Tribology of bearing surfaces used in hip arthroplasty

Munir Khan

ST 7

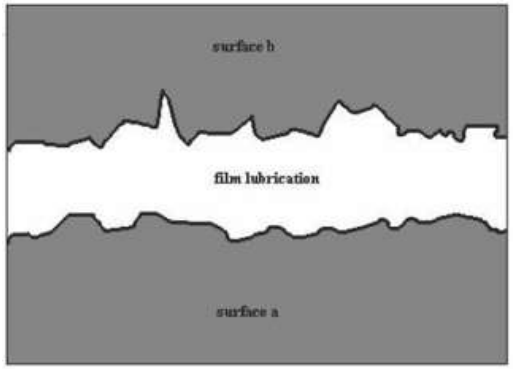
Presentation outline

- Tribology
- MOP
- MOM and
- COC
- Summary

Tribology

The science that deals with the interaction between surfaces in motion and consequences of that interaction:

- Wear: Progressive loss of material from bearing surfaces as a result of mechanical or chemical action.
- Friction: Resistance to sliding motion
- Lubrication: A substance which reduces between the two moving surfaces.

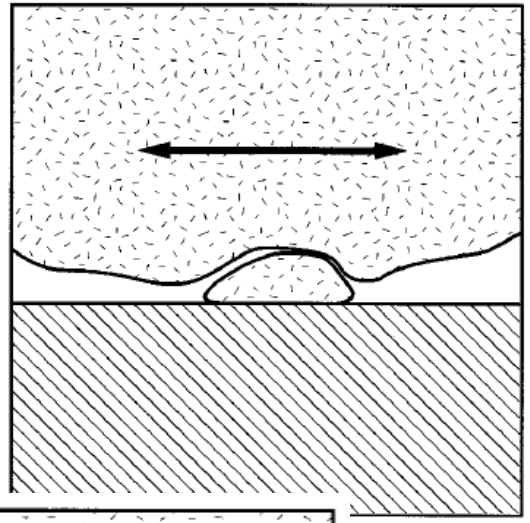


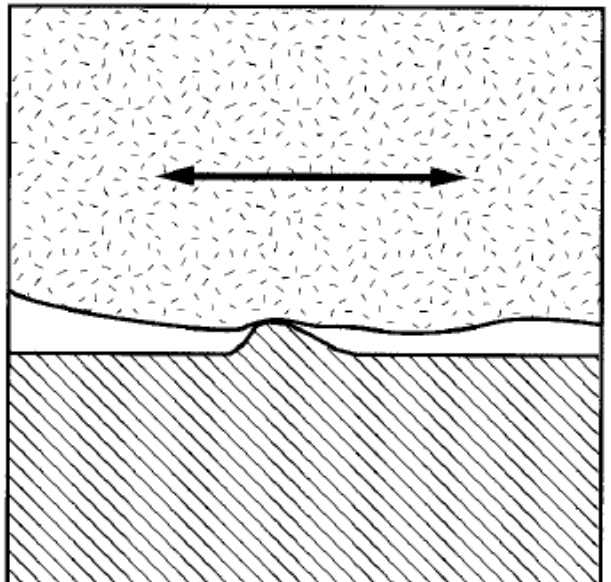
Predominant types of bearing wear in hip arthroplsty

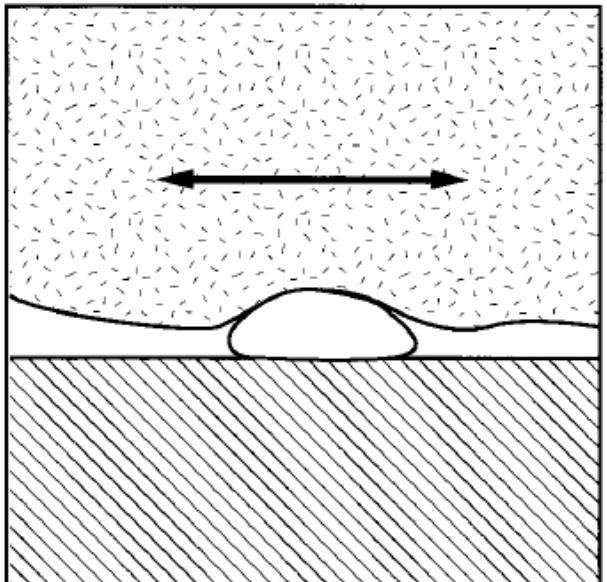
- Adhesive
- Abrasive
- Third body
- Corrosion

Mechanical

Chemical







Laws of wear

- Archard wear equation

Wear α (L) Load
(H) Hardness of a material

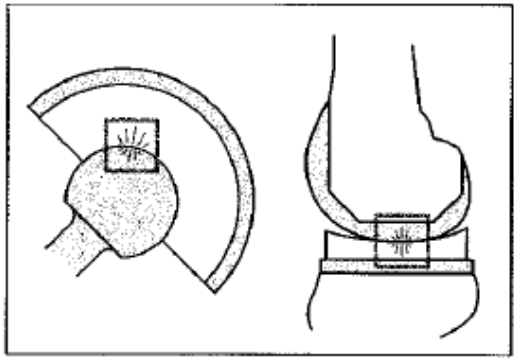
Sliding distance, toughness, roughness, number of cycles

these parameters create adverse conditions for bearing articulation e.g. lubrication etc and hence lead to increase in wear rates.

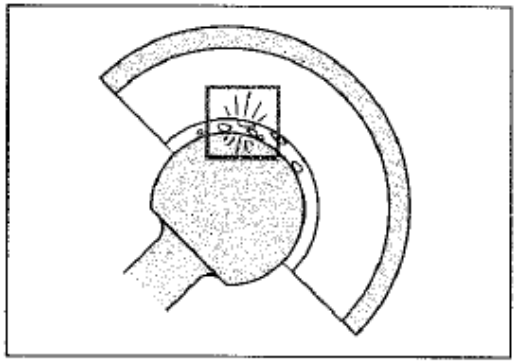
Factors affecting Wear

- Patient related
  - Weight
  - Age/activity levels
- Implant factors
  - Hardness (adhesive wear)
  - Surface damage (Adhesive/abrasive)
  - Sliding distance (Volumetric wear)
  - Number of cycles (use)
  - Third body (abrasive) –creating adverse environment
  - LUBRICATION

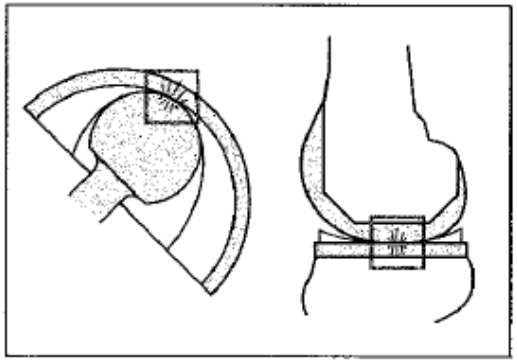
Modes of wear



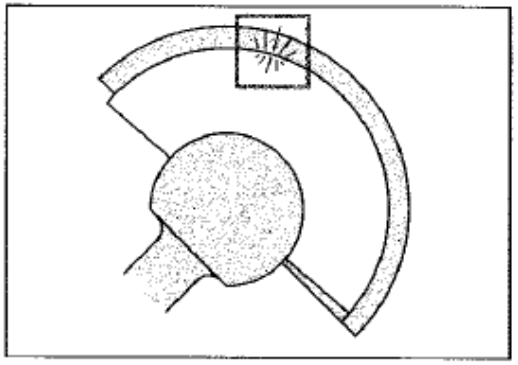
WEAR MODE 1



WEAR MODE 3

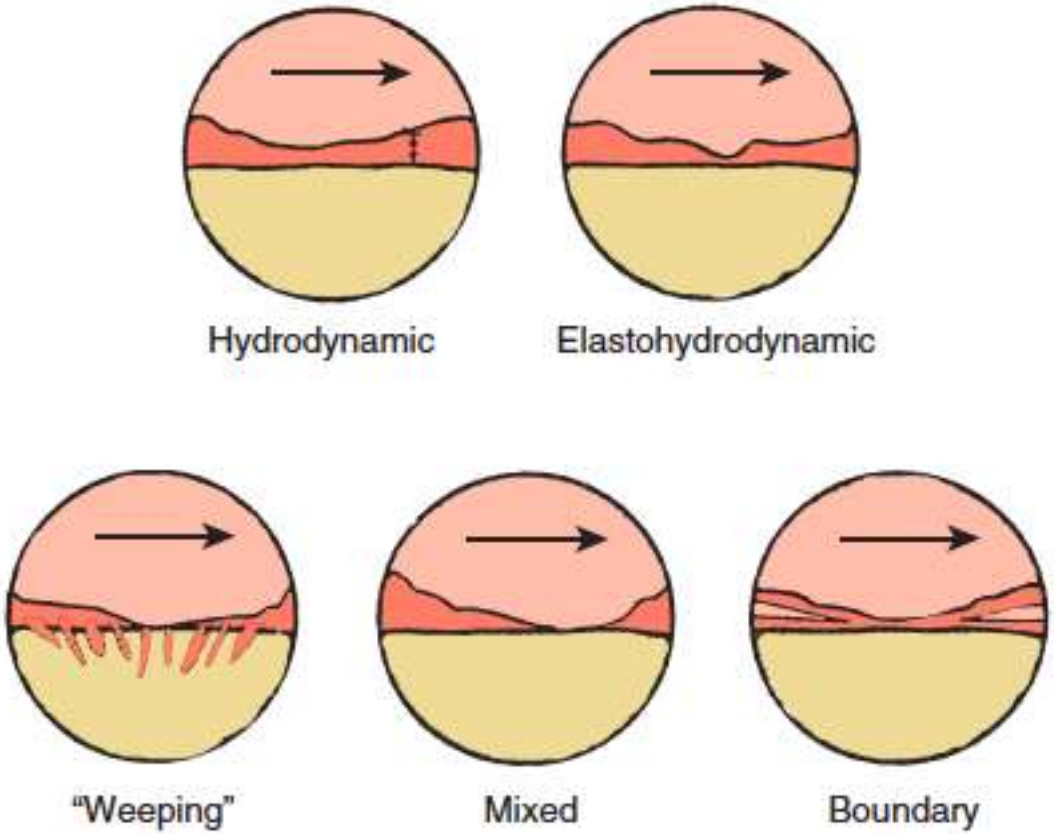


WEAR MODE 2



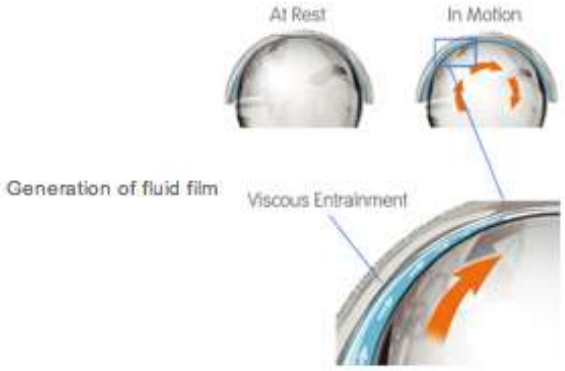
WEAR MODE 4

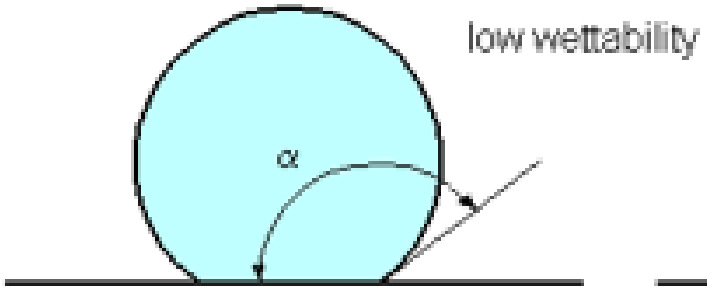
Lubrication



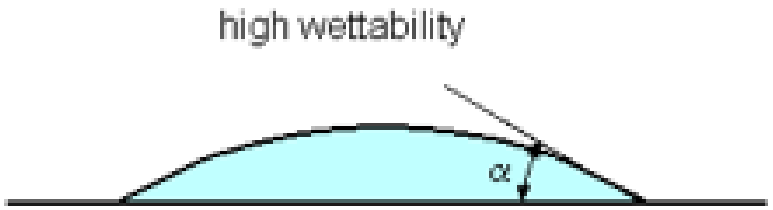
Factors affecting lubrication

- Geometry of bearing surfaces.
- Material properties of surfaces, e.g wettability.
- Velocity at which bearing operates.
- Viscosity of lubricant.





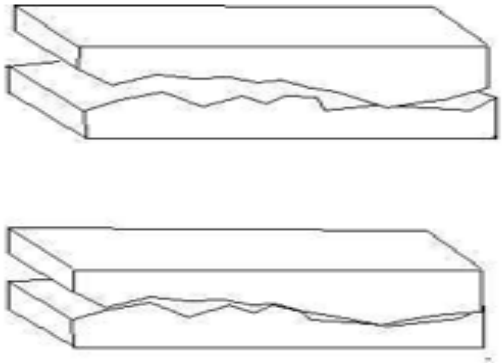
Ceramics

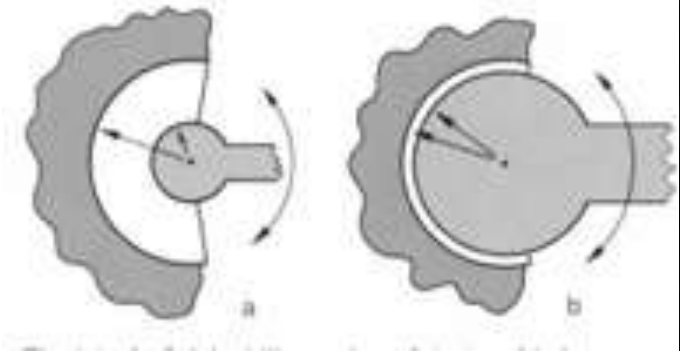


Metals

Friction

- Three laws
  - Frictional force α Applied load (W) – microscopic area of contact.
  - Independent of area of contact and
  - Independent of sliding speed (V)

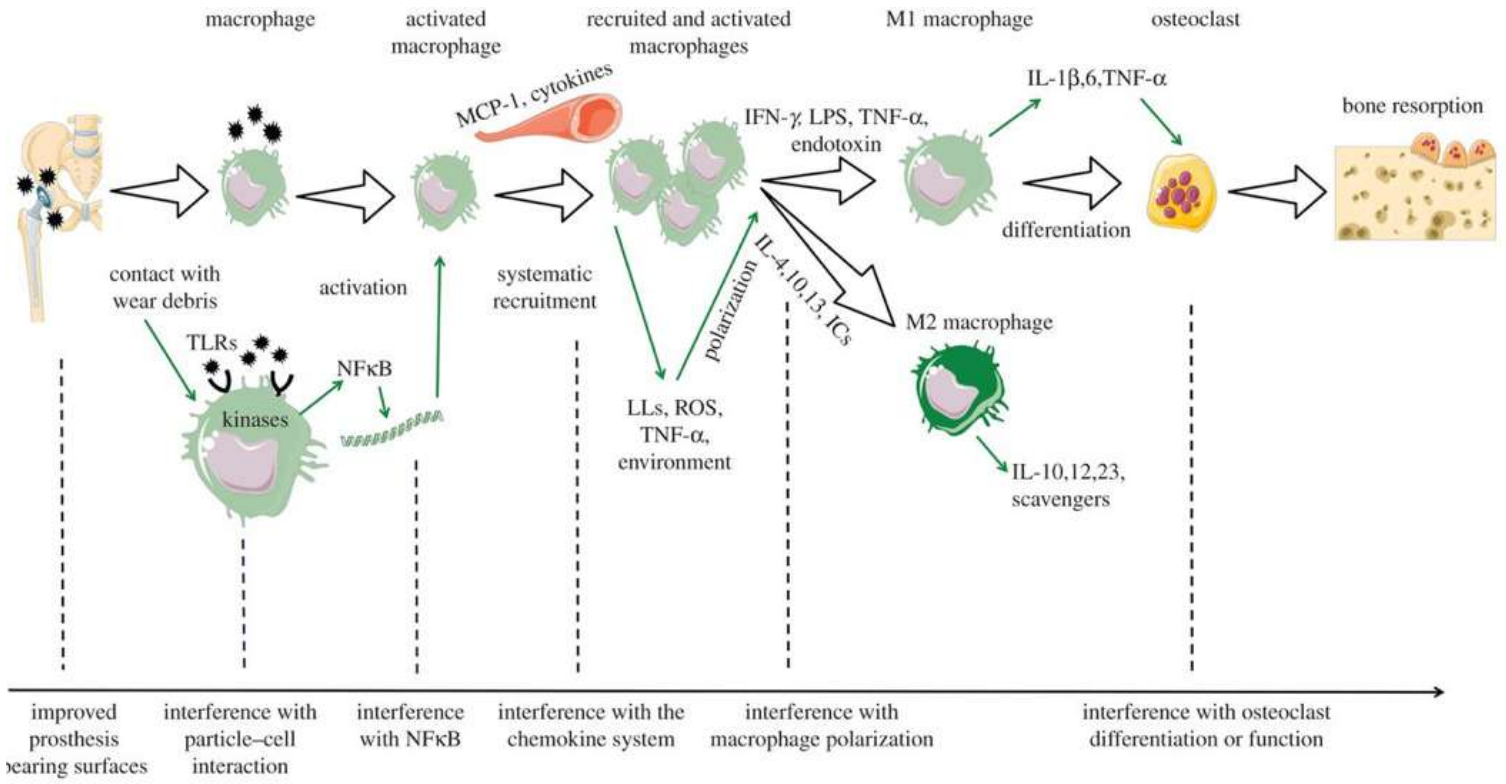


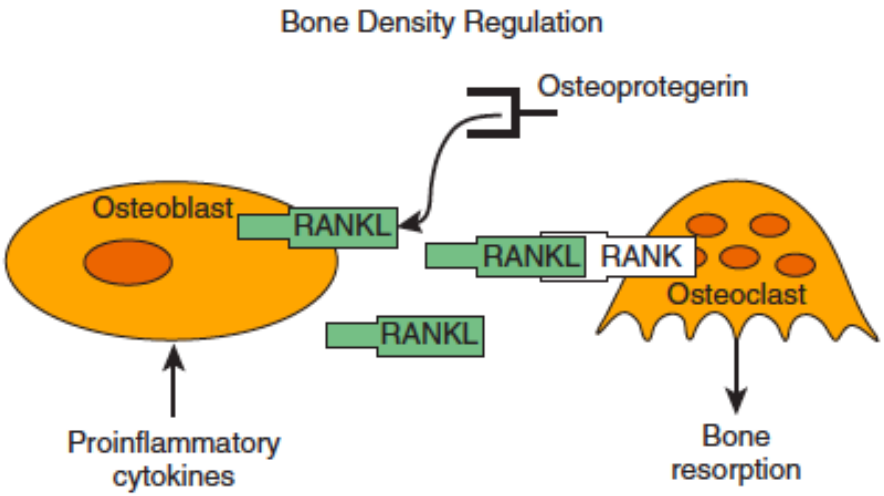


Consequence wear

- Osteolysis
- Aseptic loosening
- Systemic distribution
- Immune reaction
- Carcinogenesis
- Teratogenesis

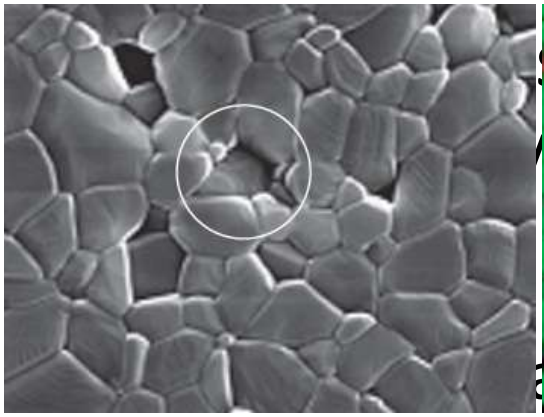
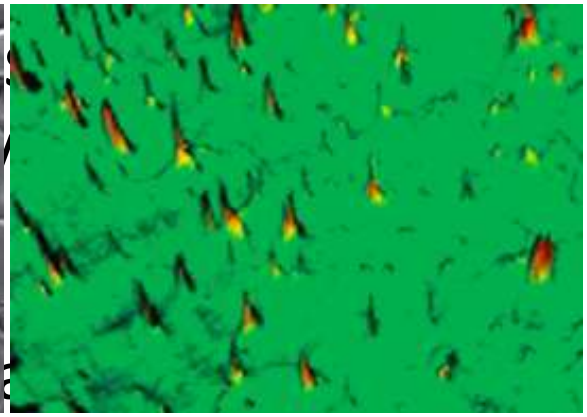
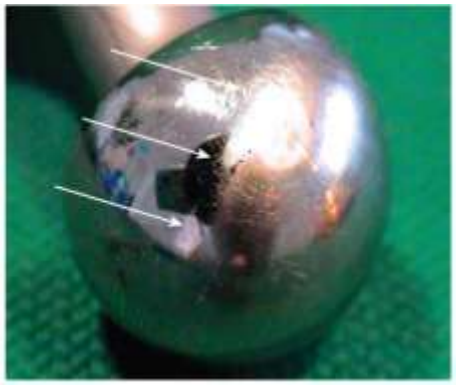
Osteolysis


macrophage
activated macrophage
recruited and activated macrophages
M1 macrophage
osteoclast
MCP-1, cytokines
IFN-γ LPS, TNF-α, endotoxin
IL-1β,6,TNF-α
bone resorption
differentiation
contact with wear debris
activation
systematic recruitment
polarization
IL-4,10,13, ICs
TLRs
NFκB
kinases
LLs, ROS, TNF-α, environment
M2 macrophage
IL-10,12,23, scavengers
improved prosthesis bearing surfaces
interference with particle–cell interaction
interference with NFκB
interference with the chemokine system
interference with macrophage polarization
interference with osteoclast differentiation or function

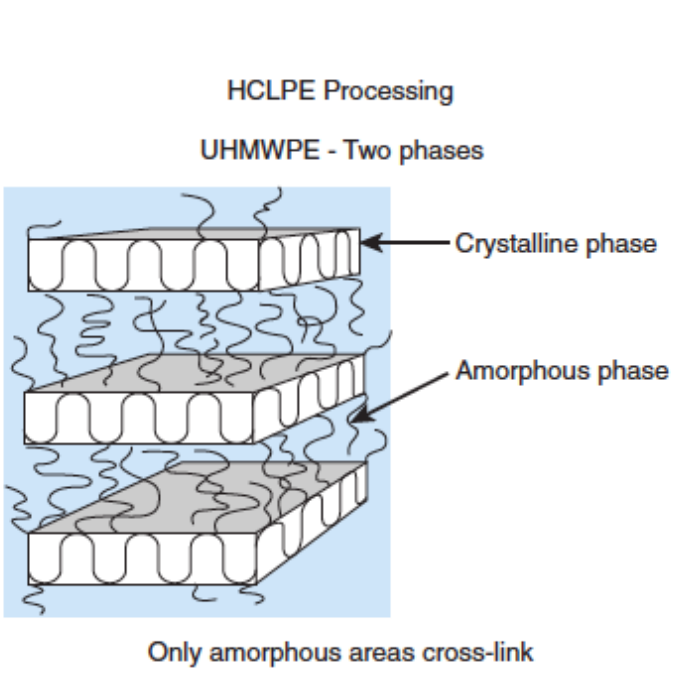

Bone Density Regulation
Osteoprotegerin
Osteoblast
RANKL
RANKL
RANK
Osteoclast
RANKL
Proinflammatory
cytokines
Bone
resorption

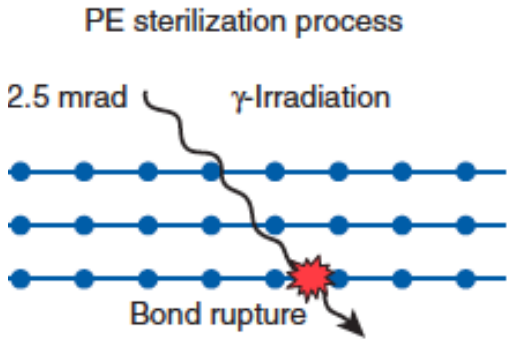
MOP BEARINGS

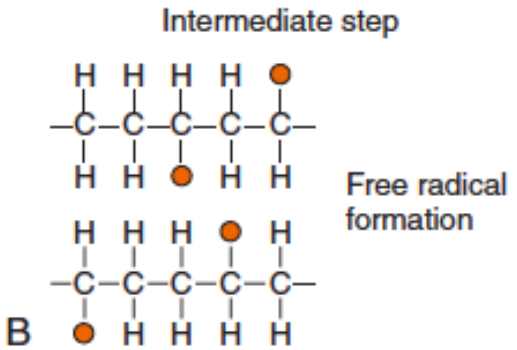
Metal on Polyethylene Bearings in hip arthroplasty

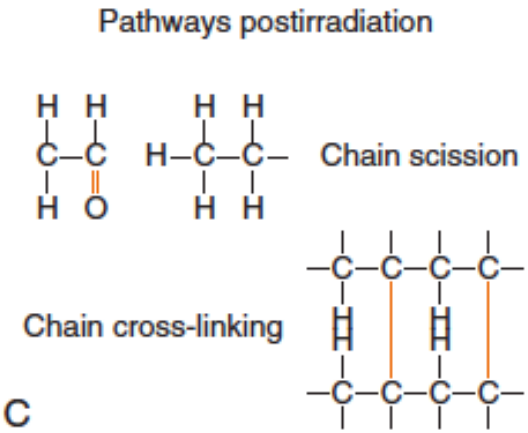
- Lubrication
  - Boundary regime
  - Surfaces always in contact with each other.
- 
- 
- 
  - Head roughness/PE manufacturing, sterilisation, irradiation/PE shelf life

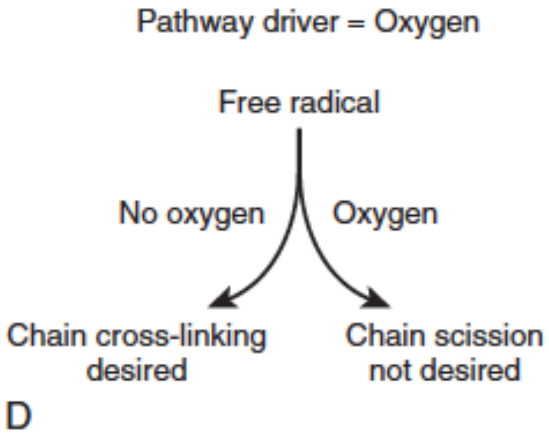
Gamma irradiation of polyethylene











PE Irradiation modification (not sterilisation)

- Leaves free radicals to be cleared by annealing or melting.
- Lower wear rates
- Smaller particles
- Changes in PE mechanical properties
  - ↓ Tensile strength
  - ↓ Fatigue strength
  - ↓ Fracture toughness
  - ↓ Fracture ductility

Irradiated and Melted	Irradiated and Annealed
Low crystallinity (<50%)	Good crystallinity (>55%)
Low strength (<40 MPa)	Good strength (>45 MPa)
No oxidation potential	Potential for oxidation
Potential for macroscopic failure	Potential for osteolysis

2nd Gen HXLPE

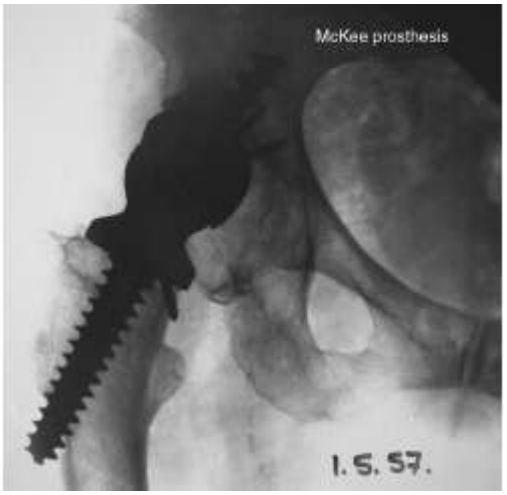
- Processing
  - High dose irradiation
  - High dose compression
  - Vit E supplementation
  - Sequential processing (repeated heating and irradiation)
- Shelf life
  - If packed in O2 free environment then 5 years or more.

MOM BEARINGS

History of bearing surfaces

Date	Prosthesis	Bearing Materials
1923–1938	Smith-Petersen mold arthroplasty	Glass, Viscaloid, Pyrex, Bakelite, CoCr
1938	Wiles metal-metal	SS/SS
1950	Judet hemiprosthesis	PMMA femoral head
1956–1960	McKee	CoCr/CoCr
1958–1962	Charnley low-friction arthroplasty	CoCr/PTFE
1962	Charnley low-friction arthroplasty	CoCr/UHMWPE
1962–1966	McKee-Farrar	CoCr/CoCr
1964–1968	Ring	CoCr/CoCr
1970	Boutin	Al_2O_3/Al_2O_3
1971	Oonishi	CoCr/UHMWPE (1000 kGy)
1977	Shikata	Al_2O_3/UHMWPE
1978	Grobbelaar	CoCr/UHMWPE (100 kGy)


McKee-Farrar
prosthesis


McKee prosthesis
1. S. 57.


Ring
prosthesis


Ring prosthesis dislocation

Why MOM was abandoned in 1970?

- Poor design and surface finish
  - ?scientific basis
  - Equatorial bearing and high frictional torque.
- Early loosening and bone loss
- Increased rate of infection
- Carcinogenic concerns
- Early success of the Charnley LFTA.

Metal on Metal

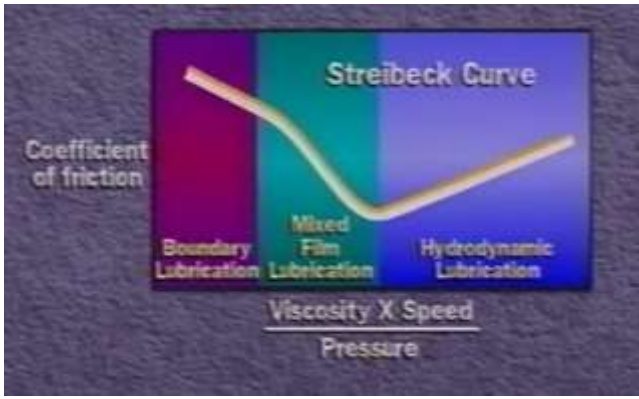
- To rectify the problem of osteolysis related to polyethylene debris
- Sulzer 1988 – Mcminn and then ------
- Low wear rates
- High number of small particles
- Wear type; adhesive, abrasive and corrosive

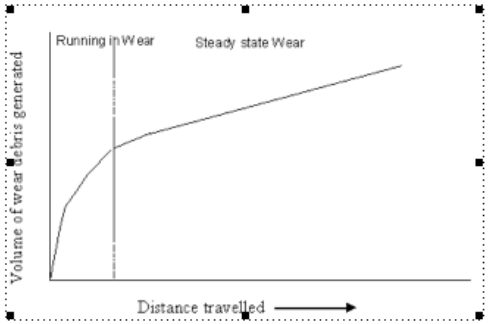
The cobalt chromium alloy

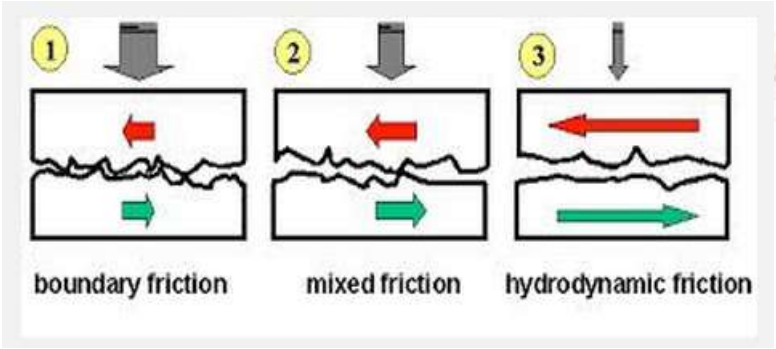
- Strong and Hard
- Corrosion resistant
- Wear resistant
- Manufacturing
  - As cast or wrought/forged
  - Heat treated
- Less carbides in heat treated ones
  - ? Excess Corrosion/wear.

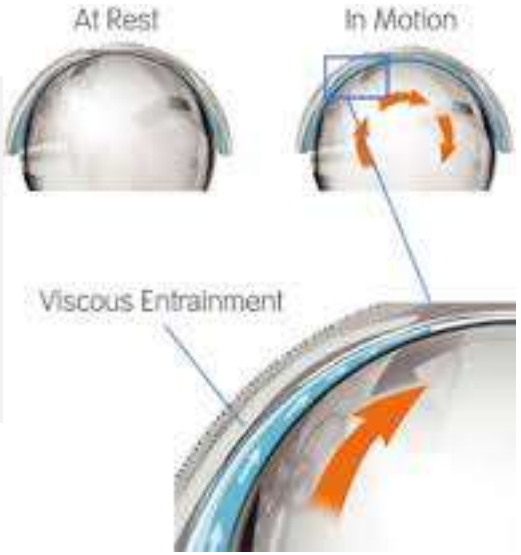
MOM lubrication

- Boundary to fluid film lubrication.
- Reduces friction between the bearing surfaces.
- Separates bearing surfaces and reduces wear.
- Has a run-in and steady state wear phases.
- The bearing benefits more from lubrication in the steady state wear.



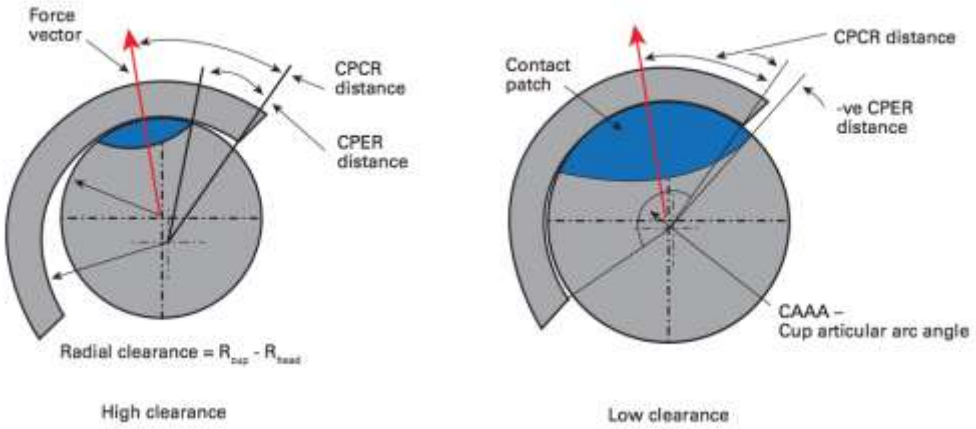






Factors affecting lubrication and wear

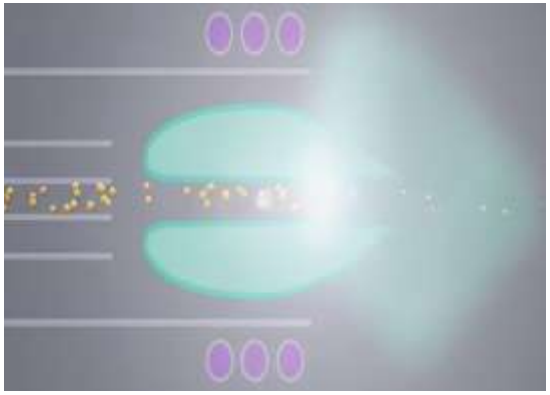
- Radial clearance
- Surface roughness
- Bearing size
- Sphericity
- Bearing material
- Excessive abduction
- Excessive anteversion

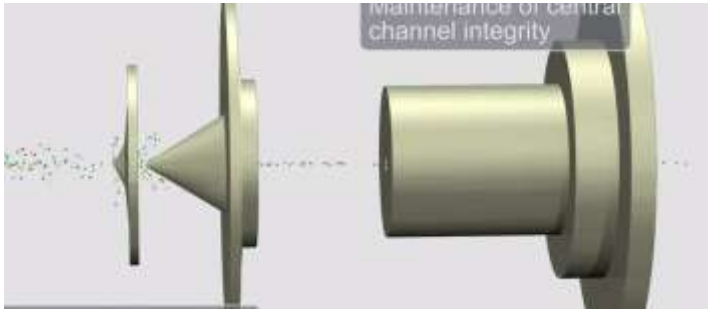


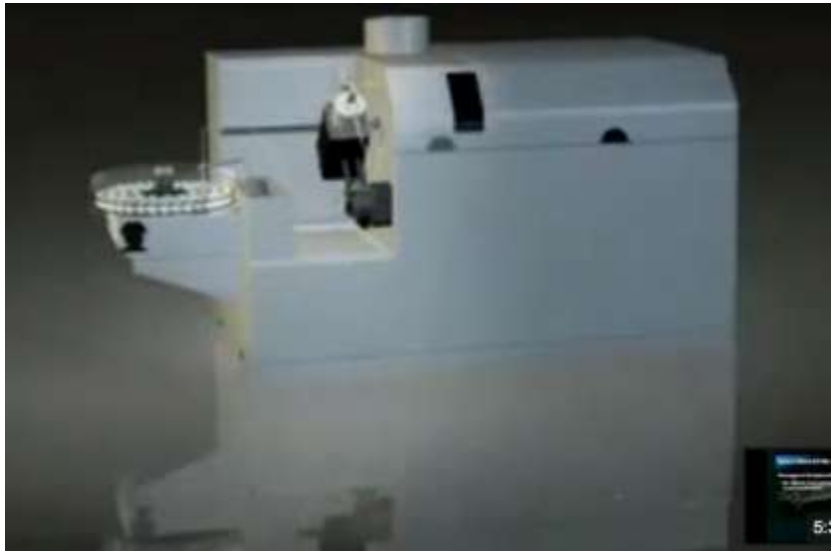
Schematic diagrams showing the effect of clearance on the CPCR (contact patch centre-to-rim) and CPER (contact patch edge-to-rim) distances. Edge loading occurs when the head-acetabular component contact patch extends over the rim of the acetabular component, and so the CPCR does not include clearance in the risk of edge loading.

How do we measure circulating metal wear debris – ICPMS

The debris is not ion but particles



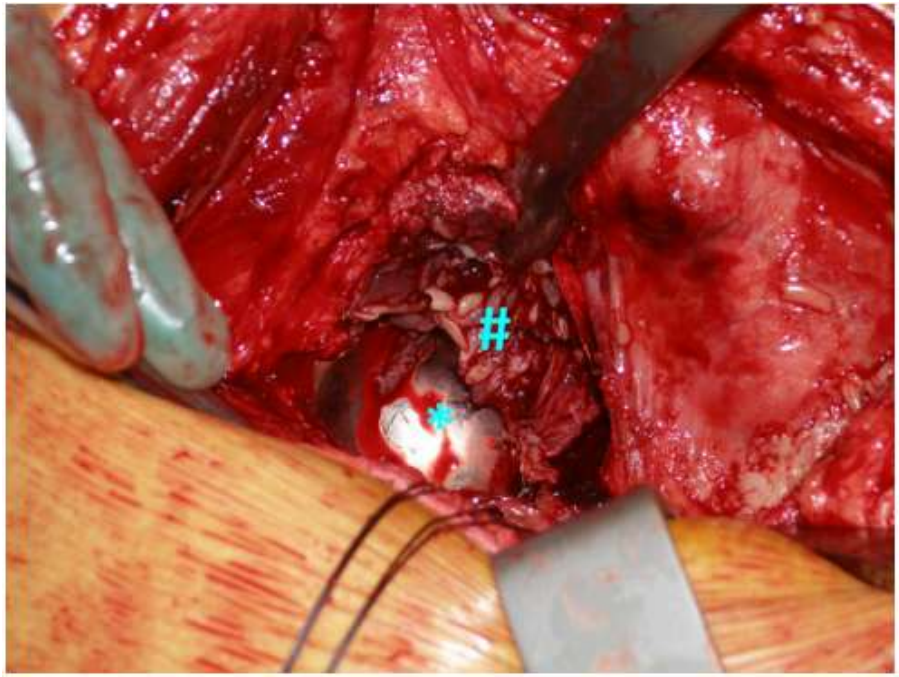


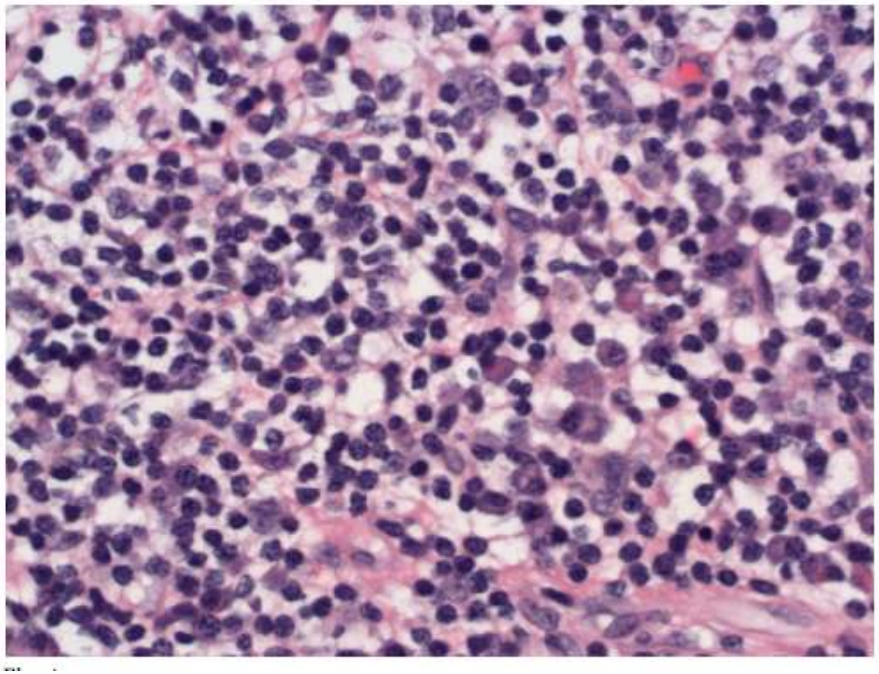


ARMD

- Metal debris is nano-meter in size
- Distributed through out the body
- Excreted in urine
- Debris is mostly particulate
- Hypersensitivity and Particle induced T-cell response (PITR) (2-5 years)
- RANK pathway
- Avoid it in woman with child bearing age and patients with renal failure
- Carcinogenesis
- Pseudo-tumour – (apotosis and necrosis)

Pseudotumours (ARMD)
Macrophage predominant and Lymphocyte predominant





Beaule 2011 --- 0.1%
Holland 2012 --- 0.3%
Pandit 2008 --- 1%
Khan 2009 – 0.14%

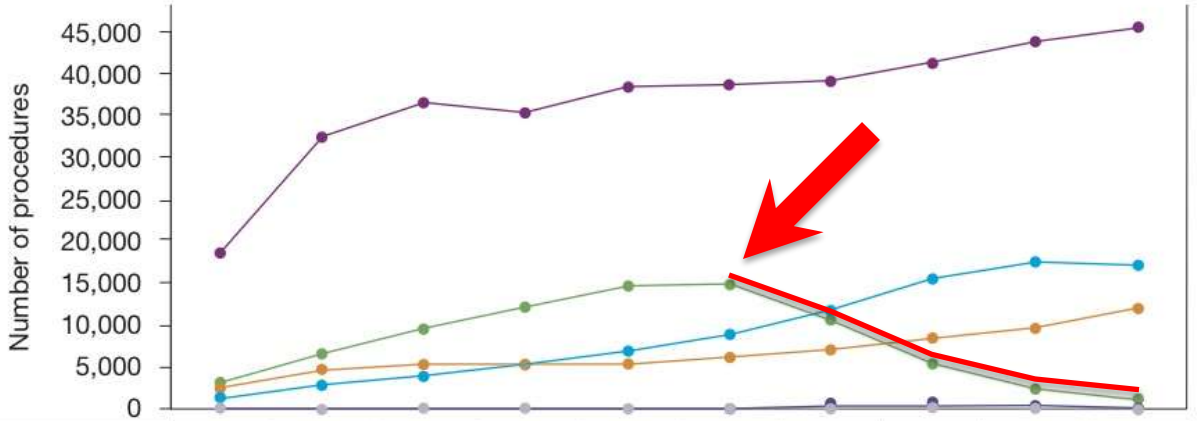
MOP HR
4.6 to 5.8%

Associated with high wear rates
BLAME PATIENT OR PROSTHESES

Metal on Metal Hips

Figure 2.15

Hip articulation, trends 2003 to 2012.



Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Number of procedures with hip articulation details	25,344	46,566	55,748	58,293	65,629	68,878	69,457	71,450	73,844	75,897

Metal-on -poly
Ceramic-on -ceramic
Ceramic-on -poly
Metal-on -metal
Ceramic-on -metal
Metal-on -ceramic*

* This combination is contra-indicated

Ceramics on ceramics

- Less wettability and wettability angle
- Brittle substance
- Risk of fracture more in 1st gen (>10%)
- First Gen problems:
  - Poor manufac/adverse head neck ratio/coarse architecture
- Third Gen
  - Better manufacturing, more ceramic density, hot isostatic pressing, removal of skirt from the head.
- Lowest wear and bio-inert debris.
- Disadvantages
  - Head size limitations, head length limitations, Squeaking

Summary

- Good knowledge of Tribology is important.
- All new bearings should be carefully monitored to avoid catastrophic outcome like ASR in future.