Hip Arthroplasty: Methods of Fixation.

Richard Jeavons
ST4 T&O
Freeman Hospital
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Introduction

- Basic principles of:
  - Cemented
  - Uncemented (Biological)
  - Pros and Cons
- Evidence for use with:
  - Femoral Implant
  - Acetabular Implant
- Current Trends

History of Bone Cement

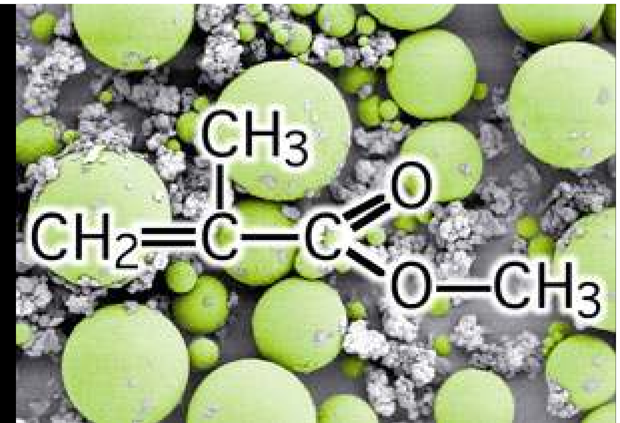
Polymethylmethacrylate (PMMA)

1902	First synthesised (O. Rohm)
1930s	First used in Humans – Dental Acrylic in skull defects
1940s	Judet Brothers develop hip implant with PMMA
1950s	First used as fixation device by Charnley
1970s	Antibiotics added
1980/90s	Focus on cemeting techniques

PMMA

- Static mechanical fixation
- Does not chemically bond to bone or prosthesis
- Mechanical bond (implant textured / pressurised)
- Poor tensile & Shear strength
- Strongest in compression
- Cyclical loading causes micro-fractures
- Unable to heal/remodel
- Loosening?

Components of PMMA



Powder

- *Polymerised PMMA*
- *Co-polymer*
  - Polystyrene or Methacrylic Acid – increases toughness
- *Initiator* (Dibenzoyl Peroxide)
- *Radiopaque Material* ($BaSO_4$ or ZrO_2)
- *Heat Stable Antibiotics* (Gentamicin)
- *Colouring agents* (Chlorophyll in Palacos)
  - Differentiate between bone and cement at revision time

Components of PMMA

Liquid

- *Methymethacrylate Monomer*
- *Hydroquinone*
  - Inhibits polymerisation
  - Prevents premature polymerisation by heat/light
- *N,N-dimethyl-p-toluidine*
  - Accelerates polymerisation on mixing with powder
  - Offsets Hydroquinone.

Polymerisation Process

- C-to-C double bonds of MMA broken
- New C-to-C single bonds formed in Polymer chain
- Exothermic
- Heat 130cal/g of monomer
- Temp. rise dictated by amount and thickness of cement
- In vivo ~40^{o}C
- Bone Necrosis 47^{o}C / Protein Denaturation 56^{o}C

Periods of Cement Setting

- **Dough Time (2-3 minutes)**
  – Start of mixing until doesn’t stick to glove
- **Working Time (5-8 minutes)**
  – End of dough time until too stiff to manipulate
- **Setting Time (8-10 minutes)**
  – Until solid (cured)
- ***Ultimate Strength at 24 hours***

Factors Affecting Cement Setting

Rapid Mixing

- Reduces Dough time

Increased Room Temperature

- Reduces Dough Time
- Reduces Setting Time (5%/degree)
- Decreased room temp. increases times

Increased Humidity

- Decreases Setting Time

Cement Types

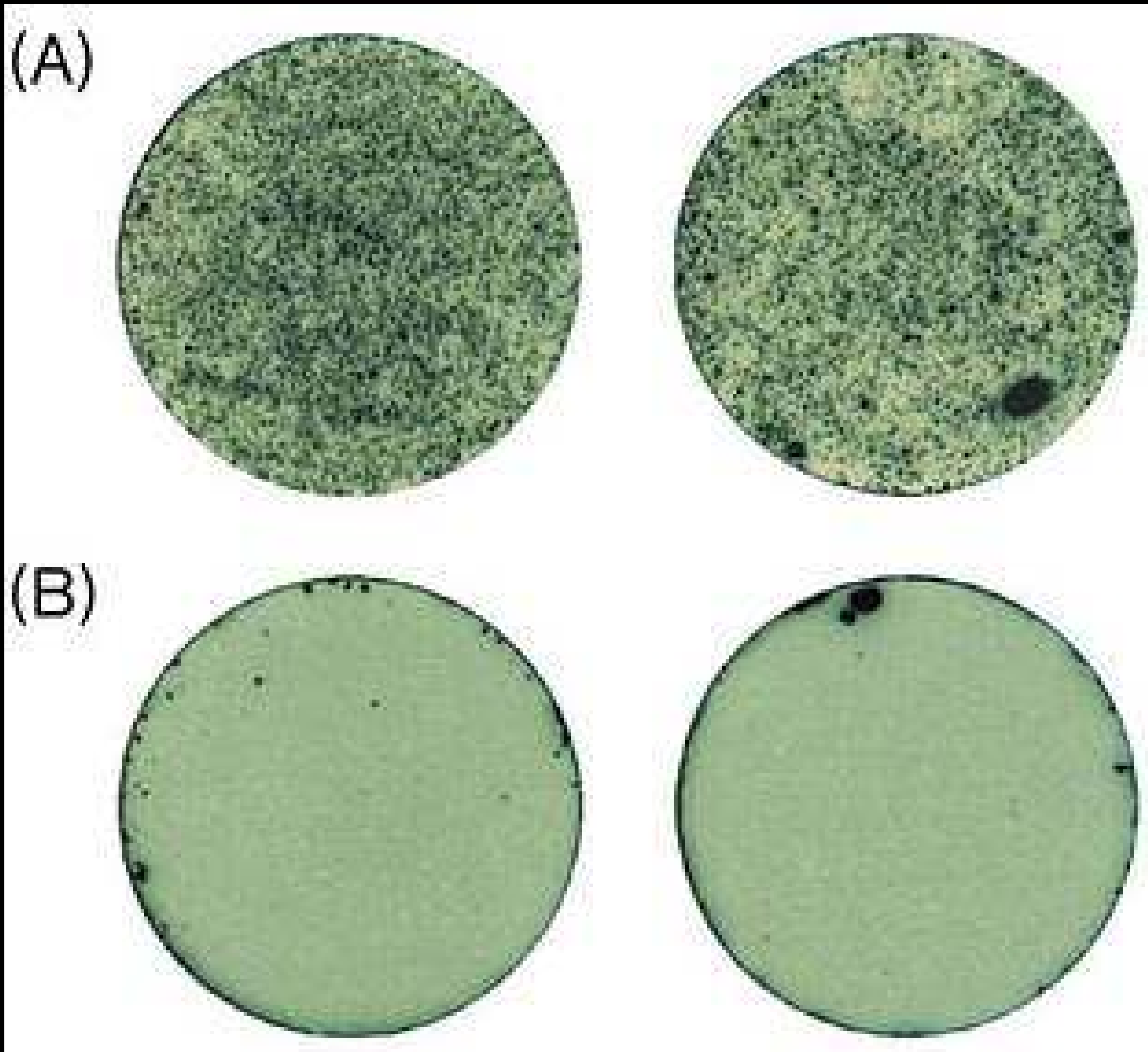
Low viscosity:
- – Long-lasting liquid or mixing phase
- – Short working phase
- – Cements requires strict adherence to application times

- **High viscosity**:
  - – Short mixing phase
  - – Longer working phase
  - – More time for application

Using Cement

Excellent technique required

- **1st Generation**
  - Finger packing, No Pressurisation, No reduction in porosity (centerfuge)
  - Aseptic loosening up to 30% @ 10yrs (Stauffer. JBJS 64-Am. 1982)
- **2nd Generation** (1975 onwards)
  - Cement gun, pulse lavage, canal prep, cement restrictor
- **3rd Generation** (1982 onwards)
  - Reduced porosity (vacuum & centrifugation), pressurisation centralisers, PMMA stem pre-coating


(A)
(B)

Cement Mantle

- At least 2 mm around femoral component
- 3mm around femoral stem and 6mm around cup – lowest incidence of loosening (Joshi et al, JBJS 80-Br. 1998)
- Ideal to reduce risk of aseptic loosening
  - No mantle defects (pores act as stress risers)
  - Neutral alignment (valgus/varus <5^{o})
  - Not abuting femur (Ebramzaden et al, JBJS 76-Am 1995)

Table 5-1 Factors Affecting PMMA Bone Cement Strength*

Factors	Outcome
UNCONTROLLED FACTORS	
Aging after implantation changes	Gradual 10% loss of strength resulting from postcuring chemical
Environmental temperature	10% weaker at body temperature than at room temperature
Fatigue	Fatigue strength (10^6 cycles) 20%-25% of single-cycle strength
Moisture content	Loss of 3%-10% strength because of water absorption
Strain rate	Significant increase in strength with increasing strain rate
PARTIALLY CONTROLLABLE FACTORS	
Cement thickness	Intermediate cement thicknesses minimize both fatigue stresses and shrinkage effects
Constraint	Cement far stronger in compression than tension
Inclusion of blood or tissue	Up to 70% loss of strength, depending on amount
Stress risers (bony bed, implant)	Cement is quite notch sensitive
FULLY CONTROLLABLE FACTORS	
Antibiotic inclusion	5%-10% loss of strength
Centrifugation/vacuum degassing	10%-25% increase in strength, possible increase in fatigue strength
Insertion pressurization	Delay may produce up to 40% loss of strength, whereas increases strength by up to 20% by reduction of porosity
Mixing speed	Up to 21% loss of strength because of too slow or too rapid mixing
Radiopaque fillers	5% weaker than unfilled

Adapted from Black J: *Orthopaedic biomaterials in research and practice*, New York, 1988, Churchill Livingstone.
*Strength and fatigue strength are in tension; behavior in compression is different and less sensitive to external conditions.

Intraoperative Cement Complications

- Embolisation Phenomena
  - fat / bone marrow / cement elements
  - From pressurisation
  - Hypoxia, cardiac arrest, death
  - Older patients, signif. Co-morbidities.
  - Lavage prior to pressurisation
  - Reduced emboli on TOE (Christie JBJS 77-Br 1995)
- Possible depressive cardiovascular effects of Monomer (McMaster et al. Clin Orthop. 98. 1974)

Cemented

- **Pro's**
- Immediate Stability
- Weight Bear Immediately
- Good in compression
- Even Load distribution
- Less stress shielding
- No thigh pain
- Long track record of use
- Cheaper (acetabulum)

- **Con's**
- Brittle
- Poor shear & tensile
- Technique vital
- Emboli/Toxicity
- No remodelling
- Finite lifespan

Cementless Fixation

- 1970s - high levels of loosening in cemented prosthesis in younger
- 1980s - Introduction of cementless fixation
  - » Aim for lifelong fixation (biological)
  - » Problems included up to 35% rate aseptic loosening
  - » Thigh pain (implant design)
- 1980/90s - Design Changes
  - » Cylindrical to anatomical to tapered
  - » Newer coatings
  - » Surgical Technique

Cementless Fixation

- Requires immediate stability on implantation (In/ongrowth)
- Intimate fit of prosthesis to bone
- Seated against cortical bone mechanically stronger (femur and acetabulum)
- Dynamic fixation
- Micro-fractures which heal and remodel on Cyclical loading
- ? Life long fixation

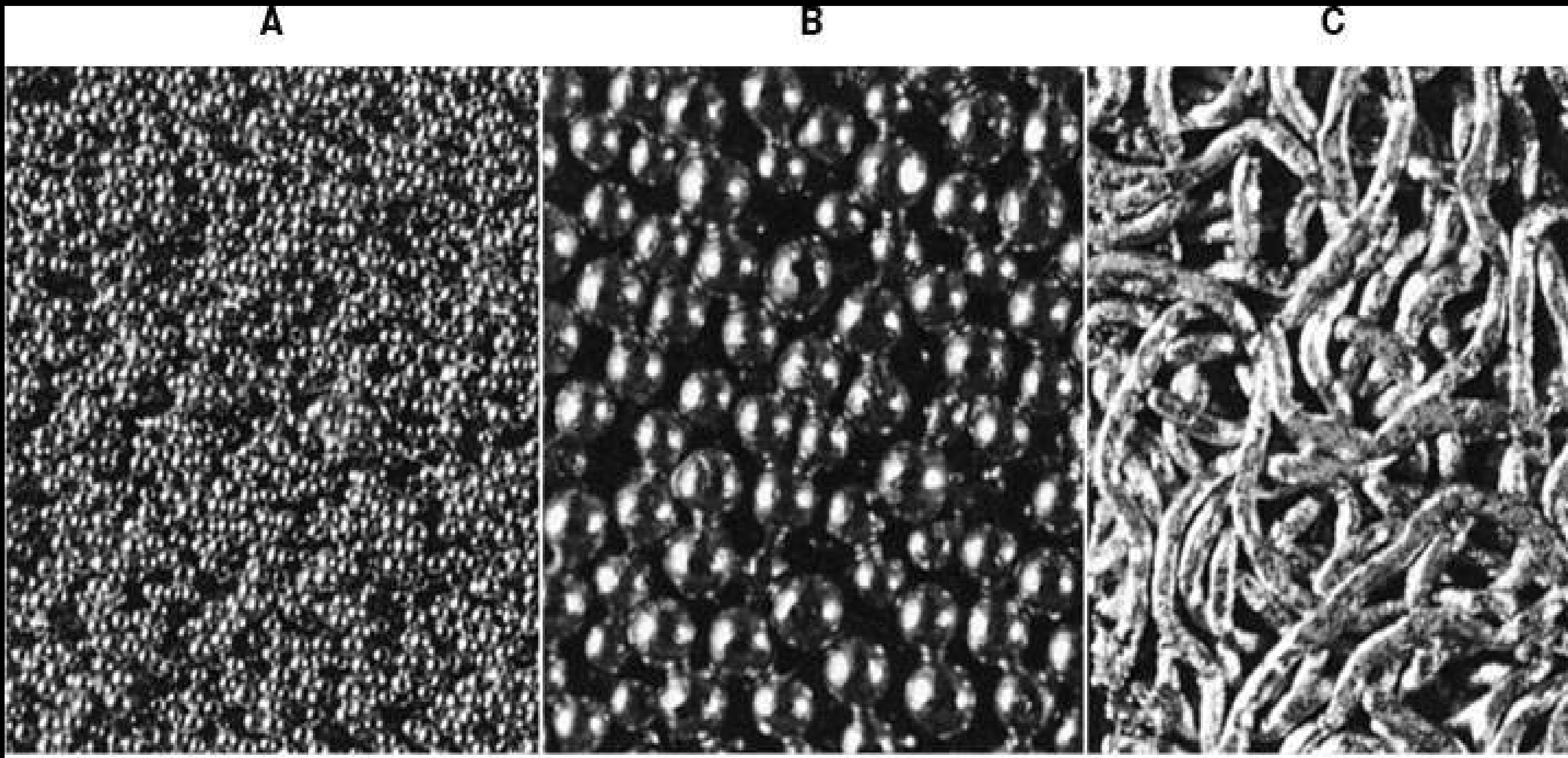
Porous Coating

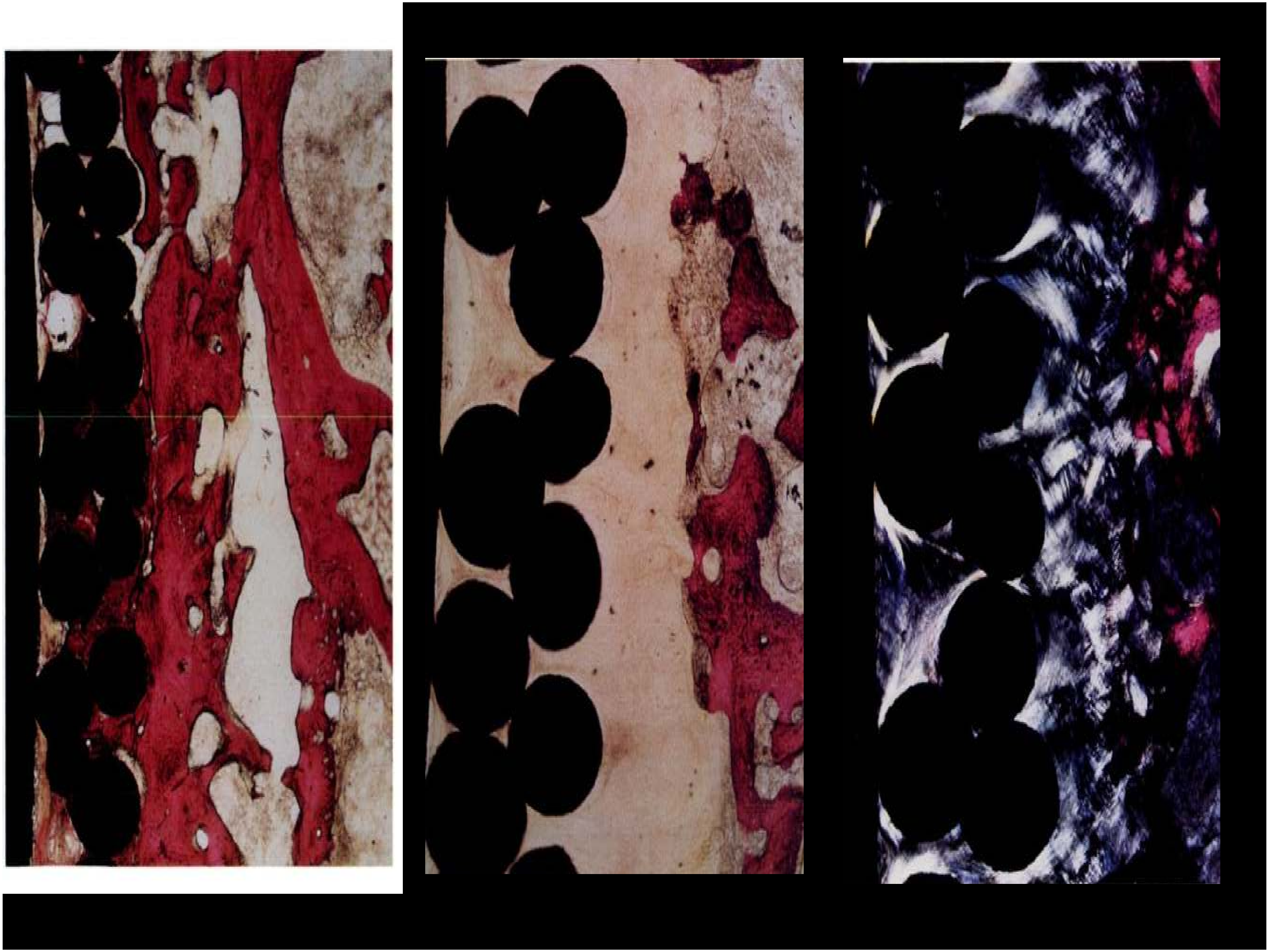
- Bone **INGROWTH** into pores on metallic surface
- Pore Size 50-350μm - Ideal 50-150μm
- ***Porosity***
  - How much bone able to fill in
  - Usually 40-50% if more coating can shear
- ***Pore Depth***
  - Strength of bone-prosthesis interlock
  - Deeper pore depth gives increased interface shear strength with loading
- ***Gaps***
  - Between coating and bone <50μm

RJ Cook et al. JBJS 69-A. 1987.

Bloebaum et al. J Biomed Mat Res. 28. 1994

Porous Coatings



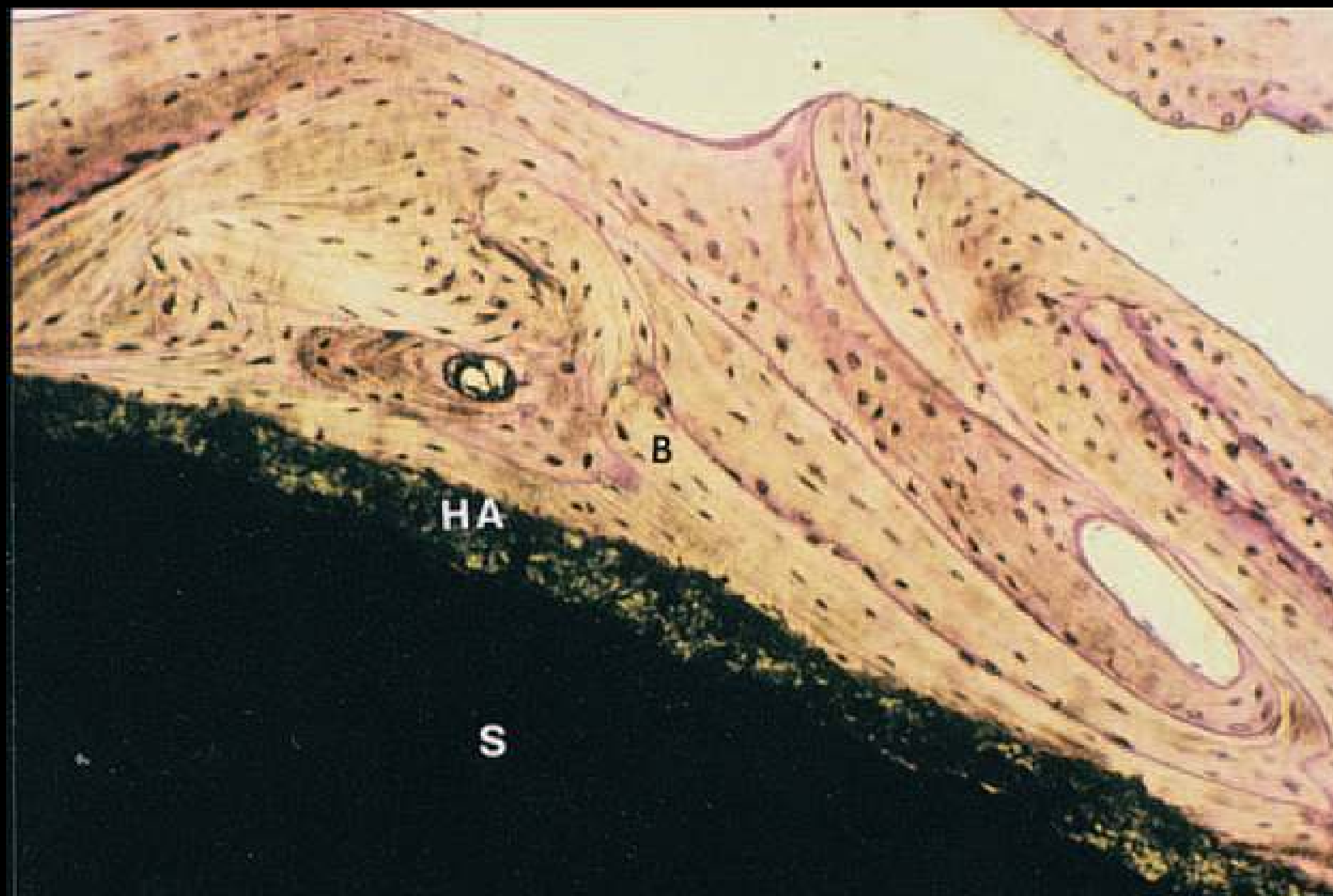


Adjuvant Coatings

Hydroxyapatite

- Osteoconductive
- Gaps closed more rapidly
- Reports of delamination if too thick
- Ideally about 50µm
- HA coating susceptible to resorption by osteoclast-like cells
- Up to 20% of coating removed within two years

HA Coating (x20 mag)



Extent of Porous coating?

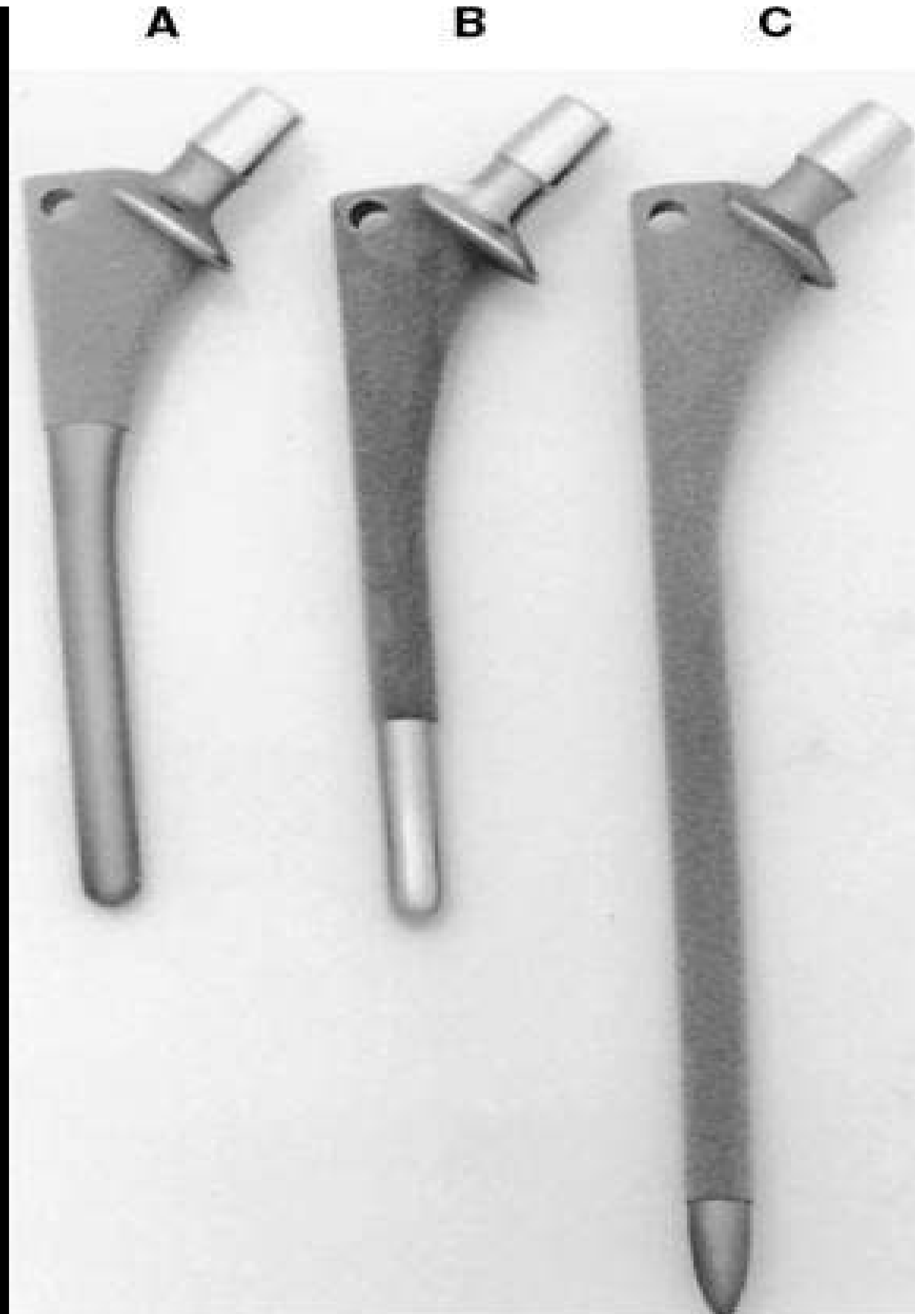
Proximal Porous Coating

- Metaphyseal and upper metadiaphyseal regions of femur
- Proximal Bone Ingrowth
- Proximal bone loading
- Less Stress Sheilding

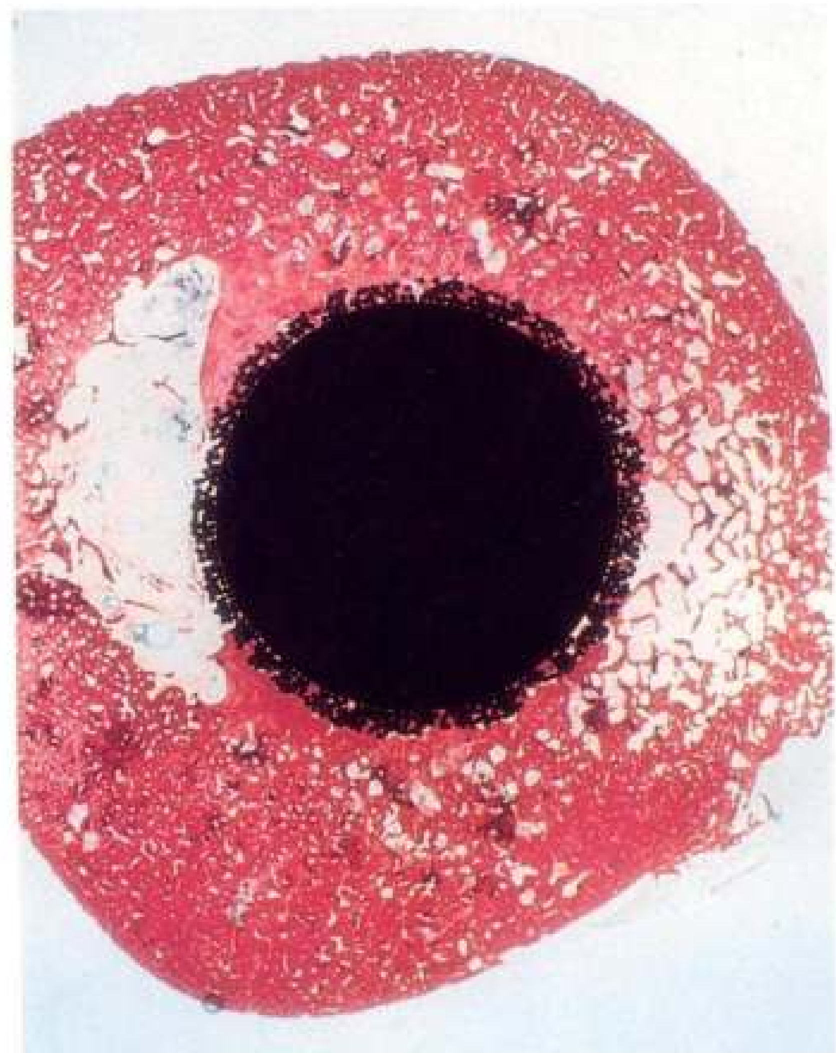
Extent of Porous coating?

Entire Stem Coated

- Maximal bone ingrowth occurs at diaphysis
- Weight bearing forces bypass proximal femur
- Proximal femur Stress Shielded
- Reduced bone density


A
B
C

Patch Coating?



Grit Blasting/Plasma Spray

- Bone ***ONGROWTH*** onto peaks & troughs
- Metallic Surface pitted with abrasive particle spray
- **Surface Roughness**
- Dictates success of ongrowth
- Average distance from peak to trough
- Increased SR increases shear strength
- Boney fixation occurs at surface
- Usually entire shaft to provide secure fixation

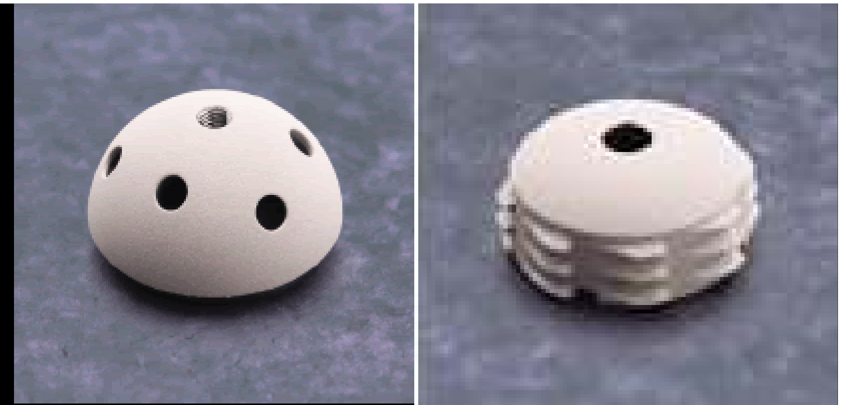
Techniques of Fixation

Rigid Fixation

- **Primary Stability**
- Essential for bone in / ongrowth
- Micro-motion <150µm required
- Radiographically
  - Spot Welds
  - No Subsidence
  - Direct bone-prosthesis contact

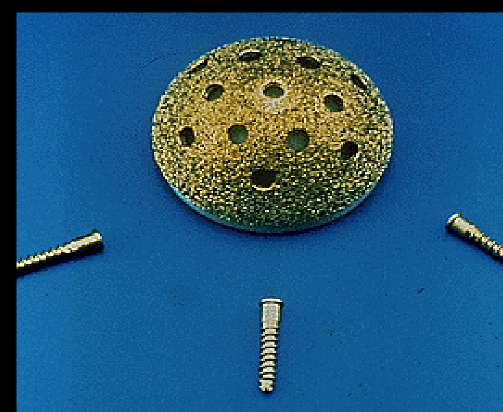
- If more motion fibrous tissue develops
- Gross motion > 150µm fibrous tissue encapsulation
- Unstable & Mobile causing pain

Rigid Fixation



Line-to Line Fit

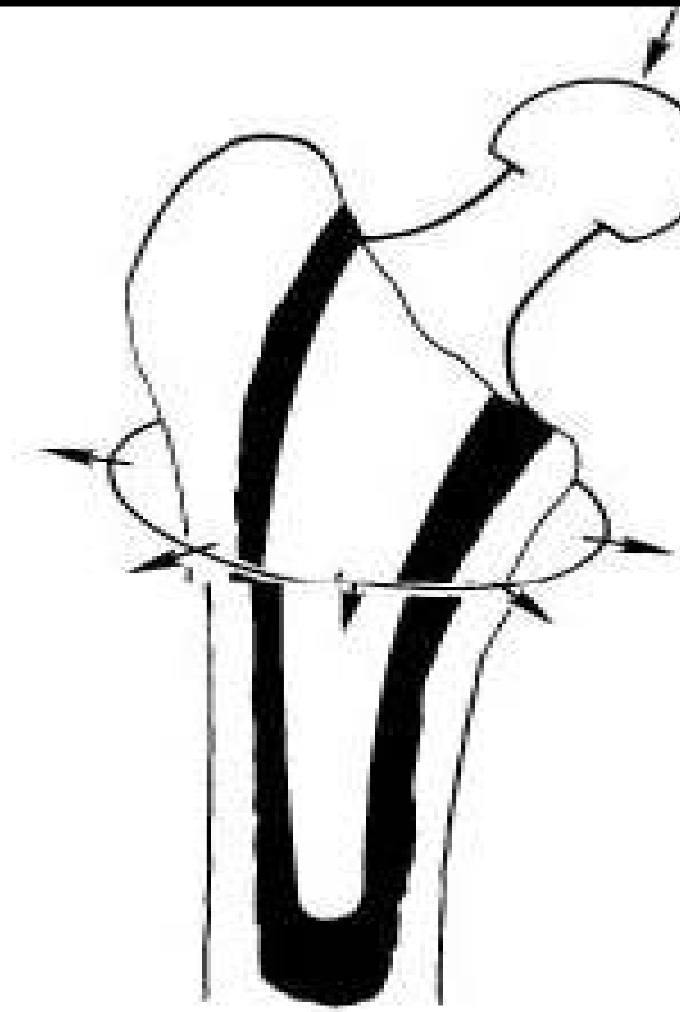
- Reamed to same size as component
- Fixation achieved by additional means
- Acetabular prosthetic screws (Harris-Galante cup)
- Extensive coating



Press-Fit

- Acetabulum and Femur
- Reamed to 1-2mm smaller than prosthesis
- On insertion bone expands (viscoelastic)
- ***Hoop Stresses*** created
- Bigger the Hoop Stress better fixation
- Keeps micro-motion to minimum
- Avoid excessive under-reaming – polar gapping
- Risk of fracture
- Cups can be augmented with screws

Hoop Stresses

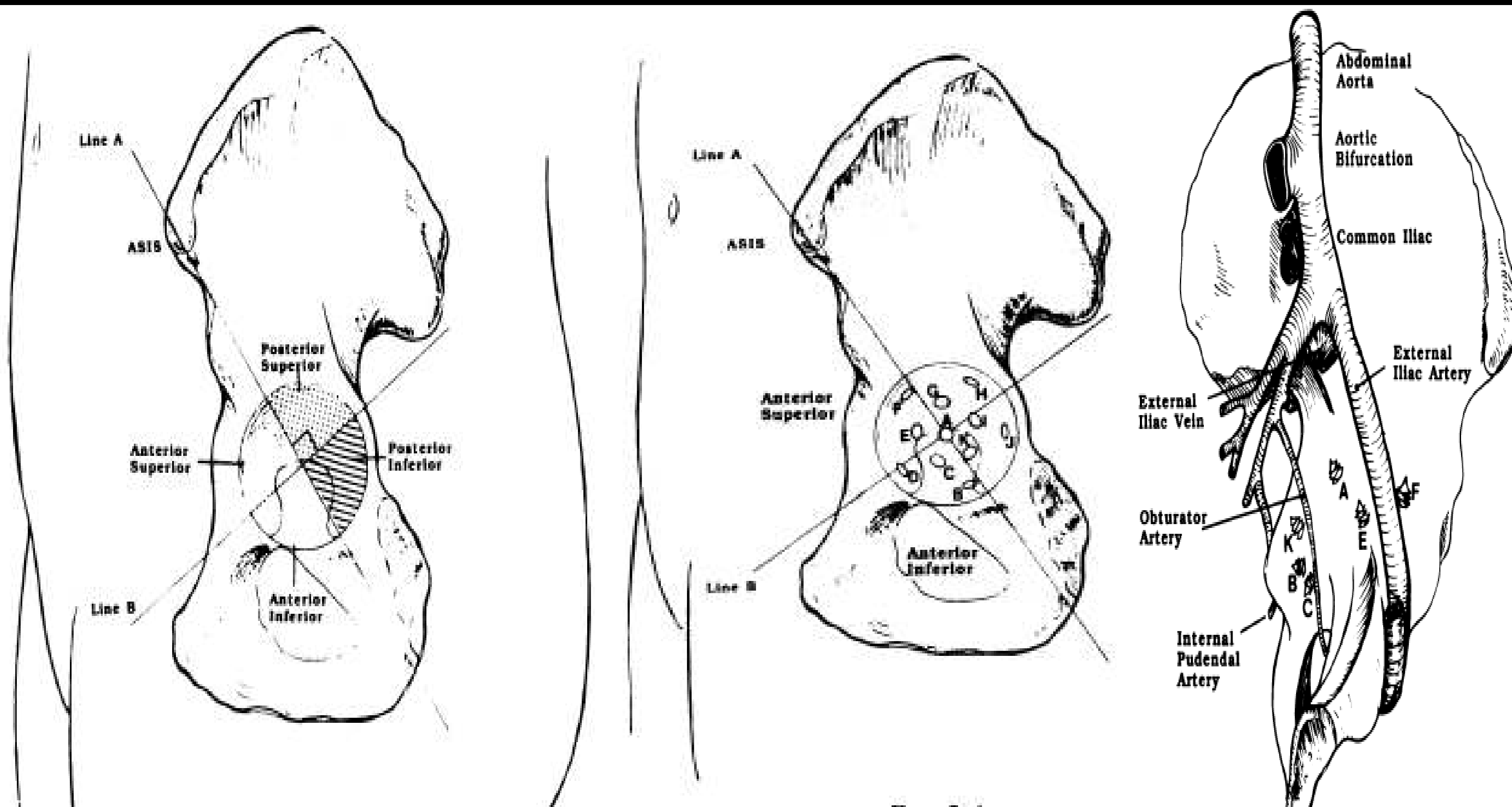


Apical Gapping

Concerns with Cups

- Backside Wear
  - Micromotion between shell & liner causing debris and osteolysis
  - Screw holes provide passage to bone
- Thinner Polyethylene needed
- Placement of screws and pelvic vasculature

Acetabular Screw Placement



Wasielewski et al JBJS 72-A 1990

2nd Generation Cups

- Improved locking mechanisms for shell and liner
- Max. conformity between shell and liner
- No Holes
- Smooth inner metallic surfaced
- Reduces debris and backside wear

Concerns with Stems

- High Level aseptic loosening (35%)
- Thigh Pain
  - Tip Micromotion - ?product of stem fit
  - Less thigh pain if distal fit tight (cylindrical)
  - Material Modulus (Bone<Ti<CoCr)
  - Tip overload in elderly – mismatch of modulus

Engh et al JBJS 69-Br 1987

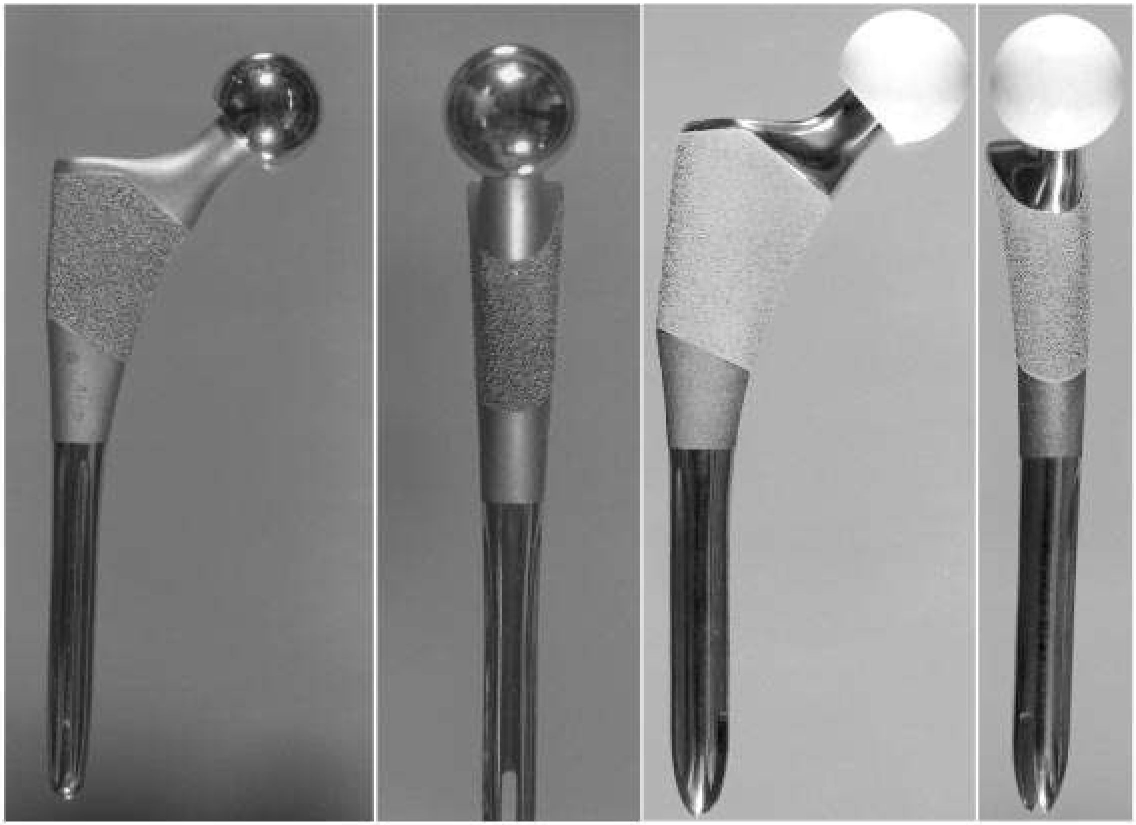
Whiteside Clin Orthop Relat Res 247. 1989

2^{ND} Generation Stems

- Improved surgical technique
  - Broaching and reaming
  - Better bone fit
- Design changes – tapered proximal wedge
- Optimised proximal fit reduces stress shielding
- Fully coated increase chance distal fit
- Use of Hydroxyapatite
- Diaphyseal fit
- Promising short to mid term results

Ragab et al JBJS 81-A 1999

A



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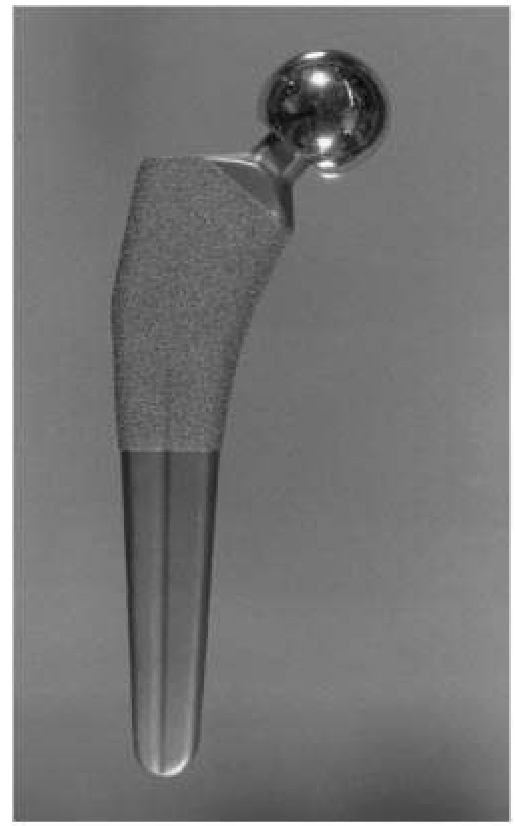


Materials

- Titanium
  - Rapidly forms adherent oxide coating
  - Allows good osteointegration
  - Low modulus of elasticity
  - High Fatigue strength
  - Easy to apply coating (mesh or beads)
  - Poor wear resistance
  - Notch sensitive
- Cobalt-Chromium alloy
  - Higher modulus
  - More stress shielding
  - Harder – more wear resistant
  - Good for bearing surfaces
  - Beads sintered on

Cementless

- Pro's
- Remodelling ability
- ? Long term fixation
- No cement complications
- Preserve bone stock

- Con's
- Initial fit vital
- Technique
- Risk of fracture on insertion
- Thigh pain
- Still developing
- Cost

Which One?

Cemented THR: Stem

2nd Generation Techniques

- Min. 15 years FU
- Average 5 % revision rate for Aseptic Loosening

Ranawat et al Clin Orth 317 1995

Maday et al JBJS 79-Am 1997

Smith el al JBJS-Am 80 1998

3rd Generation Techniques

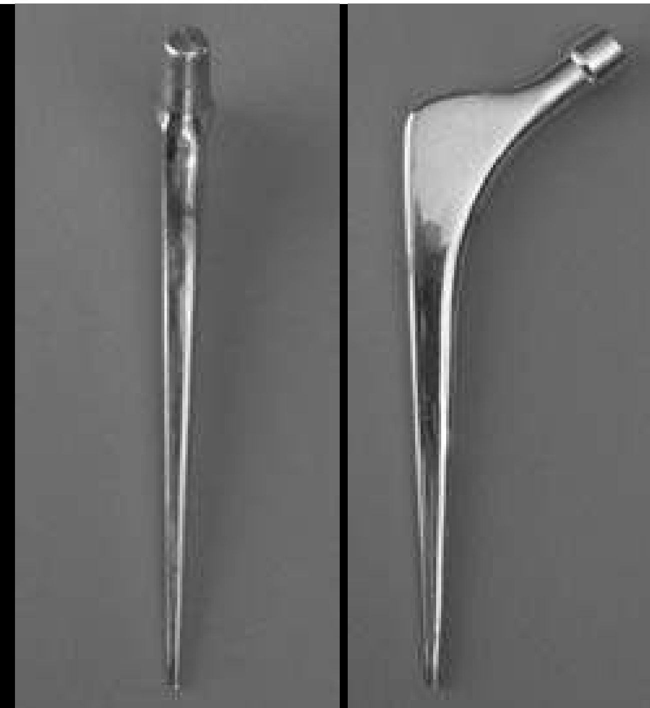
Non-precoated

- At 13.5 years FU 0/175 revised for mechanical failure (Rasquinta et al J Arthroplasty 18(1) 2003)

Precoated

- 6 years FU 1/100 failed (Oighi et al JBJS 76-Am 1994)
- 10 years FU 4/121 failed (Clohisy & Harris JBJS 81-Am 1999)

- Charnley – 40 years
  - Wrobelowski et al 89-Br 2007
  - 22066 hips implanted
  - 4.5% revision rate
  - At 31 years at least 40 THRs under FU
  - Main problem acetabular component



- Exeter
  - In use since 1970
  - At min.12 years
  - Stem 100% survival
  - Cup 97% survival

Williams et al JBJS 84-Br 2002

Cementless THR: Stem

- Really only Short to Mid-term results
- Early FU (2-6 years)
  - Loosening 0-3%, Revision up to 5%
- Mid-Term (8-12 years)
  - Loosening 0-3%
  - HAC Furlong at 17 & 21 years 97.4% survival
- Long-Term (>15 years)
  - Loosening 0.7-5.9%, Revision 0.3-4%

McAuley et al Clin Orthop Rel Res. 418 2004
Hozack et al J Arthroplasty 9(5) 1994
Sinha et al JBJS 86-Am 2004
Rajeratram et al. JBJS 90-Br 2008
Mallory et al J Arthroplasty. 16. 2001

Cups Evidence

- Cementless
  - Mid to long term results
  - Revision Rate 0.3-0.9%
  - 5% Osteolysis

- Cemented
  - Long Term (15 years plus)
  - Loosening rates of 15-54%
  - Revision Rates of 10-23%

- Over 60 years of age (lower demand)
  - Revsion rate 2% at 12 years
  - 4% AT 15 Years

Valle et al JBJS 86-A. 2004

Chen et al Clin Orthop 451. 2003

Civinini et al JBJS 90-Br. 2008

Knief et al J Arthroplasty 21(2) 2006

Brick et al Rheum Dis Clin North Am 14(3) 1998

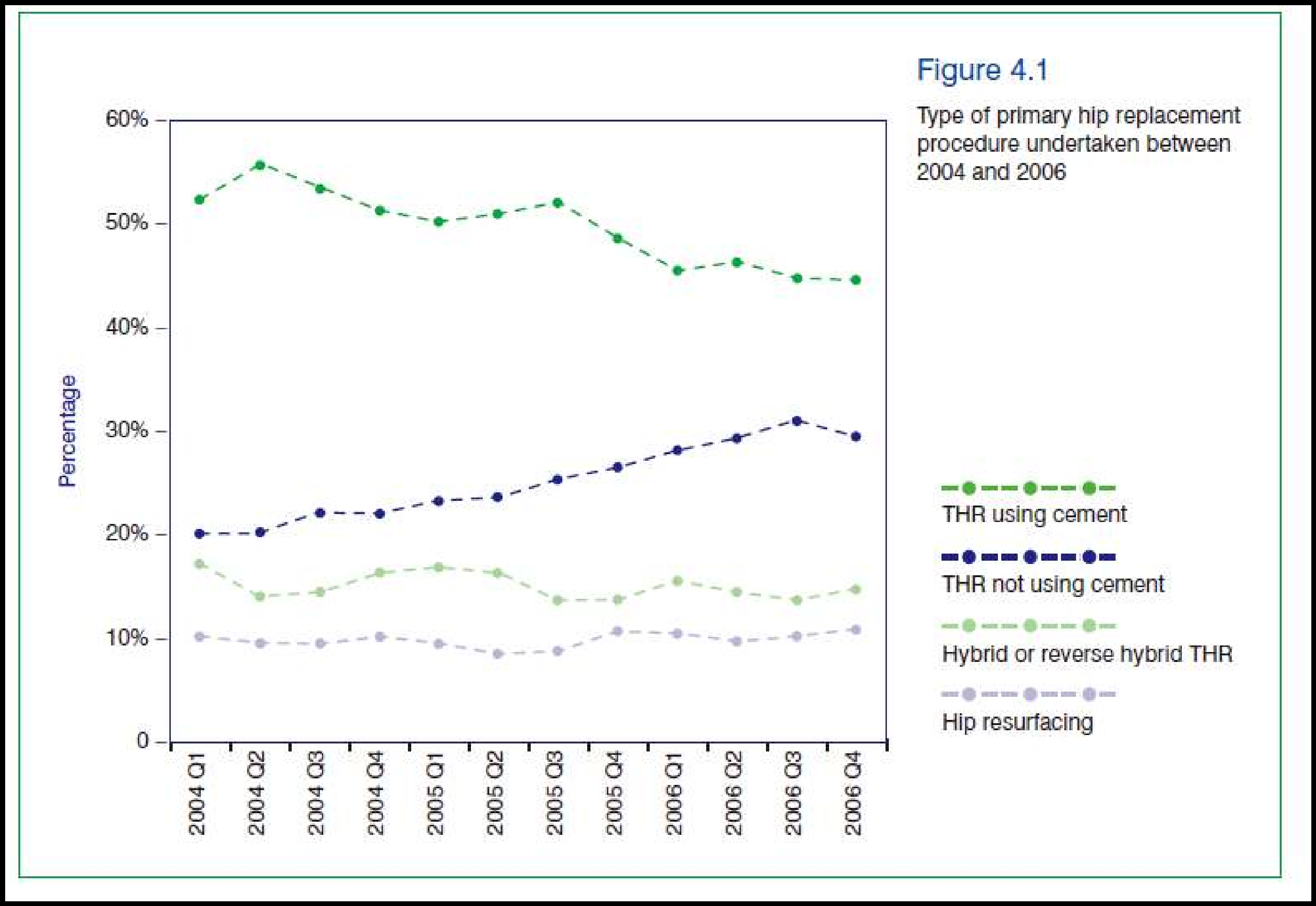
Sarmiento et al Orthop Clin North Am 19(3) 1988

Young Patients

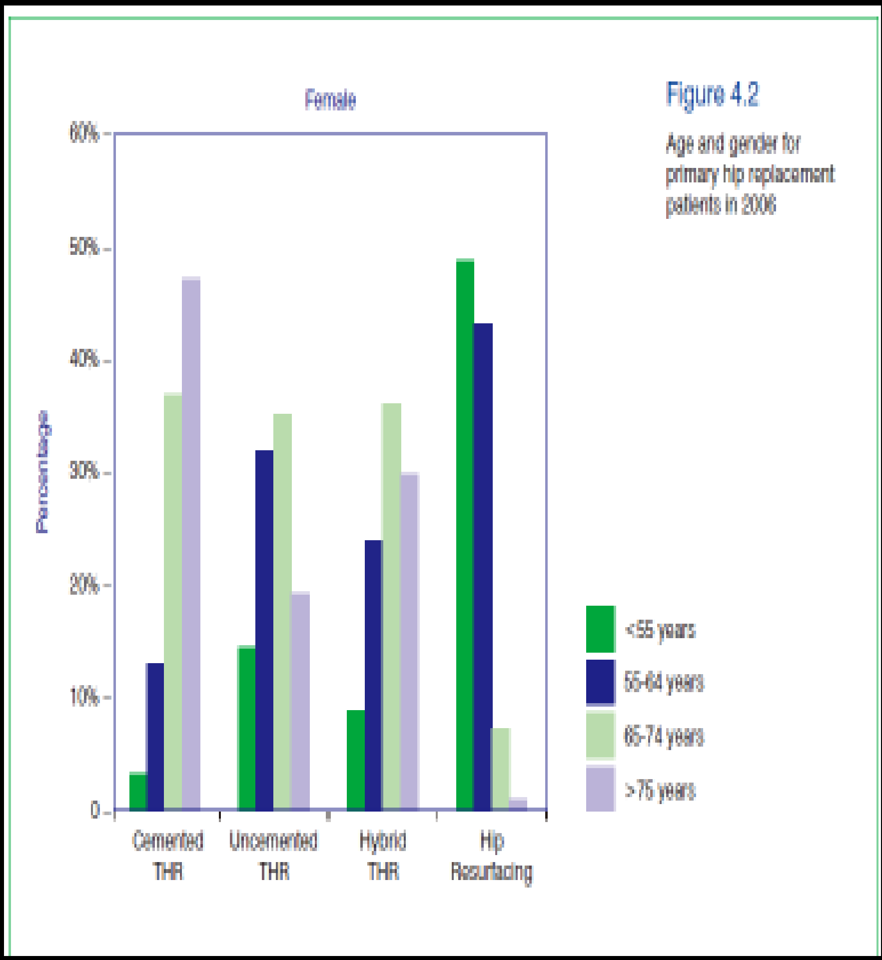
- Good Mid-term results (8-12 years)
- Cementless
  - Survival rates of 91% - 100%
  - Linear wear of liner main problem
- Cemented
- 87% survival rate at 10 years

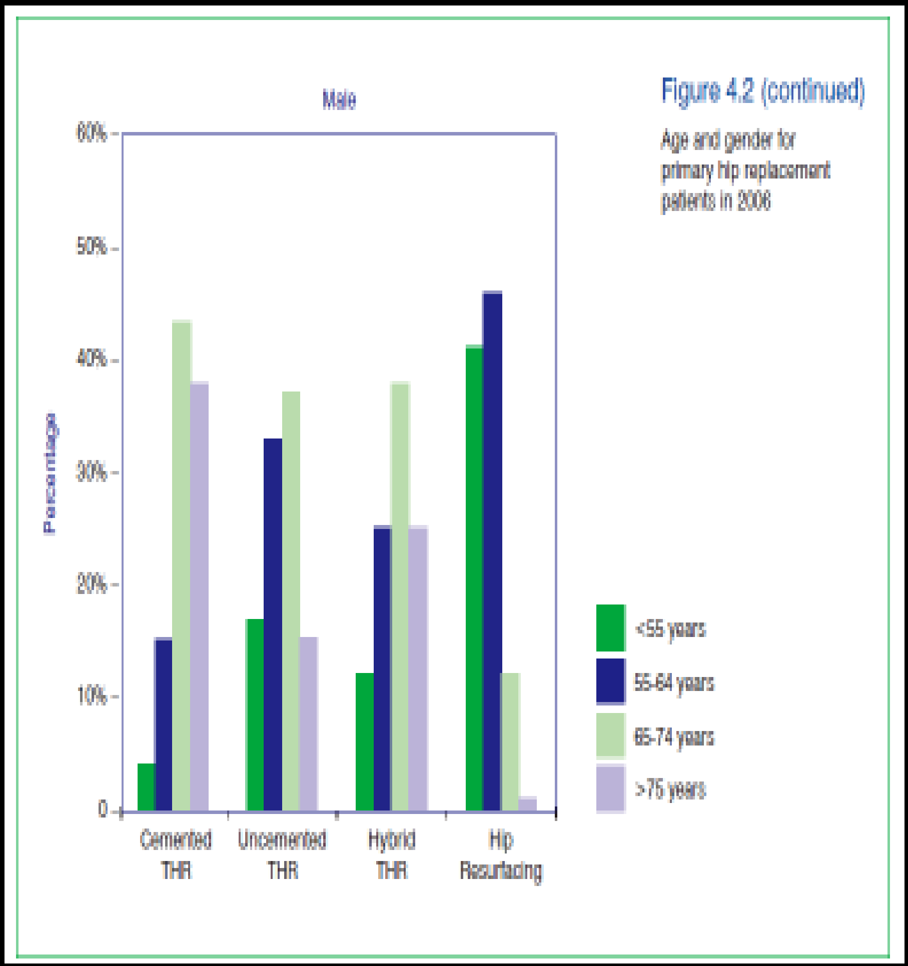
McAuley et al Clin Orthop Rel Res. 418 2004
Kim et al JBJS 85-Am 2003
Eskelinen et al Acta Orthop 76 2005
Eskelinen et al Acta Orthop 77 2006

NJR 4th Annual Report



Type of Prosthesis & Age





Overall Outcomes

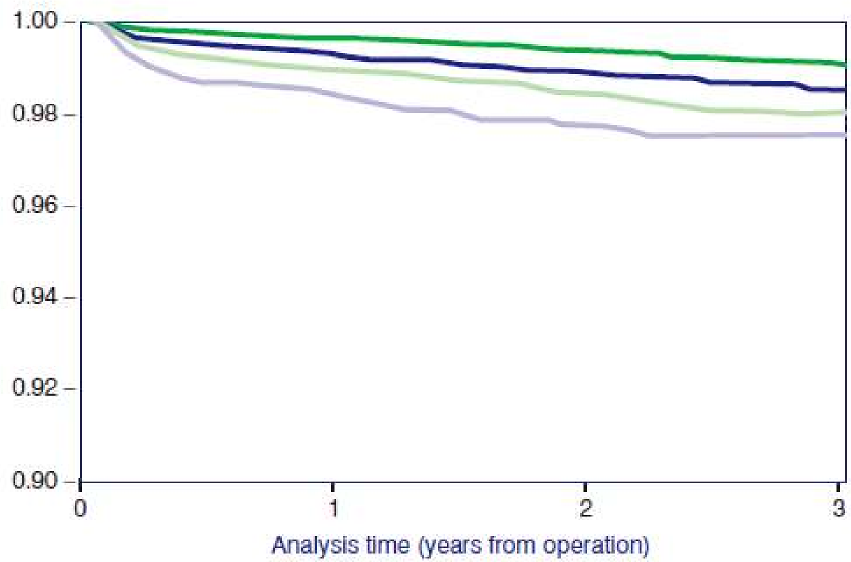


Figure 4.3

Revision rate estimates for HES-linked primary hip replacement procedures, 2003 – 2006

Revision rate (95% CI)

Procedures type (n)	3 months	1 year	3 years
Cemented (41,232)	0.2% (0.1% – 0.2%)	0.3% (0.3% – 0.4%)	0.9% (0.7% – 1.1%)
Cementless (19,022)	0.5% (0.5% – 0.7%)	1.0% (0.8% – 1.1%)	1.9% (1.6% – 2.3%)
Hybrid (10,120)	0.3% (0.2% – 0.4%)	0.7% (0.5% – 0.9%)	1.4% (1.1% – 1.9%)
Resurfacing (6,202)	0.9% (0.7% – 1.2%)	1.6% (1.3% – 2.0%)	2.4% (2.0% – 3.0%)

Cement Vs. Cementless Femoral

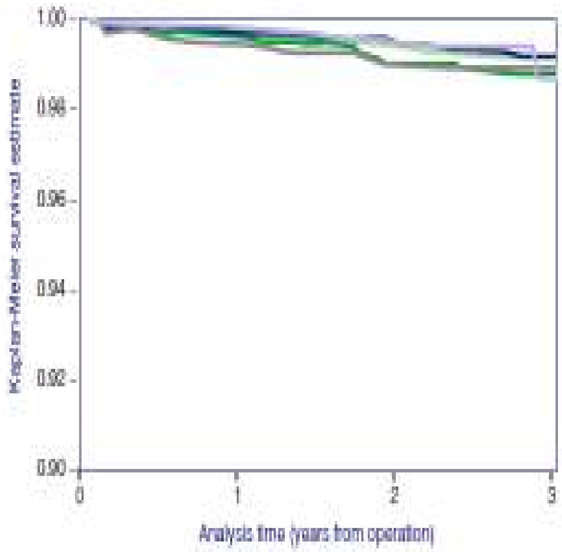


Figure 4.6

Revision rate estimates for the five most commonly used hip cemented stem brands, 2003 - 2006

Revision rate (95% CI)

Brand (n)	3 months	1 year	3 years
C-Stem (4,826)	0.1% (0.06% - 0.3%)	0.4% (0.3% - 0.7%)	1.2% (0.8% - 1.8%)
Charnley (7,806)	0.1% (0.06% - 0.2%)	0.3% (0.2% - 0.4%)	0.8% (0.6% - 1.2%)
CPT (3,081)	0.3% (0.1% - 0.5%)	0.7% (0.4% - 1.1%)	1.0% (0.7% - 1.6%)
Exeter (23,725)	0.2% (0.1% - 0.2%)	0.4% (0.3% - 0.5%)	0.8% (0.6% - 1.1%)
Stanmore Modular (1,280)	0.2% (0.07% - 0.6%)	0.3% (0.1% - 0.8%)	1.3% (0.4% - 4.3%)

C-Stem
Exeter
Charnley
Stanmore Modular
CPT

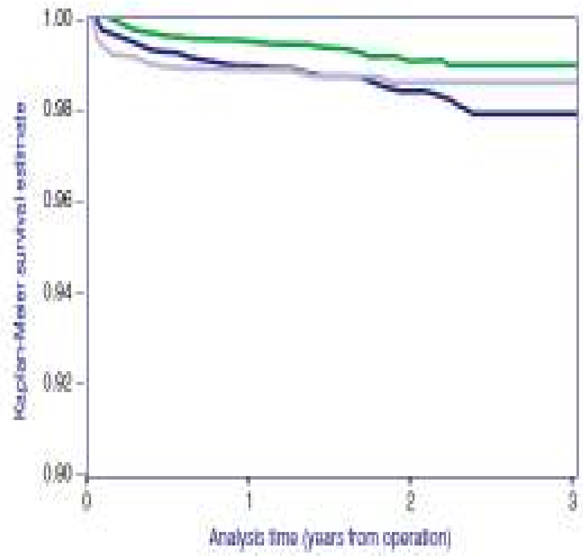


Figure 4.7

Revision rate estimates for the three most commonly used hip cementless stem brands, 2003 - 2006

Revision rate (95% CI)

Brand (n)	3 months	1 year	3 years
ABG II (1,001)	0.9% (0.5% - 1.7%)	1.2% (0.7% - 2.1%)	1.6% (0.9% - 2.7%)
Corail (5,230)	0.3% (0.2% - 0.5%)	0.6% (0.4% - 0.9%)	1.2% (0.8% - 1.9%)
Furlong (5,927)	0.6% (0.4% - 0.8%)	1.1% (0.9% - 1.5%)	2.2% (1.7% - 2.8%)

Corail
Furlong HAC
ABG II

Cement Vs. Cementless Cups

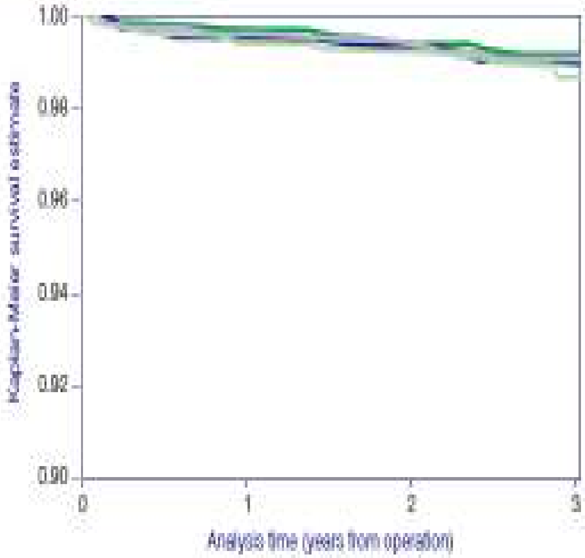


Figure 4.8

Revision rate estimates for the five most commonly used hip cemented cup brands, 2003 - 2006

Revision rate (95% CI)

Brand (n)	3 months	1 year	3 years
Charnley (5,010)	0.08% (0.02% - 0.2%)	0.2% (0.1% - 0.4%)	0.8% (0.5% -1.3%)
Charnley Ogee (3,921)	0.1% (0.05% - 0.3%)	0.4% (0.2% - 0.6%)	0.9% (0.6% -1.4%)
Contemporary (6,424)	0.2% (0.2% - 0.4%)	0.4% (0.2% - 0.6%)	0.9% (0.6% -1.5%)
Eliet Plus Ogee (6,013)	0.08% (0.03% - 0.2%)	0.3% (0.2% - 0.4%)	1.0% (0.6% -1.6%)
Exeter Duration (3,712)	0.3% (0.1% - 0.5%)	0.5% (0.3% - 0.8%)	1.3% (0.7% - 2.3%)

Charnley
Contemporary
Exeter Duration
Charnley Ogee
Elite Plus Ogee

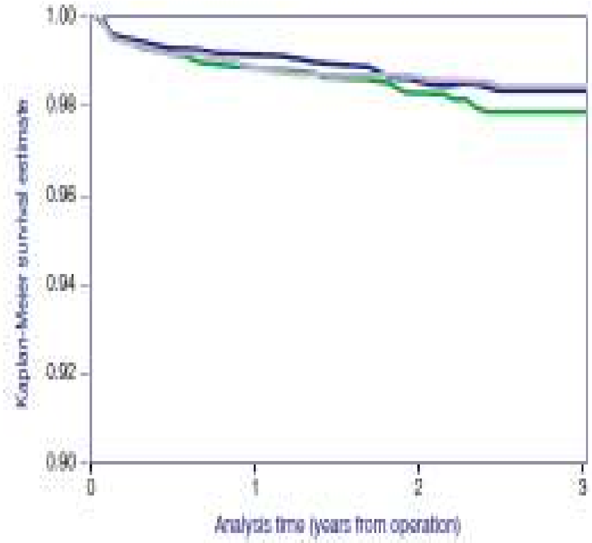


Figure 4.9

Revision rate estimates for the three most commonly used hip cementless cup brands, 2003 - 2006

Revision rate (95% CI)

Brand (n)	3 months	1 year	3 years
CSF (5,692)	0.6% (0.4% - 0.8%)	1.1% (0.8% - 1.4%)	2.1% (1.6% - 2.7%)
Duraloc (2,981)	0.5% (0.3% - 0.8%)	0.8% (0.5% - 1.2%)	1.6% (1.1% - 2.3%)
Trilogy (4,104)	0.6% (0.4% - 0.9%)	1.1% (0.8% - 1.4%)	1.5% (1.1% - 2.1%)

CSF
Duraloc
Trilogy

Conclusions

- Discussed methods of fixation
- Looked at evidence
- Cemented stem and Cementless cup?
- Current trends
- Moving away from cement?

Thank You