

# History of cemented hip replacement

# History is important

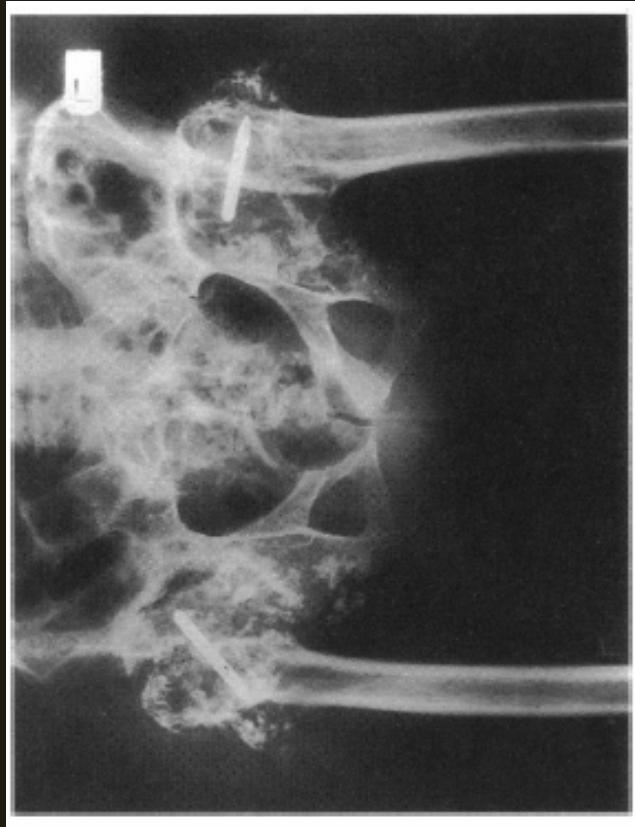
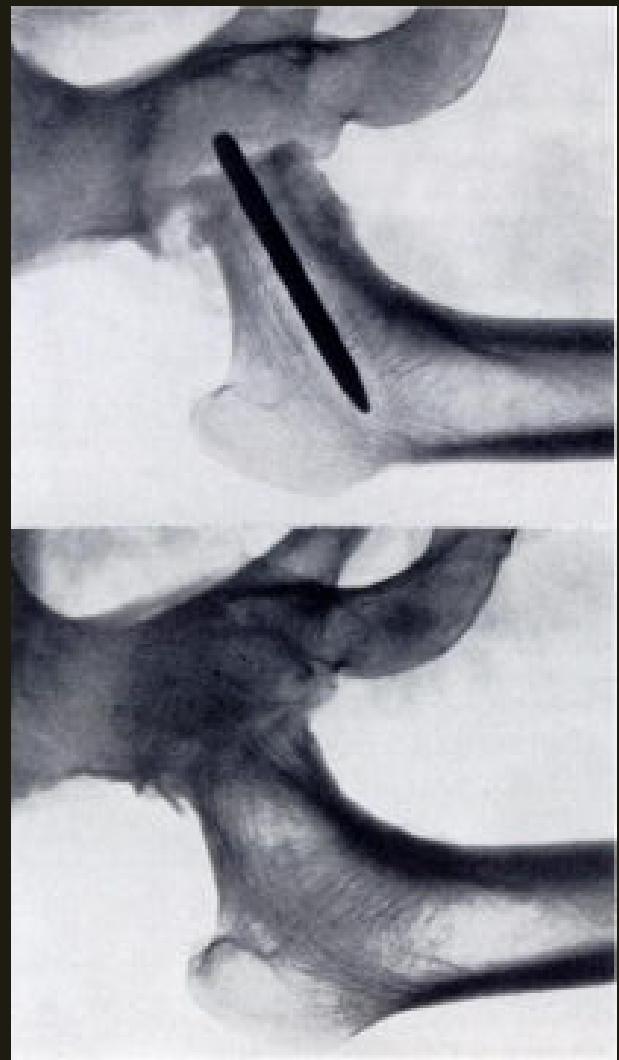
- those who can not remember the past are condemned to repeat it. Santayana.

Date	Prosthesis	Bearing Materials
1923 – 1938	Smith-Peterson mold arthroplasty	Glass, Viscosiloid, Pyrex, Bakelite, CoCr SS/SS
1938	Wiles metal-metal	
1950	Judet hemiprostheses	PMM A femoral head
1956 – 1960	McKee	CoCr/CoCr
1958 – 1962	Charnley low-friction arthroplasty	CoCr/PE
1962	Charnley low-friction arthroplasty	CoCr/UHMWPE
1962 – 1966	McKee-Farrar Ring	CoCr/CoCr
1964 – 1968		CoCr/CoCr
1970	Boutin	Al <sub>2</sub> O <sub>3</sub> /Al <sub>2</sub> O <sub>3</sub>
1971	Onishi	CoCr/UHMWPE (1000 kGy)
1977	Shikata	Al <sub>2</sub> O <sub>3</sub> /UHMWPE
1978	Grotthober	CoCr/UHMWPE (100 kGy)

Judet Prosthesis

Year: 1950





HIP  
ARTHROPLASTY  
with  
PROSTHETIC  
HEADS

•  
TECHNIQUE  
of  
Doctors  
R. and J. JUDET

Patent Pending

1. Stainless Steel Armature of high breaking strength embedded before polymerization. (By this process no plug or crowns are used in covering of the armature.)

2. Grooves preventing the risk of rotation.

3. Grooves specially suited to prevent risk of extraction.

Reinforced Monobloc and Grooved Drs JUDET'S MODEL

is made of

DRAPIER Surgical Instruments 41 Rue de Rivoli, PARIS (1<sup>e</sup>)

Manufactured by

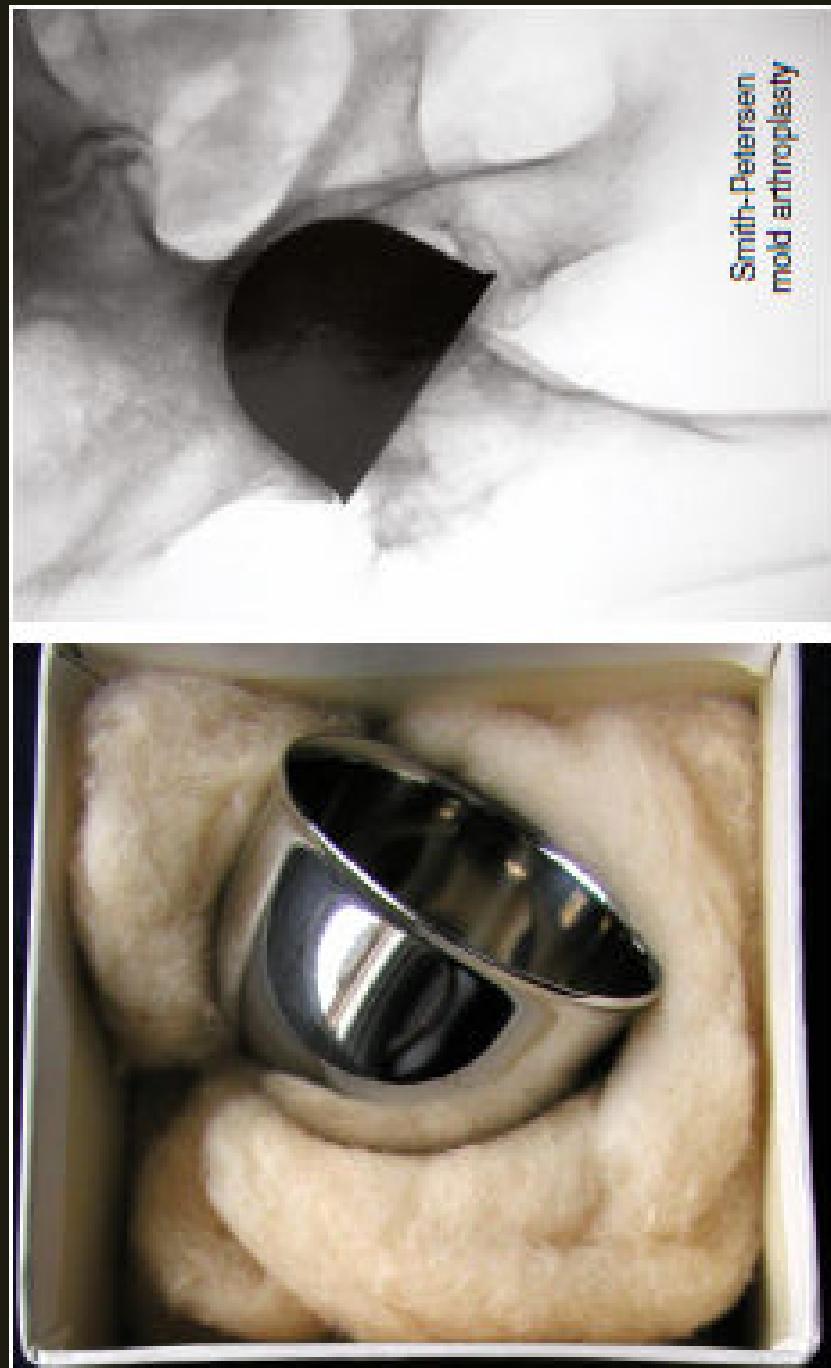
**Onacryl**  
DRAPIER Trade Mark

Explanatory leaflet P-67 giving full details on heads and instruments on request.

Scales JT, Zarek JM. Biomechanical problems of the original Judet prosthesis. BMJ 1954;1:1007-13

Journal of Royal Society of Medicine 1998.  
Kamanqu M, Acta Orthop Belgica 2002.

# Smith-Peterson mould arthroplasty



20 years = 81%, and  
30 years 59%



J Orthop Sci (2010) 15:459–462  
DOI 10.1007/s00776-010-1499-4

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## Original article

# Long-term survivorship analysis of hip arthroplasty with vitallium mold cup

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### Abstract

**Background.** Cup arthroplasty was used in the initial attempts to preserve the bone stock of the femoral head and neck for hip reconstruction. However, little conclusive data are available regarding its long-term survivorship.

**Methods.** We present a long-term survivorship analysis (mean follow-up, 19.3 years; range, 5–36.6 years) after vitallium mold arthroplasty in 77 secondary osteoarthritic hips. **Results.** Kaplan–Meier survivorship analysis predicted a survival rate for vitallium mold arthroplasty of 81.6% (95% confidence interval [CI], 76.7–86.5) at 20 years and 59.1% (95% CI, 51.8–66.5) at 30 years, with conversion to total hip arthroplasty as the endpoint. The mean Merle d’Aubigne and Postel hip score showed a significant decrease in mobility from 4.12 (range, 3.18–5.86) months after the operation to 3.19 (range, 1.7–4.6) at the last follow-up. No significant differences were observed for the pain score from 6 months after the operation (5.05; range, 4.2–5.9) to the last follow-up (4.46; range, 2.88–6.04) or score for the ability to walk from 6 months after the operation (2.5; range, 1.4–3.6) to the last follow-up (3.13; range, 1.59–4.67). Radiographically, the proximal and medial migration of the cup measured at the last follow-up was  $10.4 \pm 5.4$  mm ( $P < 0.01$ ) and  $0.2 \pm 2.1$  mm ( $P > 0.05$ ), respectively.

**Conclusions.** Our results indicate inferior long-term survivorship after vitallium mold compared with that after Charnley low-friction arthroplasty.

more active patient cohort, the results of THA are less encouraging, because of the strong possibility of multiple revision procedures over the lifespan as a result of increasing abrasion of the THA components and osteolytic bone loss. Therefore, resurfacing arthroplasty, a kind of bone-conserving procedure, has regained the attention of orthopedic surgeons worldwide as an alternative technique.<sup>1–3</sup>

Before the advent of THA, cup arthroplasty was the main method of hip reconstruction. The first arthroplasty mold was made in 1923 from glass, and in 1939 Smith-Petersen<sup>4</sup> introduced vitallium mold cup arthroplasty using a cup made from a cobalt–chromium alloy. Vitallium mold arthroplasty became a standard procedure for hip arthroplasty until the emergence of Sir John Charnley’s low-friction torque arthroplasty in the 1960s.<sup>5</sup> Cup arthroplasty was then gradually abandoned and was ultimately displaced by THA.<sup>4,12</sup>

Cup arthroplasty was used in the initial attempt to preserve the bone stock of the femoral head and neck for hip reconstruction. However, little conclusive data are available regarding its long-term survivorship. The purpose of this study was to report on the long-term survivorship of this historical procedure.

### Introduction

Hip arthritis is a common condition in older populations and is one of the leading causes of hip disability. Total hip arthroplasty (THA) was developed in the early 1960s and has been shown to provide reliable and lasting amelioration of joint function in patients with more advanced stages of arthritis. However, in a younger and

48 years ago in a woman admitted to  
A&E at the age of 74

Between 1962 and 1997, 113 consecutive hip-resurfacing procedures (107 patients, 22 male and 85 female) were performed with the vitallium mold hip-resurfacing device at our center, Kyoto University Hospital. Thirty-six hips were lost to follow-up. The remaining 77 hips were followed for an average of 19.3 years (range, 5–36.6 years), forming the study group. The mean age at the time of the operation was 38.2 years (range, 15–68 years). The initial diagnosis for all hips at the time of operation was secondary osteoarthritis caused by developmental dysplasia or congenital dislocation of the hip.

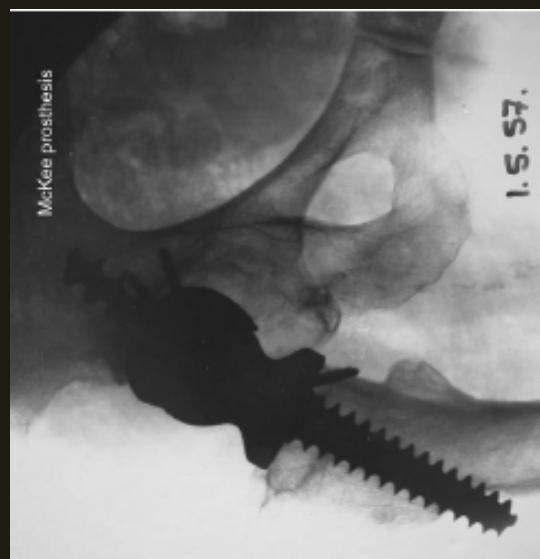
Offprint requests to: H. Akiyama  
Received: November 19, 2009 / Accepted: April 27, 2010

# First successful hip replacements by Philip Wiles



# Ring MOM prosthesis McKee

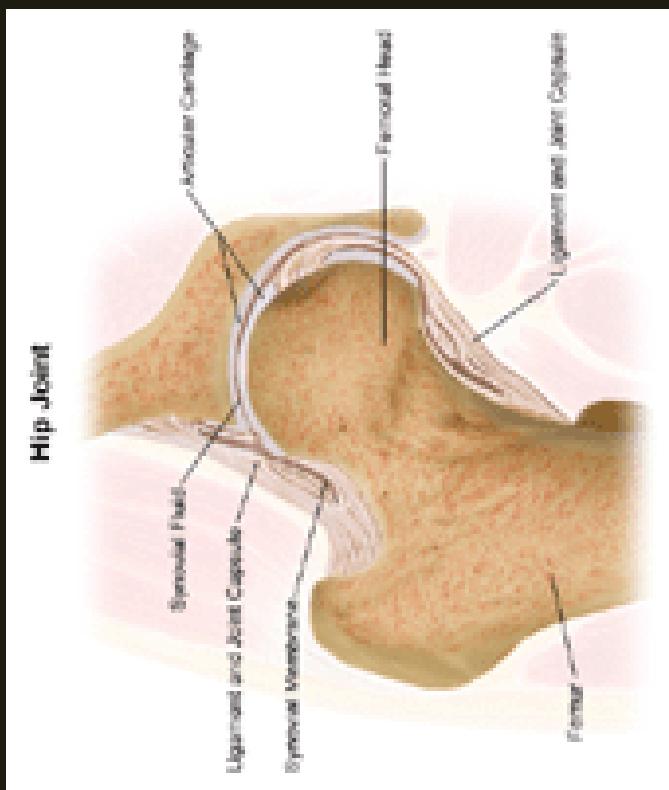
## Farrar and Ring



# John Charnley's Low Friction Arthroplasty

Charnley said in 1959

"attempts to lubricate any artificial joint must be based on the idea of using boundary lubrication. The substance which seems ideally suited for this purpose is PTFE because not only has this a low coefficient of friction (0.04–0.05) but it is a substance which is readily tolerated by animal tissues by virtue of its chemical inertness."



# Metal on polyethylene hip replacement AND CEMENT

# Metal On Poly Cemented Hips

- Low friction and wear.
- UHMWPE
  - Nature (composite).
  - Sterilisation.
  - Biological reactions.
- Acetabular cups
  - Introduction to hip arthroplasty.
  - Biomechanical properties.
- Cement
  - Cement disease.
  - French paradox.
  - Available cements.
- Stem designs
  - Charnley stems.
  - Exeter Stems.
  - C stems.

# Charnley

- Teflon (PTFE) – The most slippery material.
- Five design changes occurred.
- First: Double cup arthroplasty using PTFE.



# Charnley designs continued

- Second to forth: Use of metallic heads against PTFE.



# Fifth design with PTFE

- 22.225mm femoral stemmed and cemented femoral component and PTFE cup.
- Published his results in *Lancet* 1961.
  - He claimed negligible wear at 10 months from radiographs.



# Fabrication of the components



# Fabrication Contd.



Replacement of PTFE

Glass and poroperosity filled =  
Fluorosint



# Failure of PTFE (TEFLON)

- Charnley J. The Man and the Hip. New York, NY: Springer;
- 1990:120–143.
- 5. Coventry MB, Nolan DR, Beckenbaugh RD. ‘Delayed’ prop

# May 1962 – The introduction of UHMWPE

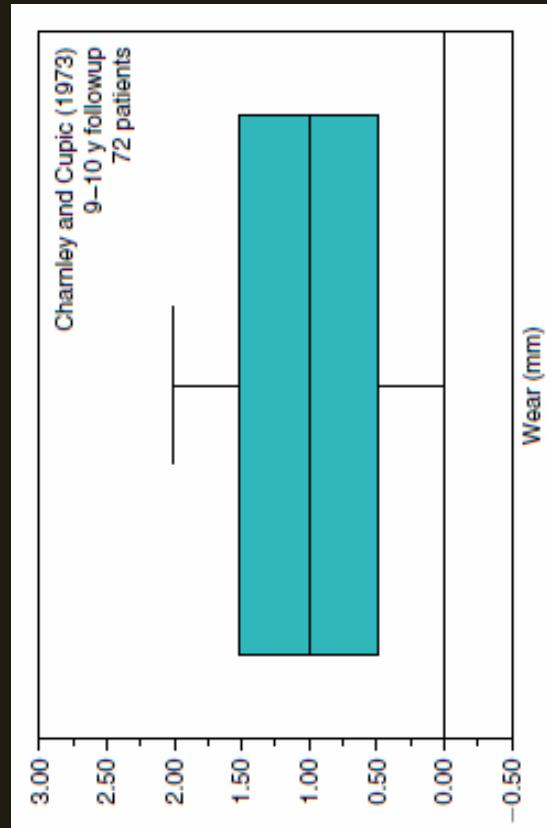
- Mr V C Binns.
- “When shown the material, Charnley dug his thumb-nail into it and walked out, telling Craven he was wasting his time”
- After running day and night for three weeks, this new material, which very few people even in engineering circles had heard about at that time, had not worn as much as PTFE would have worn in 24 hours under the same conditions. There was no doubt about it, “we were on.”

# The UHMWPE cup

Charnley and Cupic, 1973.CORR.



- Introduced wire marker in 1963.
- Measures distance between the wire and femoral head in the weight bearing and non-weight bearing regions – and then divide by 2.
- Accuracy of only 0.5mm.
- The cohort of the paper: 185 arthroplasties in 170 patients. Many had died and most were unable to come to the clinic for assessment so only 106 could be assessed.



# Sterilisation of UHMWPE

Wrightington Hospital Management Committee  
Centre for Hip Surgery  
Wrightington Hospital  
Near Wigan

19th October, 1971

Mr. G. Robinson,  
Chas. F. Thackray Limited,  
P.O. Box 171  
Park Street,  
LEEDS LS1 1RQ.

Dear Mr. Robinson,

Sterilisation of Charnley Total Hip Sockets of High Density Polyethylene  
Report of Dr. Weymes, Sterilisation Research Unit,  
Scottish Home and Health Department

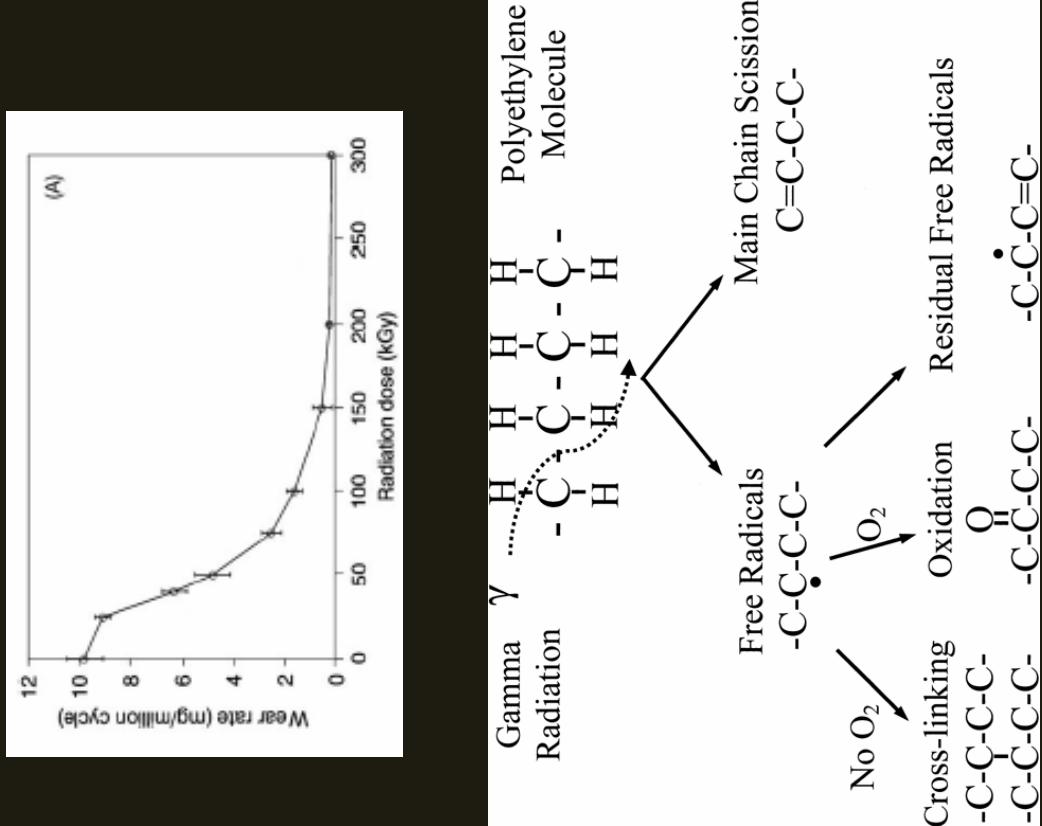
I have read this report sent to Mr. Bury and dated 7th October, 1971, and feel it incumbent upon me, as advisor to Thackrays in the Charnley total hip programme, to make some comments. I will send a copy of this letter direct to Dr. Weymes.

I think it is important first of all to emphasise that this report is, of course, a personal opinion of Dr. Weymes and this should not be lost sight of in the categoric manner in which the statements are made.

1. In our own Biomechanical Laboratories here where we have apparatus for the testing of wear second to none in the world, and we have shown that gamma radiation up to 10 Mrad does not increase the rate of wear of high density polyethylene. There are some slight changes in colour from white to slightly cream colour but absolutely no alteration in the rate of wear. This amount of radiation is four times the medical sterilisation dose.
2. In the categories into which the U.K. Atomic Energy Authority at Wantage groups different plastics in their sensitivity to radiation, it is notable that high density polyethylene is rated as next to the most resistant group of plastics.
3. Wright of Petrochemicals published one of the first studies of high energy irradiation of high density polyethylene (Journal of Applied Polymer Science, Vol. 7 1963, pp. 1905-1918) and stated "ultimate tensile strength and impact strength increased with electron radiation, but very large doses (of the order of 25 Mrad) are required to effect a worthwhile improvement".
4. There is a paper from Japan (Matsubara Watanabe, Wear, 10, (1967) 214-222) indicating an improvement in the wear properties of high density polyethylene after gamma irradiation.

# Polyethylene Sterilisation

- 1960's: Gamma radiation in air.
- 1990's: Renewed interest due to poly osteolysis.
- Dual role of Gamma radiation
  - Cross linking and oxidation competing reactions.
- Free radicals persists for years.



Company	Package environment	Sterilization/packaging trade name
Biomet	Argon flushed, near-vacuum sealed	ArCom
DePuy, Inc.	Near vacuum	GVF (gamma vacuum foil)
Stryker Howmedica Osteonics	Nitrogen	N2-Vac; Duration
Zimmer, Inc.	Nitrogen	

# Sterilization



**FIGURE 3.3** Historical air permeable packaging used with gamma sterilization (DePuy, Warsaw, Indiana, USA).



**FIGURE 3.8** Contemporary gas-permeable packaging for ethylene sterilization of Durasul highly crosslinked UHMWPE components, used by Zimmer, Inc. (Warsaw, Indiana, USA).

**TABLE 3.1** Summary of Sterilization Processes for UHMWPE Implants (Note that gamma air sterilization is listed as a historical reference\* for comparison purposes only.)

Sterilization process	Packaging type	Gamma radiation dose	Contemporary method?
Gamma air	Gas permeable	25–40kGy	No* (historical)
Gamma inert	Barrier packaging, reduced oxygen atmosphere	25–40kGy	Yes
Gas plasma	Gas permeable	None	Yes
Ethylene oxide	Gas permeable	None	Yes

\*Certain small manufacturers in Europe may still use gamma irradiation in air [1].

# Timeline of early UHMWPE development in THA

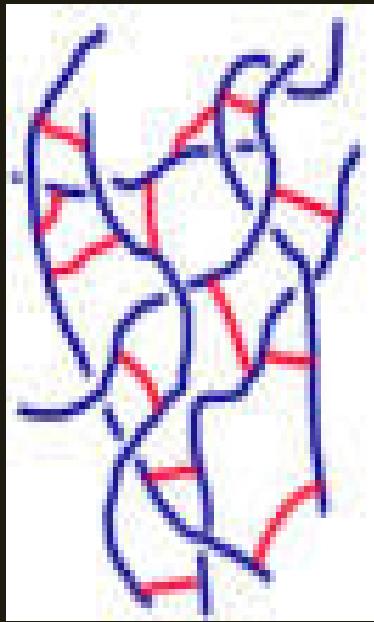
Date	Comment
1958	Charnley develops the technique of low friction arthroplasty (LFA). Using PTFE as the bearing material [10], implants were fabricated either by Charnley in his home workshop or in the machine shop at Wrightington and chemically sterilized.
1962	Charnley adopts UHMWPE for use in his LFA. Components were chemically sterilized.
1968	Start of Leeds production of the Charnley LFA by Chas F Thackray, Ltd. of Leeds. The UHMWPE was gamma irradiated.
1969	General commercial release of the Charnley LFA by Chas F Thackray, Ltd. of Leeds. UHMWPE were marketed as gamma irradiated (in air) with a minimum dose of 2.5 Mrad.
1970s	Commercial release of Poly II—Carbon Fiber Reinforced UHMWPE for THA/TKA by Zimmer, Inc.
1972	Use of alumina ceramic heads articulating against UHMWPE in Japan.
1980 to 1984	Codevelopment of silane-crosslinked HDPE by University of Leeds, Wrightington Hospital, and Thackray.
1980s	Commercial release of Hyamer (Extended Chain Recrystallized UHMWPE) for THA/TKA/TKSA by DePuy Orthopedics.
1998	Clinical introduction of first-generation highly crosslinked and thermally stabilized UHMWPEs for THA.

# Current work: Optimization of Microstructure for improved wear and fatigue resistance

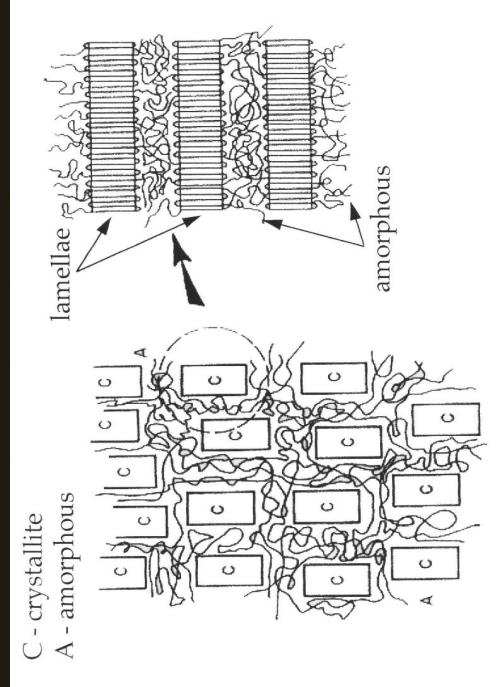
- Improve wear and fatigue resistance by combining technologies :

- For better wear → crosslink the amorphous region using radiation
- For better fatigue → enhance the crystallinity of the material using high pressure

Crosslinking



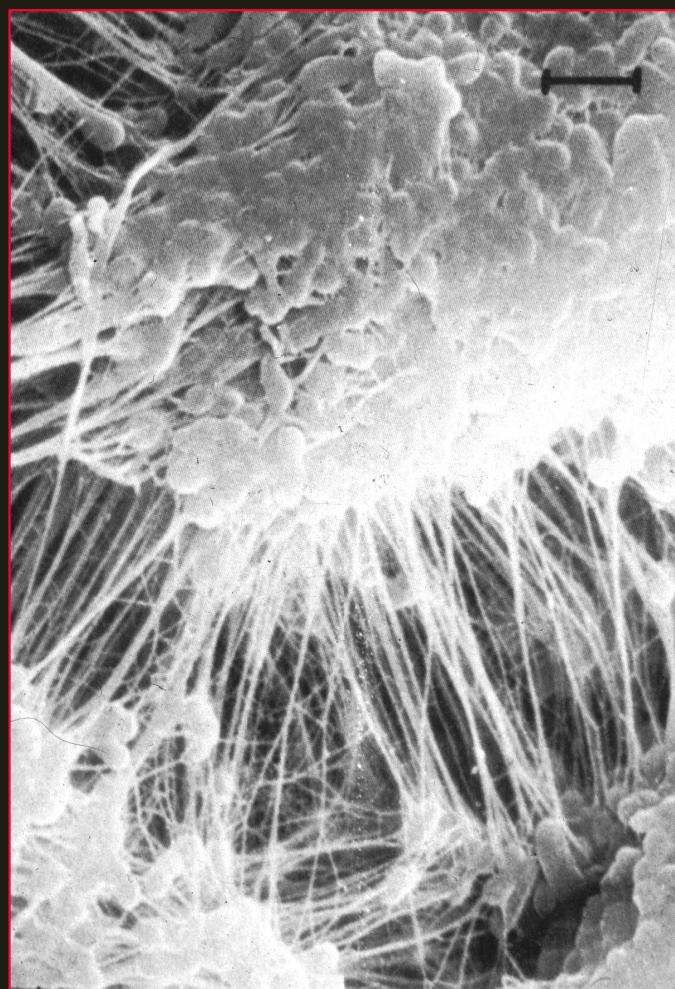
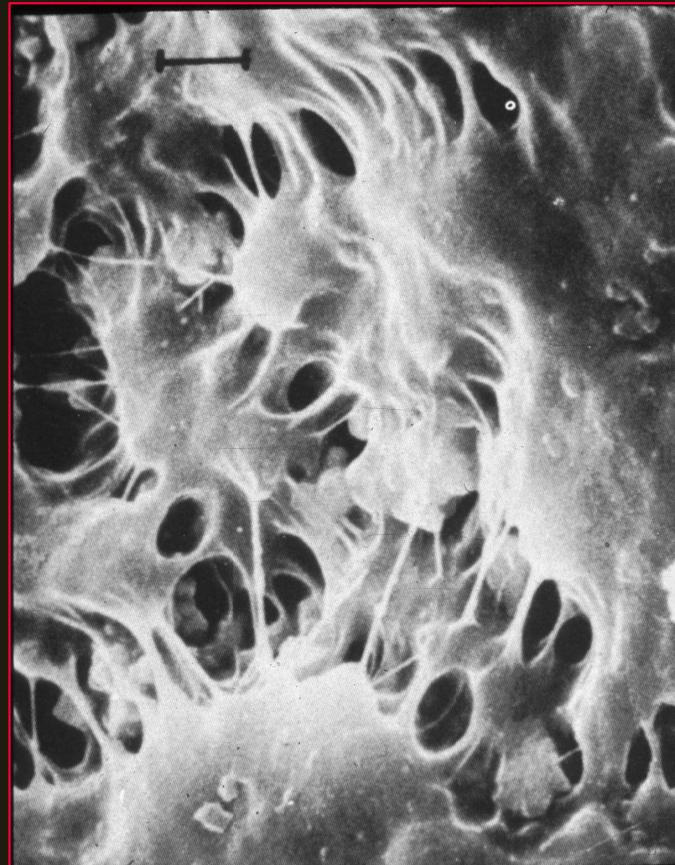
Crystalline Lamellae



# Crosslinked PE

UHMWPE

XLPE



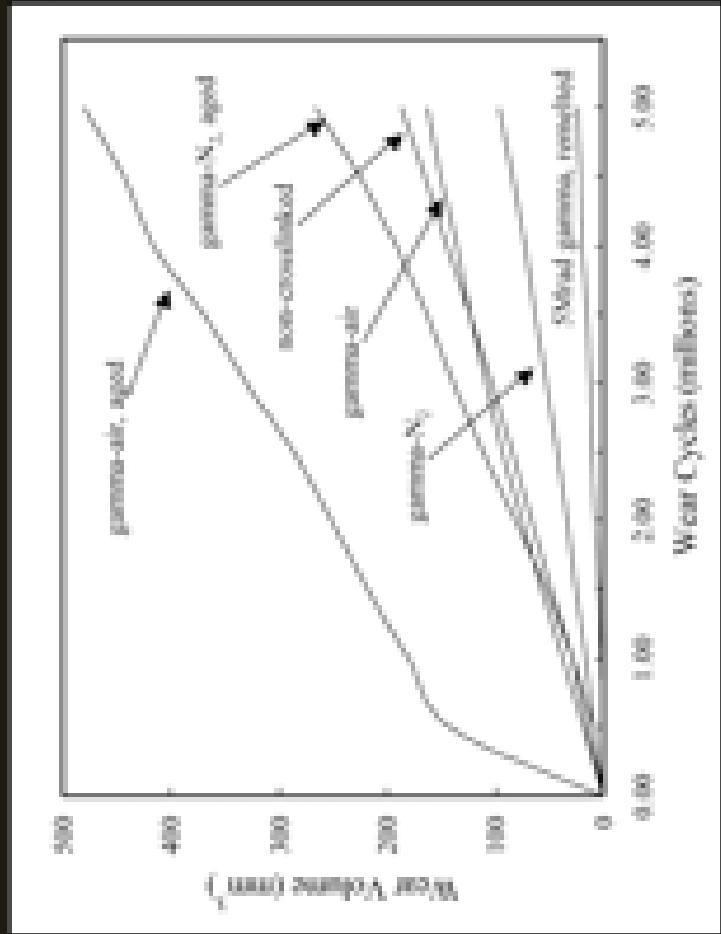
Name and Manufacturer	Radiation Type and Dose	Thermal Stabilization	Final Sterilization	Total Cross-Linking Dose and Type
Marathon™ DePuy, Inc	Gamma radiation to 5 Mrads at room temperature	Remelted at 155 °C for 24 hours	Gas plasma	5 Mrads gamma
XLPE™ Smith & Nephew–Richards, Inc	Gamma radiation to 10 Mrads at room temperature	Remelted at 150 °C for 2 hours	Ethylene oxide	5 Mrads gamma
Longevity™ Zimmer, Inc	Electron beam radiation to 10 Mrads at warm room temperature	Remelted at 150 °C for approximately 6 hours	Gas plasma	10 Mrads electron beam
Durasulf™ Sulzer, Inc	Electron beam radiation to 9.5 Mrads at 125 °C	Remelted at 150 °C for approximately 2 hours	Ethylene oxide	9.5 Mrads electron beam
Crossfire™ Stryker-Osteonics-Howmedica, Inc	Gamma radiation to 7.5 Mrads at room temperature	Annealed at about 120 °C for a proprietary duration	Gamma at 2.5 to 3.5 Mrads while packaged in nitrogen	10 to 11 Mrads of gamma
Aeonian™ Kyocera, Inc	Gamma to 3.5 Mrads at room temperature	Annealed at 110 °C for 10 hours	Gamma at 2.5 to 4 Mrads while packaged in nitrogen	6 to 7.5 Mrads of gamma

(The processing parameters shown in this table were compiled from various publications, and information provided by the manufacturers and are subject to ongoing modification.)

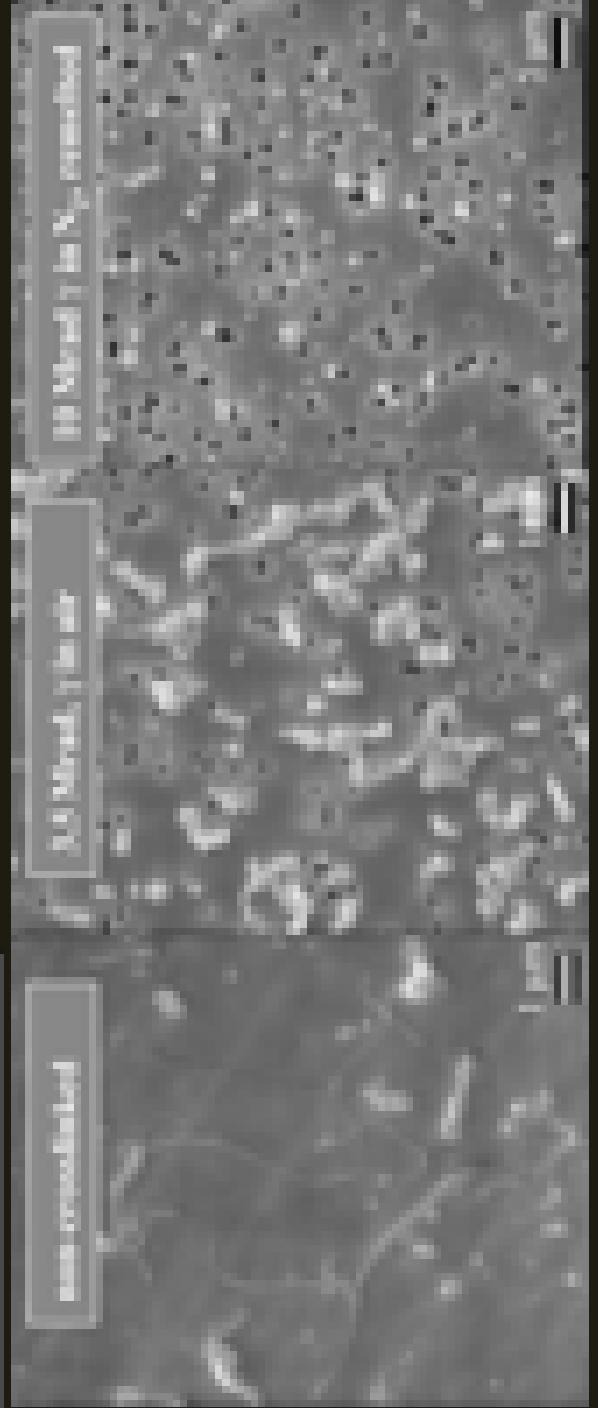
For Crossfire™ and Aeonian™, the total cross-linking dose will depend on how much irradiation is used for terminal sterilization. The allowable range is 2.5 to 4 Mrads.

(Modified with permission from McKellop HA: Bearing Surfaces in Total Hip Replacements: State of the Art and Future Developments. In Sim FH (ed). Instructional Course Lectures. Rosemont IL, American Academy of Orthopaedic Surgeons 165–179, 2001.)

LPE



→ For this reason,  
each material needs  
to be considered  
separately



# EFFECTS OF CROSSLINKING

- Crosslinking → decreased modulus, decreased hardness, decreased fatigue resistance, increased wear resistance
- High Pressure treatment → increased modulus\*\* , increased fatigue resistance, increased ultimate stress, increased hardness, increased lamellar size
- Coupled effect enhances fatigue and wear
- \*\* A limitation is that the increased modulus will drive up contact stresses

# Mixed Clinical Performance

- Clinical Performance of a Highly Crosslinked at Two years in Total Hip Arthroplasty: A Randomized Prospective Trial. Martell JM, Verner JJ, Incavo SJ. J Arthroplasty 2003. **50% reduction in wear**
- Highly cross-linked polyethylene in cemented THA: randomized study of 61 hips. Degas G, Karrholm J, Thanner J, Malchau H, Herberts P. Clin Orthop. 2003 **50% reduction in wear with highly crosslinked UHMWPE**
- L. Bradford-Collons, D.A. Baker, J. Graham, A. Chawhan, M.D. Ries, L. Pruitt, “Wear and Surface Cracking in Early Retrieved Highly Crosslinked Durasul Acetabular Liners,” Journal of Bone and Joint Surgery 86:1271-1282 (2004). **Surface damage observed in all implants**
- L. Bradford, R. Kurland, M. Sankaran, H. Kim, L. Pruitt, M. Ries, “Early Failure due to Osteolysis in Highly Cross-linked UHMWPE: A Case Report,” Journal of Bone and Joint Surgery 86:1271-1282 (2004). **Bone loss due to osteolysis**

# Charnley Stem designs

- 1969 first changed to vanquashed finish for surface hardness.
- 2<sup>nd</sup> generation 1973 – round cross section.
- 3<sup>rd</sup> generation – Cobra flanged.
- 1984: changed the head neck ratio, reducing neck from 12.5 to 10mm.

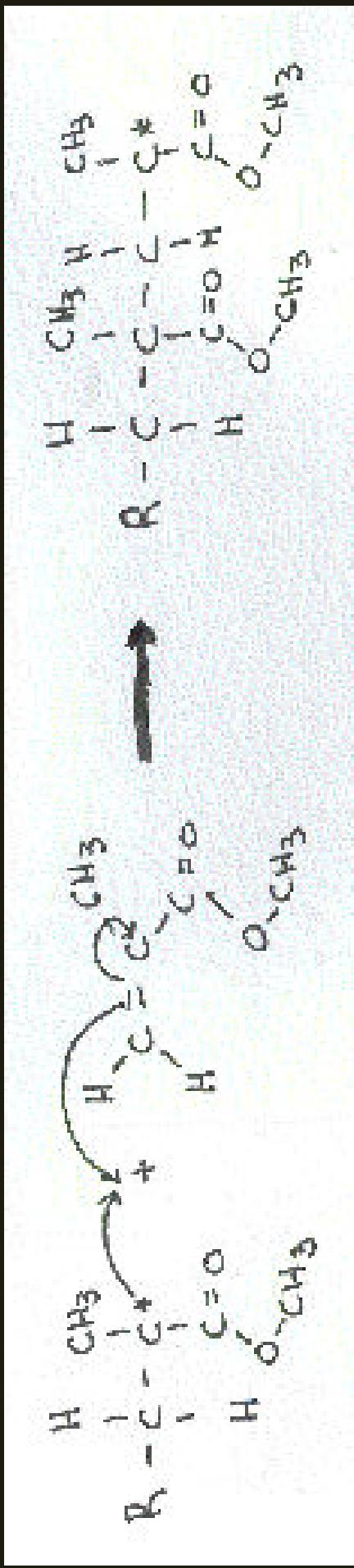


# Poly(methyl Methacrylate)

## PMMA

Polymerization - MMA radical plus MMA :repeated many, many times

- Reaction produced by liquid + solid.
- Liquid contains monomer and initiator.
- Exothermic reaction.
- Some initial expansion and then volume shrinkage.
- Final volume is 3-5% increase in size.



# Mechanical properties Of cement

Cement is a viscoelastic brittle material characterized by relatively high compressive strength resistance but weakness in tension and bending

Compressive strength	90 Mpa
Shear strength	50 Mpa
Tensile strength	25 Mpa

Acrylic bone cements: mechanical and physical properties  
Orthop Clin North Am 2005; 36: 29-39 Kuehn KD and coll

# Mechanical basis of stem cemented fixation

## Bone, cement and stem make a **composite structure**

- All mentioned materials have different E-Moduli
  - Cortex: 12 - 18 Gpa
  - PMMa:** 1.8 Gpa
  - Stainless Steel 250 Gpa
- Each of these materials had different strains under cyclic axial and torsional load that induce micromotion at the interfaces
- Micromotion primary occurs at the stem-cement interface
- Micromotion can only be partially absorbed by cement elasticity
- Micromotion is settled by the stem which is the stiffest component

# Improvement in cementation technique

## Generations of Cement Technique

**First (Before 1975)**      **Second (Begins 1975)**      **Third (Begins 1982)**

<b>Cement finger packing</b>	<b>Cement gun (1971)</b>	<b>Porosity reduction</b>
<b>No formal canal preparation</b>	<b>Pulsatile lavage</b>	<b>Pressurization</b>
<b>Sharp edges</b>	<b>Canal brush</b>	<b>Centralizer</b>
<b>Cast stem</b>	<b>Round medial border</b>	<b>Stem precoat or rough surface</b>
<b>No pressurization</b>	<b>Cement restrictor</b>	
<b>No cement restrictor</b>		

No significant difference between second- and third-generation techniques has been well established (6).

The cement–prosthesis interface does not seem to be influenced by cement timing when using smooth stems (1).

# Exeter Stem

- 1969 in Exeter.
- Avoid trochanteric osteotomy and lacks collar.
- First change in 1976 due to fractures of femoral stem – to matt finished .
- 1986 return to polished stem.
- 1988 modularity of stem.



# Taper slip vs Composite beam

## Taper-slip system

## Composite-beam system



Exeter      Flanged  
CPT, C-stem      Charnley  
                    Harris Precoat



# Efforts to improve cemented arthroplasty

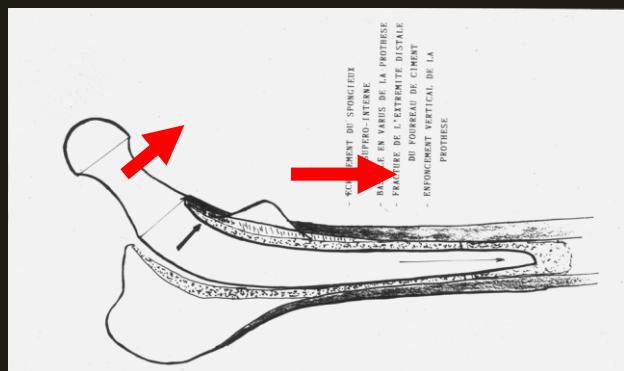
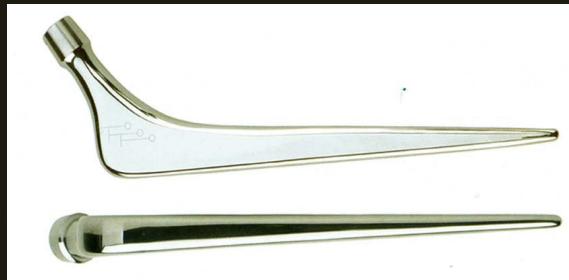
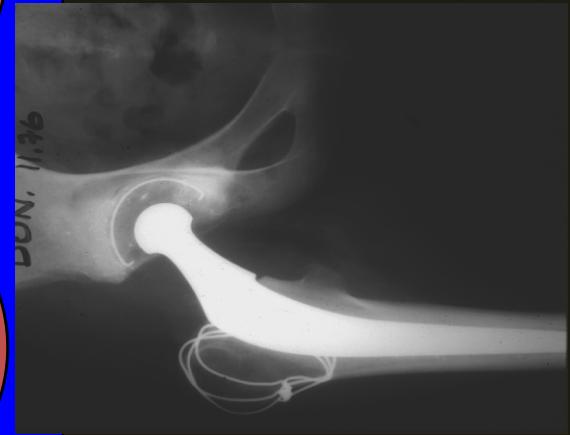
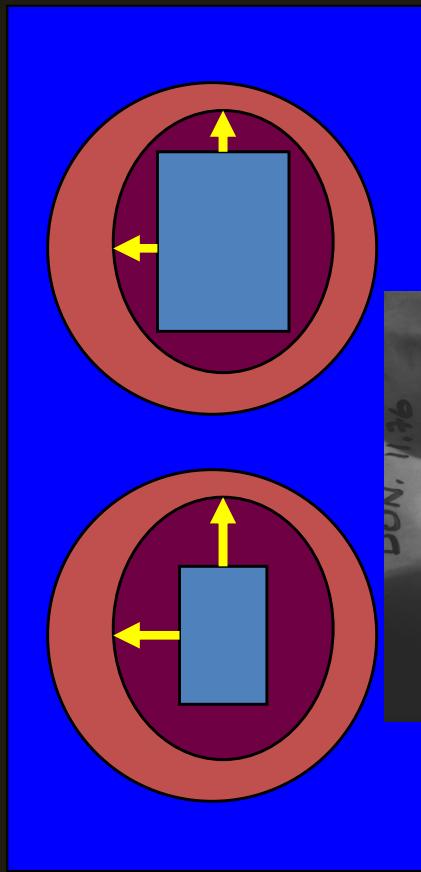
1. Improve mechanical properties of cement
2. Increase cement layer thickness
3. Improve cementing technique
4. Improve bone-cement interface
5. Modify stem design to decrease stresses supported by cement
6. Look for a secondary fixation through a distal migration \subsidence
7. Increase link between stem and cement through a rough surface

# Improve cement bone and stem interfaces

Importance of  
supero-medial  
cement mantle

Composite-beam  
system OR  
Taper Slip

Range of sizes to get the best  
fit in the femoral canal



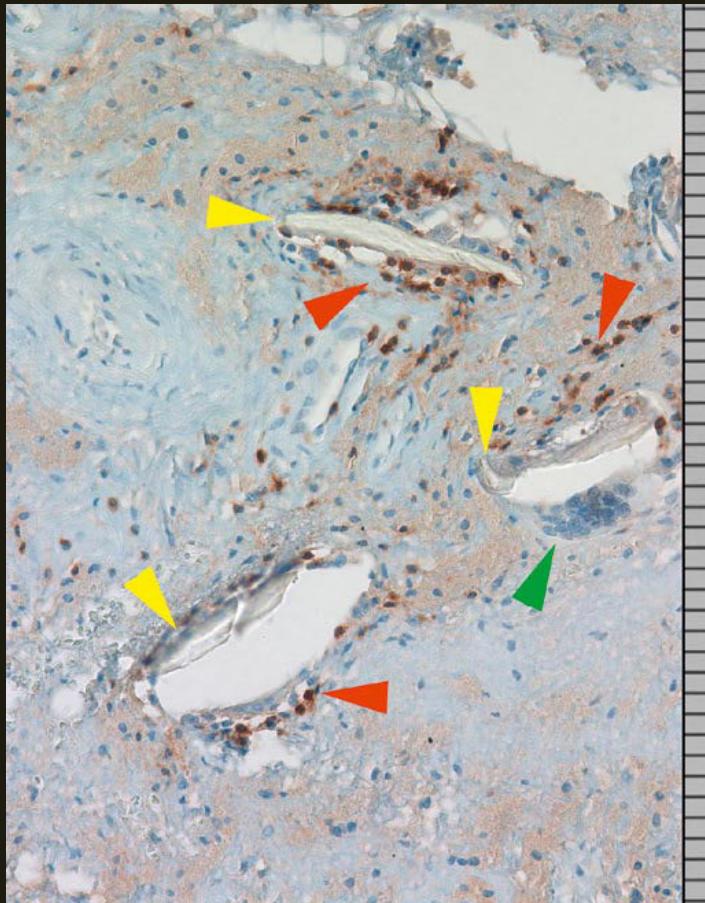
# OSTEOLYSIS

- Willert and Semlitsch 1977 **wear debris** within macrophages of the periprosthetic tissue.
- Mirra et al. 1976 found **PMMa** particles in the fibrous stroma around hip prostheses.
- Goldring et al. 1983 **collagenase** and **prostaglandin E2 (PGE2)**.
- Kim et al. few differences existed failed cemented and uncemented hip components, implying similar mechanisms of aseptic loosening.
- **Kim 1994: UHMWPE** - high levels of **collagenase** and **IL-1**

# Particle dynamics

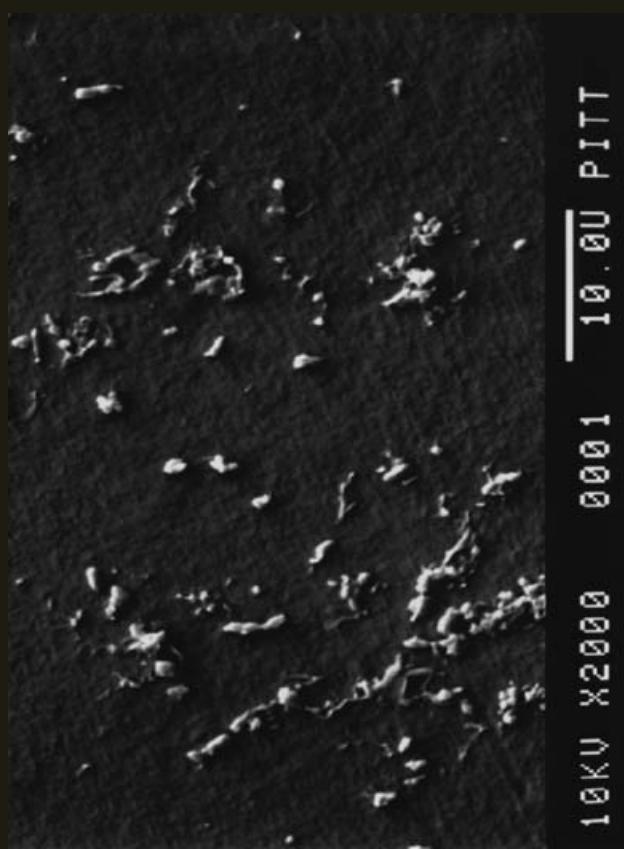
- 1976-77: Wear debris is cleared from the joint space by macrophage phagocytosis and transported via the lymphatic system to the reticuloendothelial system.
- 1990: Granulation tissue is formed at the periprosthetic interface, which compromises bony anchors and results in implant loosening.
- Willert et al. and later Schmalzried et al. 1994: the concept of the “effective joint space”
- Linear and focal osteolysis.

# UHMWPE debris



CD3 immunostained T cells (red arrows) and foreign body giant cell (green arrow) localized with UHMWPE wear debris (yellow arrows) from a historical, gamma-air sterilized UHMWPE hip replacement revised 14.2 years post-implantation. 200 $\mu$ m magnification.

Scale interval represents 10  $\mu$ m.



Scanning electronmicrograph of UHMWPE (ultrahigh-molecular-weight polyethylene) particles isolated from failed total hip arthroplasties.

# Impingement as a cause of cup loosening

- Wroblewski BM: J Arthroplasty 2009.
  - 12.5mm (972) and 10mm (261) neck diameter femoral prosthesis.
  - Loosening occurred at 2mm head penetration in 12.5mm neck diameter prosthesis group; and not until 4mm of cup penetration in 10mm group.

# Long-term survival of Charnley LFA

**Table 8.7.** Survivorship analysis. Endpoint – revision for any reason

Follow-up [Years]	Number at Start	Withdrawn	Failure	Number at Risk	Cumulative Success Rate	Confidence Limits	
						Higher	Lower
0	1434	0	0	1434	100.00	100.00	100.00
1	1434	0	0	1434	100.00	100.00	100.00
2	1434	27	3	1420.5	99.79	100.00	99.55
3	1404	24	4	1392	99.50	99.87	99.13
4	1376	13	5	1369.5	99.14	99.62	98.65
5	1358	19	4	1348.5	98.84	99.41	98.27
6	1335	23	10	1323.5	98.08	98.82	97.35
7	1302	21	6	1291.5	97.62	98.44	96.80
8	1275	23	16	1263.5	96.35	97.37	95.34
9	1236	26	12	1223	95.17	96.52	94.22
10	1198	29	20	1183.5	94.00	95.02	92.34
11	1149	49	21	1124.5	91.81	93.35	90.28
12	1079	43	16	1057.5	90.30	92.00	88.61
13	1020	56	24	992	87.88	89.79	85.98
14	940	61	8	909.5	83.5	89.04	84.96
15	871	72	17	835	81.78	87.20	82.73
16	782	59	24	752.5	80.27	84.27	79.28
17	699	73	10	662.5	78.90	82.98	77.55
18	616	66	8	583	78.90	81.84	75.95
19	542	68	8	508	70%	80.52	74.12
20	466	59	10	436.5	70%	78.55	71.51

# Conclusion

# Good results of Charnley LFA

- Charnley 1979:
  - 0.21% revision rate (23 revisions)
  - 10,913 low-friction arthroplasties (LFA) (1966 – 1976)
  - 2–12 year follow-up.
- Wroblewski 1998: 94%
- Garrellick 1999: 93.2%
- Fender 1999: revision rates of almost 10% at 5 years.
- Charnley J. Low Friction Arthroplasty of the Hip: 1979.
- Wroblewski BM. CORR 211:30–35, 1986.
- Garellick G, J Arthro 14(4):414–425, 1999.
- Fender D, J Bone Joint Surg (Br), 81:577, 1999.

# Conclusion

- A history of trial and error.
- Many dedicated people.
- Polyethylene and cement are the weakest links.
- Research works.
- Results keep improving.

Thank you