



Massachusetts Institute of Technology
Harvard Medical School
Brigham and Women's Hospital
VA Boston Healthcare System

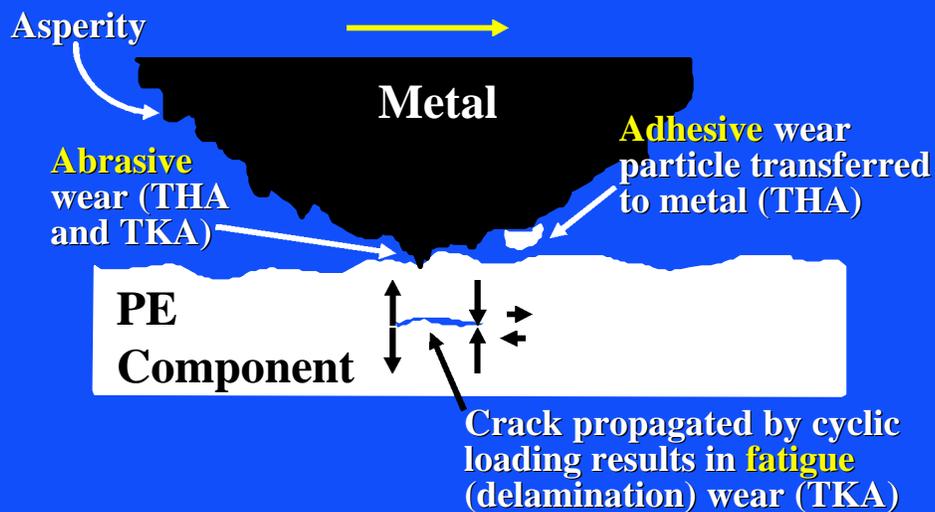


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WEAR AND CORROSION

M. Spector, Ph.D.

WEAR PROCESSES Total Joint Replacement Prostheses



WEAR PROCESSES

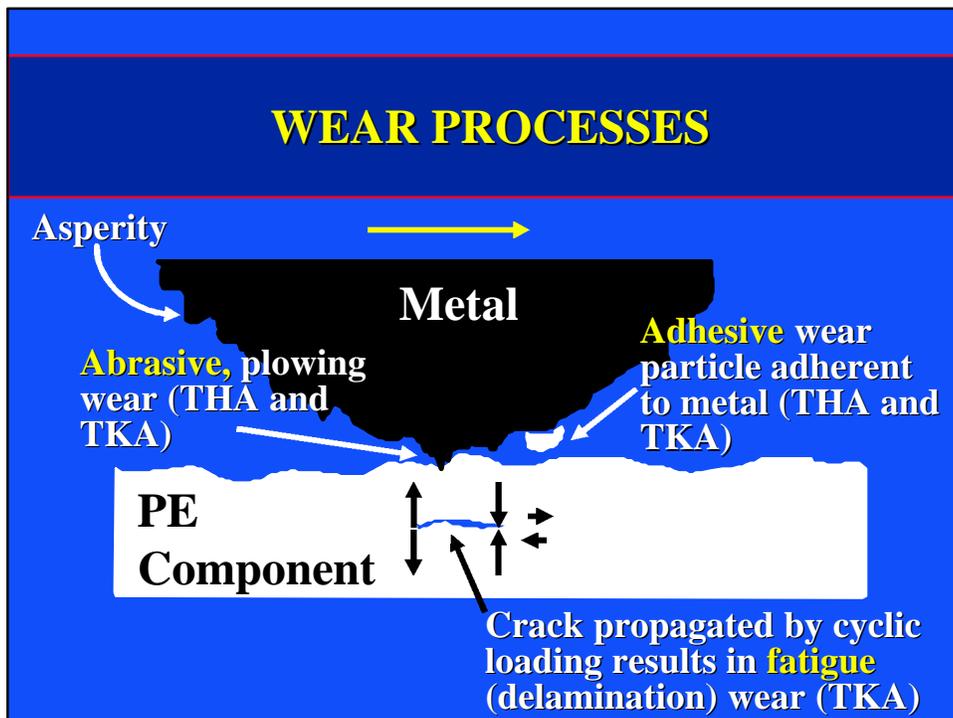
TYPE	MECHANISM	PART. SIZE
Adhesive THA and TKA	Chemical adhesion of PE to asperity on metal	nm to μm
Abrasive (2-body) THA AND TKA	Plowing of metal asperity through PE	μm
Abrasive (3-body) THA AND TKA	Entrapment and plowing of particle (bone, PMMA, coating)	μm
Fatigue/ Delamination TKA	Propagation of subsurface cracks to the surface by cyclic compression, tension, shear	μm to mm

Adhesive Wear

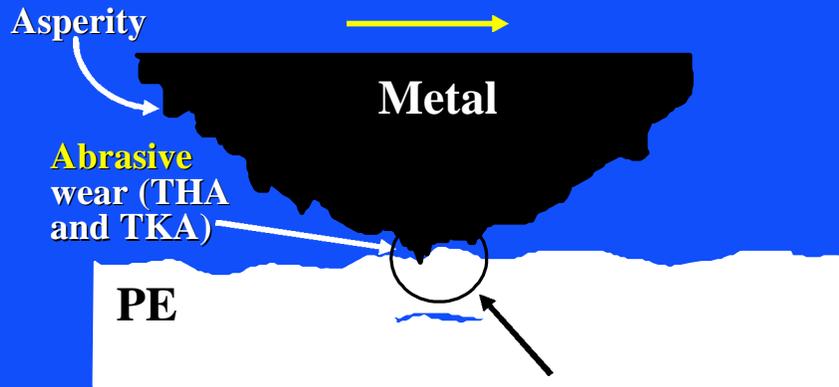
Text removed due to copyright restrictions.
Definition of adhesive wear.

Abrasive Wear

Text removed due to copyright restrictions.
Definition of abrasive wear.

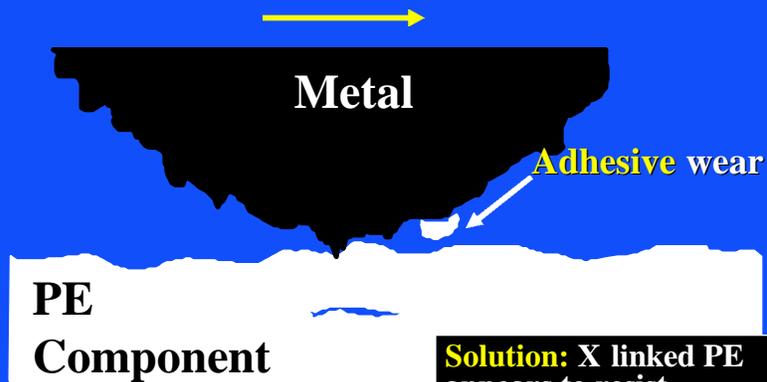


WEAR PROCESSES



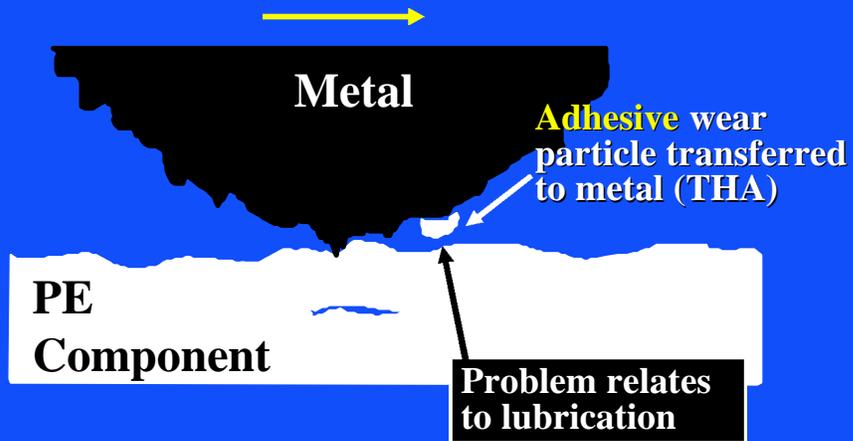
Solutions are a scratch-resistant metal/ceramic counterface (and abrasion-resistant PE – x-linked PE?)

WEAR PROCESSES

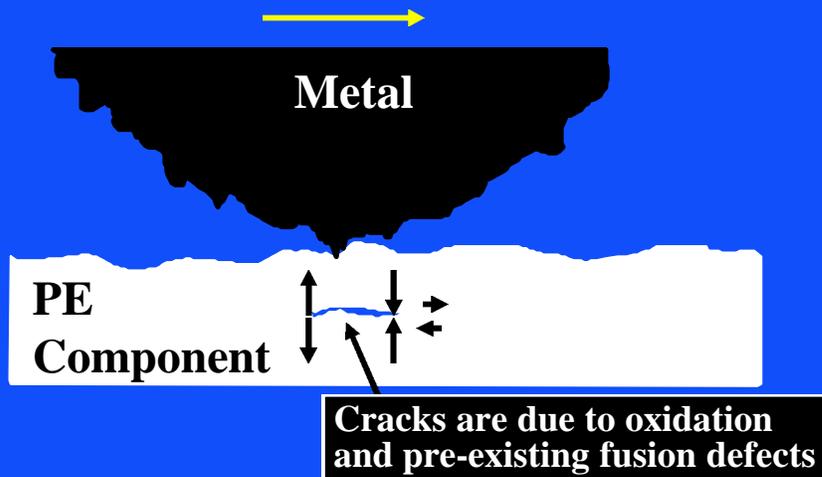


Solution: X linked PE appears to resist adhesive wear

WEAR PROCESSES



WEAR PROCESSES



γ -Radiation-Induced Oxidation

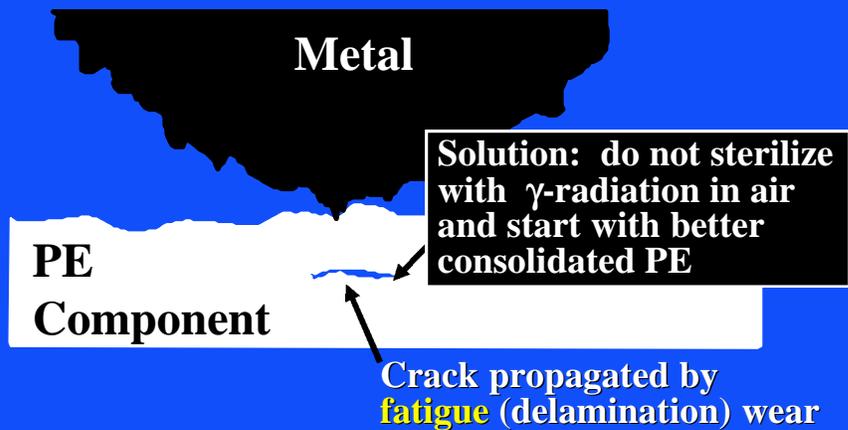
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Fusion Defects

Sutula, *et al*

Radiation-induced x-linking

WEAR PROCESSES

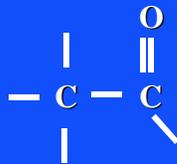


EFFECT OF GAMMA RADIATION ON PE: OXIDATION

Diagram of PE crystallite structure removed due to copyright restrictions.

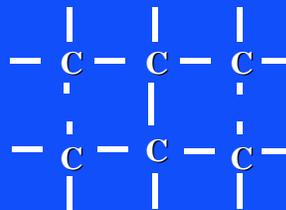
GAMMA-RADIATION INDUCED MODIFICATION OF POLYETHYLENE

Oxidation



Oxidation shortens PE chains and thus reduces strength.

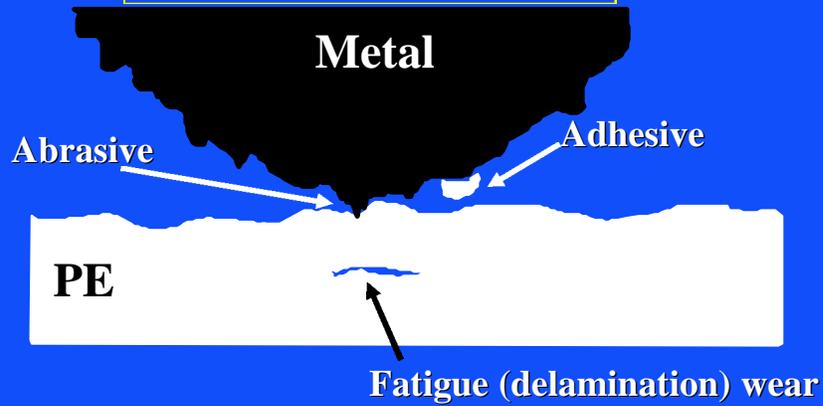
Cross-linking



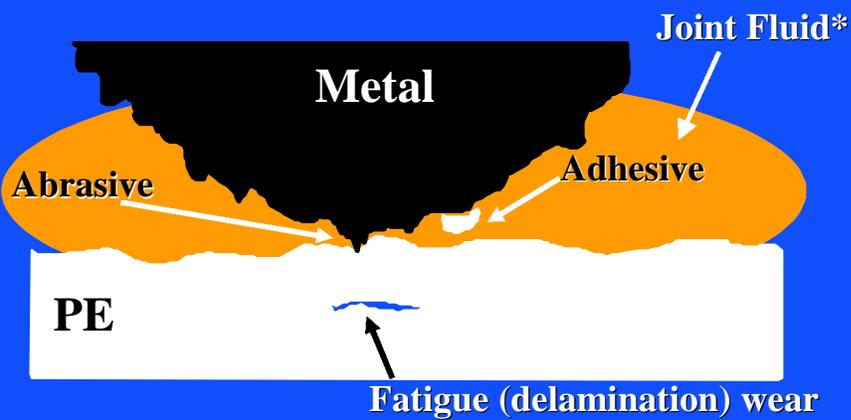
Cross-linking increases the size of the molecule and thus increase strength, but this reduces ability of the PE to elongate (reduces toughness).

WEAR PROCESSES

What is missing from this picture?

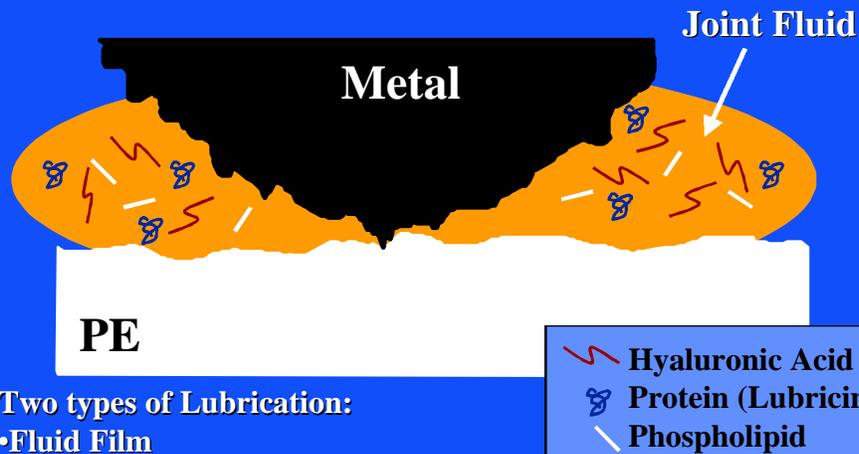


WEAR PROCESSES



* What role does the joint fluid play in the wear of TKA?

COMPOSITION OF JOINT FLUID



TRIBOLOGY

Lubrication

Friction

Wear

What are the interrelationships?

Does reduced friction correlate with reduced wear?

How does lubrication affect friction and wear?

WEAR IN TKR

Tribology

- **Lubrication**
 - Depends on amount, composition and mechanical properties of joint fluid
- **Friction**
 - Better the lubrication lower the friction
- **Wear**
 - Lower the friction, less wear

ROLE OF SYNOVIAL FLUID IN THE LUBRICATION OF ARTIFICIAL JOINTS

- How do the amount, composition and mechanical properties of synovial fluid affect the performance of total joint replacements?
- What is the mechanism of lubrication of artificial joints?
- If injection of hyaluronic acid helps the patient with osteoarthritis would it help the total joint replacement patient?

Image removed due to copyright restrictions.

Diagram explaining coefficient of friction in artificial ball/socket joint.

Example Coefficients of Friction

Cartilage - Cartilage: 0.002 - 0.004

Metal - Metal (dry): 0.4

Metal - Metal (saline): 0.15-0.35

Metal - UHMWPE (serum): 0.05-0.15

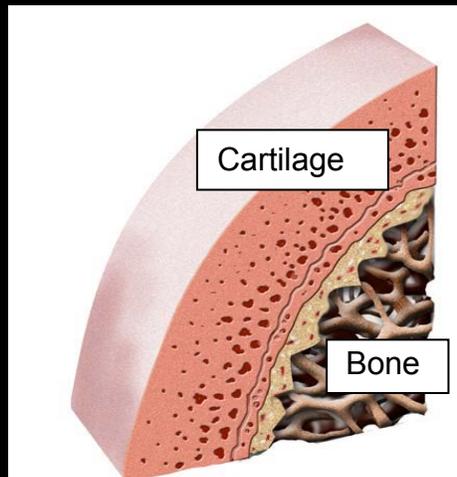
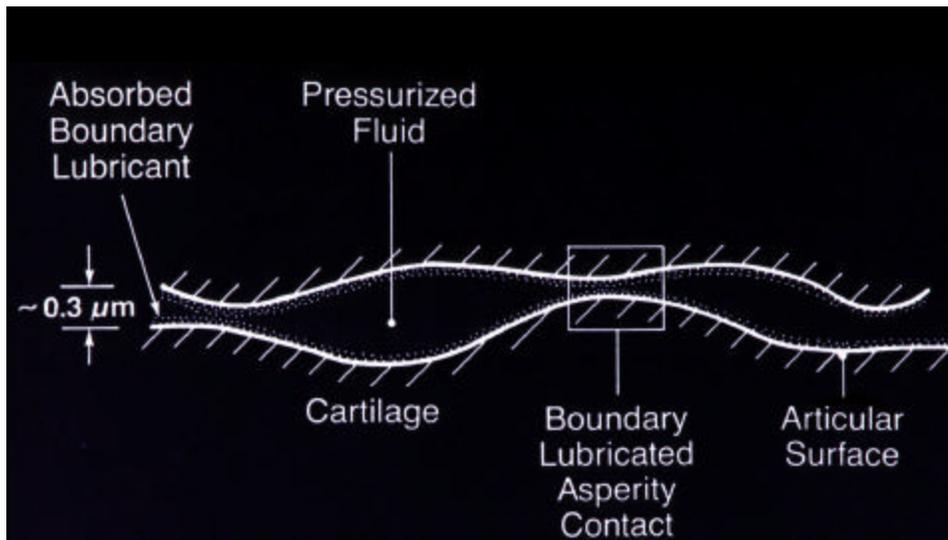


Image removed due to copyright restrictions. Cartilage-lined knee joint.

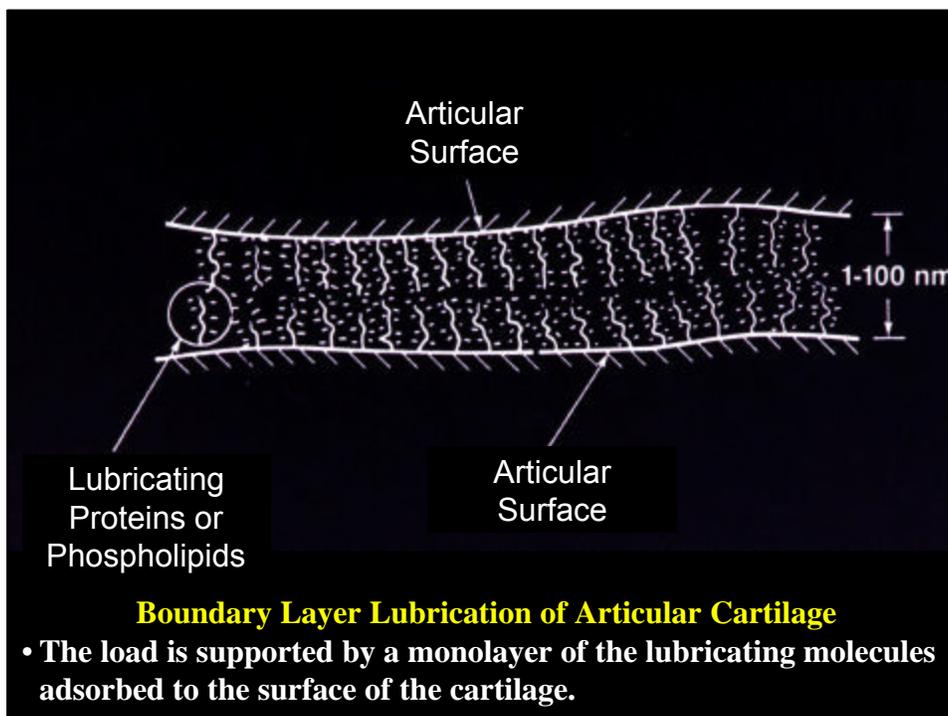
Figure by MIT OCW.

Mechanism of lubrication?



Several Mechanisms of Lubrication in the Joint

- Boundary layer lubrication at the surface.
- Fluid film (hydrodynamic) lubrication in regions where surfaces are separated also elastohydrodynamic and weeping lubrication.



Boundary Layer Lubrication of Articular Cartilage

- The load is supported by a monolayer of the lubricating molecules adsorbed to the surface of the cartilage.

LUBRICATION OF NATURAL AND ARTIFICIAL JOINTS

Lubrication Mechanisms	Natural	Artificial
• Hydrodynamic	yes	yes (?)
• Elastohydrodynamic	yes	no
• Weeping	yes	no
• Boundary Layer	yes	yes (?)

LUBRICATION OF THE NATURAL AND ARTIFICIAL JOINT

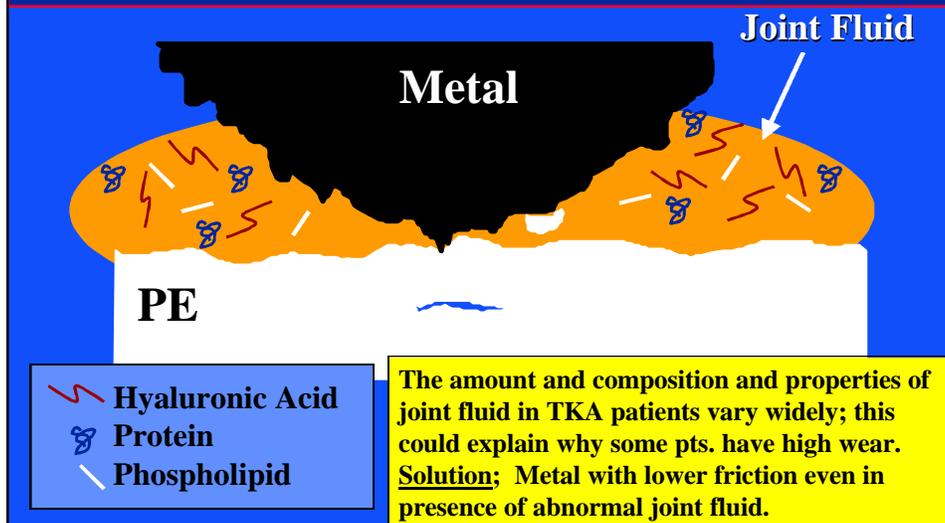
- **Composition**
- Amount of fluid
- Rate of turnover
- Mechanical properties

ROLE OF SYNOVIAL FLUID IN THE LUBRICATION OF NATURAL JOINTS

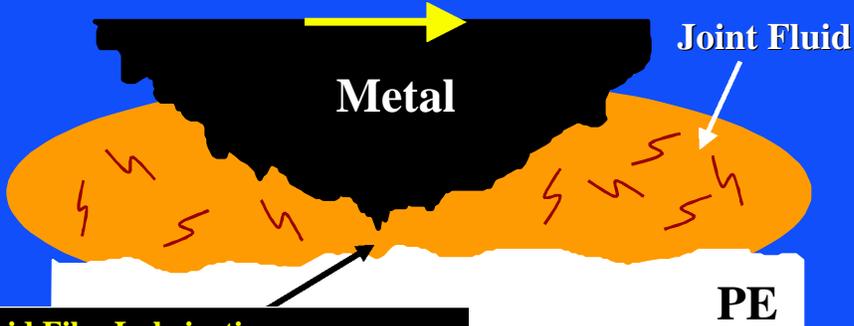
Composition of Synovial Fluid

Constituent	Role
Hyaluronic Acid (GAG)	Provides viscosity-lubricity; viscoelastic damping of loads; hydrodynamic lubrication
Phospholipid (Lipid)	Adsorbs to the surface for “boundary layer” lubrication
Lubricin (Protein)	Adsorbs to the surface and binds phospholipid for “boundary layer” lubrication

COMPOSITION OF JOINT FLUID



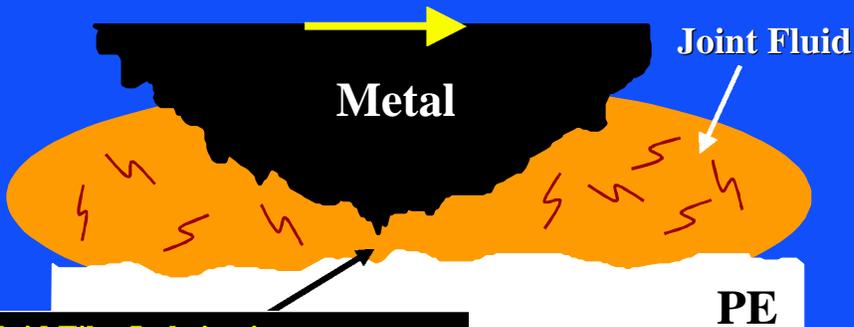
WEAR PROCESSES
Fluid Film Lubrication



Fluid Film Lubrication;
surfaces separate – no friction and
no wear; due to viscosity of fluid
(HA conc. and MW), topography of
counterfaces, and velocity: TKA?

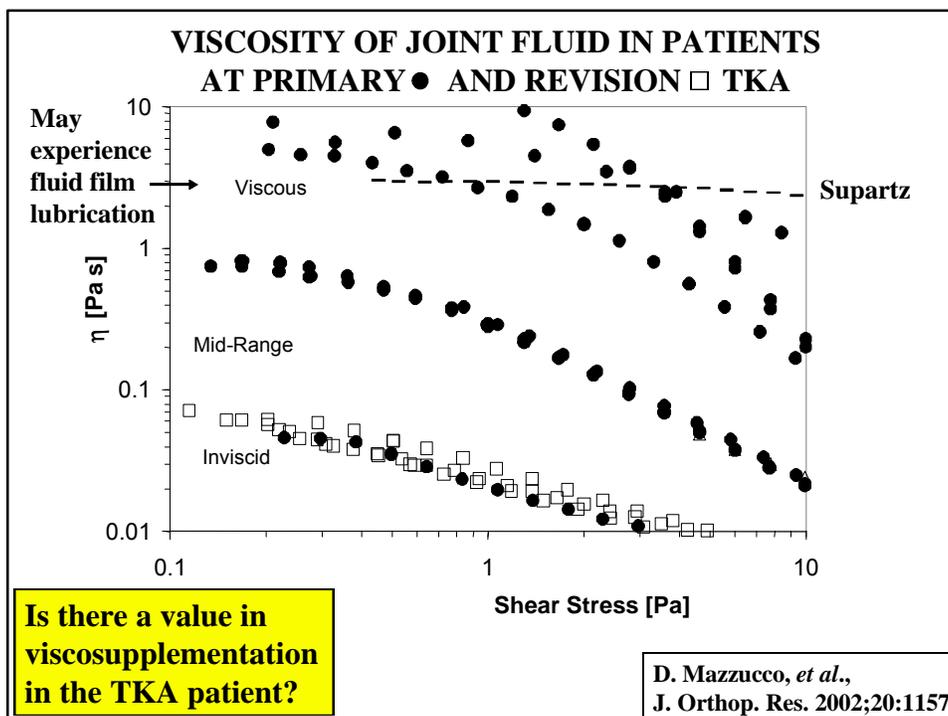
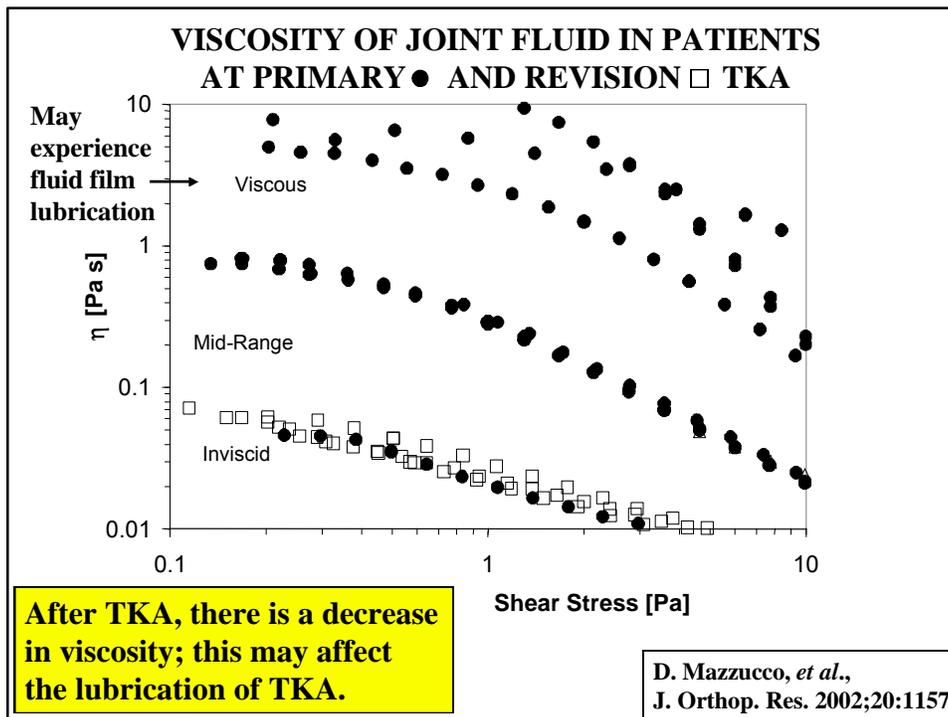
~ Hyaluronic Acid, HA

WEAR PROCESSES
Fluid Film Lubrication

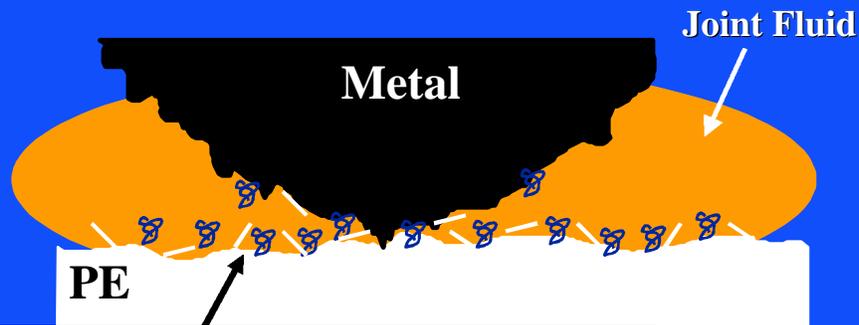


Fluid Film Lubrication;
determine the patient's fluid
viscosity (HA conc. and MW);
benefit of HA injection?

~ Hyaluronic Acid, HA

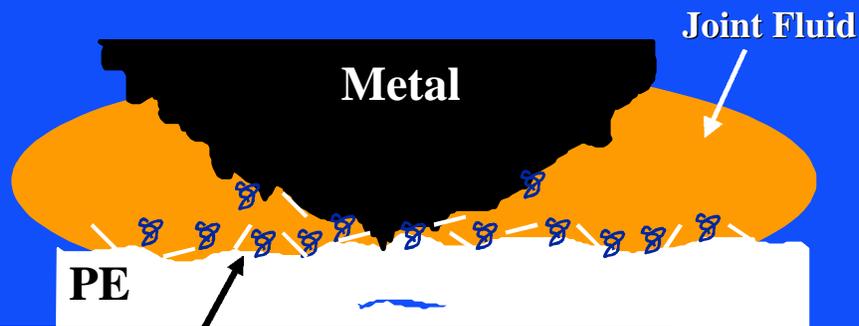


WEAR PROCESSES Boundary Layer Lubrication



Boundary Layer Lubrication;
protein and lipid adsorb to the surfaces to decrease friction and reduce adhesive wear; can contribute to reducing abrasive and fatigue wear

WEAR PROCESSES Boundary Layer Lubrication



Boundary Layer Lubrication;
Determine the protein and lipid content of the joint fluid; employ a metal counterface that will best adsorb the lipid and protein; Oxinium

LUBRICATION OF THE NATURAL AND ARTIFICIAL JOINT

- Composition
- Amount of fluid
- Rate of turnover
- Mechanical properties

Wear testing of a total knee
replacement prosthesis in a
“knee simulator.”

Photos removed due to copyright restrictions.

ROLE OF SYNOVIAL FLUID IN THE LUBRICATION OF ARTIFICIAL JOINTS

- How do the amount, composition and mechanical properties of synovial fluid affect the performance of total joint replacements?
- What is the mechanism of lubrication of artificial joints?
- **Does injection of hyaluronic acid help the patient with osteoarthritis, and if so, would it help the total joint replacement patient?**

HA INJECTION FOR THE TREATMENT OF OSTEOARTHRITIS

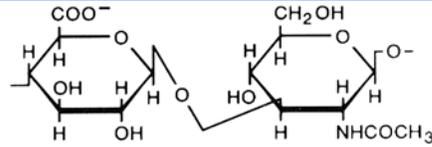
- Does not reverse the degenerative changes of OA.
- Cannot yet determine if it slows progression.
- Has an analgesic effect that mimics NSAIDs and steroid injection
 - placebo effect?
- Affects lubricity of the joint?

HYALURONIC ACID

(provides the viscosity in synovial fluid*)

- A long chain polymer with a molecular weight between 10^6 and 10^7 produced by synovial cells.
- At low molecular weight ($< 10^6$) and concentration (< 1 mg/ml), HA molecules form random coils, and do not interlock with each other (lower viscosity).
- At higher molecular weight and concentration, HA chains interlock to form an entanglement network that has a high viscosity.

*May require interaction with proteins in joint fluid.



HA INJECTIONS FOR THE TREATMENT OF OSTEOARTHRITIS

- The half-life of HA in the joint is less than 24 hours.
- The lasting effect of an HA injection may be related to its stimulation of the endogenous production of HA by the synovium.
- How does the synovial membrane in the TJA patients compare with that in the OA patient?

**No difference between HA● and placebo□
(saline) with respect to pain relief in OA pts.**

Graph removed due to copyright restrictions.

L.S. Lohmander, *et al.*, Ann. Rheum. Dis., 55:424 (1996)

CORROSION

- **Contributes to degradation of mechanical properties of implants**
- **Releases metal ions that can elicit an adverse biological response**

Several slides removed due to copyright restrictions.

- Diagram of concentration cell
- Anodic and Cathodic reactions
- Table of electrochemical series of metals with normal electrochemical potentials
- How oxygen-depleted crevices foster corrosion