OTA Core Curriculum: Nonunions with Bone Loss

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Overview

- Initial Management of bone loss
  - Amputation vs. limb salvage
  - First stage management of bone loss

- Definitive Management of Bone Loss
  - Bone grafting options and techniques (covered elsewhere)
  - Induced Membrane (Masquelet) technique
  - Distraction Osteogenesis techniques
Critical Bone Loss

• “Critical” bone loss is defined as a bone defect that by necessity will not heal without intervention

• Multiple clinical definitions for this exist but “critical” defect varies on patient, injury, and bone involved

• Femoral defects up to 15cm have healed spontaneously with IMN or plate stabilization

• In the tibia, 1.5 to 2 cm circumferential may be critical
Etiology of Critical Bone Loss

- Open fracture
  - Segmental loss
  - Post debridement
  - Blast injury
- Infection
- Tumor resection
- Osteonecrosis
Should we salvage the limb?

- Degree of soft tissue injury
- Vascularity / ischemia time
- Associated injuries
- Host health: tobacco/DM/nutrition etc.
- Magnitude of reconstructive effort vs patient’s tolerance
- Ultimate functional outcome – foot/ankle function
- Degree of bone loss not a significant factor influencing decision to amputate
Amputation

- Primary amputation is a viable option in the right patient with a large segmental bone defect especially if the function following a limb salvage is likely to be poor.

- Factors that make amputation attractive in a bone loss situation include:
  - Debilitated patient
  - Dysfunctional/painful foot
  - Injury location such that a good BKA is possible
Bone Defect Counseling

• Patient should be counseled about the process, prognosis, time, etc involved with managing a large bone defect
  • Long course of treatment ~ sometimes a year or more
  • Work issues
  • Social support
  • Financial support
  • Pain medication
  • Transportation to appointments
Optimize the Patient

• Thorough medical history

• Smoking cessation:
  • 3x higher complication rates (Chantix?)

• Check labs: (Brinker et al) refer if needed
  • Vitamin D (75% are deficient < 32ng/ml)
  • Parathyroid/thyroid
  • Testosterone
  • Albumin / prealbumin
  • HgbA1c
  • Secondary hyperparathyroidism common in low vit D

Surgical debridement
32 y/o male - distal tibial infected nonunion

Staged 6 cm total debridement to healthy bone
Culture + for MRSA & serratia
Debridement - Principles

• Debride until healthy tissue envelope

• Temporary stabilization – cross joints
  prevent knee flexion contracture
  prevent ankle equinus

• Manage the dead space/antibiotic beads
• Early wound coverage/closure
Debridement - Bone

- Dead bone mandates debridement
- ALWAYS send for culture – a nonunion may be an occult infection (aerobic/anaerobic/and fungus)
- Bone should be debrided to bleeding surfaces
- Geometry of debridement planned based on reconstruction technique:
  - Masquelet – oblique bone edges can increase surface area
  - Bone Transport – transverse cuts for docking stability
Dead Space Management

- Antibiotic Impregnated PMMA beads or blocs typical

- Vacuum-Assisted-Closure devices either alone or over antibiotic beads.

- Antibiotic bead pouch without VAC also very useful with a good track record
Soft tissue coverage

Usually achieved prior to treating critical defect

Provides a good environment for second stage of treatment
Case Example: 31 yo male s/p mca
damage control external fixator – serial debridement
Preparation for Bone Transport
Bone defects- options

< 2 cm: Acute shortening (well tolerated)
Masquelet or acute bone graft

2-6 cm: Masquelet
Acute shortening / lengthening
Distraction Osteogenesis

> 6 cm: Vascularized autograft
Masquelet
Distraction Osteogenesis
Vascularized Autograft

• Pedicled ipsilateral fibula
• Free bone flap
  – Fibula, medial femoral condyle
  – Iliac crest
  – Rib
• Structural support, rapid healing, independent of host bed
• Will hypertrophy, but this takes time
Vascularized Fibular Autograft

- Ideal for the upper extremity
- Size mismatch in leg
- Donor site morbidity (20%)
- Prolonged restricted WB
- Long time to hypertrophy
- Technically challenging
Induction Membrane (Masquelet) Technique
Reconstruction des os longs par membrane induite et autogreffe spongieuse

A.C. Masquelet, F. Pitoussi, T. Begue, G.P. Muller
Service de chirurgie orthopédique, traumatologique et réparatrice, hôpital Avicenne, université Paris XIII, 123, route de Stalingrad, 93009 Bobigny cedex, France

Masquelet was a French plastic surgeon. Technique published in 2000

2 stage technique

Summary – Reconstruction of the long bones by the induced membrane and spongy autograft.
In the reported series of 35 cases bone reconstruction of large diaphyseal defects was performed in two stages. The first stage was the insertion into the defect of a cement spacer which was responsible for the formation of a pseudosynovial membrane. The second stage was the reconstruction of the defect by a huge fresh autologous cancellous bone graft. The membrane induced by the spacer prevents the resorption of the graft and favors its vascularity and its corticalisation. In weight bearing diaphyseal segments the normal walking was possible at 8.5 months on average. The length of the reconstructed defects was 4 to 25 cm. © 2000 Éditions scientifiques et médicales Elsevier SAS
Stage 1

• Debridement of all necrotic bone and tissue

• Insertion of PMMA block spacer within defect

• Bridging stable fixation

• Identify and treat infection

• Residual dead-space management

• Soft tissue reconstruction
Spacer

- Spacer should cover healthy bone and periosteum
- Continuous irrigation and tissue protection for exothermic spacer materials – prevent necrosis
- Material – creates an inflammatory membrane
  - Most surgeons use antibiotic impregnated PMMA
  - Calcium sulfate, titanium, etc also evaluated
Antibiotic Spacer

• Antibiotic Toxicity
  • Dose dependent osteoblastic cytotoxicity
  • Dose dependent impact on osteoblastic metabolic activity
  • Vancomycin and Tobramycin are less toxic and commonly used
  • More toxic: cephalosporins, macrolides, rifampin, tetracyclines, and fluoroquinolones

• Clinical Results
  • Clinical data suggests that some tissue toxicity may be outweighed by antibacterial properties
Infection

• Eradication of infection is paramount prior to bone grafting

• Clinical and laboratory evaluations should be used to eradication- m

• Infection noted between stages necessitates re-debridement including spacer
Induction Membrane

• Spacer induces formation of a foreign body membrane
  • Histologically complex with three layers
    • Inner adjacent to spacer is highly cellular
    • Middle layer is primarily collagen
    • Outer layer (thickest) consists of loose tissue with dense vascular network
Induction Membrane

- Membrane bioactivity thought to be important for osteointegration.
  - PGE-2, BMP-2, VEGF, FGF-2, ANG-II, TGF-β, CBFA-1
  - Mesenchymal Stem Cells
Timing of Stage 2 Grafting

- Ideal timing based upon bioactive markers
  - Markers and bioactivity peaks from 4-6 weeks
  - BMP-2 peaks @ 4 weeks post-implantation

- Not all studies take into account the degree of soft tissue damage and impact on membrane formation

- Typical teaching is 4 to 8 weeks
Induced membrane – expression of VEGF, TGF-β1 and BMP-2 at 2, 4, 6 & 8 weeks

4 to 8 weeks optimal time to graft
Stage 2: Preparation

• Induction membrane is carefully incised
  • Membrane present around the implant is preserved

• Spacer is then removed often in fragments with osteotome

• Bone ends are then curetted back to bleeding edges

• Canal debrided for endosteal communication
Stage 2: Bone Grafting

• Autograft remains gold standard
  • Anterior/posterior iliac crest
    • 10% complication rate
  • Greater trochanter
  • Distal femur metaphysis
  • Proximal, distal tibia metaphysis
  • Femoral, tibial diaphysis (RIA)

• Expanders (allograft, DBM, etc) used if needed
  • Up to 25% volume without compromising
Autogenous bone graft

- Don’t pack too tightly: can lead to poor graft consolidation and vascularization: This is particularly true with RIA – considering adding cancellous allograft to RIA to increase porosity

- DO NOT use BMP-7 (increased deformity and graft resorption)

- Membrane is closed to contain bone graft
Reamer-Irrigator-Aspirator - RIA

- Irrigation ports
- Aspiration ports
- Filter to catch the bone graft
Reamer-Irrigator-Aspirator- RIA

- Tibia: 30cc (range: 25-40)
Stage 2: Bone Stabilization

- Ensure adequate construct stability
- Maintain reduction
  - Intramedullary fixation typically sufficient +/- augments
  - Extramedullary fixation may require additional stabilization during second stage
    - Example: Lateral femoral bridge plate fixation may benefit from supplementary medial plate or intramedullary fixation to prevent fatigue varus failure

- Stability promotes healing and revascularization
• Varus collapse from fatigue prior to complete consolidation

3 Months Post Grafting

6 Months Post Grafting
Consider medial plate at the time of 2\textsuperscript{nd} stage grafting to prevent this problem and prolong fatigue life of the construct.
Case Example: 25 y/o man s/p MCA

Temporary spanning external fixation
8 cm defect – plating / antibiotic spacer
6 weeks – spacer removed and bone graft from iliac crest placed
Repeat Cycles

• Complete union of bone segment may not occur following the first round of grafting.

• Repeat grafting or repeating complete induction membrane technique may be necessary

• Be wary of occult nonunion within the graft column. May have an implant-dependent union
Induced Membrane Effectiveness

- Best results in the “A Host”
  - Likely more bioactive membrane
  - More bioactive autogenous bone graft

- Reliable results in the femur

- Less reliable in the proximal tibia

- Questionable reliability in the distal tibia
Induced Membrane Summary

- Make it stable (plate/nail/ex-fix)
- Bring spacer past defect onto normal bone
- Don’t create thermal damage - cool
- 4-8 weeks for next stage
- Good autograft harvest
- Consider adding allograft to RIA to increase porosity
- Preserve membrane during grafting
- Consider adding additional fixation at time of grafting
Distraction Osteogenesis
Distraction Osteogenesis

Creation of new bone through an atraumatic osteotomy and controlled distraction:
Progressive closure of bone defect (bifocal tx)
Requires stability and control of shear strain
GAVRIEL A. ILIZAROV
Father of Distraction Osteogenesis

“The Magician from Kurgan”
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 - basics

- Stable fixation (Ilizarov used ring fixator/wires)
- Atraumatic corticotomy
- Latency period (7-14 days) – early tissue forms
- Gradual distraction 0.25 mm q60
- Parallel fibrovascular interface
- Columns of ossification
Distraction Osteogenesis Techniques

- Hardware options in application
  - Ring or rail fixator
  - Transport over a nail or along a plate (ring or rail)
  - Transport then nail/plating
  - Cable assisted transport then nailing
  - Plate assist segmental bone transport (PABST)
  - Motorized transport nail.
Modes of Bone Transport in Acute Bone Loss

- Intercalary Transport – length constant
- Transport then Lengthening
- Acute Shortening then Lengthening
- Gradual Shortening then Lengthening
Regenerate Bone

80% Intramembranous Bone
20% Endochondral Ossification
High levels of BMP 2, 4 and 7 maintained in the interzone during distraction

The fracture that never heals
Radiology of Regenerate Bone
Corticotomy = Atraumatic Osteotomy
General Principles

• Very difficult to recover from a bad corticotomy
• Limited incisions
• Protect periosteum
• Low energy technique
• No thermal injury
• Maintain alignment
• Compress for stability
Corticotomy: Location

- Metaphyseal better than diaphyseal
- More reliable regenerate formation
- Particularly in the adult tibia
- Assumes that the metaphyseal segment is stable
- Healthy segment of bone
Corticotomy: Techniques

- Osteotome / osteoclasis (classic Ilizarov)
- Multiple drill hole / osteotome (DiBastianni)
- Gigli saw (Afghan technique)
  - Proximal tibia / distal femur
- IM saw – in femur when nailing
Classic Corticotomy
Multiple Drill Hole Osteotomy
*Dibastianni 1987*

- Tension bone 2-3 mm
- Protect periosteum
- Sharp 2.5-4.5mm drill
- Water cooled
- Osteotome to connect drill holes
- Complete: rotation or osteotome
- Recompress
Multiple Drill Hole Osteotomy

Dibastianni 1987
Gigli Saw Osteotomy (1990)

- **Advantages**
  - Clean transverse cut
  - No rotational osteoclasis required
  - Easier x-ray verification
  - Closer proximity to transfixion wires or half pins

- **Very useful in proximal tibia**

- **Disadvantages**
  - Potential neurovascular injury

Courtesy of Jim Binski MD
Gigli Saw osteotomy example

- 14 y/o with recurvatum deformity of proximal tibia
- Planning a Hexapod correction
Knee in 20 deg. flexion

Two 1.5 cm incisions
- 1-2 cm lateral to crest of tibia
- posteromedial border of tibia
Pass a large suture first prior to placing frame.
• Tie suture to gigli saw and pass behind tibia.

• Stop cutting prior to anteromedial cortex

• Complete anterior cortical cut with sharp osteotome
Intramedullary Saw

Useful in selected femur transport cases
Lengthening with motorized IM nail
Intramedullary Saw
Done by hand
low energy – no thermal damage
Motorized IM nail s/p IM saw
Acute Shortening / lengthening

• Acute shortening of ~3cm acceptable in the tibia
• Gradual shortening of up to 6-7 cm possible
• Important to monitor N/V status during any shortening

• Low demand patients, may accept shortening + shoe lift
• Lengthening can be done simultaneously or delayed
Case example: 28 yo MCA with type III B open tibia
Damage control frame and dead space management with VAC

Received ALT flap at 8 days
4 cm shortening over 7 days: docking and nailing
Soft tissue ex-fix placed around nail
12 weeks later converted to motorized lengthening nail (Precise – Nuvasive) with proximal corticotomy
4 cm lengthening at 0.75 mm/day
Case example – bifocal treatment
31 yo male s/p mca
Damage control ex-fix and serial debridement
ALT flap - preparation for bone transport
Ring fixator applied 7 days after free flap
Bone grafting to docking site
Confirmation of restoration of leg length
Patient wanted to return to labor job
IM nail placed 2 weeks after frame removal
Lag screws removed at the ankle
At 2 years
Typical Bifocal Transport

Run next 22 slides rapidly as an animation
Corticotomy site
(7-10 day delay)

Transport ring

Bone defect
(7 cm)
Bone defect (7 cm)

3 cm shortening
0.5 to 1.0 mm/day
Regenerate bone
Regenerate bone
Docking 80 Days from corticotomy
Autogenous Bone Graft

90 Days from corticotomy
Fibular osteotomy
Transport continued as a leg lengthening.

3 distal rings move as a unit
Total regenerate length:
defect + lengthening
7 cm + 3 cm = 10 cm

3 cm leg lengthening
Transport complete: 110 days from corticotomy
Regenerate consolidation
14 months

Total time in frame
Index 17 months
1.7 mo./cm
Smoker: 24 months
2.4 mo./cm
Frame Removal
Case example: 48 yo male type IIIB open pilon fx s/p fall

• Transferred 2 weeks post injury
• Serratia infection
• Critical bone defect
- Transport to ankle fusion
- Rectus free flap
- Ilizarov frame placed 5 days later
Bifocal treatment with proximal corticotomy
0.5 mm/day transport rate
Rectus flap elevated
Iliac crest bone graft to docking site
Converted to hexapod frame to fine tune alignment
Solid ankle fusion
Length restored
Infection free
Plate Assisted Segmental Bone Transport
PABST

• Case example:
  • 52 yo male:
  • tibial nonunion
  • broken implant
  • critical defect

Case courtesy of Matt Gardner MD
Plate Assisted Segmental Bone Transport (PABST) - antegrade

- Use of a motorized IM nail along a plate to treat a segmental defect

  - Plate to span involved bone
  - Motorized lengthening nail
  - Corticotomy
  - Defect

Case courtesy of Matt Gardner MD
Plate Assisted Segmental Bone Transport (PABST)

- Lengthening at 0.75mm/day
- Regenerate bone formation
- Gap closing

Case courtesy of Matt Gardner MD
Plate Assisted Segmental Bone Transport
PABST

Docking site compressed and bone grafted

Case courtesy of Matt Gardner MD
Plate Assisted Segmental Bone Transport (PABST)

After docking site healed (8 weeks)

Converted to trauma nail and plate removed

Case courtesy of Matt Gardner MD
Bone Transport

- High rate of ultimate success, good restoration of length and alignment
- No donor site morbidity
- Usually WBAT during treatment
  - But...
- Requires prolonged time in the frame ~1.5 - 2 mon/cm
- Frequent docking site problems requiring bone grafting
Bone Transport

Powerful Techniques

Reliable as transport rate can be adjusted to biologic response

Newer methods are reducing the time in a frame (motorized nails – PABST etc)

Technically demanding with a long learning curve
Summary
Nonunion with Critical Bone defects

• Select well and optimize the patient
• Counsel the patient - long road
• Remove devitalized bone – treat infection
• Soft tissue coverage as needed
• Plan the complete reconstruction – stable fixation
• Consider acute or gradual shortening in select cases
• Weight bearing as early as possible
• Masquelet cases – may need second grafting
• Bone transport cases – simultaneous or sequential use of internal fixation to reduce frame time