Nonunion with Bone Loss

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Original Authors; March 2004; Revised June 2006 and 2010

Etiology

- Open fracture
  - segmental
  - post debridement
  - blast injury
- Infection
- Tumor resection
- Osteonecrosis

Classification

Type		Defect	Size	Articular
I	A	Minor	<1cc or <1cm^2	Either
	B	Minor	<1cc or <1cm^2	Either
II	A	Major	>5 cc or 3 cm^2	Non-articular
	B	Major	>5 cc or 3 cm^2	Non-articular
III	A	Major	>1 cm^2	Articular
	B	Major	>1 cm^2	Articular

Salai et al. Arch Orthop Trauma Surg 119

Classification

Type		Defect	Size	Articular
I	A	Minor	<1cc or	Either
	B			Either
II	A			Non-articular
	B	Major	>5 cc or 3 cm^2	Non-articular
III	A	Major	>1 cm^2	Articular
	B	Major	>1 cm^2	Articular

Not Widely Used
Not Validated
Not Predictive

Salai et al. Arch Orthop Trauma Surg 119

Evaluation

- Soft tissue envelope
- Infection
- Joint contracture and range of motion
- Nerve function: sensation, motor
- Vasculature: perfusion, angiogram?
- Location and size of defect
- Hardware
- General health of the host
- Psychosocial resources

Is it Salvageable?

- Vascularity - warm ischemia time
- Intact sensation or tibial nerve transection
- other injuries
- Host health
- magnitude of reconstructive effort vs patient's tolerance
- ultimate functional outcome

Priorities

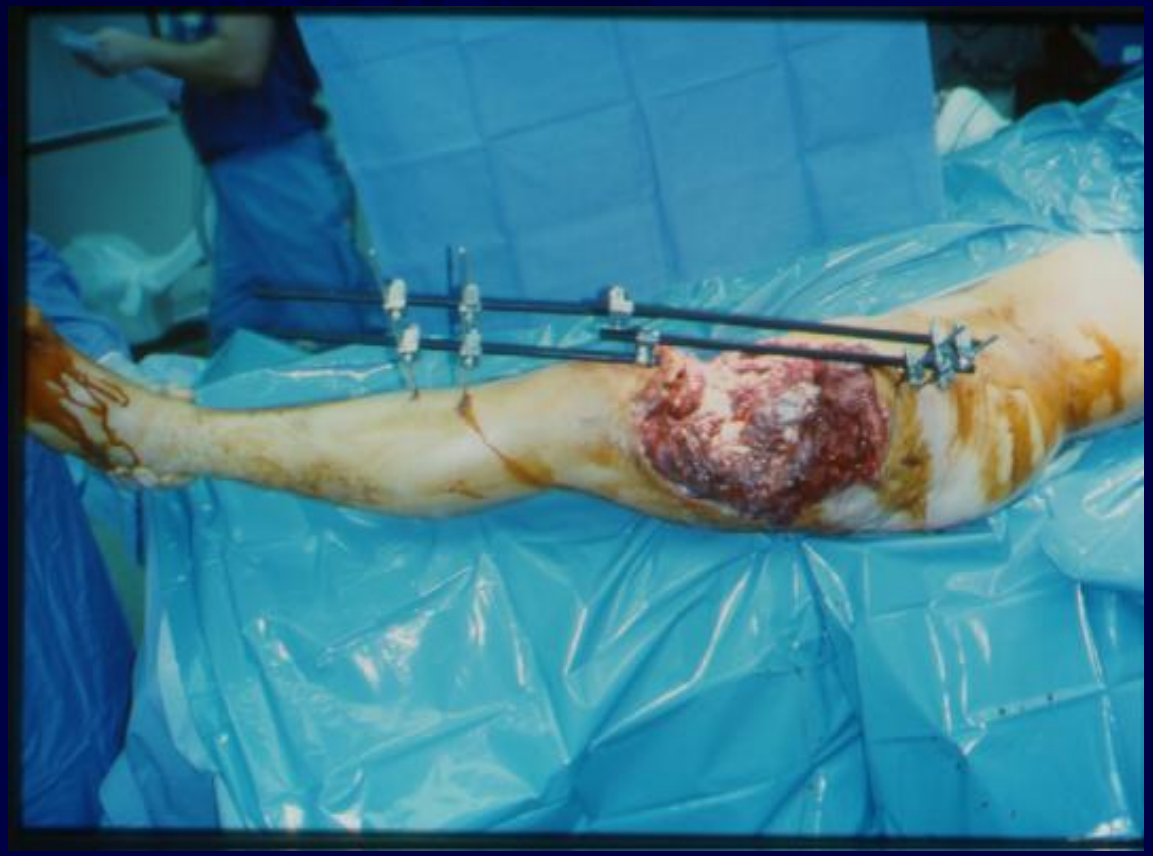
- Resuscitate
- Restore blood supply
- Remove dead or infected tissue (Adequate debridement)
- Restore soft tissue envelope integrity
- Restore skeletal stability
- Rehabilitation

Bone Loss - Initial Treatment

- Irrigation and Debridement

Bone Loss - Initial Treatment

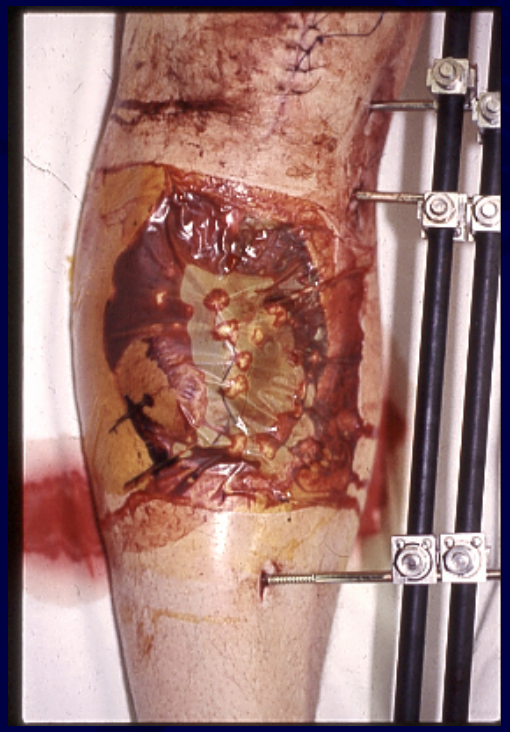
- Irrigation and Debridement
- External fixation



Bone Loss - Initial Treatment

- Irrigation and Debridement
- External fixation
- **Antibiotic bead spacers**

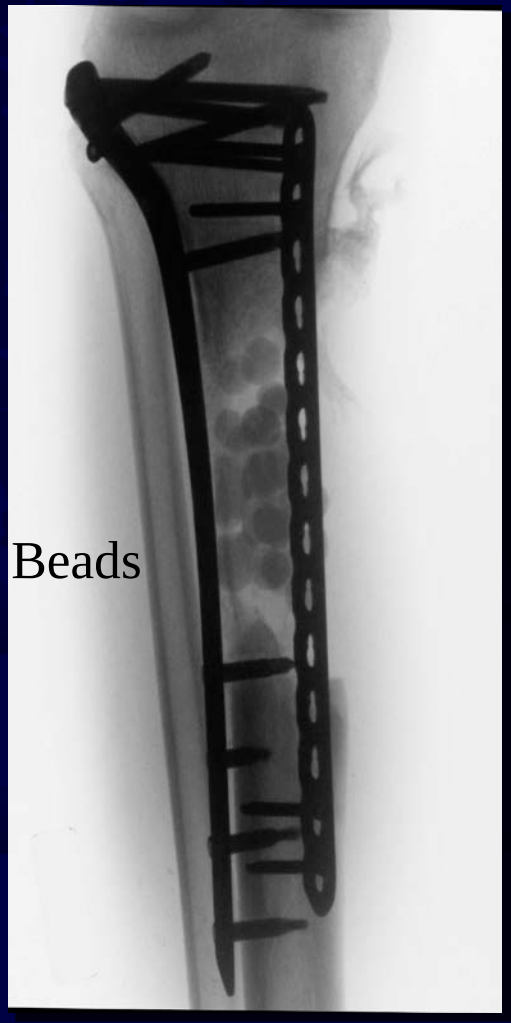
Bone Loss - Initial Treatment

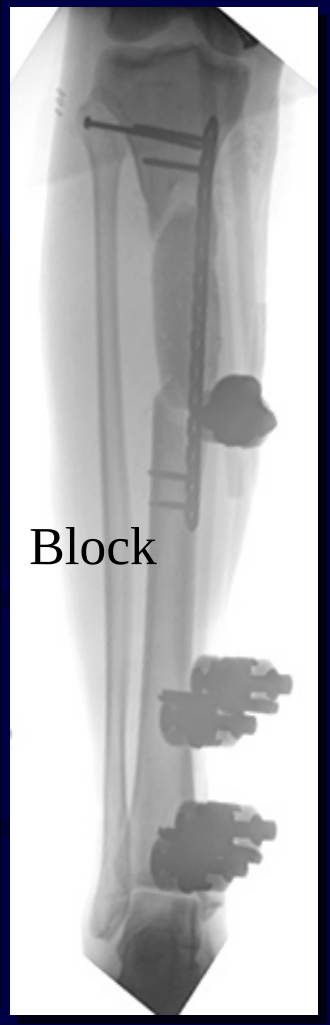


- **ANTIBIOTIC BEAD POUCH**
  - **ANTIBIOTIC IMPREGNATED METHYL-METHACRALATE BEADS**
  - **SEALED WITH IOBAN**

Bone Loss - Initial Treatment

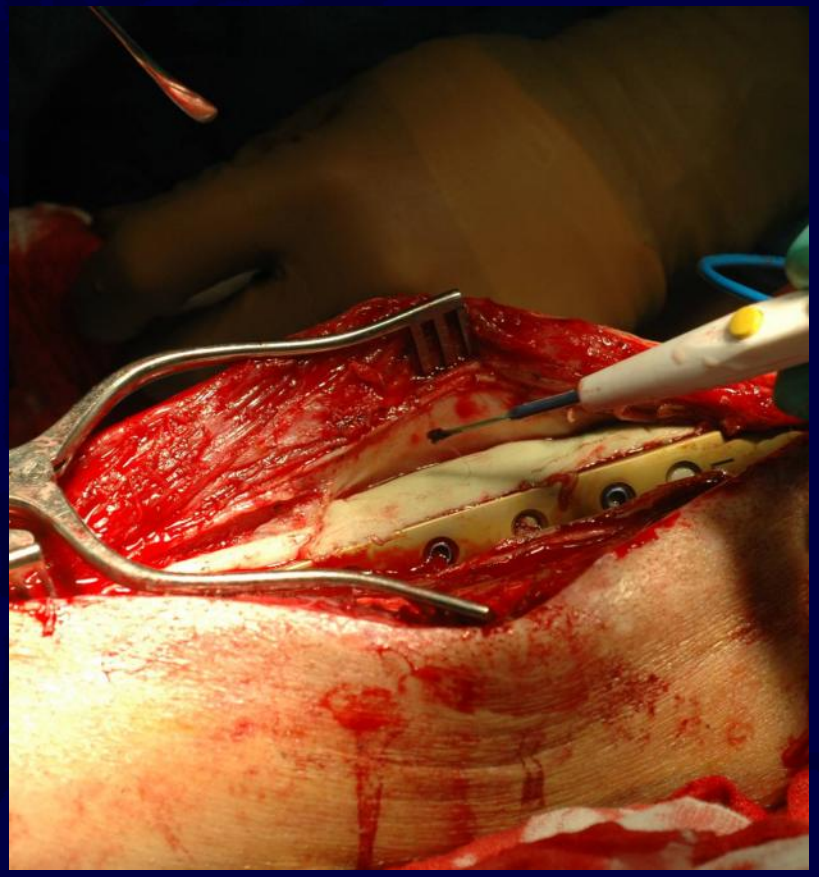
- Irrigation and Debridement
- External fixation
- **Antibiotic block spacers**





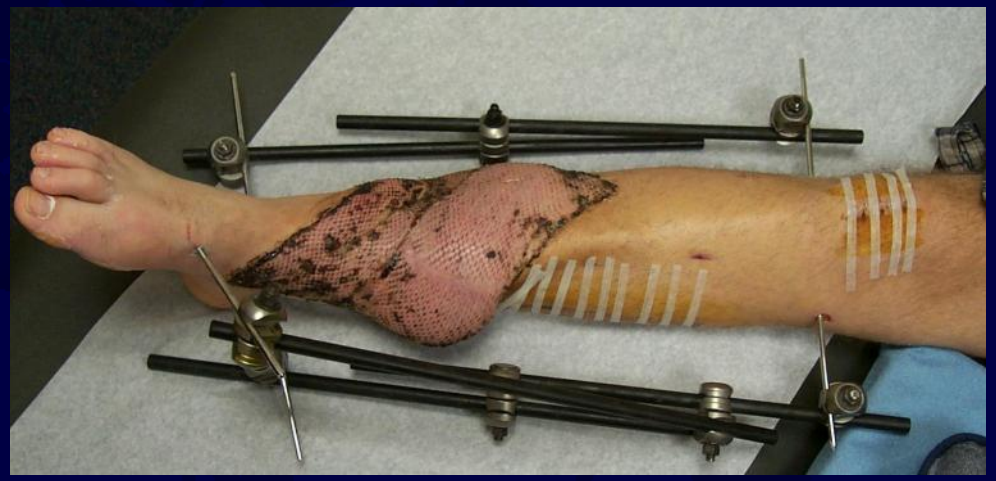
Bone Loss - Initial Treatment

- Irrigation and Debridement
- External fixation
- **Antibiotic block spacers**



Bone Loss - Initial Treatment

- Irrigation and Debridement
- External fixation
- Antibiotic bead spacers
- **Soft tissue coverage**



Bone Loss - Initial Treatment

- Irrigation and Debridement
- External fixation
- Antibiotic bead spacers
- Soft tissue coverage
- **Sterilization and Re-implantation?**

Potential Segment Re-implantation

- Young, healthy patient
- well vascularized soft tissue bed (femur, not tibia)
- single cleanable fragment
- early, aggressive, meticulous wound care
- adequate sterilization of the fragment
- Antibiotics, local and systemic

Mazurek et al J. Ortho Trauma 2003

Skeletal Stability: Treatment Options

- Significant loss of joint surface
  - osteochondral allograft
  - total joint or hemi- arthroplasty
  - arthrodesis

Skeletal Stability: Treatment Options for Diaphyseal Defects

- Autogenous bone graft
  - cancellous
  - cortical
  - vascularized
- Allogeneic bone graft
  - cancellous
  - cortical
  - DBM
- Distraction osteogenesis
  - multifocal shortening/ lengthening
  - bone transport
- Salvage procedures
  - shortening
  - one bone forearm

Bone Grafting

- Osteogenesis - bone formation
  - Survival and proliferation of graft cells
- Osteoinduction- recruitment and stimulation of bone-forming cells
- Osteoconduction- micro scaffold
- Structural Support

Graft Incorporation

- Hemorrhage
- Inflammation
- Vascular invasion
- Osteoclastic resorbtion/ Osteoblastic apposition
- Remodelling and reorientation

Autogenous Cancellous Bone Grafting

- Quickest, highest success rate
- little structural support
- best in well vascularized bed
- donor site morbidity
- quantity limited - short defects?

Papineau Technique

- Direct open cancellous grafting of granulation bed
- typically large metaphyseal defect

- 22 year old man
- RHD
- MCA
- open segmental humerus fracture with bone loss and radial nerve out

Irrigation and Debridement
Application of external fixator
Wound care
Antibiotics

Posterior plate fixation

Iliac crest bone grafting
+ antibiotic $CaSo_4$ beads

Implantable bone stimulator

2 months

3 months

5 months

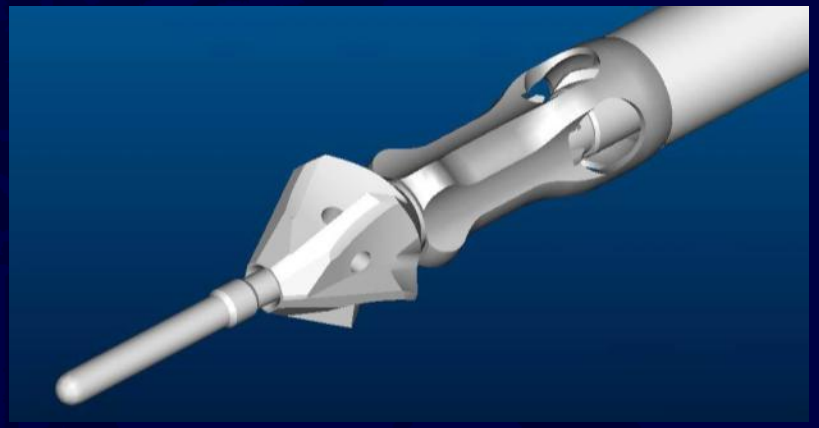
Essentially full function at 5 months

40 year old female

10 years after cancellous grafting of distal tibial defect

Reamer-Irrigator-Aspirator

- Irrigation ports
- Aspiration ports
- Filter to catch the bone graft



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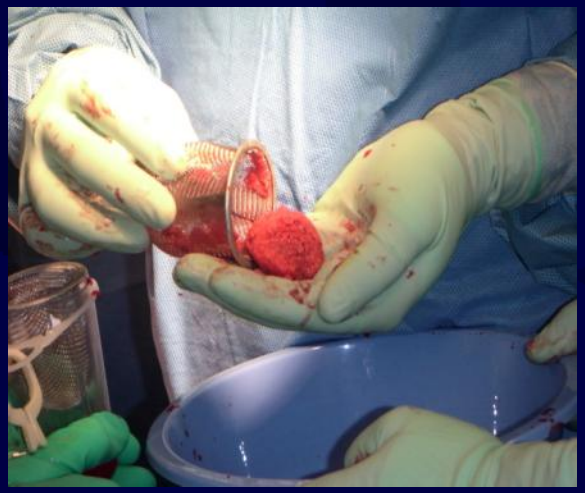

- 45 year old female
- Motorcycle accident
- Open distal femur
- Initially treated with irrigation and debridment and plate stabilization with ABX block spacer

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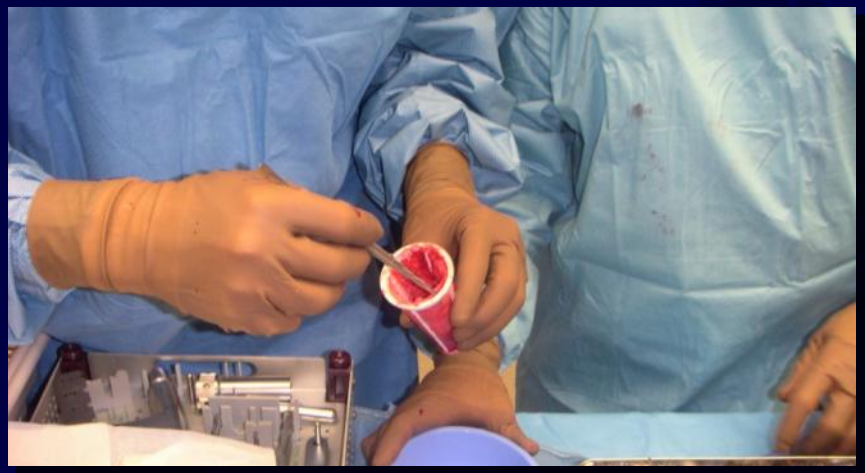
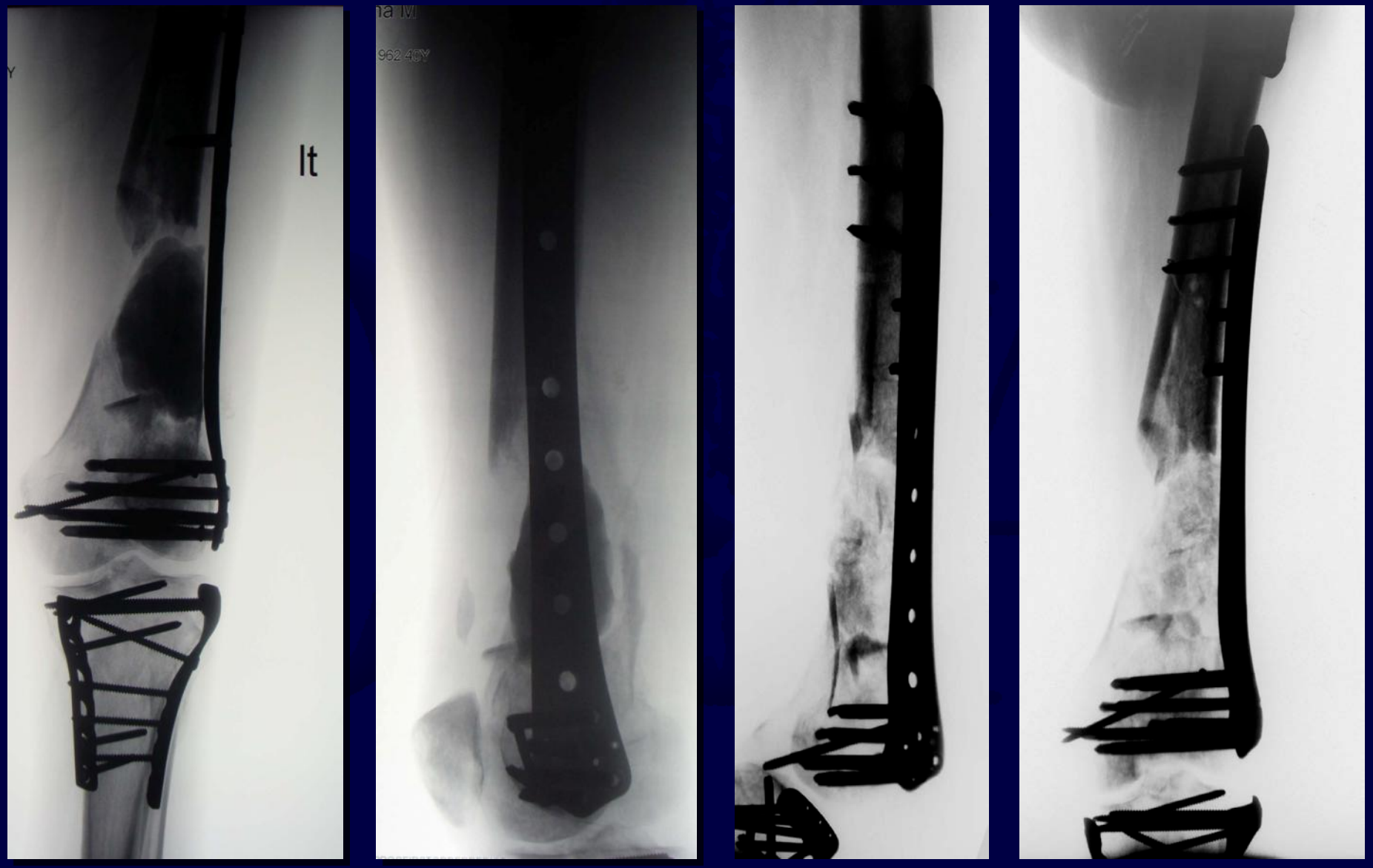
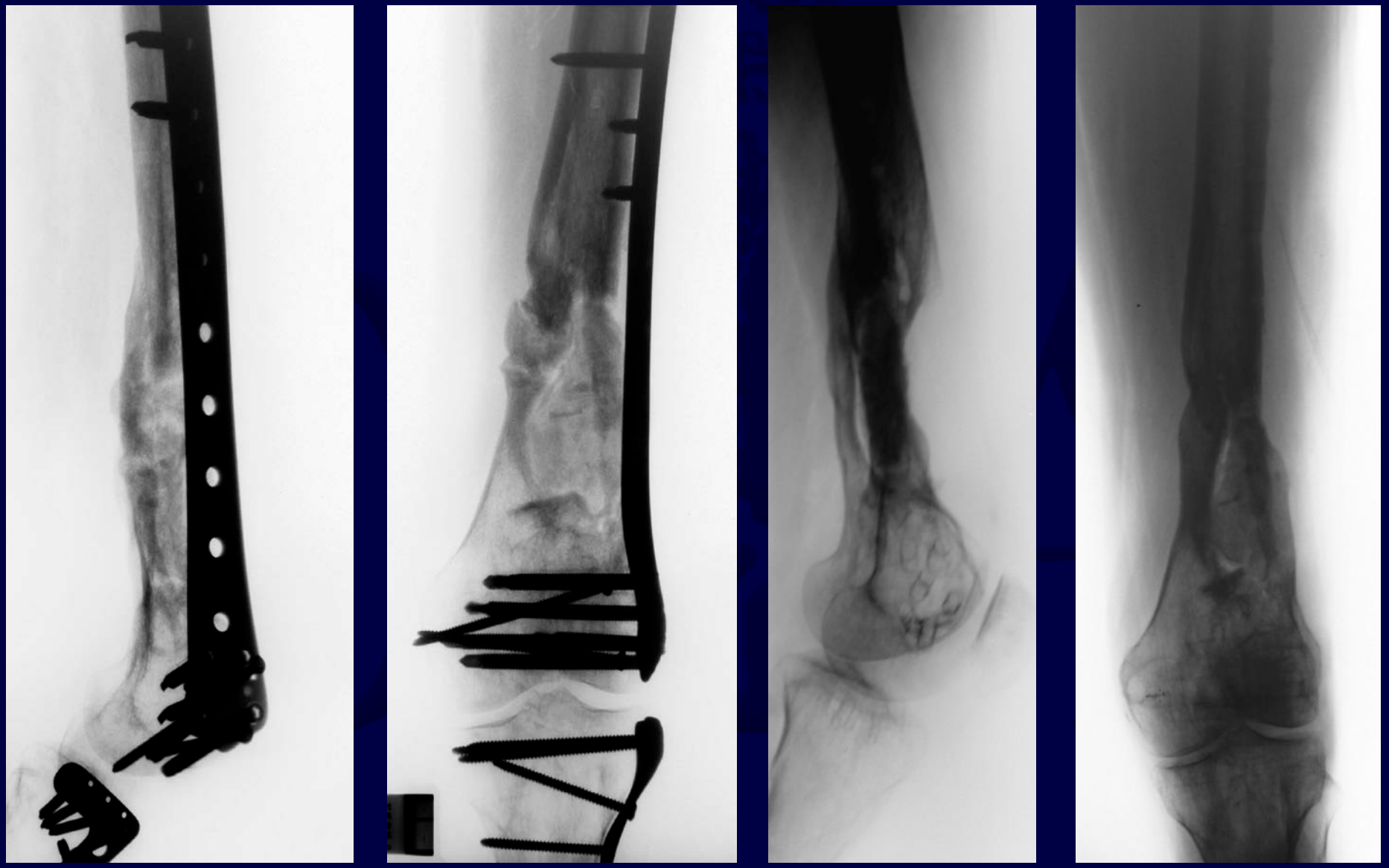
RIA bone graft at 6 weeks



RIA bone graft at 6 weeks



Full WB at 4 mo HWR at 15 mo

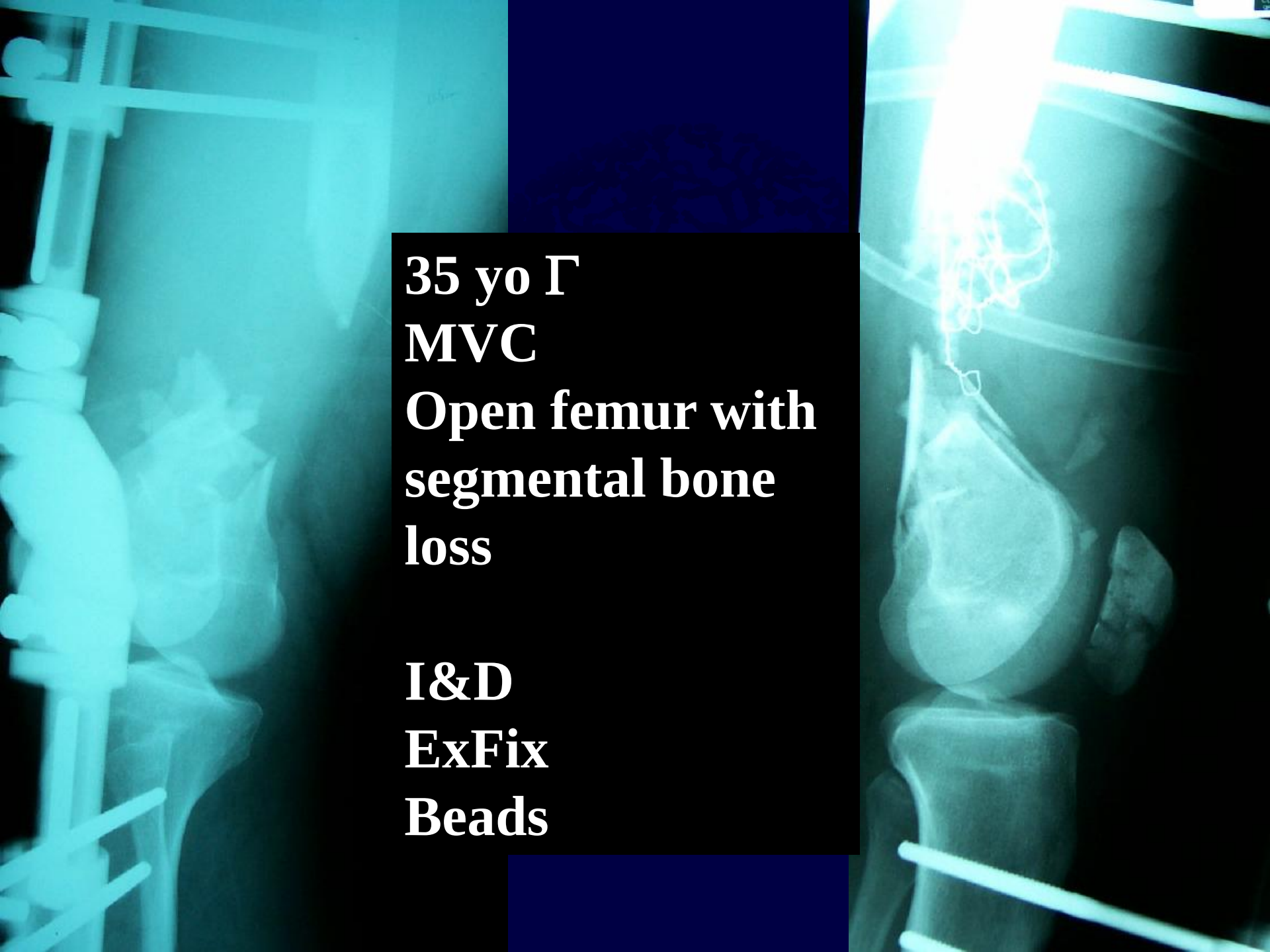


Allograft

- Incorporates like autograft, but slower
- No cells survive
- may include joint
- No size or quantity limitation
- risk of disease transmission
- infection rate ~ 5-12%
- Intercalary grafts for tumor resection >80% success (Ortiz-Cruz, et al.)
- can be combined with autograft

Cortical Strut Grafting

- Provide structural support
- weakly osteogenic
- revascularize slowly
- initially become weaker
- frequently needs supplementary cancellous graft for union (Enneking, JBJS 62-A, 1980)



35 yo Γ
MVC
Open femur with segmental bone loss

I&D
ExFix
Beads

ORIF with bladeplate

fibular strut allograft
cancellous autograft
$CaSO_4$ pellets
Bone stimulator

8 months
FWB without pain
return to work

Cancellous Allograft

- **May be similar to cancellous AUTOgraft when combined with recombinant human bone morphogenic protein (rhBMP) or other growth factors**
  - **Cook et al. Evaluation of INFUSE Bone Graft in a Canine Critical Size Defect: Effect of Sponge Placement on Healing, OTA annual meeting 2005 http://www.hwbf.org/ota/am/ota05/otapa/OTA050936.htm**
  - **Volgas and Stannard, A Randomized Controlled Prospective Trial of Autologous Bone Graft versus Iliac Crest Bone Graft for Nonunions and Delayed Unions , OTA annual meeting 2004 http://www.hwbf.org/ota/am/ota04/otapa/OTA041165.htm**

Vascularized Graft

- Pedicled ipsilateral fibula
- Free bone flap
  - fibula
  - iliac crest
  - rib
- Structural support, rapid healing, independent of host bed
- will hypertrophy, but maybe best utilized in upper extremity

The Free Fibula

- Taylor 1975
- branch of the peroneal and periosteal vessels
- Can be transferred with skin or with skin and muscle to reconstruct several tissues at once (Jupiter et al., Heitmann et al.)
- donor site morbidity
  - mod. Gait changes up to 18 months
  - sl. ↓ calf strength, ↓ eversion
  - FHL contracture
  - peroneal paresthesias

29 yo RHD female

GSW L arm

Pulses intact

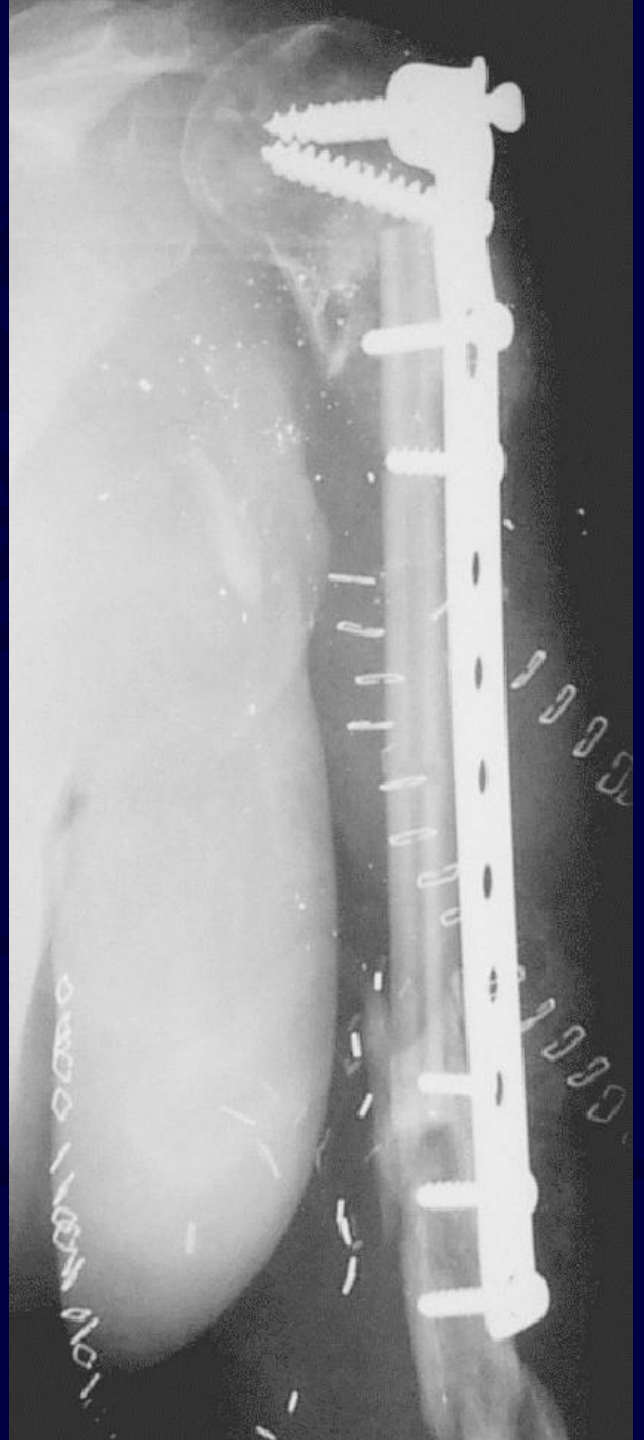
Hand neuro exam intact

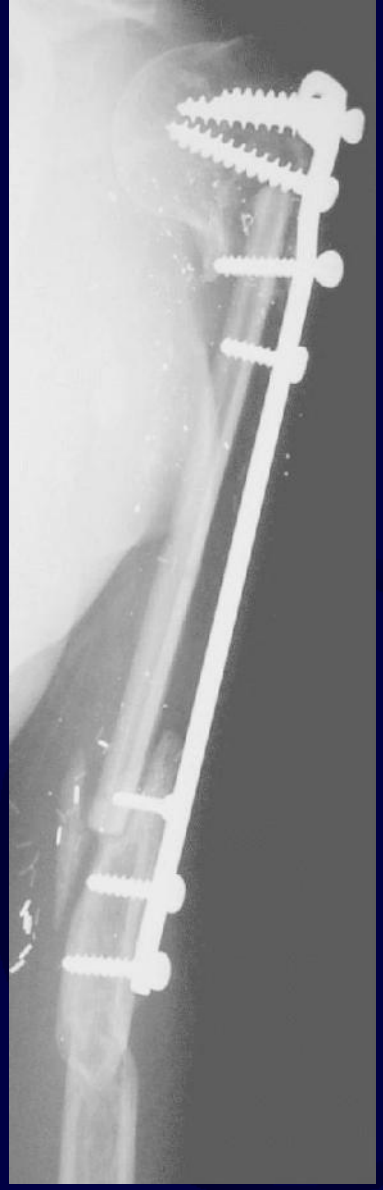
Irrigation
Debridement
ExFix

wound care

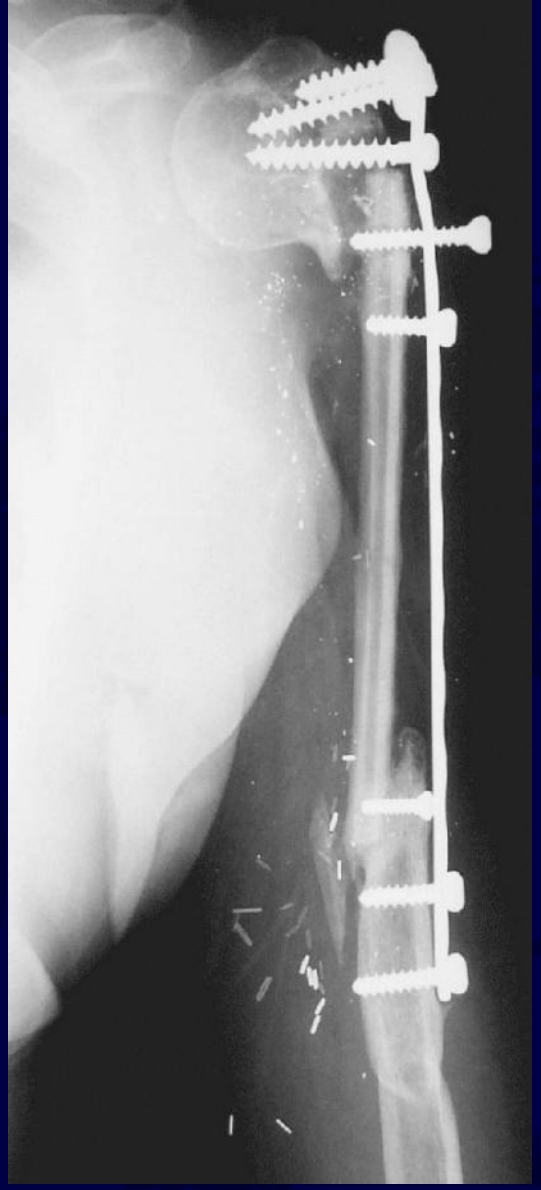
5 months

Free fibula graft fixation with long T plate

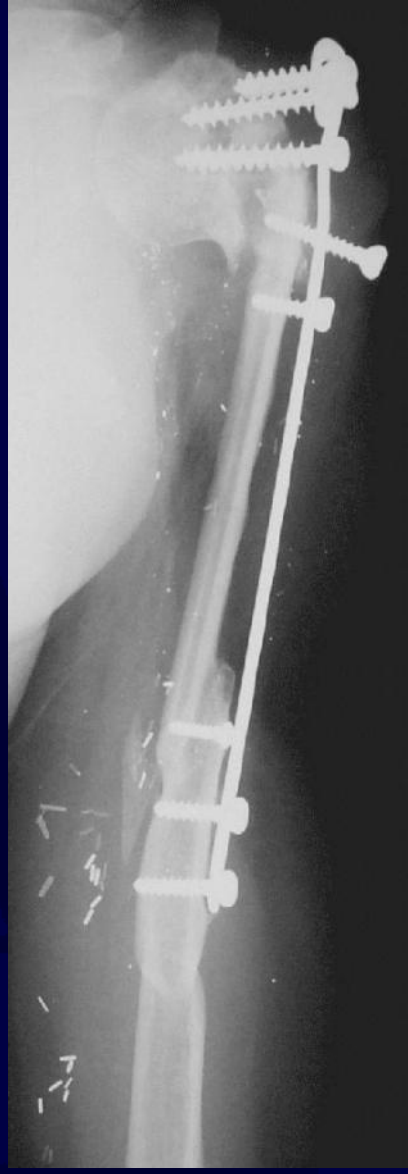




10 mon.



14 mon.



21 mon.

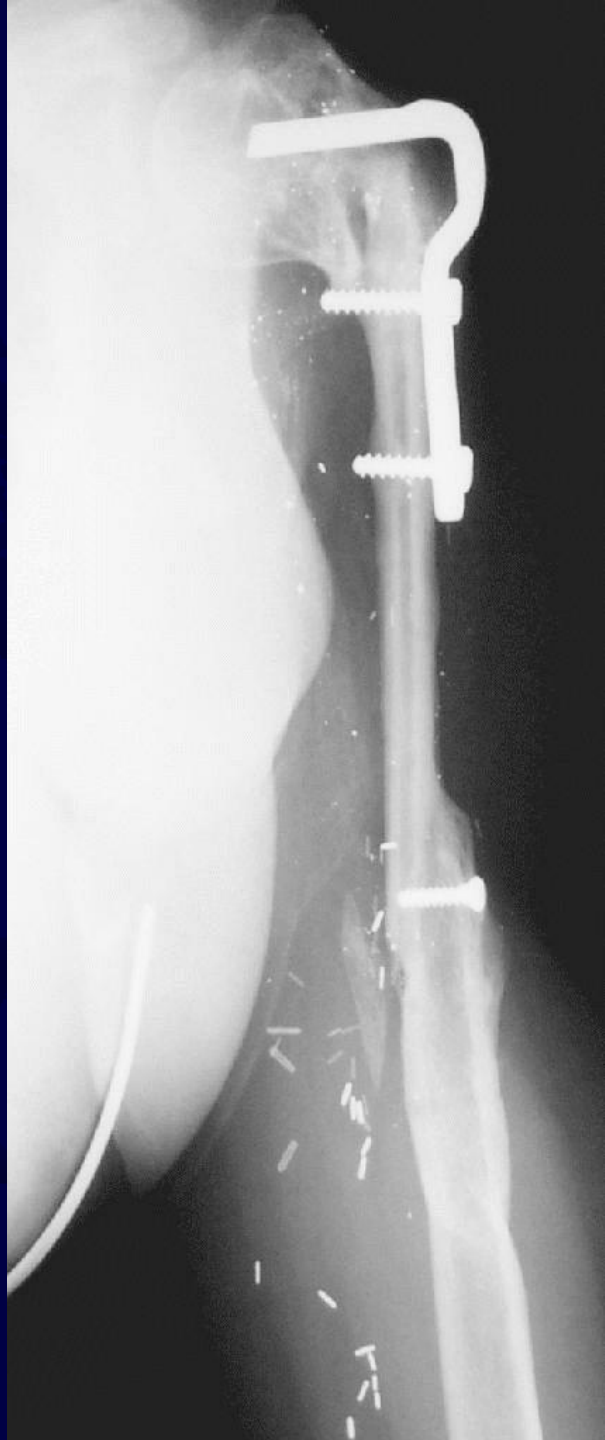
24 months post injury

revision fixation proximally with bone graft

3 years post-injury

healed

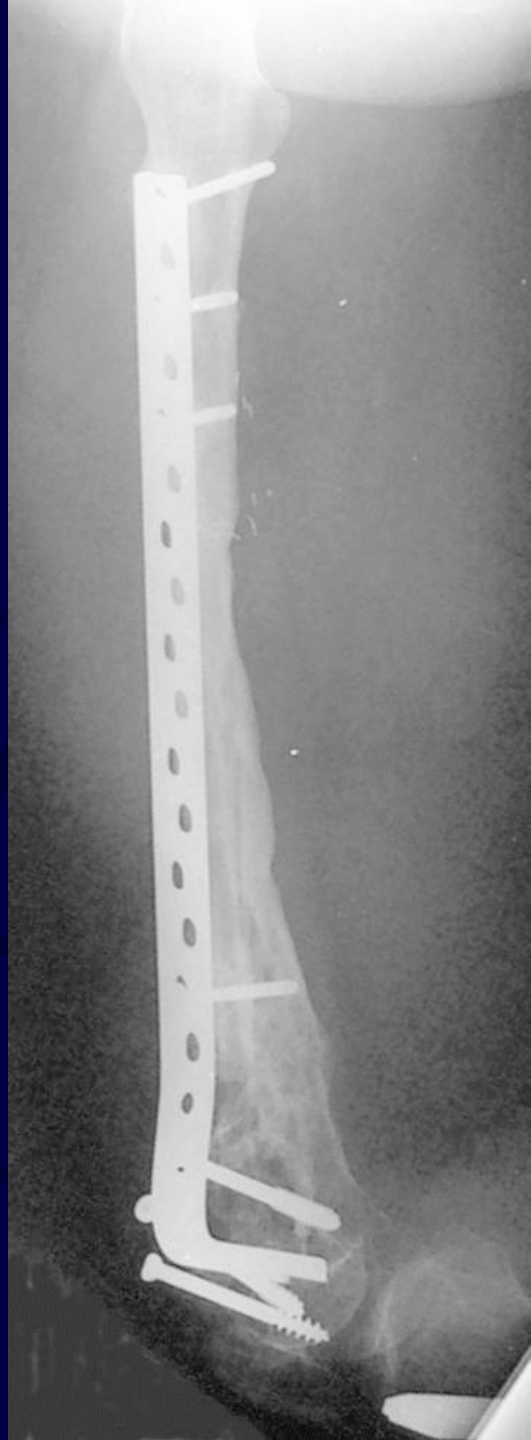
uses hand for ADLs



40 year old female

10 years after
free fibula graft
for femoral defect

Hypertrophy and
consolidation



Distraction Osteogenesis

- Ilizarov 1951 “tension-stress effect”
- mechanical induction of new bone formation
- neovascularization
- stimulation of biosynthetic activity
- activation and recruitment of osteoprogenitor cells
- intramembranous ossification

Ilizarov Technique

- Rings and Tensioned wires
- corticotomy
- latency period
- gradual distraction, .25 mm $q6^0$
- parallel fibrovascular interface
- columns of ossification

Ilizarov Technique

- Acute shortening and compression at fracture site, followed by lengthening at a separate site
  - reduces soft tissue defect
  - protects vascular/nerve repair
- Bone Transport - internal lengthening of one or both segments to fill gap
  - allows normal length and alignment during treatment

Bone Transport

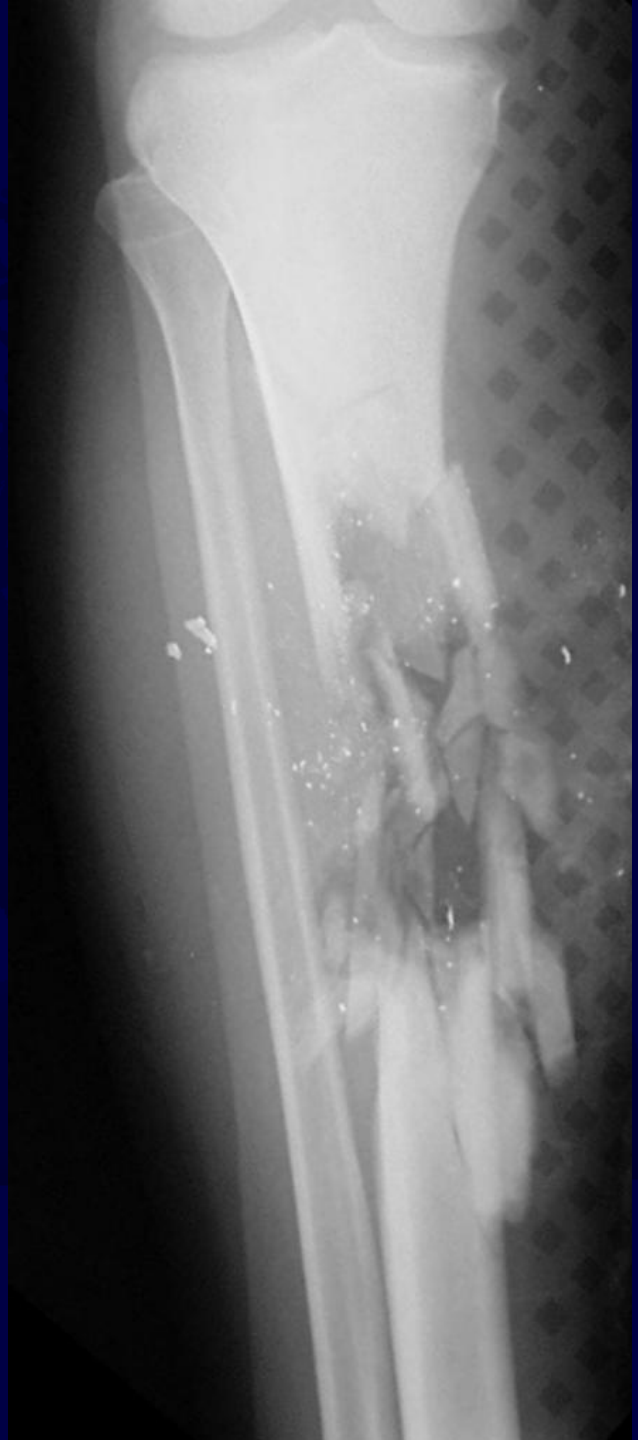
- **High rate of ultimate success, good restoration of length and alignment**
- **No donor site morbidity**
- **May be functional during treatment**

But...

- **Requires prolonged time in the frame ~ 2 mon/cm**
- **frequent docking site problems requiring bone grafting**
- **frequent complications**

Transport over an IM nail (Monorail technique) or under a MIPO plate

25 yo ♀
AK-47 GSW



This case and images courtesy of
Kevin Pugh, MD
Ohio State University

Irrigation
Debridement
External Fixation

This case and images courtesy of
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Ohio State University

Application of circular frame with half-pins for transport

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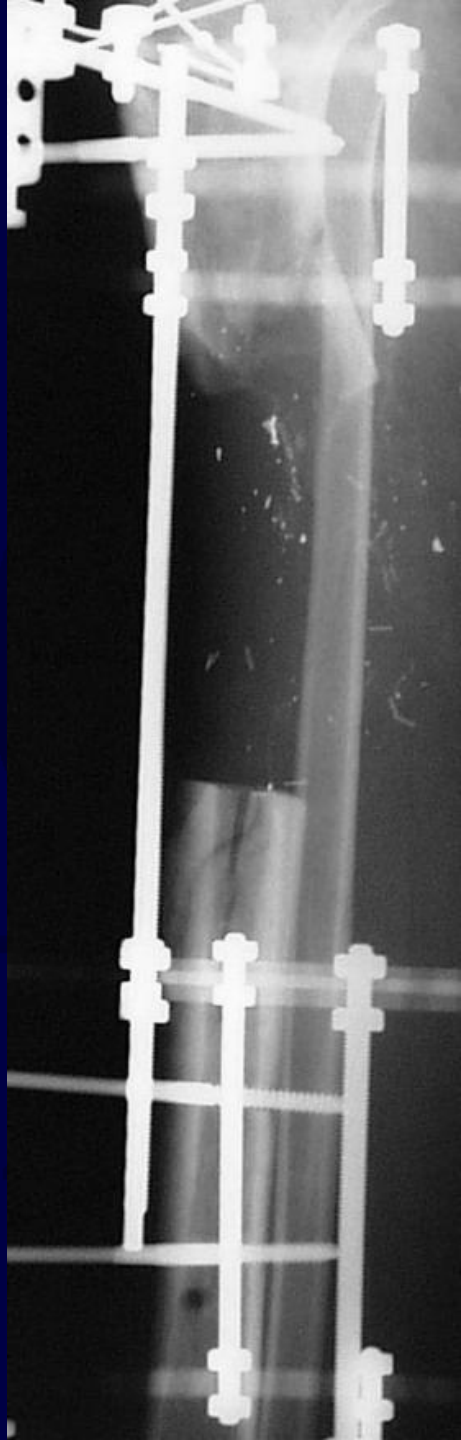

Retrograde transport of a
14 cm segment required
2 years in the frame

This case and images courtesy of
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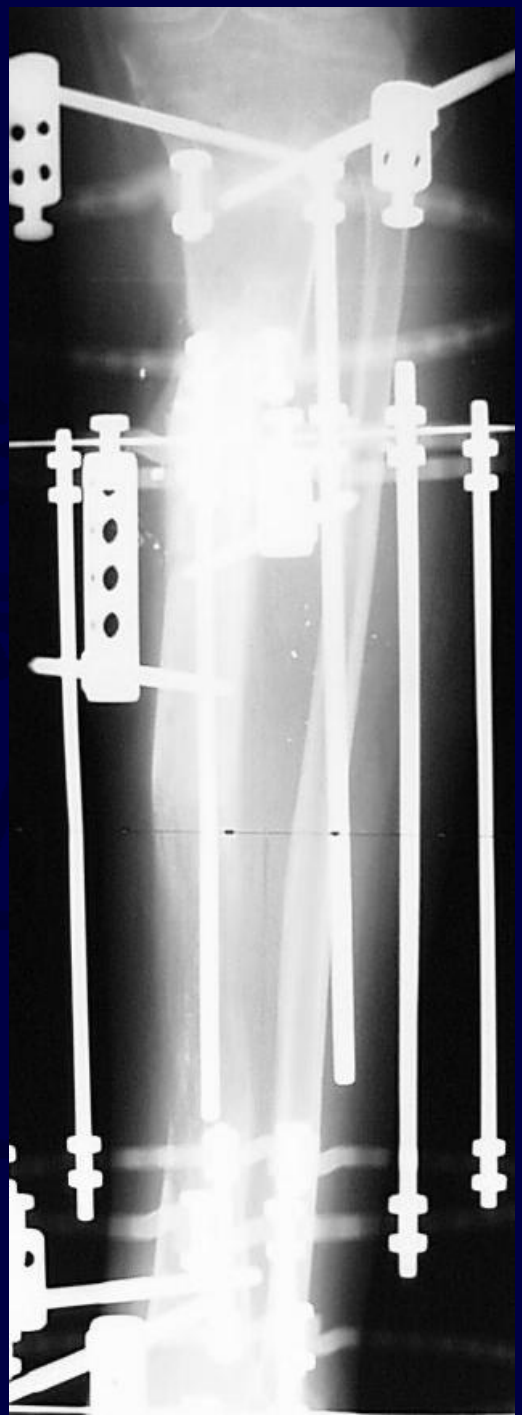
Patients can bear weight in the frame while the segment is consolidating and healing at the docking site



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Final Union Achieved

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Comparisons - Ilizarov to Conventional Techniques

- 3 studies: Green, Cierny, Marsh
- CORR 301, 1994
- different outcome measures
- 2 retrospective, 1 “prospective” with historical controls
- None with concurrent treatment or randomization
- All Ilizarov advocates to variable degree

Comparisons - Ilizarov to Conventional Techniques

- **Number of patients: "conventional"(C)=53, Ilizarov(I)=48**
- **avg defect: C=5.7 cm, I=5.5 cm**
- **"success": C=77%, I=81%**
- **2^0 procedures: C=112, I=35**
- **complications: C=48, I=37**

Other Modalities

- Bone Graft Extenders
- Bone Graft Substitutes
- Titanium Mesh Cages
  - Attias and Lindsay, CORR 2006
- Bone Morphogenic Proteins
- Electrical Stimulation

Future directions

- Stem cells
- Gene transfer
- Bioabsorbable structural carriers

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