Impaction Grafting
October 25, 2002

Anneliese D. Heiner, Ph.D.
Associate Research Engineer
University of Iowa
Department of Orthopaedic Surgery
Biomechanics Laboratory
Revision THA

• Loosening failure rates of primaries = 15% – 61% after 8 years
• Number of revision surgeries
  – 24,000 in 1990
  – 32,000 in 2000 (est.)
• Direct costs = $570 million / year (est.)
• Re-revisions do worse than revisions
Revision indications

- Progressive disabling pain
- Sepsis
- Limitation of function
- Osteolysis
  - Often little or no pain
- Quality of life / expected outcome
Cavitary defects

Segmental defect
Cavitary defects
Impaction grafting

- Impaction grafting with morselized cancellous bone (MCB) has recently become of high clinical interest in revision total hip arthroplasty
- Cancellous bone (usually from femoral heads) is ground up (morselized) and impacted into a cavitary defect
  - Restores bone stock
  - Avoids use of an oversized prosthesis
  - Allows anatomic placement of acetabular cup
- Impacted bone is resorbed and replaced by host bone, resulting in a fused, contiguous mass
Normal femur

Cavitary defect

Impaction grafted
4mm MCB
Restrictor insertion

Distal impaction
Proximal impaction

Cement insertion
Normal acetabulum

Cavitary defect

Impaction grafted
Medial wall defect
Superolateral rim defect

Screws
Mesh

Original acetabulum
Close defects
Add MCB and impact
Impaction graft

Add cement and pressurize

Final construct
Clinical results – good news

- **Femur**
  - Zero revisions at 5-7 years (n=43)
    - 3 early dislocations & 2 femoral fx
  - Zero revisions at 4-8 years (n=29)
    - 3 femoral fx, 1 moderate subsidence, 1 distal osteolysis

- **Acetabulum**
  - 94% survival at 10-18 (avg. 13) years (n=34)
    - 3 revisions (2 aseptic loosenings, at 7 & 11 years; 1 during femoral stem revision, at 12 years)
  - 89% survival at 2-11 (avg. 5.8) years (n=88)
    - 4 revisions (2 infections & 2 aseptic loosenings w/ migration), 5 radiographic failures
Clinical results – good news

Impaction grafts can revascularize, remodel, and become incorporated with the host bone

9 months

48 months
Clinical results – bad news

- Subsidence/migration
- Aseptic loosening
- Intraoperative fx
- Radiolucencies
- Dislocation
- Resorption
- Late fx
Biomechanical issues
Mechanical tests

Stiffness
Recoil

Strength
Subsidence

Confined compression

Shear box

Semiconfined compression

Triaxial compression
Mechanical tests - cadaver
How to increase the degree of impaction and mechanical properties of an impacted graft

Material
Morselization
Preparation
Impaction
Graft material

• Start with good quality bone (higher density & mineralization)
  – Higher bone density = less subsidence
  – Don’t remove cortical bone from femoral head before morselizing
    • Similar impaction properties vs. cancellous bone particles alone
    • Provides 15% more graft material
  – Use cortical rather than cancellous bone
    • Mechanical advantages
    • Clinical advantages
  – BUT no correlation between bone apparent density & shear properties
Graft material

• Exclude articular cartilage
  – Cartilage prevents efficient impaction
  – Graft less stiff and dense
  – Cartilage doesn’t incorporate
Graft morselization

• Increase particle size
  – Larger particles = better mechanical properties
  – Don’t get too large; large particles don’t arrange well, and create more void space

• Have a good grading of particle sizes
  – Soil mechanics – optimum shear strength with logarithmic grading curve
  – Absolute particle size is less important than the grading

• Have an optimal particle shape
Graft treatment

• De-fat (remove fat & marrow)
  – Improves mechanical properties
  – May reduce host immunologic response by extracting immunoreactive proteins
  – Improves bone ingrowth & incorporation (animal study)
  – BUT de-fatting process could extract bone morphogenic proteins, growth factors

• Remove blood
  – Heparinized blood reduces graft strength
  – BUT containment of hemATOMA (host blood) within impacted graft is a possible bone stimulation factor
Graft treatment

- Remove (excess) water
  - Improve mechanical properties
  - Remove fluid expressed after each impaction blow
- Optimize water content
  - Soil mechanics – small quantities of residual water may enhance the mechanical performance of aggregate structures (wet vs. dry sand)
  - Mechanical properties improved by optimal water content (species-dependent; porosity differences)
  - “Mushiness” from water content can aid impaction
Graft treatment

- Freeze-dry
  - Have it sufficiently rehydrated, or it’s too difficult to impact
- Irradiate
- Cross-link (Formalin fix)
- Determine immunologic compatibility
  - Match HLA (human leukocyte antigens)
  - Avoid Rh conversion (women)
Graft treatment

Many surgeons don’t do any graft treatment, and still get good results
Graft impaction

- Increase impaction pressure/energy/force/impulse
  - Can’t overdo it; need to avoid bone fracture
- Increase number of impaction pulses
  - Compensate for poor bone quality
- Have well-designed impaction instruments
Graft impaction – other issues

- A too-solid impacted graft may not allow cement interdigitation; cement interdigitation increases construct stability.
- Some investigators don’t seem concerned about this (but “tight” and “solid” not well-defined).
- Excessive cement interdigitation may inhibit bone revascularization and remodeling.
  - Don’t want cement to contact the cortex.
- Tightly impacted bone may inhibit bone revascularization and remodeling.
Does the impaction graft really need to incorporate or remodel?
Does the impaction graft really need to incorporate or remodel?

- Good clinical results with incomplete graft incorporation
- A dead but stable (nonresorbing) graft could be mechanically functional
- Fibrous tissue armoring of MCB particles could be mechanically sufficient
- If remodeling reaches cement-graft interface, a fibrous membrane could develop, leading to prosthesis loosening (seen in goat study, but not yet reported in humans)
- Resorptive phase could be detrimental to implant stability
Hypotheses

- Prostheses with a fused impaction graft will be more stable than prostheses with a non-fused impaction graft.
- If bone fusion is incomplete, the location of fused vs. nonfused areas will affect the stability of the impaction grafted construct:
  - Proximal vs. distal femur
  - Superior vs. inferior acetabulum
Requirements of MCB fusion simulation

- Mechanical properties of morselized-then-fused bone must be in the range of intact bone
- Fusion process must not disturb an in-place surgical construct
- MCB must not fuse immediately
- Fusion time must be reasonably short, to minimize host bone degradation
MCB fusion model

- Simulate by mixing MCB particles with an amine epoxy
  - Mixture is impacted into the bone
  - Epoxy sets up, resulting in a fused mass
- Recovers modulus of intact cancellous bone
- Can produce a desired modulus
- Has a reasonable cure time
The compressive properties of the fused MCB depend on many variables:

- MCB size
- MCB:epoxy weight ratio
- Impaction pressure
- Impactions per layer
- MCB amount per layer
- Position along fusion mass
Determine surgical impaction grafting force

Accelometer
Impulse = area under curve

Distal femur = 1.7 Ns
Proximal femur = 2.0 Ns
Acetabulum = 1.6 Ns
Implant design
Should femoral stems be designed to subside?
Should femoral stems be designed to subside?

• YES – Subsidence is self-limiting and results in a stable stem position
  – Converts shear forces into compression forces
    • Aids in bone remodeling?
    • Reduces shear at stem-cement and cement-bone interfaces
  – Contributes to torsional stability
  – Collarless, polished, tapered (CPT) stem

C-Stem (DePuy)
Should femoral stems be designed to subside?

• NO – Subsidence is not necessarily benign
  – Massive subsidence (>10mm)
  – Can result in thigh pain, dislocation, late fracture, revision
  – Failures = 19mm; matched controls = 1.5mm
  – Other stem designs studied
    • Roughened stems
    • Stepped stems
    • Precoated, collared, straight stems
Other causes of stem subsidence

- Extent of bone defect

Endo-Klinik classification
Figs. 1A–1E. Femoral defect classification. (A) Type 1 femoral defect has minimal bone loss and an intact metaphysis, diaphysis, and calcar. (B) Type 2A femoral defect exhibits an absent calcar but some of the proximal support remains and offers resistance to axial and torsional forces. The bone loss does not extend to the subtrochanteric region. In both the 2B and 2C femoral defect types, the metaphysis is non-supportive and offers minimal resistance to axial and torsional forces. (C) Type 2B femoral defects have extensive anterolateral subtrochanteric metaphyseal bone loss. (D) Type 2C femoral defects have extensive posteromedial subtrochanteric metaphyseal bone loss. (E) Type 3 femoral defects present with extensive metaphyseal and diaphyseal bone loss.
Other causes of stem subsidence

- Cement mantle defects & thickness
- Stem malalignment (varus)
- Axial resistance of distal restrictor?
- Impaction graft properties & surgical technique
- Graft resorption or no remodeling
- Early weightbearing?
Acetabular cup design

- Not studied much
- One clinical study (cementless cups) could not detect a difference between cup designs
  - PCA
  - Duralock
  - Harris-Galante
  - Omnifit
Effects of impaction grafting on bone biology

Morselization
Impaction
Postoperative loading
Help or hinder bone biology?
Morselization

• Helps
  – Large fracture surface area releases BMPs
  – Large fracture surface area allows the bone access to osteoinductive and osteogenic factors

• Hinders
  – Cell trauma from morselization process
Impaction

• Helps
  – Increases likelihood of bone incorporation and implant stability
  – Causes (transient?) growth factor release

• Hinders
  – Too much impaction may inhibit revascularization & reincorporation
  – Cell trauma from impaction process
Postoperative loading

• Helps
  – Mechanical stimulation of bone remodeling process

• Hinders or doesn’t help
  – Micromotion and formation of fibrous soft tissue at interface
  – Little effect in early stages (animal study)
  – Other factors may be much more important
Other biomechanical issues

• Cemented vs. uncemented implants
• Surgical technique
  – Technically difficult & demanding procedure
• Cement mantle
  – Uninterrupted (reaches distal part of canal)
  – Sufficiently thick ($\geq 2\text{mm}$)
  – Cement penetration into graft (viscosity of introduced cement)