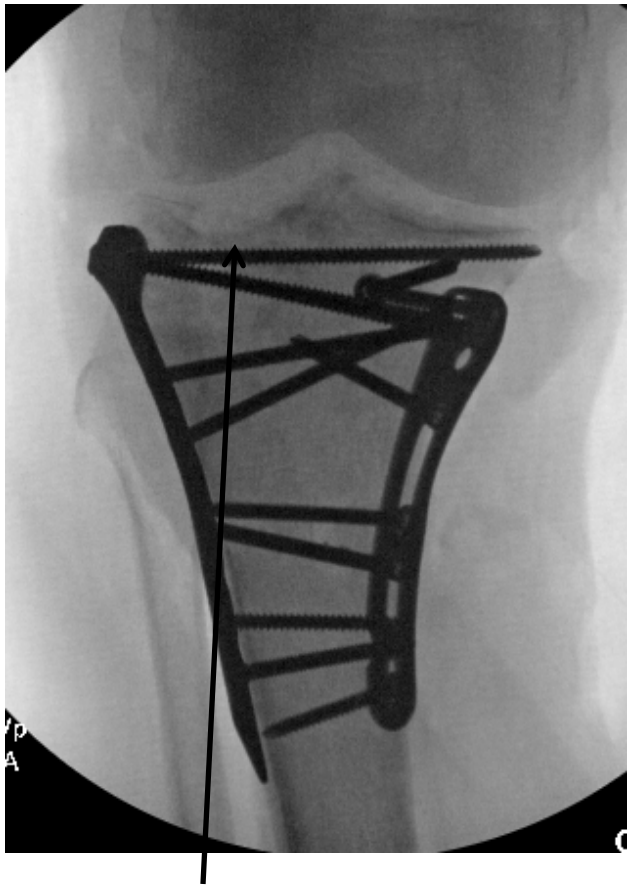


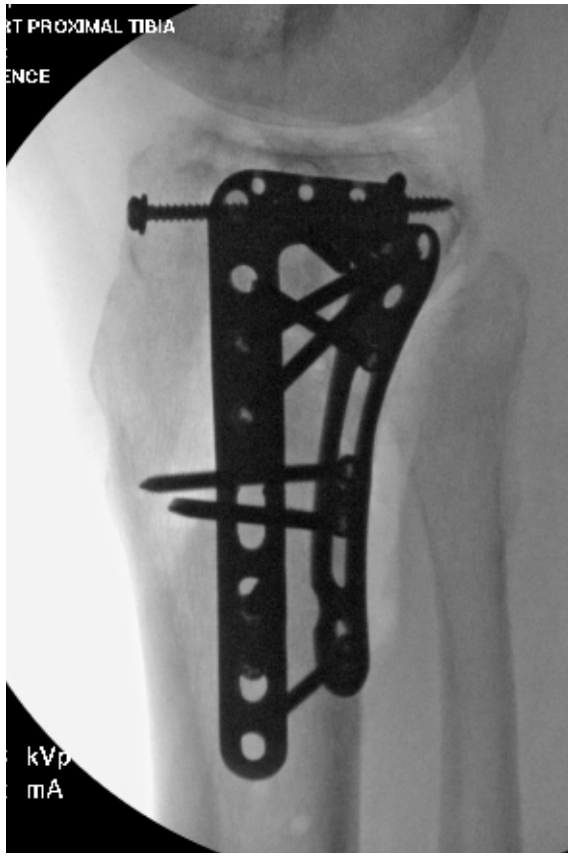
Part two: six weeks later
revision ORIF
iliac autograft (+ vanco)



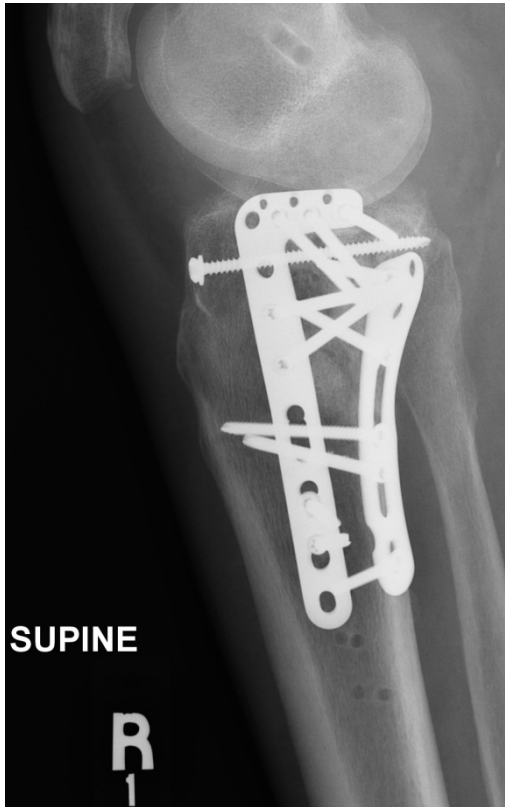








Joint surface elevated and supported with autograft


SUPINE
R

3 mo s/p ORIF

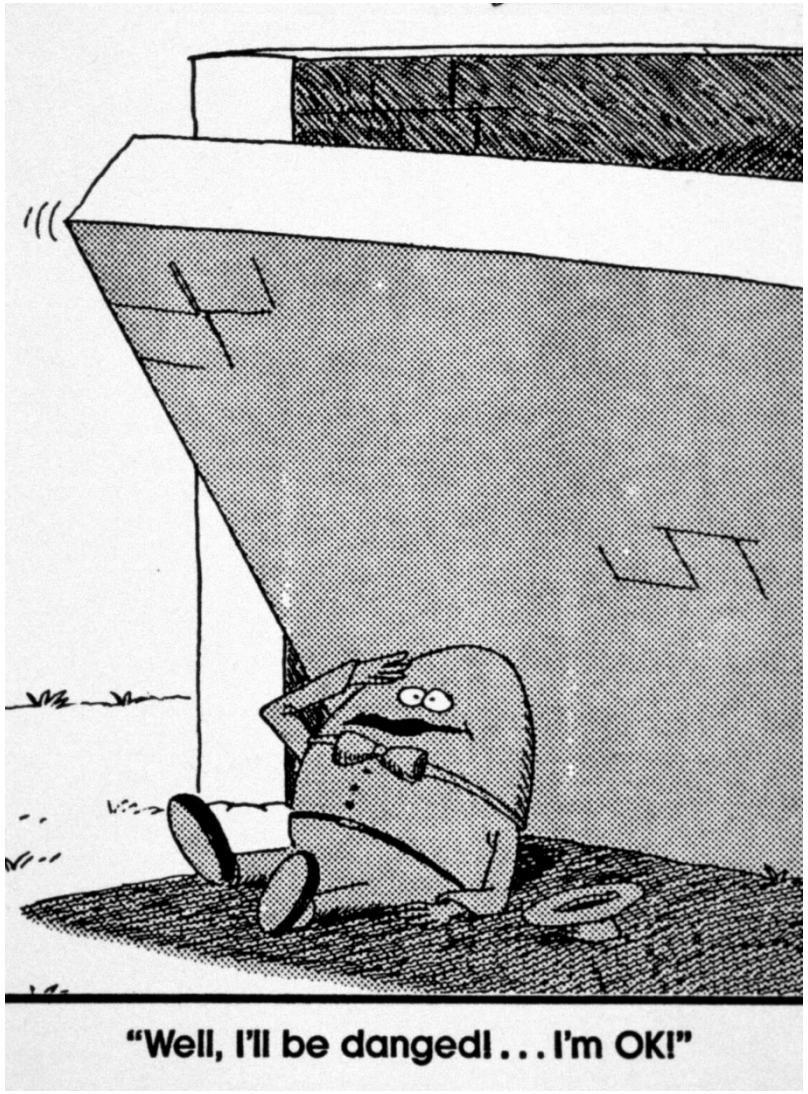
10 – 85 ROM

No infection

Infected Nonunion

- Image as needed to stage it
- Plan throughly – refer if necessary
- Optimize host factors
- Debride aggressively
- Shorten judiciously
- Create stability and axial alignment
- Immuno-competent coverage
- Bone graft / substitute / transport

Thank You!



Topic