

# BIO-TRIBOLOGY

## TRIBOLOGY OF TOTAL HIP ARTHROPLASTIES

C.B. Rieker, PhD  
OrthoSave Sàrl  
CH – 8458 Dorf



# TRIBOLOGY OF TOTAL HIP ARTHROPLASTIES

- Introduction
- Why is tribology important
- Materials
- Possible methodology
- Other aspects
- Conclusions

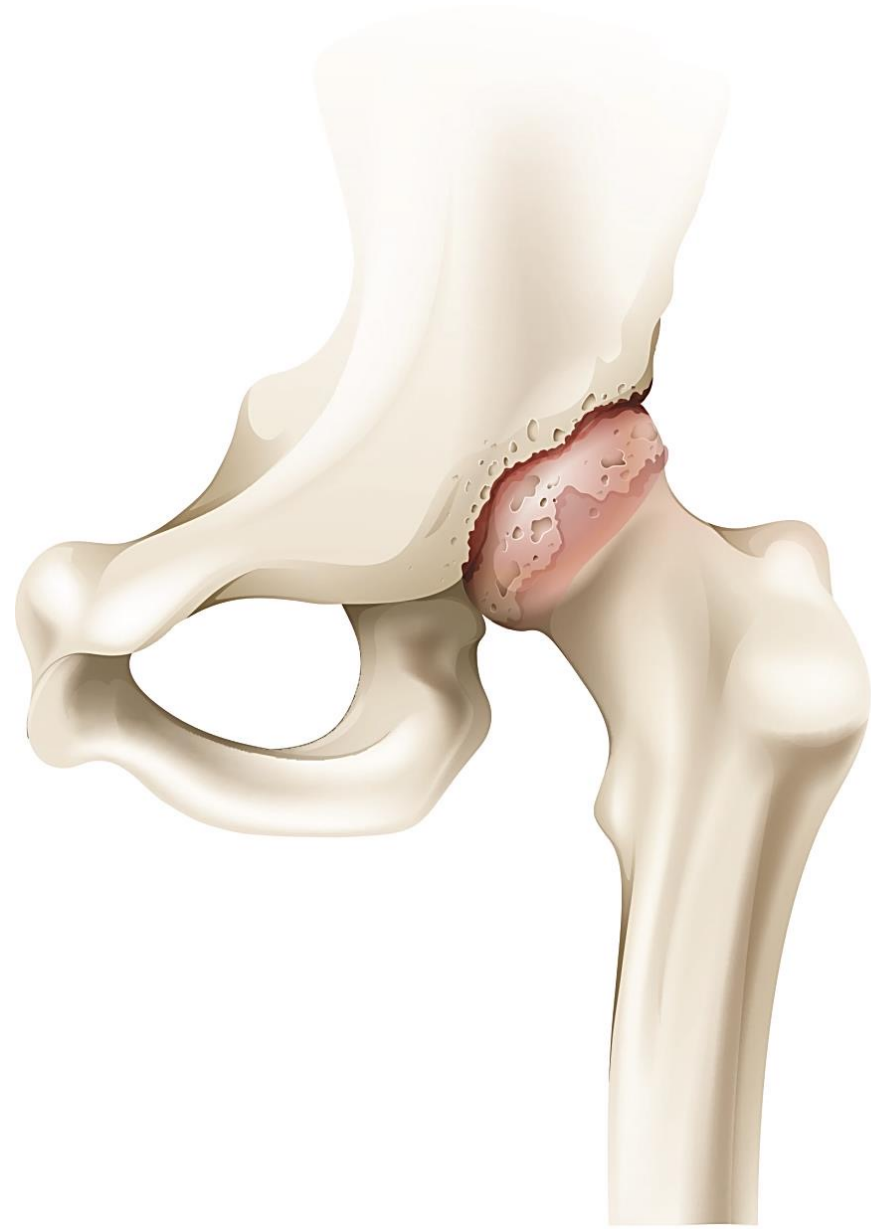
**EPFL**



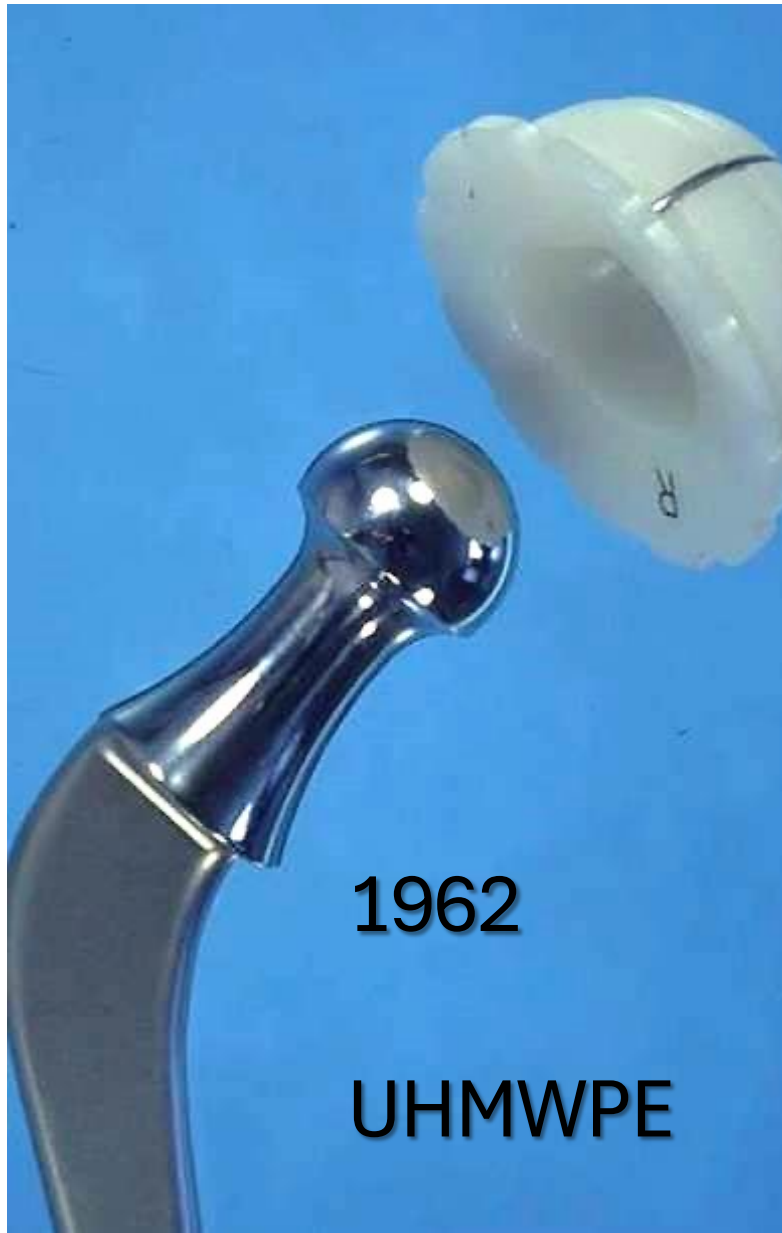






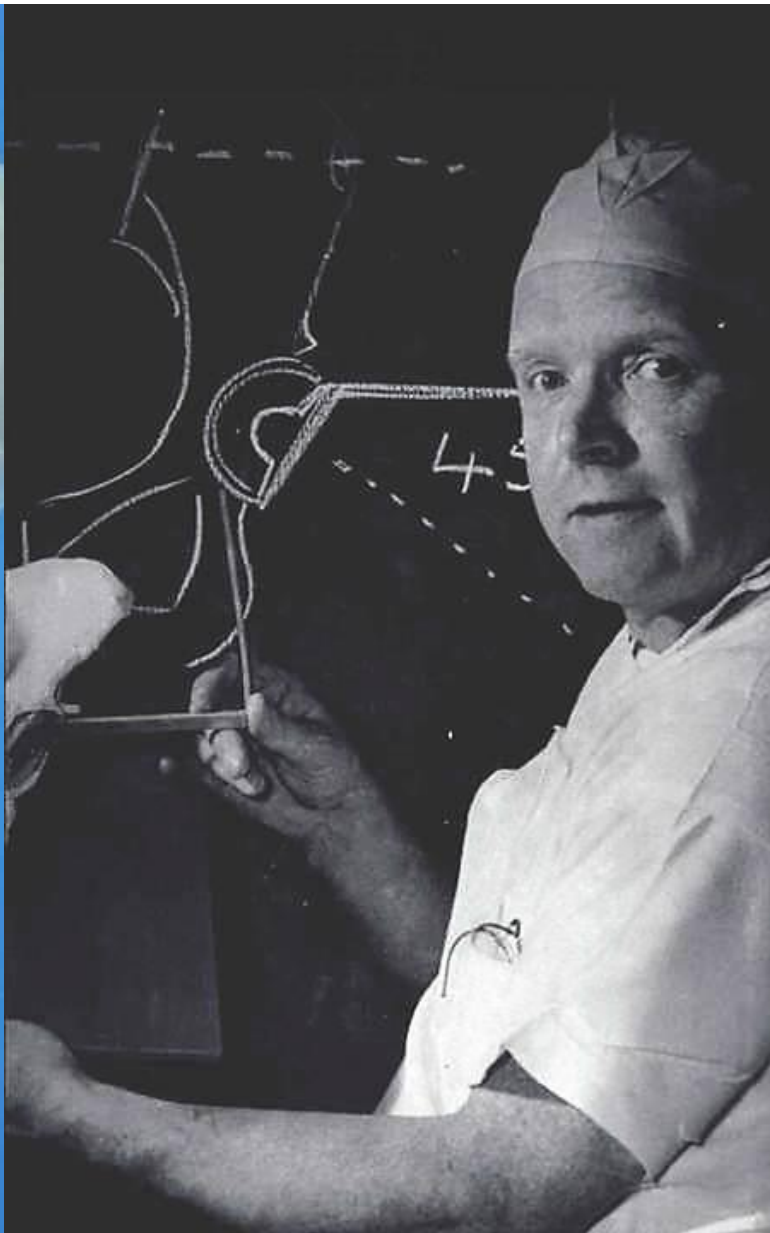






1962

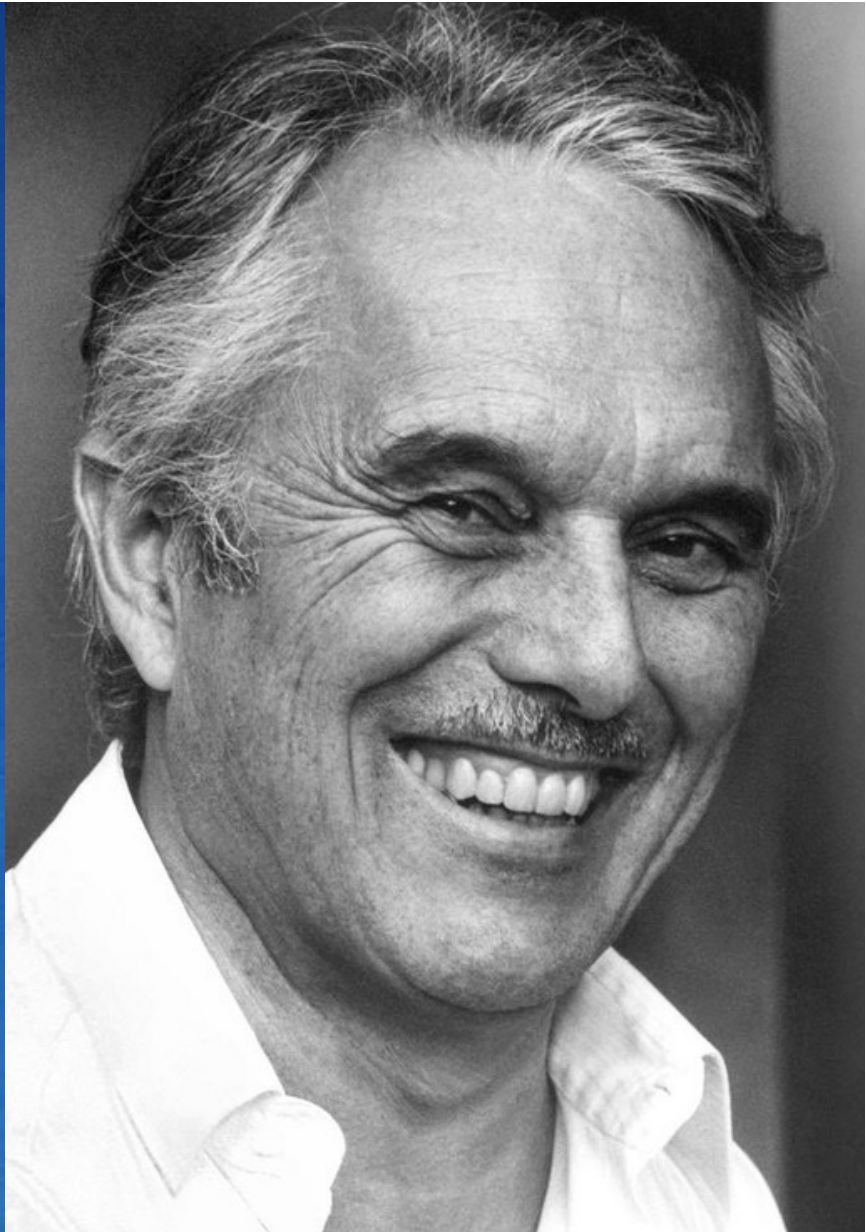
UHMWPE



Sir John Charnley  
1911 - 1982



Wrightington,  
Wigan and Leigh  
NHS Foundation Trust



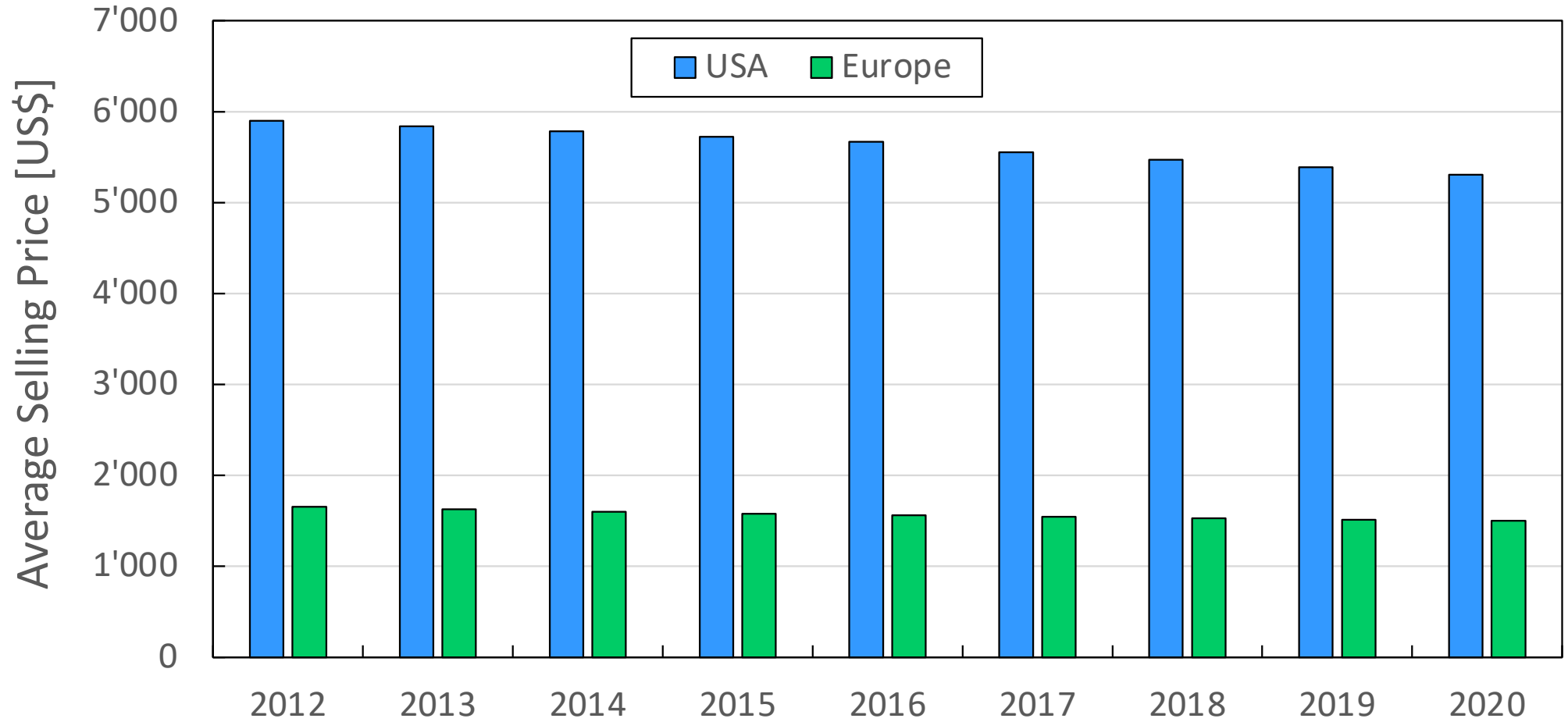
Maurice Müller  
1918 – 2009

Surgeon of the  
century

 **INSELSPITAL**  
UNIVERSITÄTSSPITAL BERN  
HOPITAL UNIVERSITAIRE DE BERNE  
BERN UNIVERSITY HOSPITAL



# TOTAL HIP PROSTHESES



# TOTAL HIP PROSTHESES

Australian Orthopaedic  
Association  
National Joint  
Replacement Registry

2025 ANNUAL REPORT

Hip, Knee  
and Shoulder  
Arthroplasty

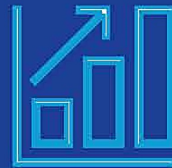


AOA  
AUSTRALIAN  
ORTHOPAEDIC  
ASSOCIATION

Australian  
Orthopaedic  
Association  
National  
Joint  
Replacement  
Registry

# CLINICAL RESULTS SURVIVAL RATES

## AOANJRR Data Snapshot 2024



**2,285,453**

Total number of joint  
replacement procedures  
reported by the Registry  
at the end of 2024



**171**  
Data  
Requests

\$\$\$\$

Over a billion dollars  
of estimated benefit  
to the national health  
system accruing from  
AOANJRR activities

Joint replacement procedures performed in 2024

**60,414**

Hips

**79,331**

Knees

**11,306**

Shoulders



**43**

Hospital Audit  
Requests



**1,173**

Individual Surgeon  
Reports



**33**

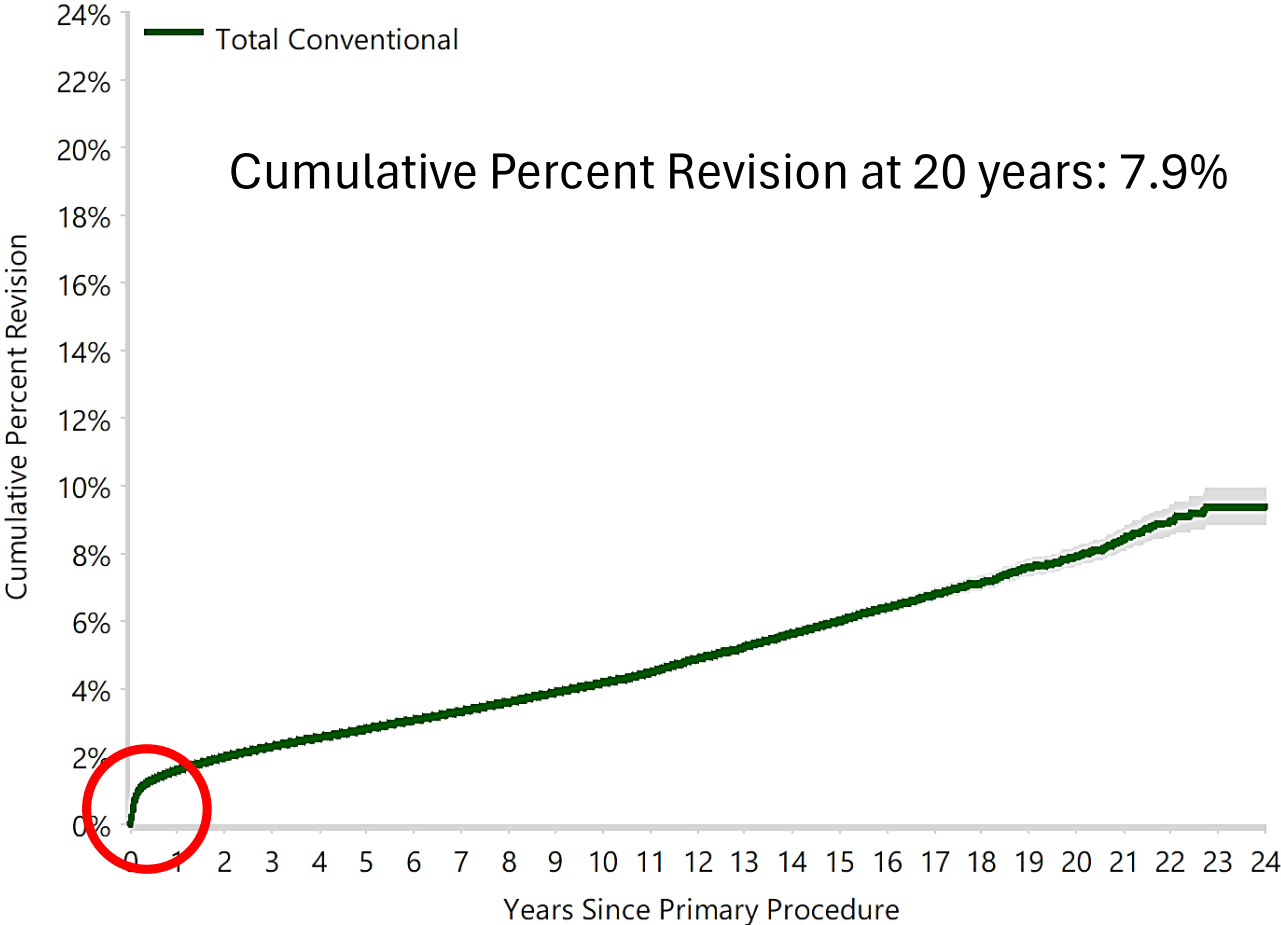
Conference  
presentations



**37**

Journal  
Articles  
Published

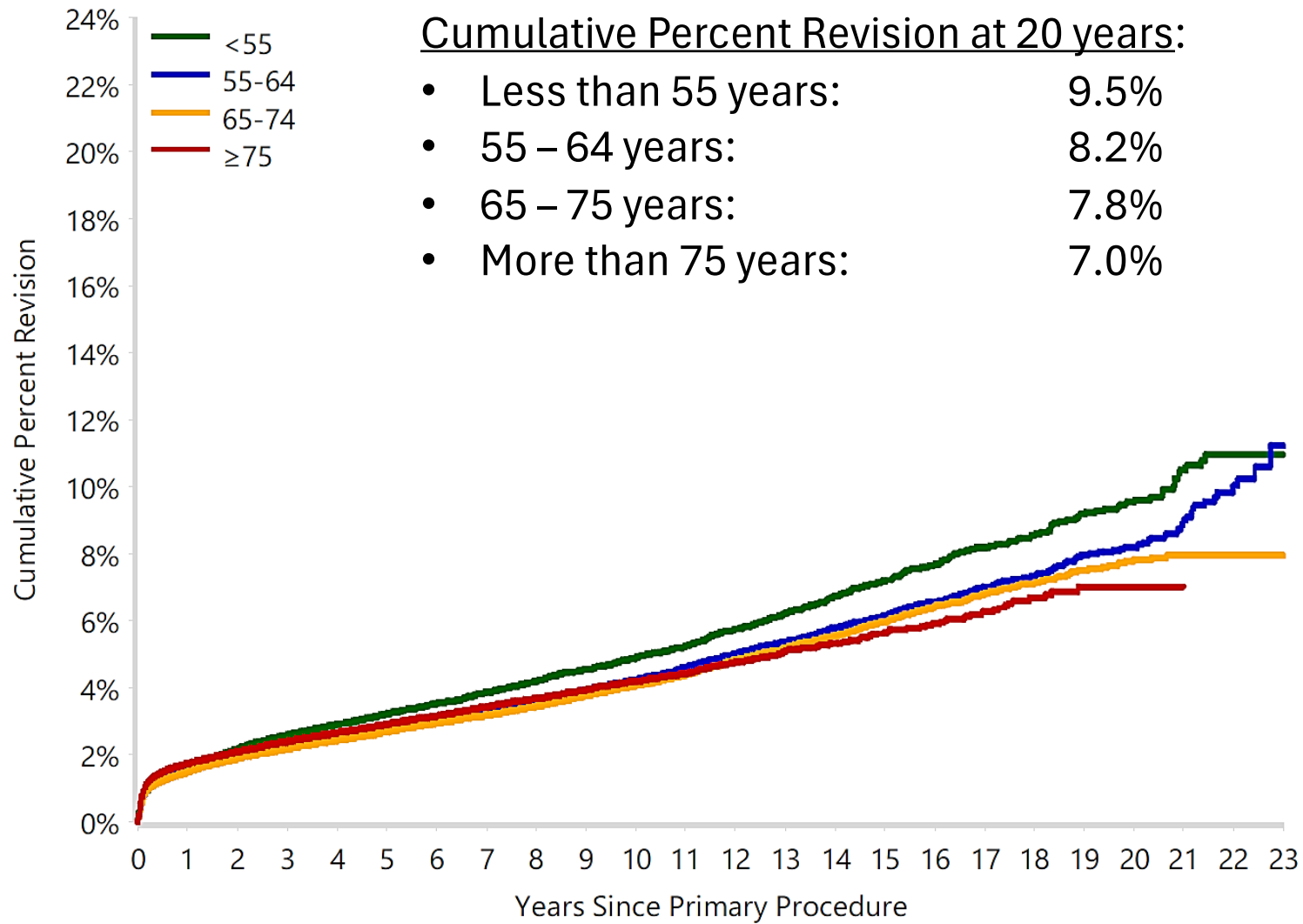
# Cumulative Percent Revision of Primary Total Conventional Hip Replacement (Primary Diagnosis OA)



# THE OPERATION OF THE CENTURY: TOTAL HIP REPLACEMENT

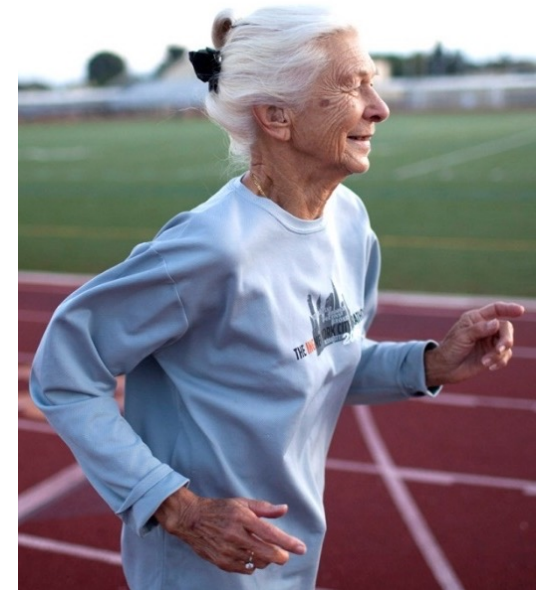


- I. Learmonth et al,  
The Lancet, 370,  
2007, p. 1508



# PATIENT ACTIVITY

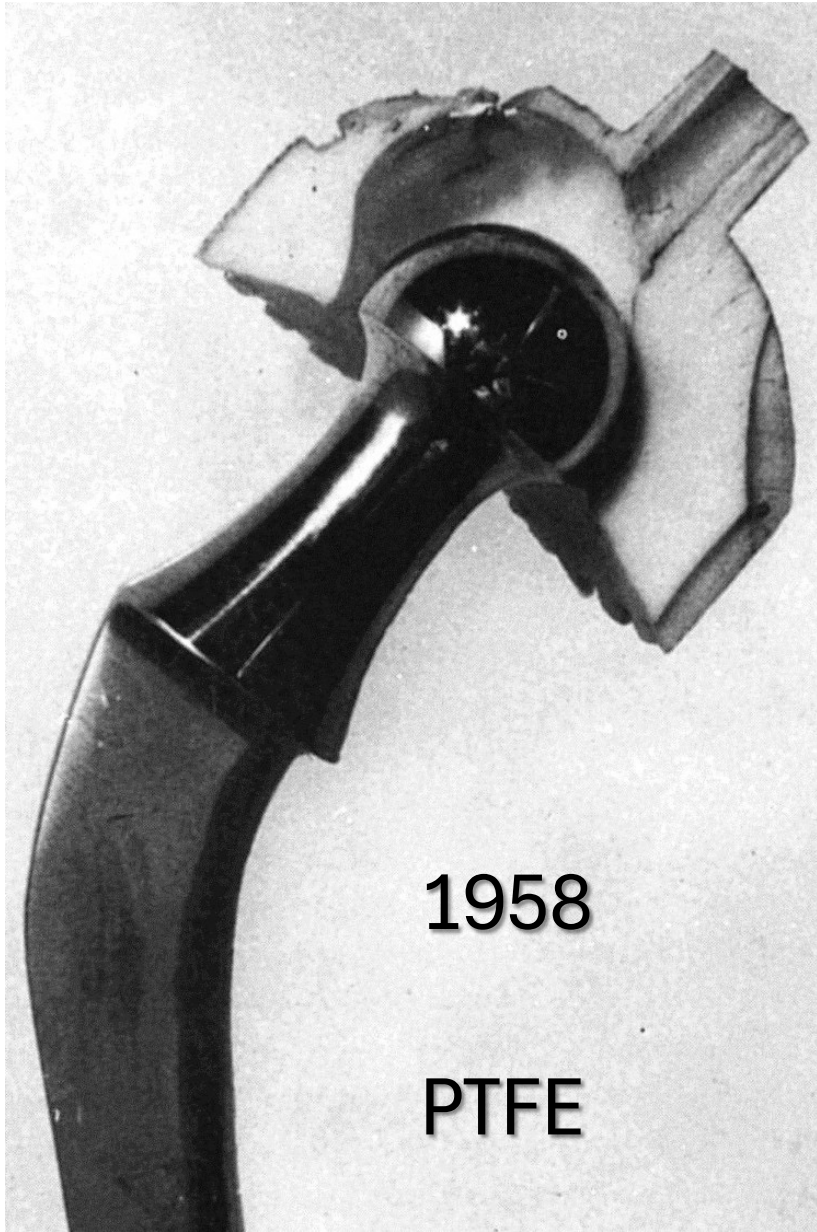
- As the mean age of the patients is steadily decreasing, the mean activity of the patients is increasing.



# TRIBOLOGY OF TOTAL HIP ARTHROPLASTIES

- Introduction
- Why is tribology important
- Materials
- Possible methodology
- Other aspects
- Conclusions

**EPFL**



1958

PTFE



1962

UHMWPE

Sir John Charnley  
1911 - 1982



Wrightington,  
Wigan and Leigh  
NHS Foundation Trust

# PARTICLE DISEASE

**SULZER**

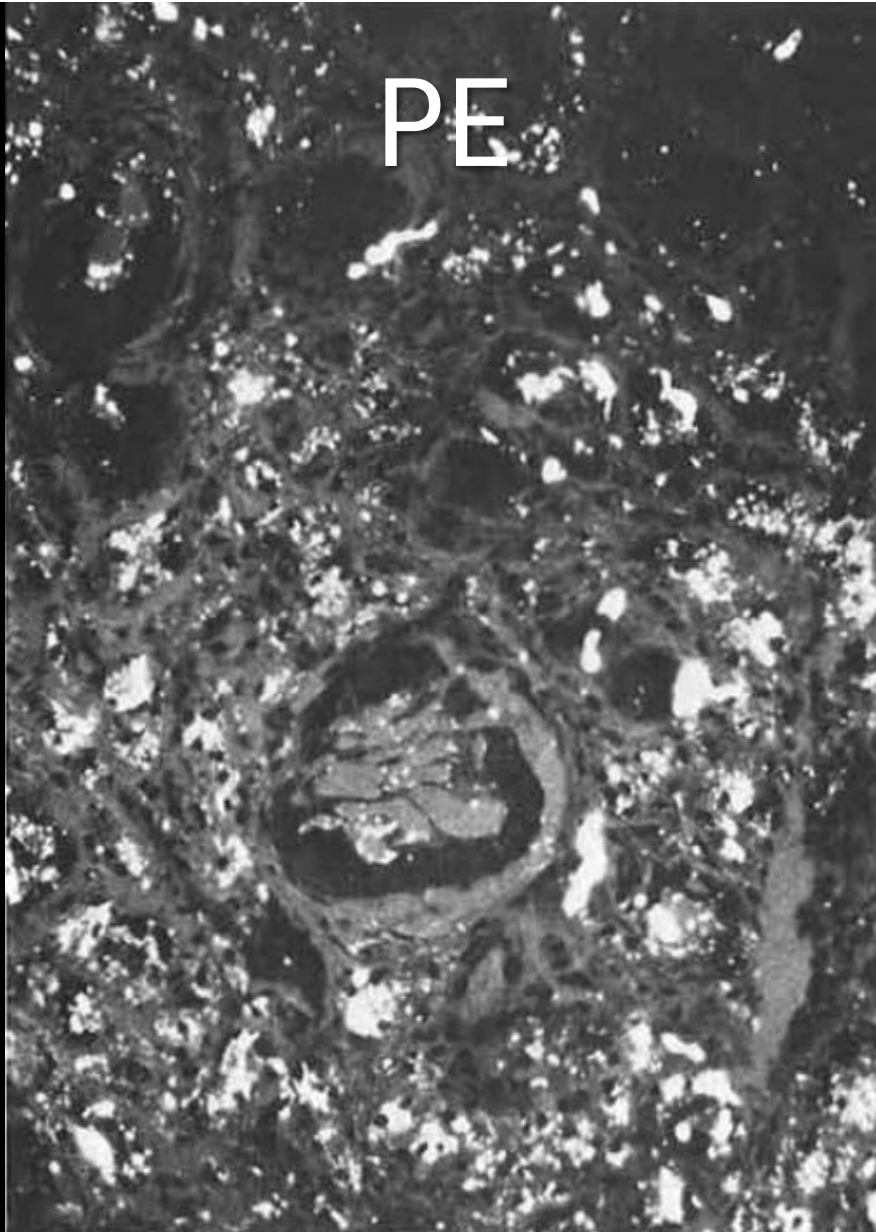
- The first description of this phenomenon was published in 1974 by Prof. H.G. Willert (Germany) and Dr. M. Semlitsch (Sulzer Orthopaedic)
- Dutch-Swiss Orthopaedic Societies, Lausanne, 1974

Kapselreaktionen bei  
Gelenkendoprothesen

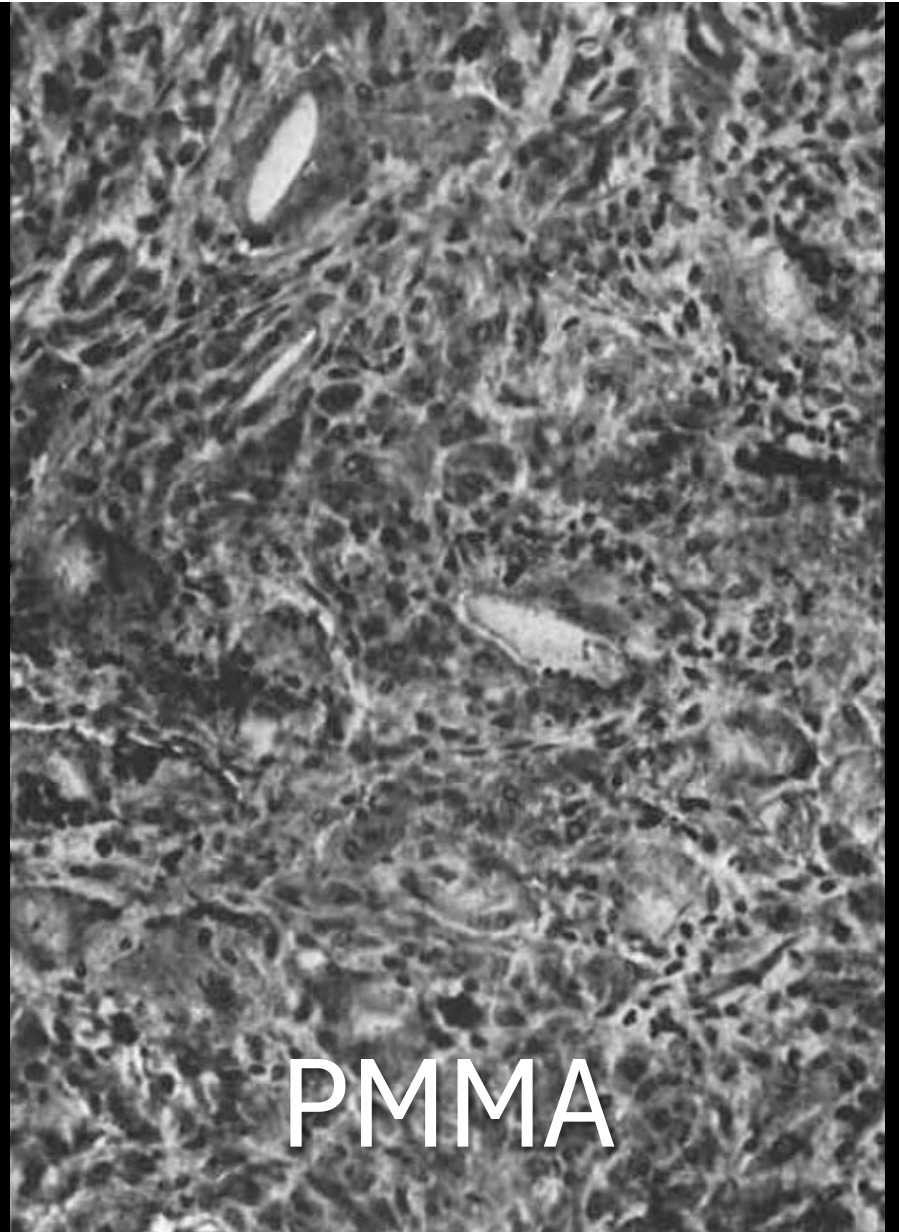
Articular Capsule Reactions  
associated with  
Joint Endoprostheses

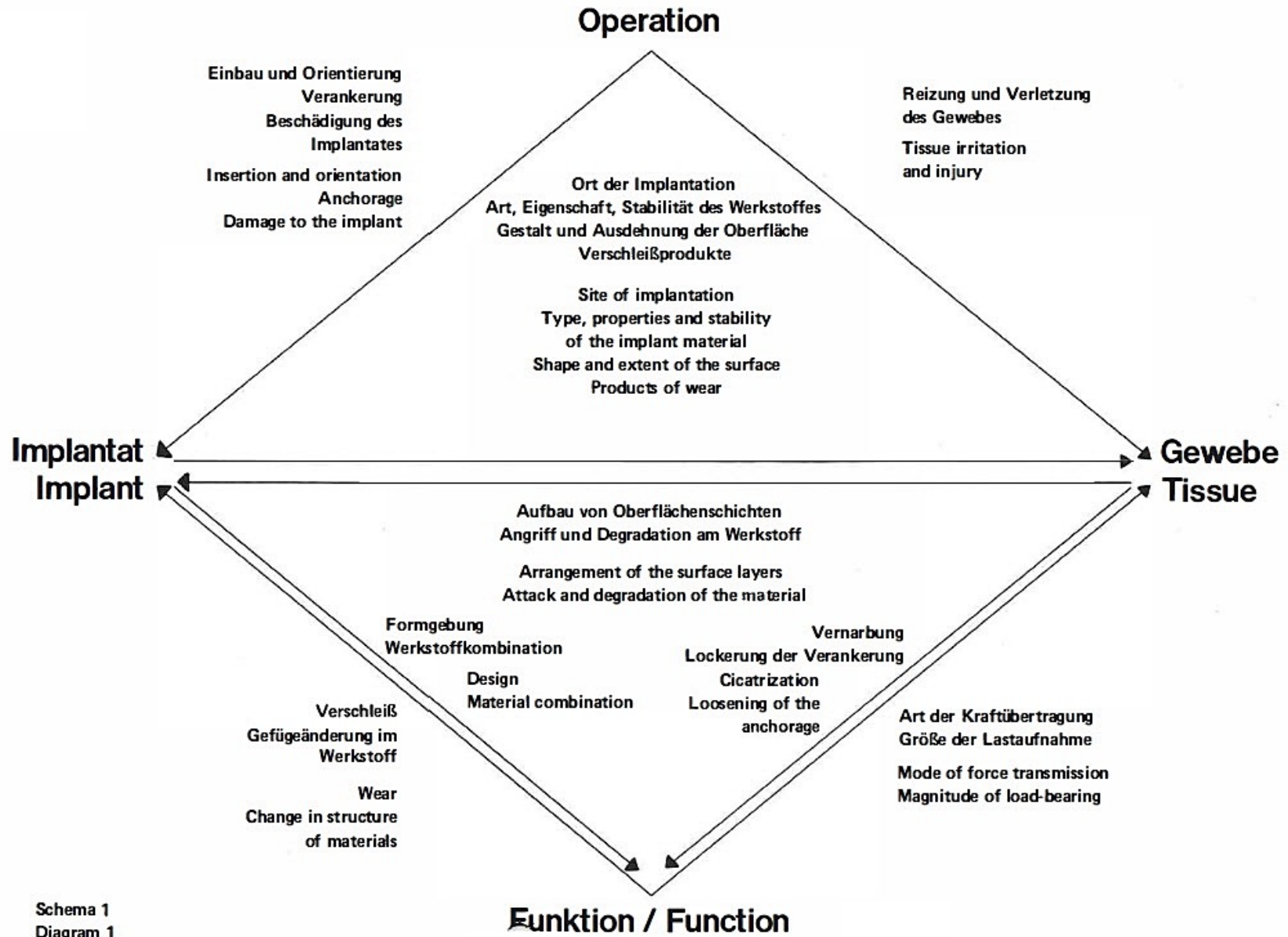
H. G. Willert, M. Semlitsch

PE

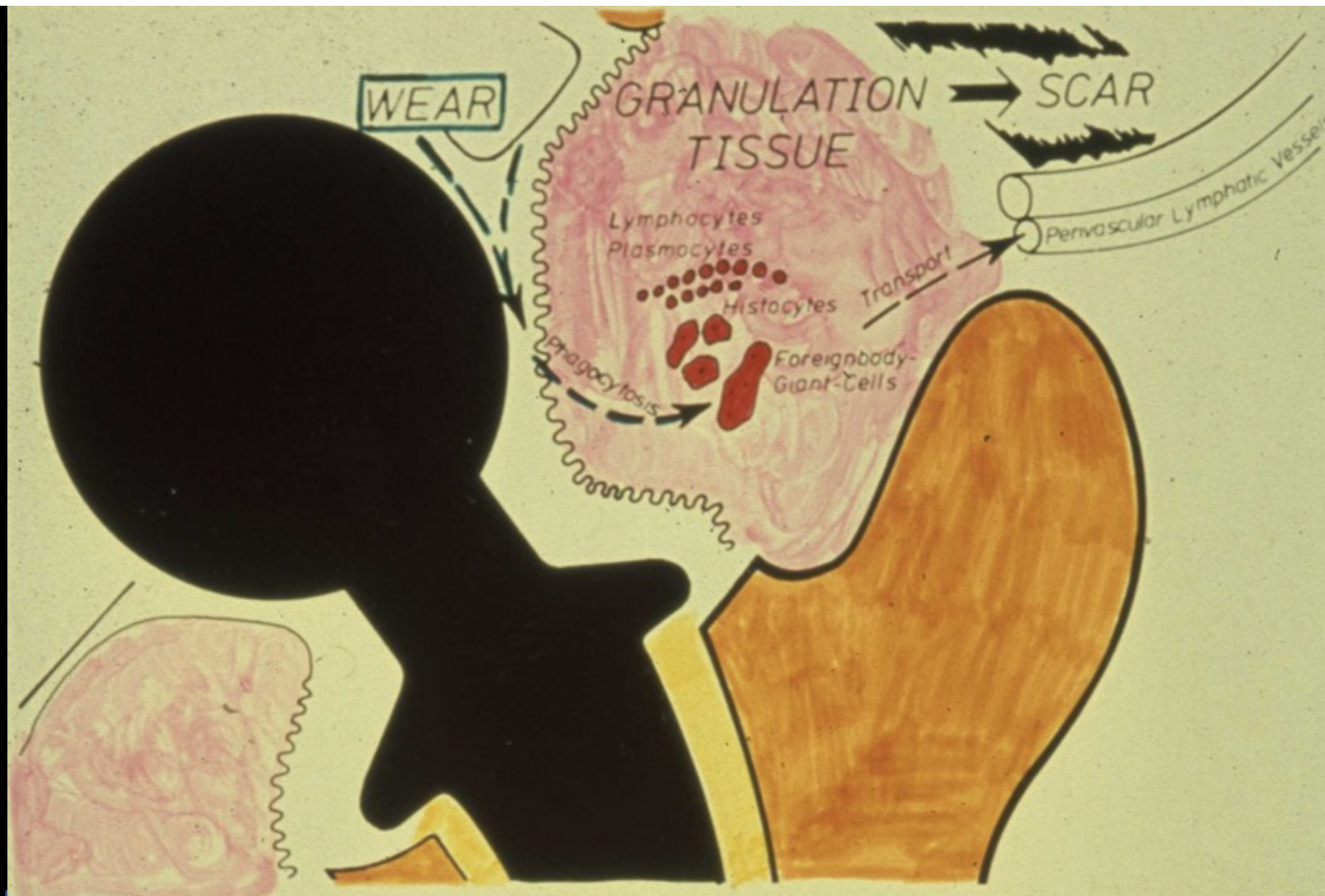


PMMA





Schema 1  
Diagram 1

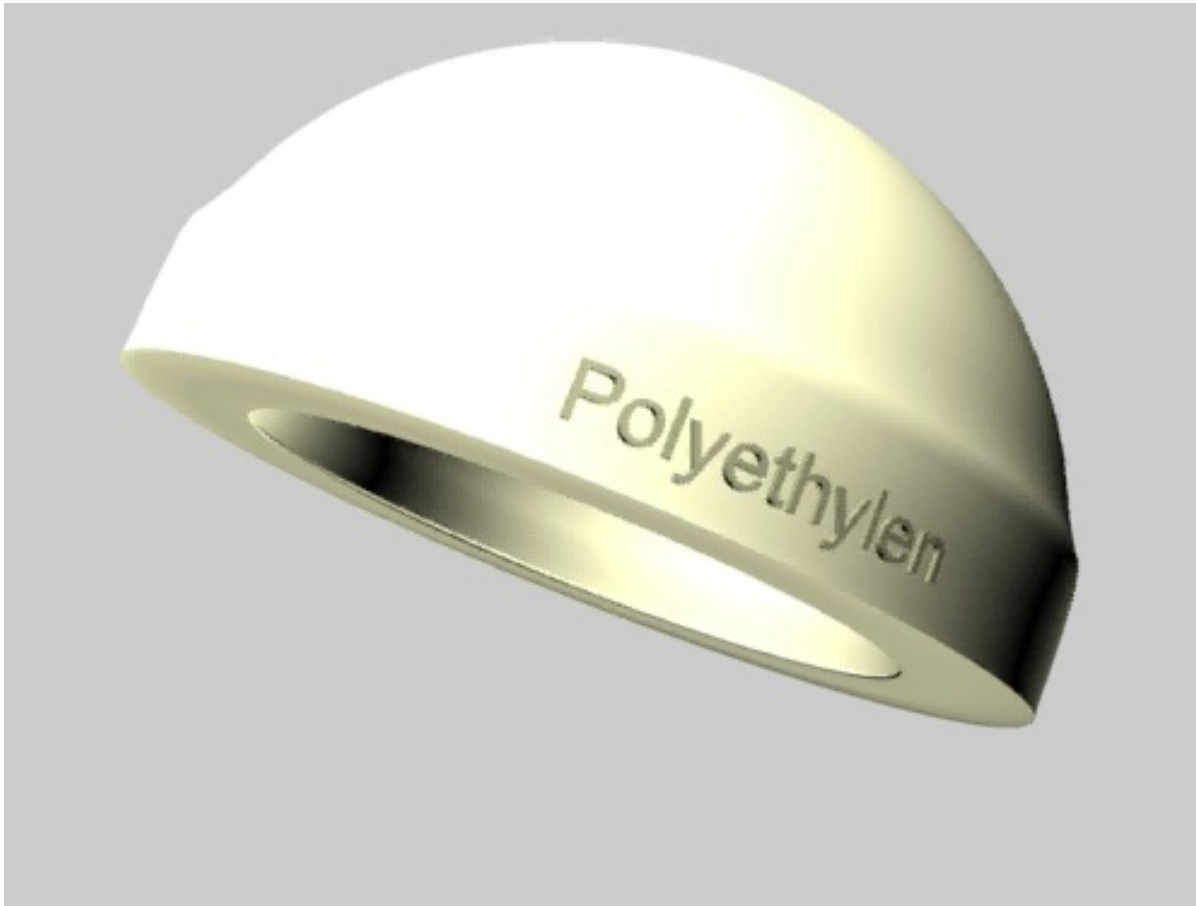


H.G. WILLERT, M. SEMLITSCH - 1974



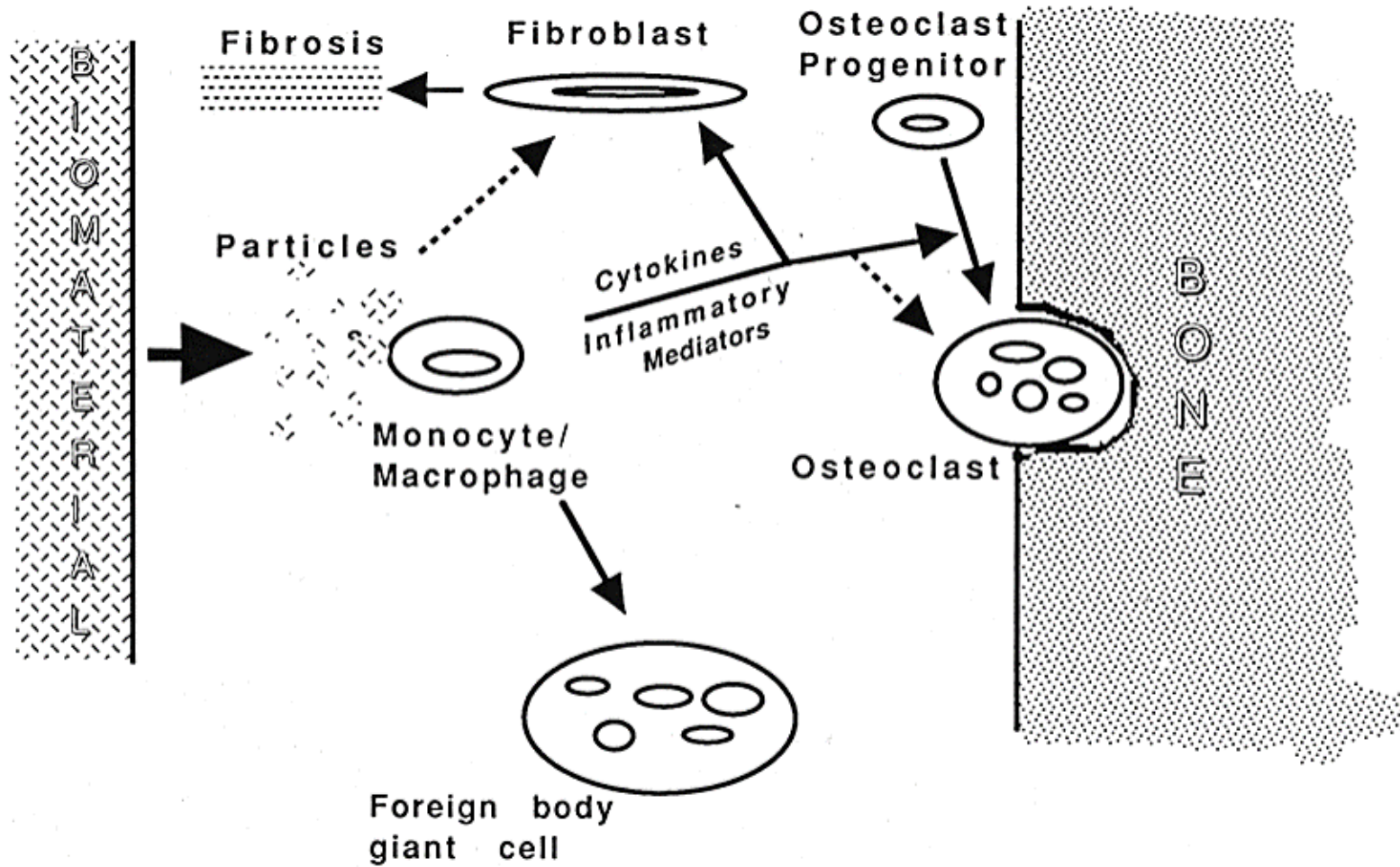
H.G.WILLERT, M.SEMLITSCH - 1974

# PARTICLE DISEASE

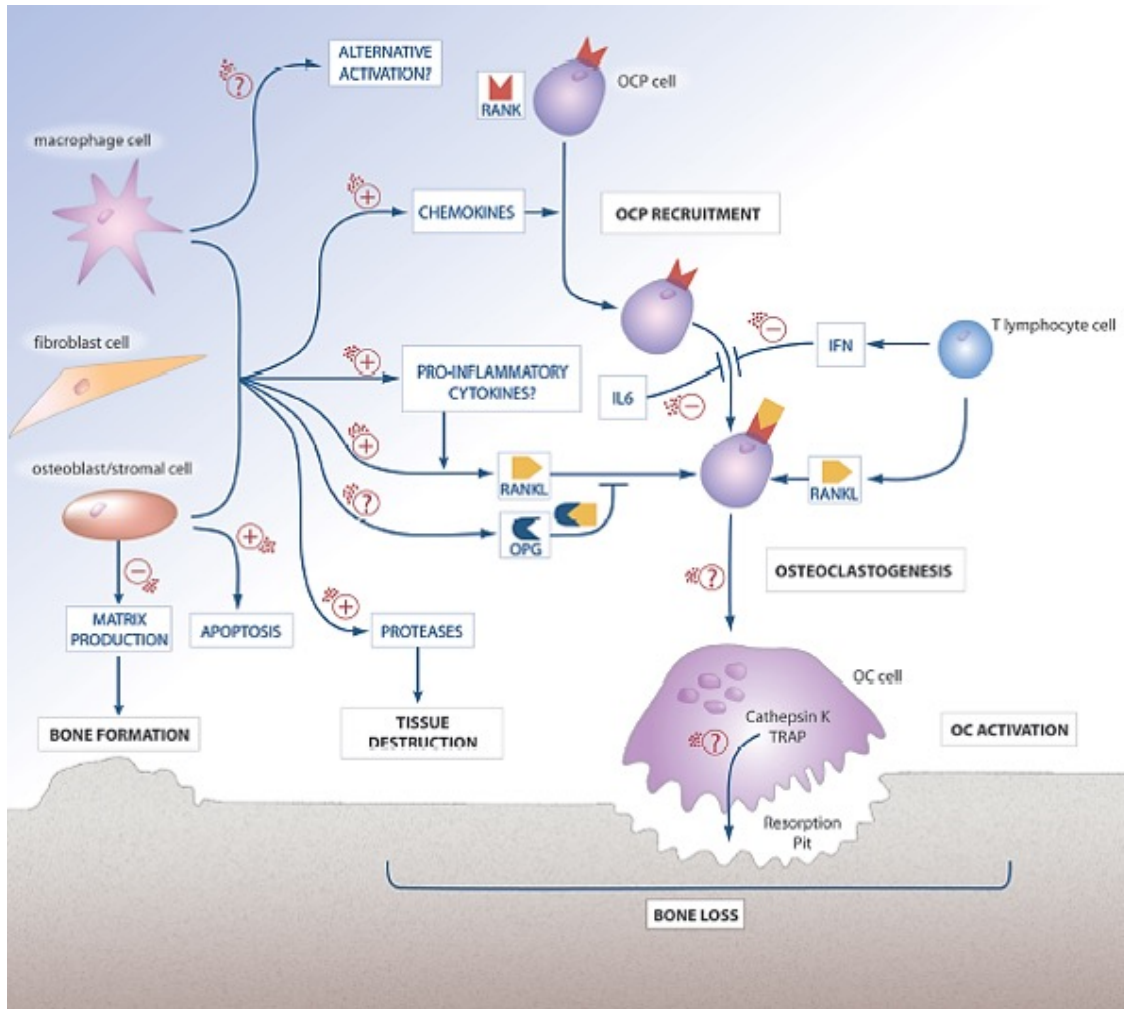


Courtesy of CeramTec

# PARTICLE DISEASE



# PARTICLE DISEASE

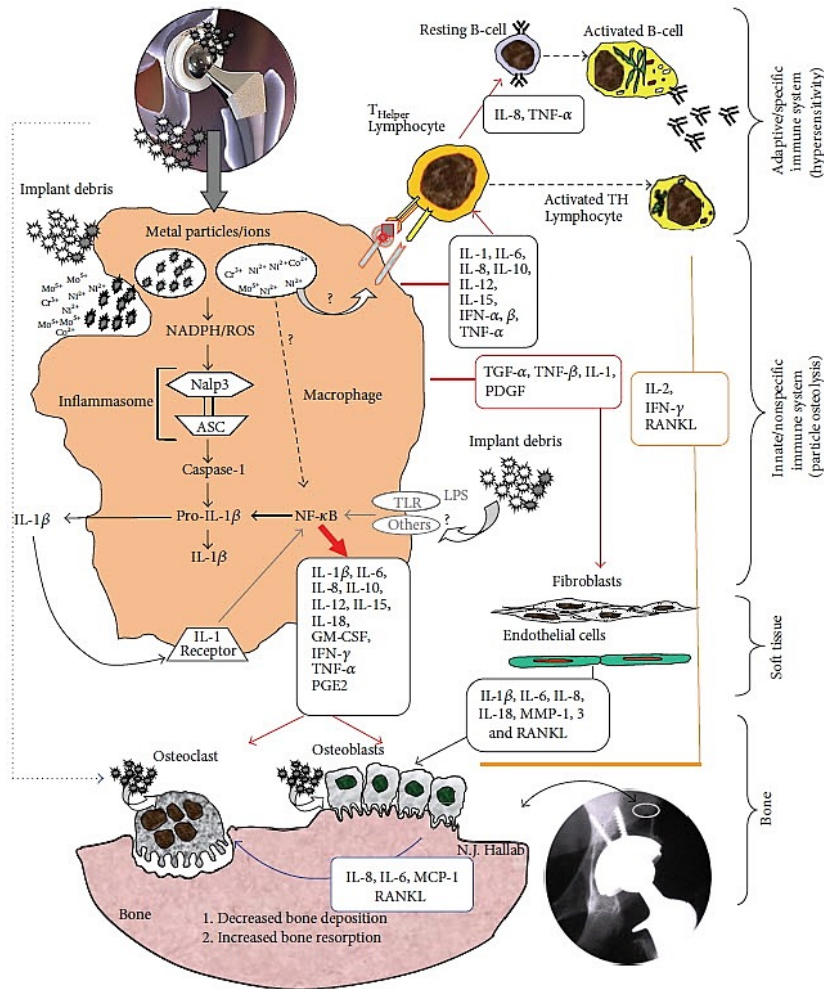


The Cellular and Molecular  
Biology of Periprosthetic  
Osteolysis

P.E. Perdue et al

CORR, 454, 2006, p. 454

# PARTICLE DISEASE



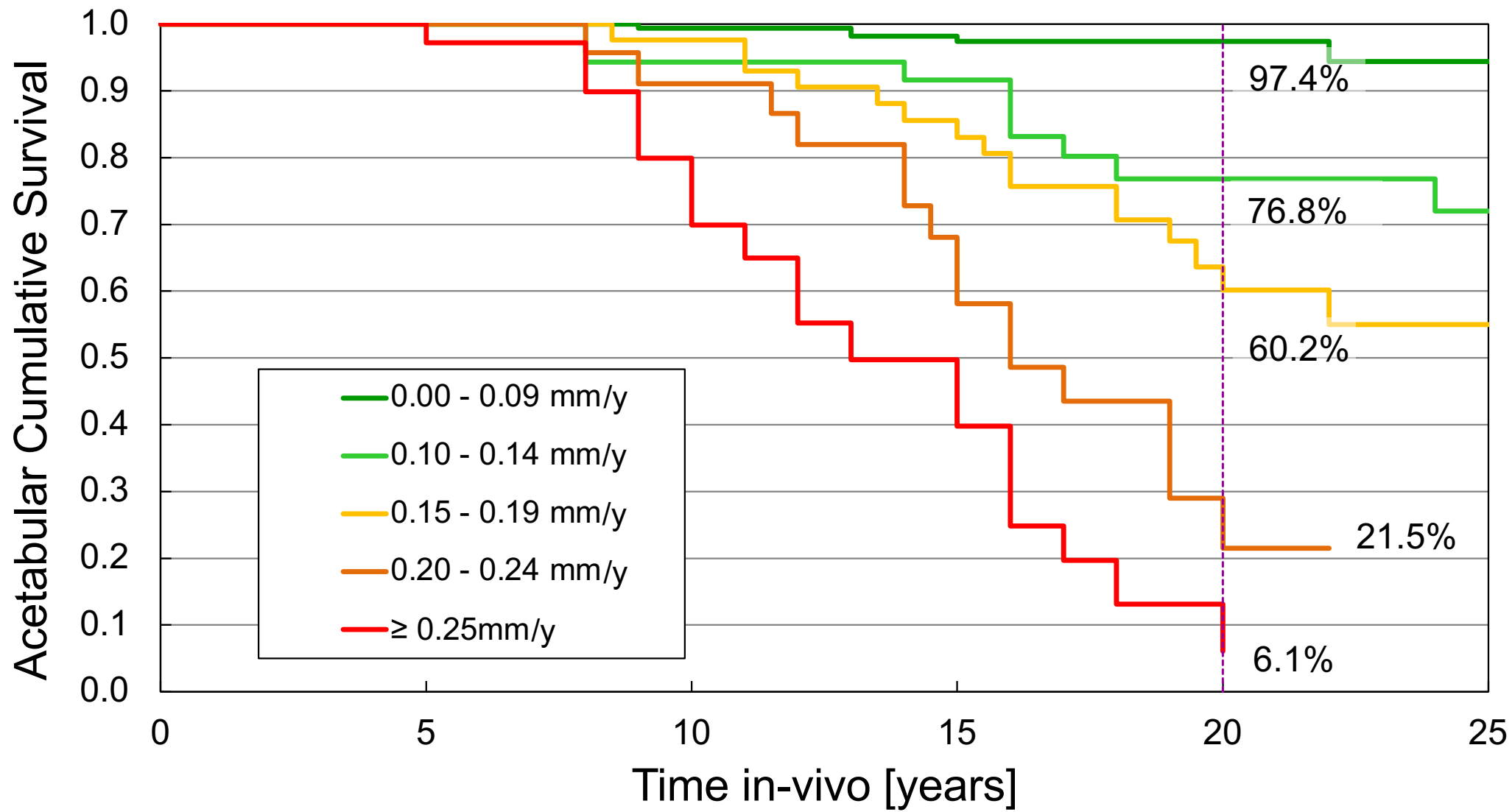
The Pathology of Orthopedic Implant Failure Is Mediated by Innate Immune System Cytokines

S. Landgraeber et al

Mediators Inflamm. 2014:185150

# RELATIONSHIP OF ACETABULAR WEAR TO OSTEOLYSIS AND LOOSENING IN THA

- “Increasing annual acetabular wear correlated strongly with aseptic loosening, failure, and revision of the acetabular component.”
- “Increasing annual acetabular wear correlated strongly with aseptic loosening, failure, and revision of the femoral prosthesis.”
- D.H. Sochart, CORR, 363, 1999, p. 135



# TRIBOLOGY OF TOTAL HIP ARTHROPLASTIES

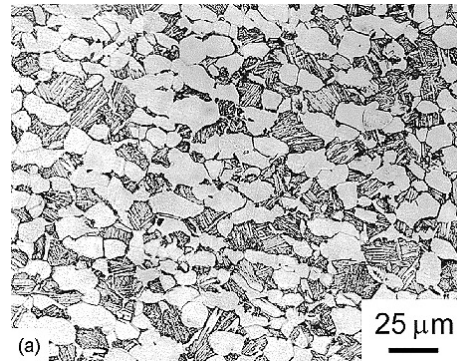
- Introduction
- Why is tribology important
- **Materials**
- Possible  
methodology
- Other aspects
- Conclusions

**EPFL**



- Stem

- $\alpha/\beta$  titanium alloy
- Titanium – 6% aluminium – 4% vanadium

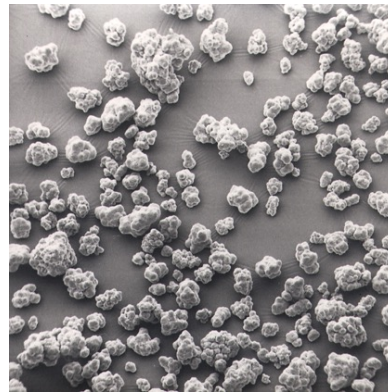


- ISO 5832-3  
First edition in 1983



- Insert

- Ultra High Molecular Weight Polyethylene



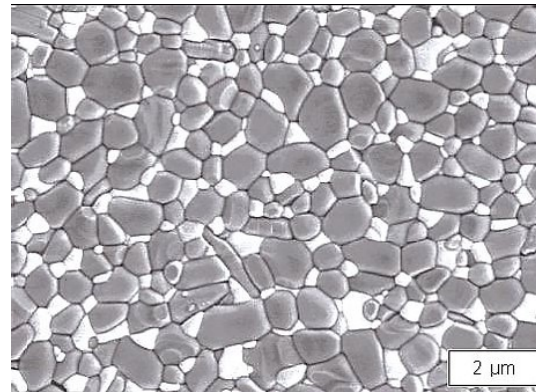
- ISO 5834-2

First edition in 1985



- Head

- 82% alumina – 17% zirconia – 1% different oxides



- ISO 6474-2  
First edition in **2012**

# MATERIAUX

INTERNATIONAL  
STANDARD

ISO  
5832-2

First edition  
1999-07-15

---

**Implants for surgery — Metallic materials —  
Part 2:  
Unalloyed titanium**

*Implants chirurgicaux — Produits à base de métaux —  
Partie 2: Titane non allié*



Reference number  
ISO 5832-2:1999(E)

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Le présent document est l'édition française de l'ISO 5832-2:1999, sous le numéro  
ISO 5832-2:1999(E)

INTERNATIONAL  
STANDARD

ISO  
5834-1

Third edition  
2005-06-01

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**Implants for surgery — Ultra-high-  
molecular-weight polyethylene —  
Part 1:  
Powder form**

*Implants chirurgicaux — Polyéthylène à très haute masse  
moléculaire —  
Partie 1: Produits sous forme de poudre*



Reference number  
ISO 5834-1:2005(E)

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Le présent document est l'édition française de l'ISO 5834-1:2005, sous le numéro  
ISO 5834-1:2005(E)

# MATERIAUX

- ISO 5832-1: Stainless steel (316L)
- ISO 5832-2: Unalloyed titanium
- ISO 5832-3: Ti6Al4V alloy
- ISO 5832-4: Cast CoCrMo alloy
- ISO 5832-9: Stainless steel (high nitrogen)
- ....

# MATERIAUX

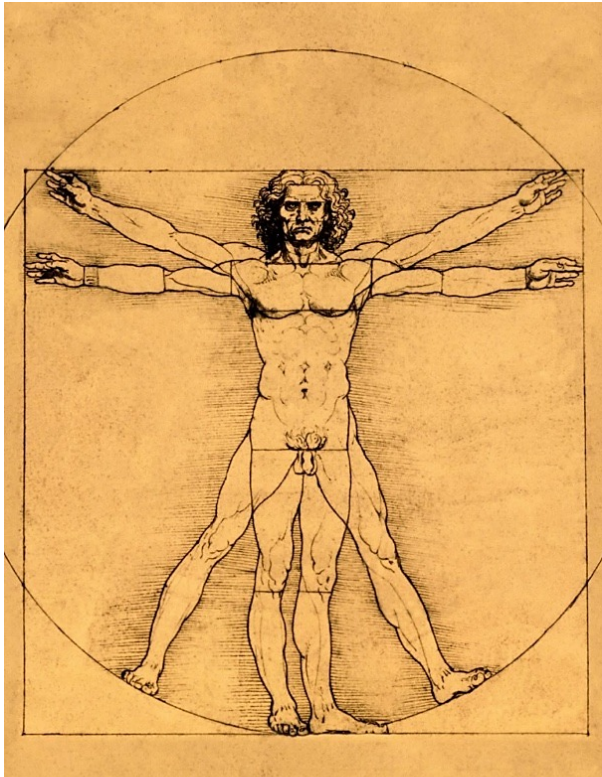
- ISO 5834-1: UHMWPE powder
- ISO 5834-2: Moulded UHMWPE
- ...
- ISO 6474-1: Alumina
- ISO 6474-2: Zirconia-toughened alumina
- ISO 13356: Zirconia

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**EPFL**

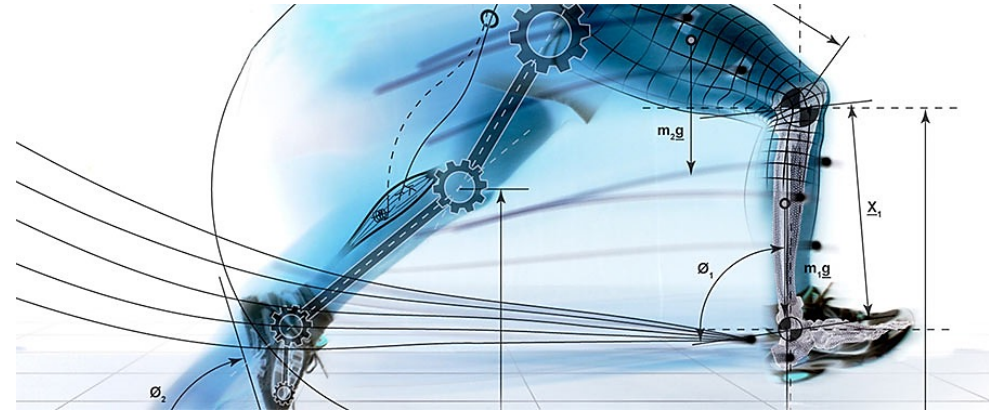
# IN-VIVO SITUATION?



Anatomy

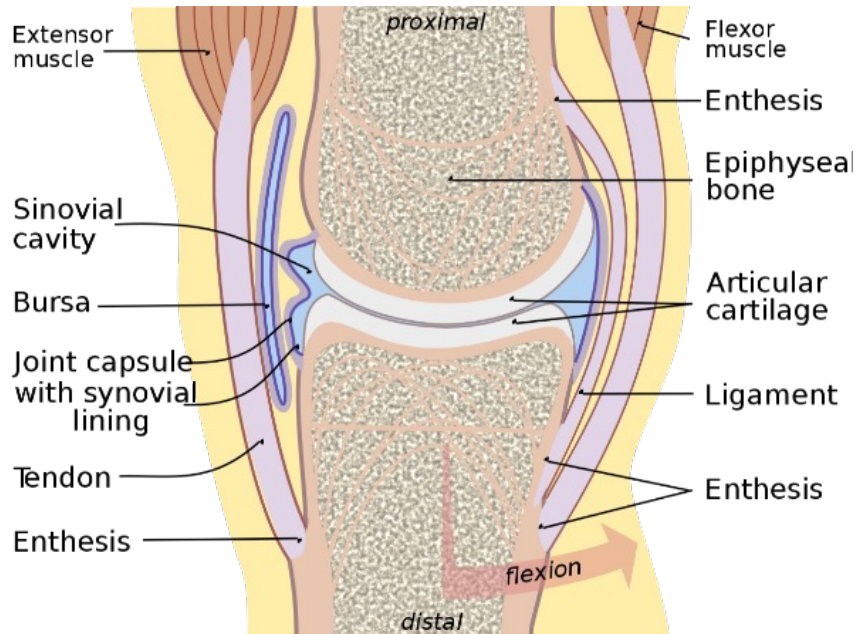


Temperature



Biomechanics

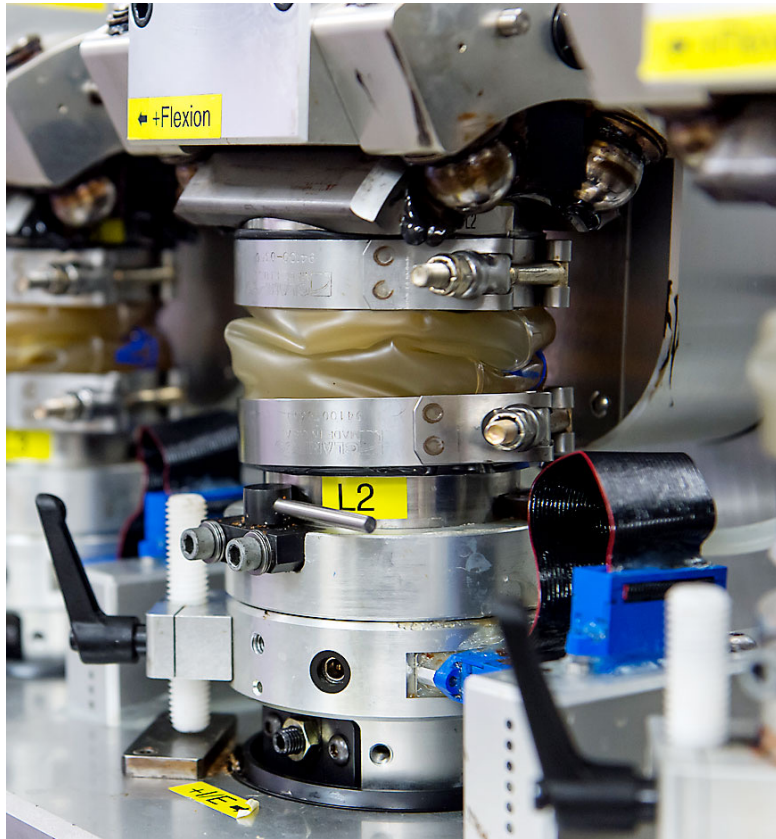
# IN-VIVO SITUATION?



Synovial fluid

- Composition:
  - Proteins: 1.8 g/dl
    - Albumin 60%
    - Globulin 40%
  - Hyaluronate: 0.3 g/dl
  - Glucose: 90 mg/dl
  - Uric acid: 5 mg/dl

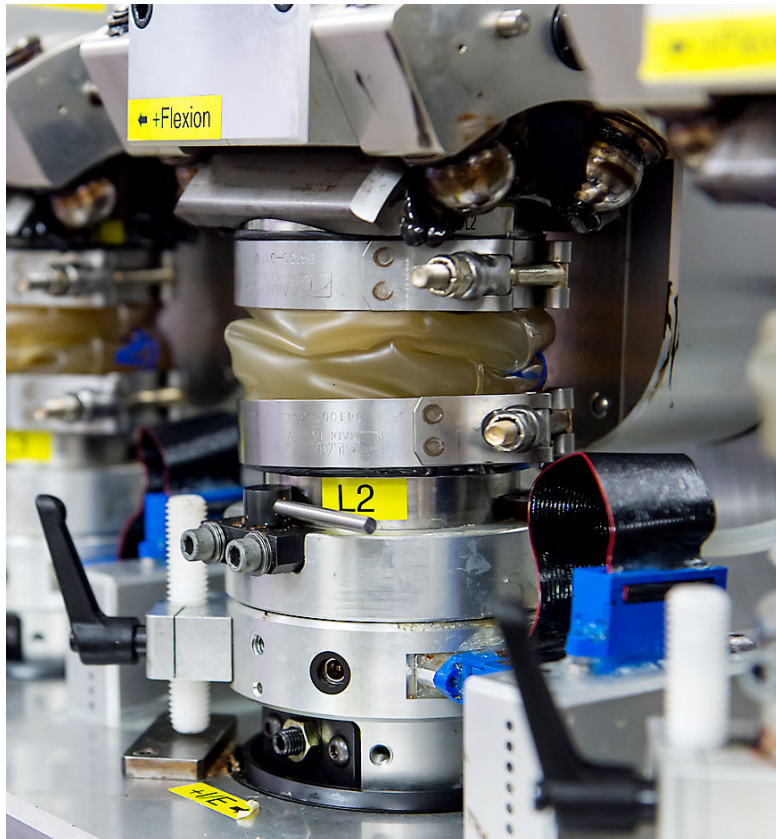
# IN-VITRO SITUATION?



Hip simulator

- Composition:
  - 33% Calf serum
  - 67% Ringer solution
  - Proteins concentration: 2 g/dl
  - Filtration by a 0.2  $\mu\text{m}$  filter
  - pH: 7.2

# IN-VITRO SITUATION?



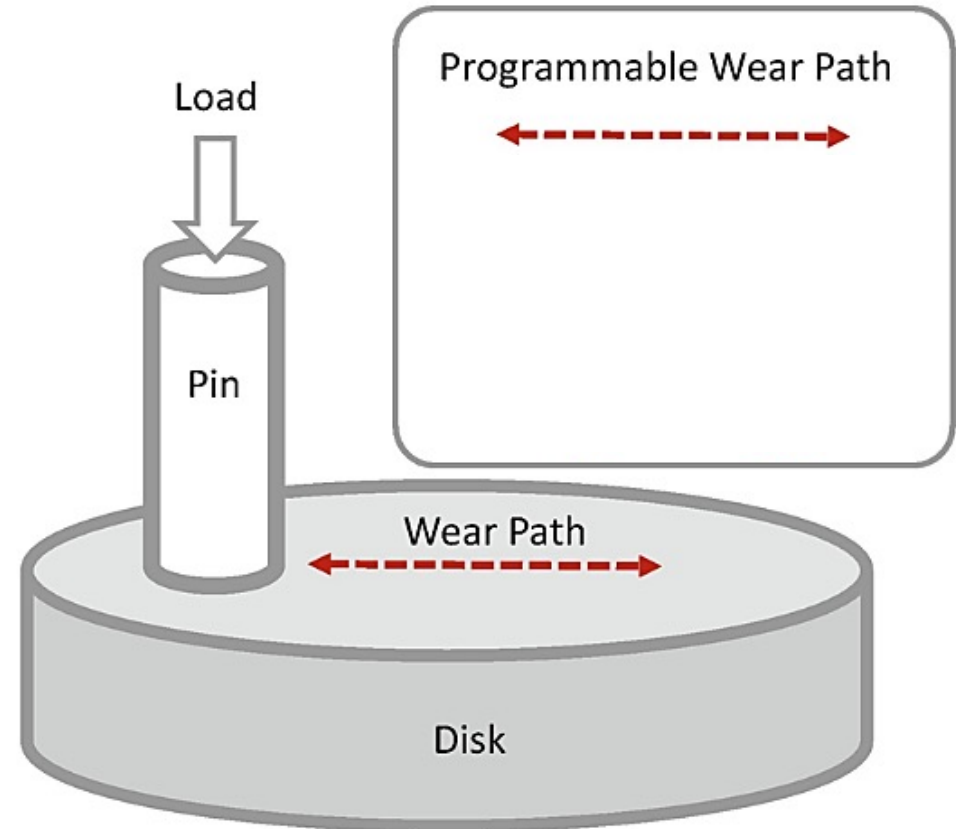
Hip simulator

- Composition:
  - Diluted calf serum
  - Deionized water
  - Proteins concentration: 3 g/dl
  - Filtration by a 0.2  $\mu\text{m}$  filter
  - Antimicrobial reagent:  
Sodium azide

# PIN-ON-DISC

- For a first material evaluation, there is a need for screening tests with the following characteristics:
  - Same wear mechanism
  - Same amount of wear
- First standardized tests were developed in the early 80's (ASTM F-732).

# PIN-ON-DISC



# ABRASIVE / ADHESIVE WEAR

## ARCHARD EQUATION

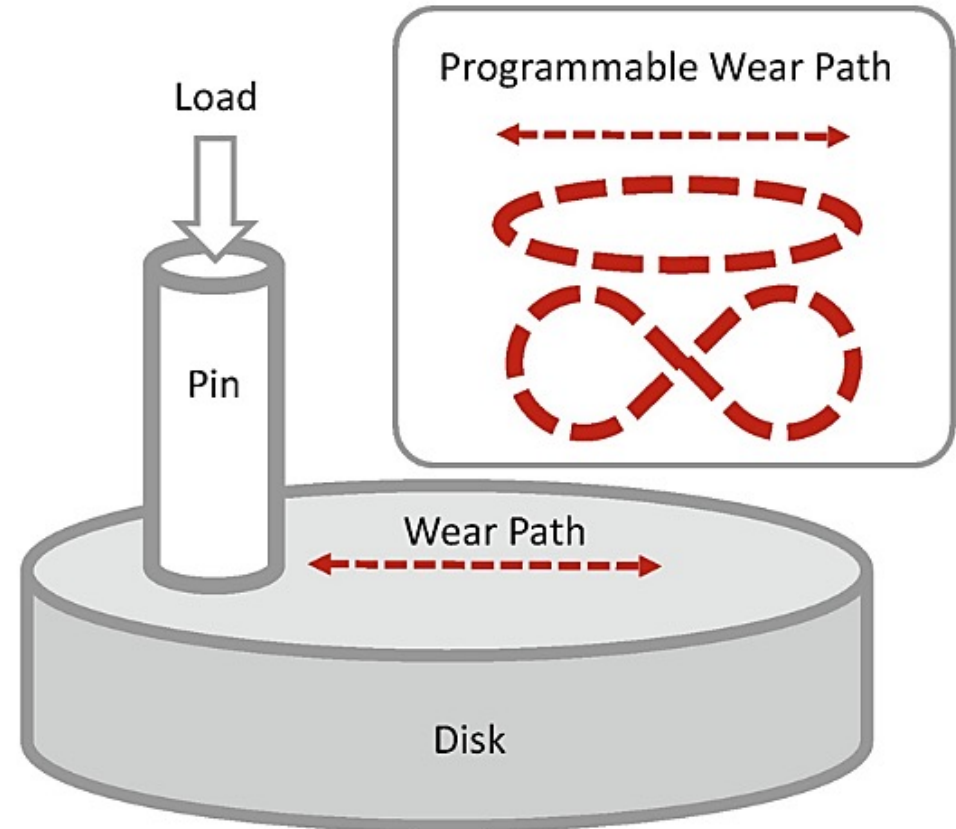
- V: Wear Volume
- L: Normal load
- W: Distance
- H: Hardness
- $K_{\text{Wear}}$ : Wear Factor
  - Abrasive:  $10^{-4} - 10^{-1}$
  - Adhesive:  $10^{-7} - 10^{-2}$

$$V = K_{\text{Wear}} \cdot \frac{WL}{3H}$$

# COMPARATIVE STUDY OF THE WEAR OF UHMWPE WITH ZRO<sub>2</sub> AND STAINLESS STEEL FEMORAL HEADS IN ARTIFICIAL HIP JOINTS

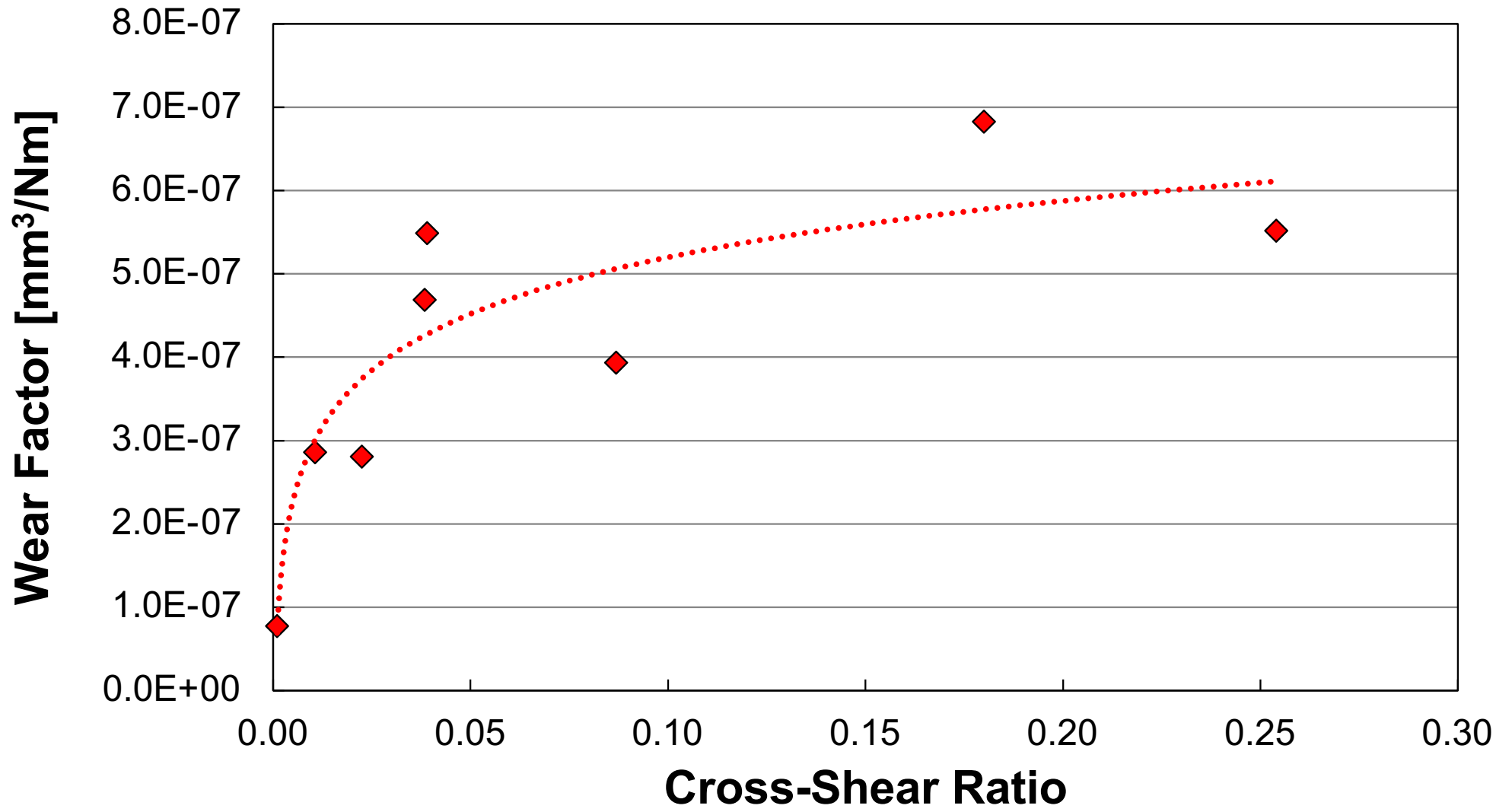
- In-vitro wear factors: about  $10^{-8}$  mm<sup>3</sup>/Nm
- In-vivo wear factors: about  $10^{-6}$  mm<sup>3</sup>/Nm
- B. Derbyshire et al, Med Eng Phys, 16, 1994, p. 229

# PIN-ON-DISC



# QUANTIFICATION OF THE EFFECT OF CROSS-SHEAR ON THE WEAR OF CONVENTIONAL AND XLPE UHMWPE

- Cross-shear increased the apparent wear factor for both polyethylenes by more than fivefold compared to unidirectional wear.
- L. Kang et al, JoB, 14, 2008, p. 340



# AMTI – HIP SIMULATOR



# AMTI – HIP SIMULATOR



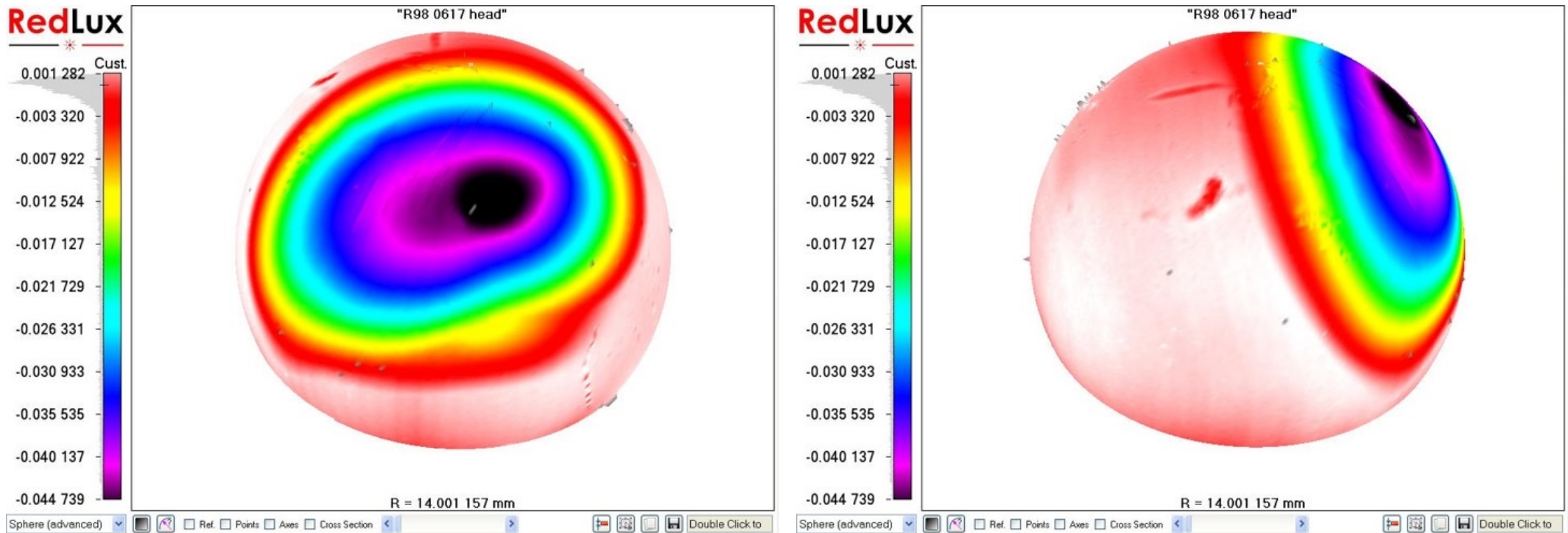
# HIP SIMULATOR

- AMTI – ISO 14'242-1:
  - Flexion - Extension: 25° - 18°
  - Abduction - Adduction: 7° - 4°
  - Int. - Ext. Rotation: 2° - 10°
  - Maximum load (double peak): 3'000 N
  - Temperature: 37 °C
  - Frequency: 1.0 Hz

# HOW TO MEASURE THE WEAR?

- Gravimetric method:
  - High resolution balance (better than 0.2 mg)
  - Fluid absorption
  - Material transfer
- Dimensional method:
  - High resolution method (better than 1  $\mu\text{m}$ )
  - Volume of measurement: 12 – 8 – 8 cm
  - Creep

# OPTICAL SENSOR



800'000 measuring points / 20 nm resolution



ELSEVIER  
SAUNDERS

Orthop Clin N Am 36 (2005) 135 – 142

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ORTHOPEDIC  
CLINICS  
OF NORTH AMERICA

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## Influence of the Clearance on In-Vitro Tribology of Large Diameter Metal-on-Metal Articulations Pertaining to Resurfacing Hip Implants

Claude B. Rieker, PhD<sup>a,\*</sup>, Rolf Schön<sup>a</sup>, Reto Konrad<sup>a</sup>, Gernot Liebentritt<sup>a</sup>,  
Patric Gnepf<sup>a</sup>, Ming Shen<sup>a</sup>, Paul Roberts, MA(Oxon), MB, FRCS<sup>b</sup>,  
Peter Grigoris, FRCS, FACS<sup>c,d</sup>

<sup>a</sup>*Tribology–113 955, Zimmer Europe GmbH, Sulzer Allee 8, CH 8404 Winterthur, Switzerland*

<sup>b</sup>*Department of Orthopaedics and Trauma, Royal Gwent Hospital, Cardiff Road, Newport NP9 2UB, Wales, UK*

<sup>c</sup>*2nd Orthopaedic Department, University of Athens, Ag. Olga Hospital, 142 33 N. Ionia, Athens, Greece*

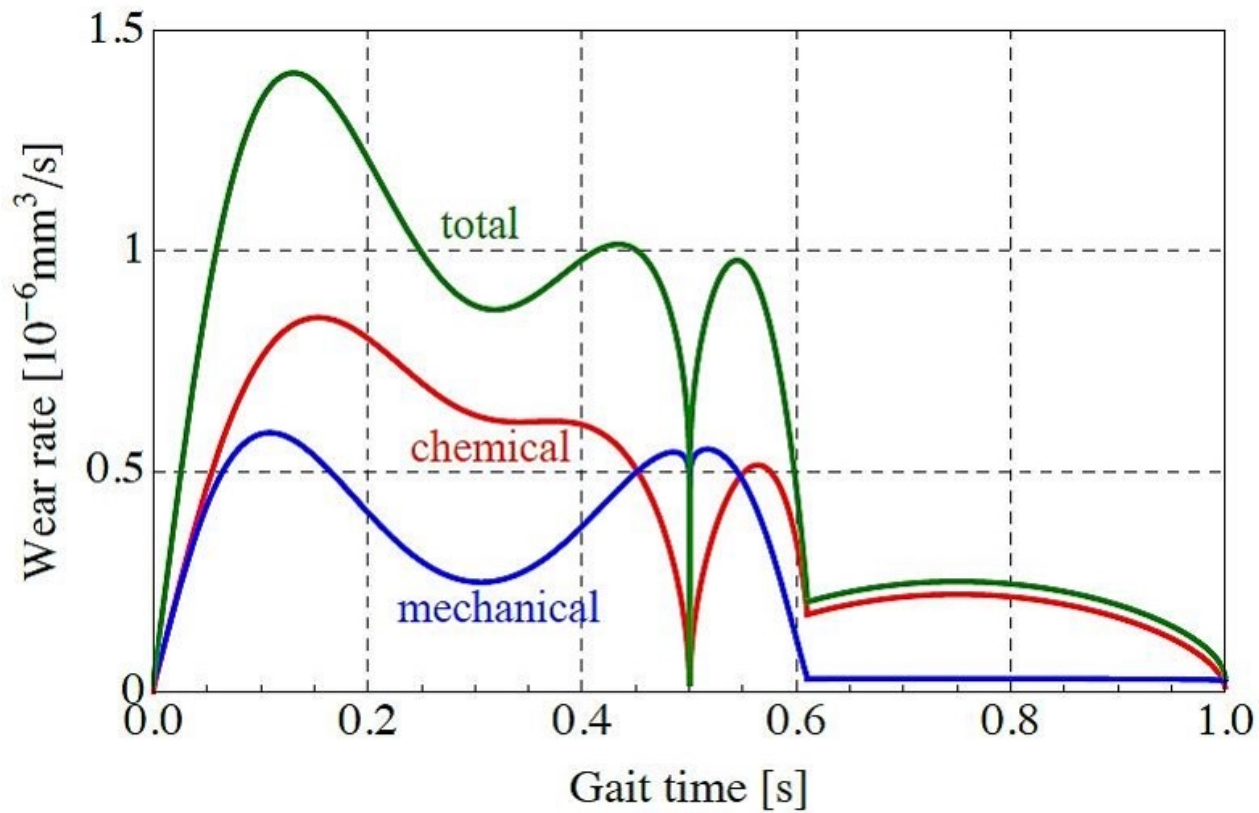
<sup>d</sup>*Department of Medical Engineering, School of Engineering, Design, and Technology, University of Bradford, Richmond Road, Bradford, West Yorkshire BD7 1DP, UK*

# TRIBOCORROSION

Shoufan CAO

Tribocorrosion under fluid lubrication:  
Modeling wear of CoCrMo artificial hip joints

Thèse N° 7433



École  
Polytechnique  
Fédérale  
de Lausanne

2016



# Rationalizing the in-vivo degradation of metal-on-metal artificial hip joints using tribocorrosion concepts

Shoufan Cao,<sup>1\*</sup> Anna Igual Muñoz<sup>1,2</sup>, and Stefano Mischler<sup>1</sup>

<sup>1</sup> *Ecole Polytechnique Fédérale de Lausanne (EPFL), Tribology and Interface Chemistry Group (SCI-STI-SM), Station 12, CH-1015 Lausanne, Switzerland*

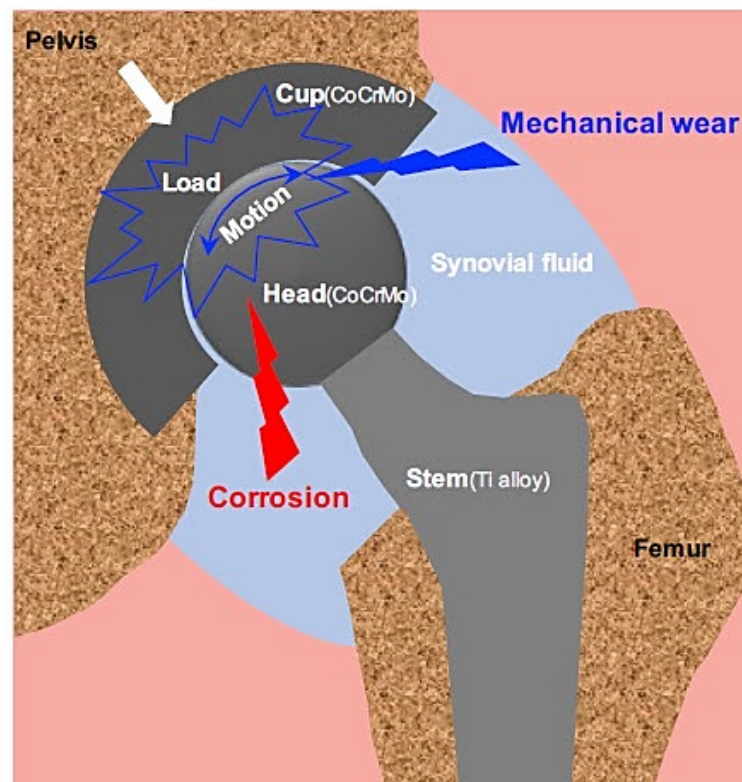
<sup>2</sup> *Universitat Politècnica de València (UPV), Research Institute for Industrial, Radiophysical and Environmental Safety (ISIRYM), Camino de Vera s.n. 46022, Valencia, Spain*

\*Corresponding author. Telephone: +41 21 6932948. E-mail: shoufan.cao@epfl.ch.

## ARTICLE INFO

### Article history:

Received Day Month Year  
Accepted Day Month Year  
Available Day Month Year



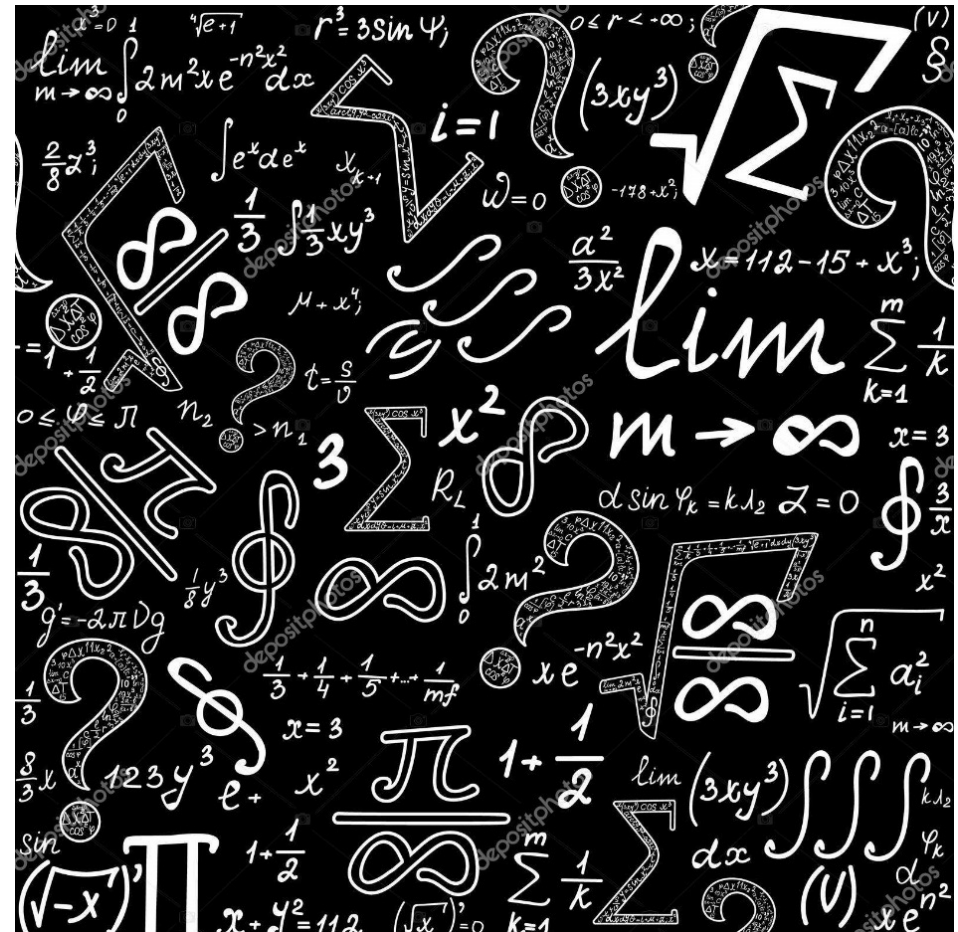
# HIP SIMULATOR

- Open questions:
  - Acetabular Liner/Shell Angle
  - Third Body Particles
  - Changing Load Parameters
  - Stop-Dwell-Start (Stiction)
  - Microseparation
  - Corrosion
  - ...



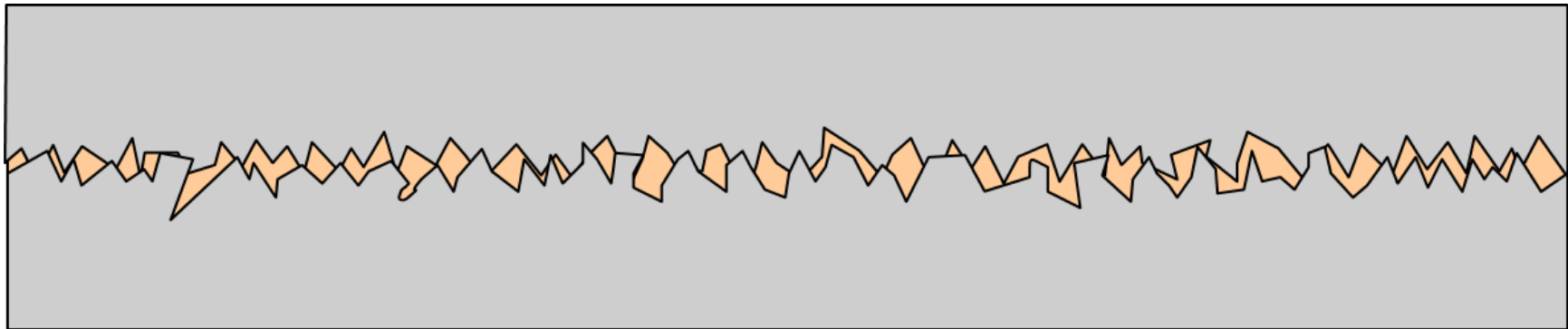
# ANALYTIC APPROACH?

- Difficult to the (too) large number of parameters
- The wear and the friction are controlled by the whole system



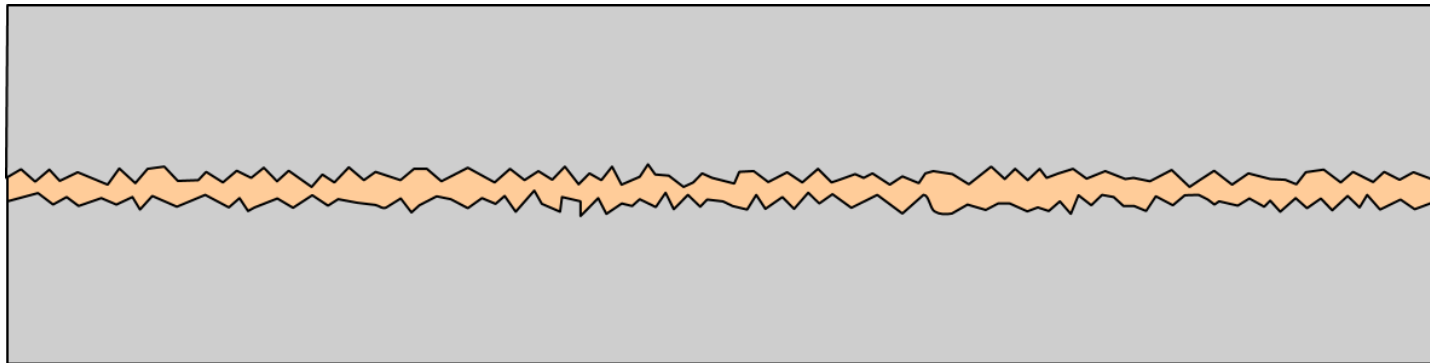
# BOUNDARY LUBRICATION

- The thickness of the lubricant is not high enough to avoid a contact between the head and the cup.



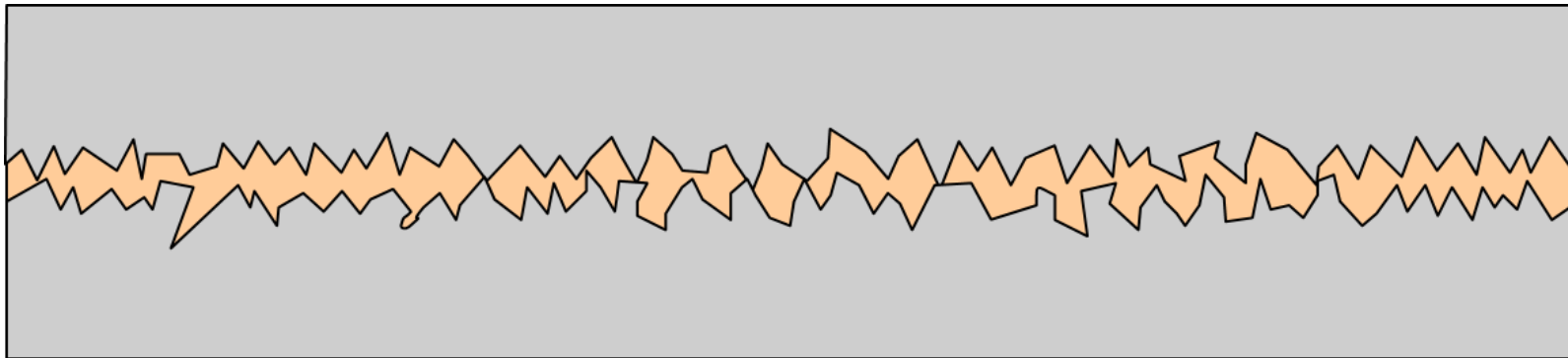
# FLUID FILM LUBRICATION

- The thickness of the lubricant is high enough to avoid a contact between the head and the cup.



# MIXED LUBRICATION

- Intermediate situation between the boundary and fluid film lubrication.



# LUBRICATION OF HARD-ON-HARD ARTICULATIONS

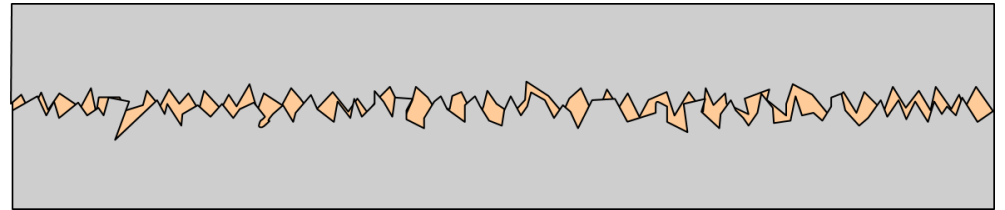
- The lambda coefficient  $\lambda$  describes the lubrication mode:

$$\lambda = \frac{h_c}{\sqrt{R_{qCup}^2 + R_{qHead}^2}}$$

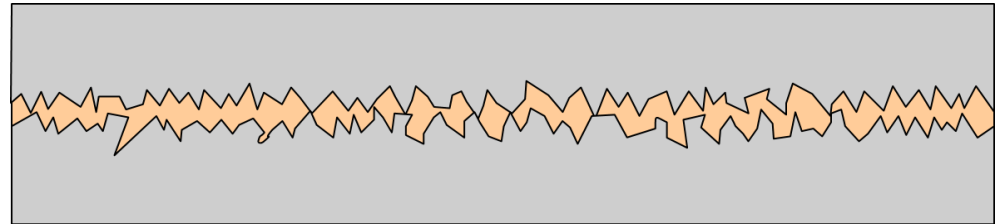
- $h_c$ : Central film thickness
- $R_q$ : Root mean square roughness

# MODE OF LUBRICATION

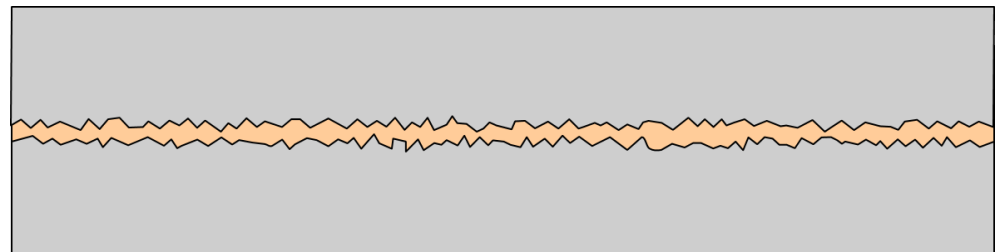
- Boundary lubrication  
 $\Lambda < 1$



- 
- Mixed lubrication  
 $1 < \Lambda < 3$



- 
- Fluid film lubrication  
 $\Lambda > 3$



# LUBRICATION OF HARD-ON-HARD ARTICULATIONS

- The lambda coefficient  $\lambda$  describes the lubrication mode:

$$\lambda = \frac{h_c}{\sqrt{R_{qCup}^2 + R_{qHead}^2}}$$

- $h_c$ : Central film thickness
- $R_q$ : Root mean square roughness

# FILM THICKNESS

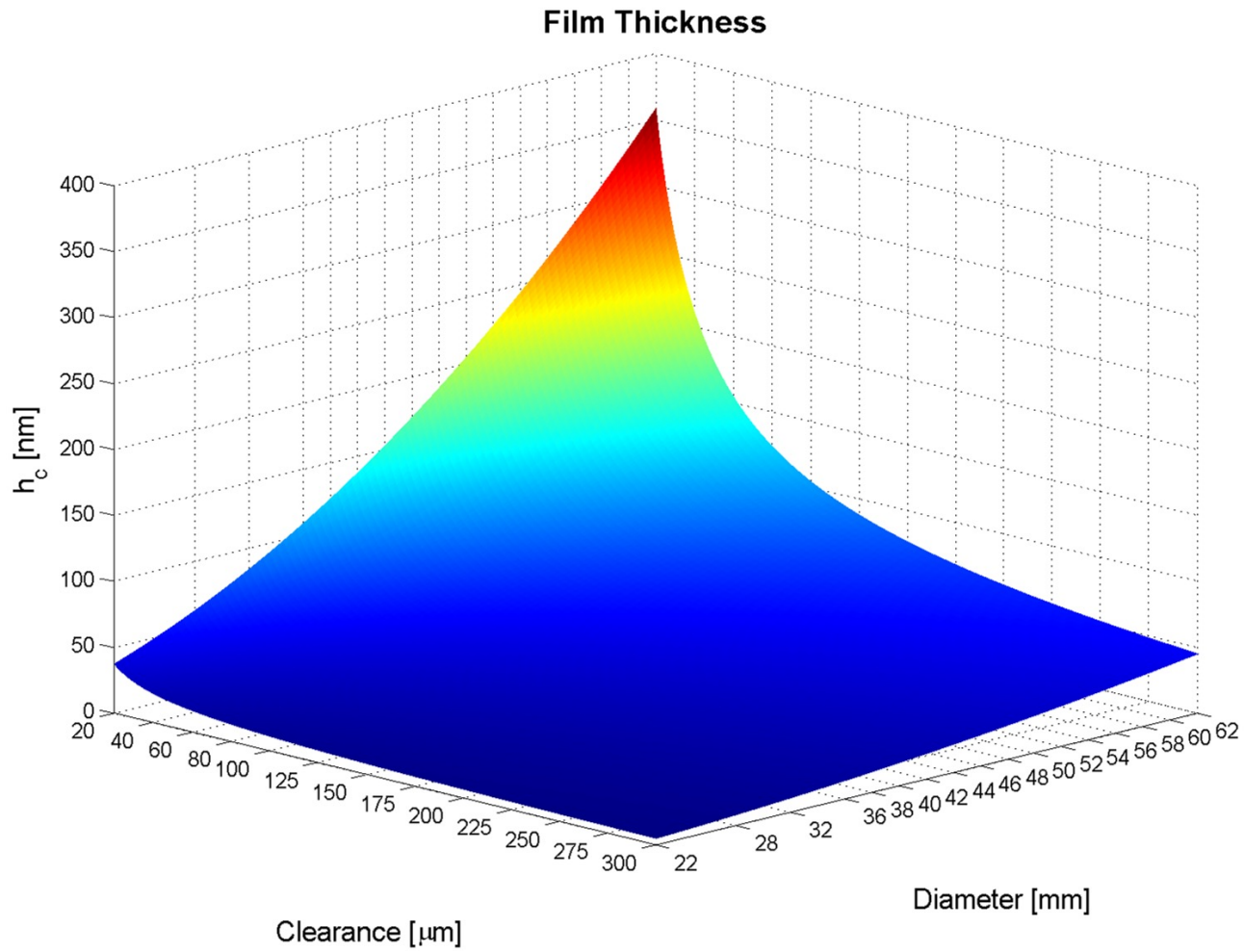
- Hamrock - Dowson equation (1978):

$$h_c = 2.80R \left( \frac{nu}{E'R} \right)^{0.65} \left( \frac{w}{E'R^2} \right)^{-0.21}$$

- $h_c$ : Central film thickness
- $R$ : Relative radius
- $n$ : Viscosity

- $u$ : Relative velocity
- $E'$ : Equivalent elastic modulus
- $w$ : Load

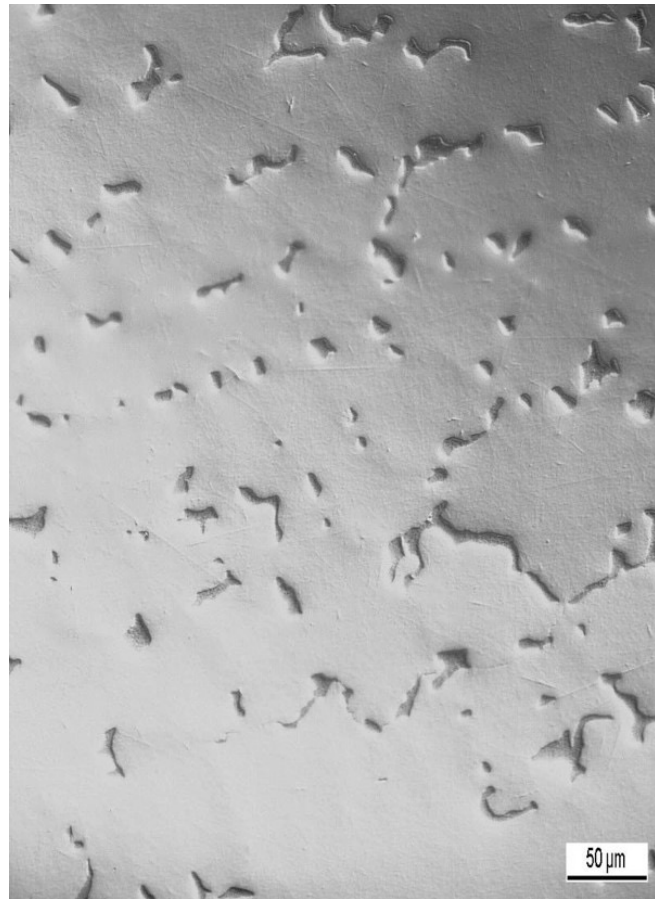
# LUBRICATION



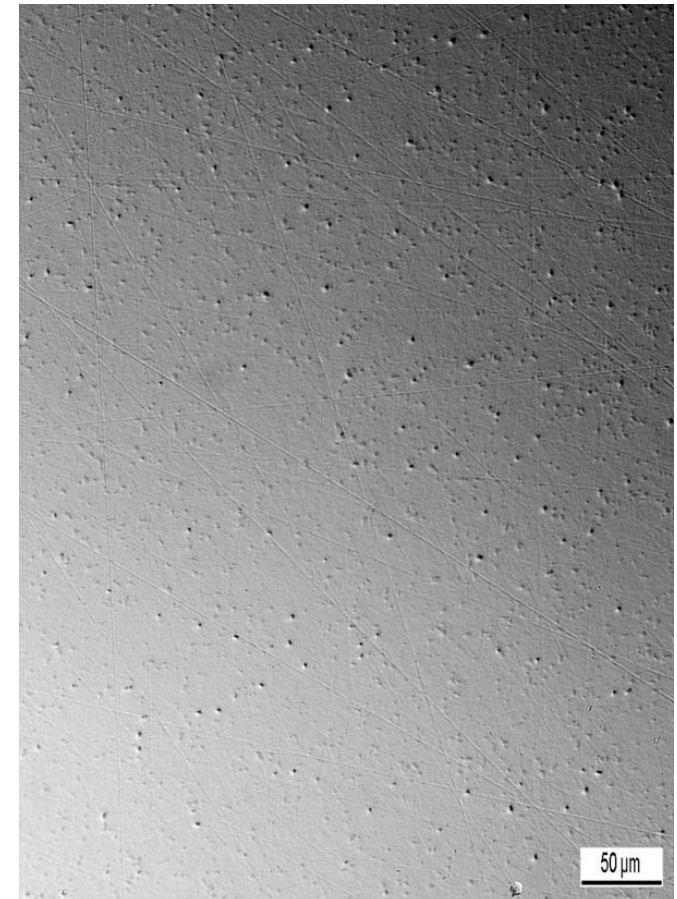
Load: 3000 N

Viscosity: 0.005 Pas

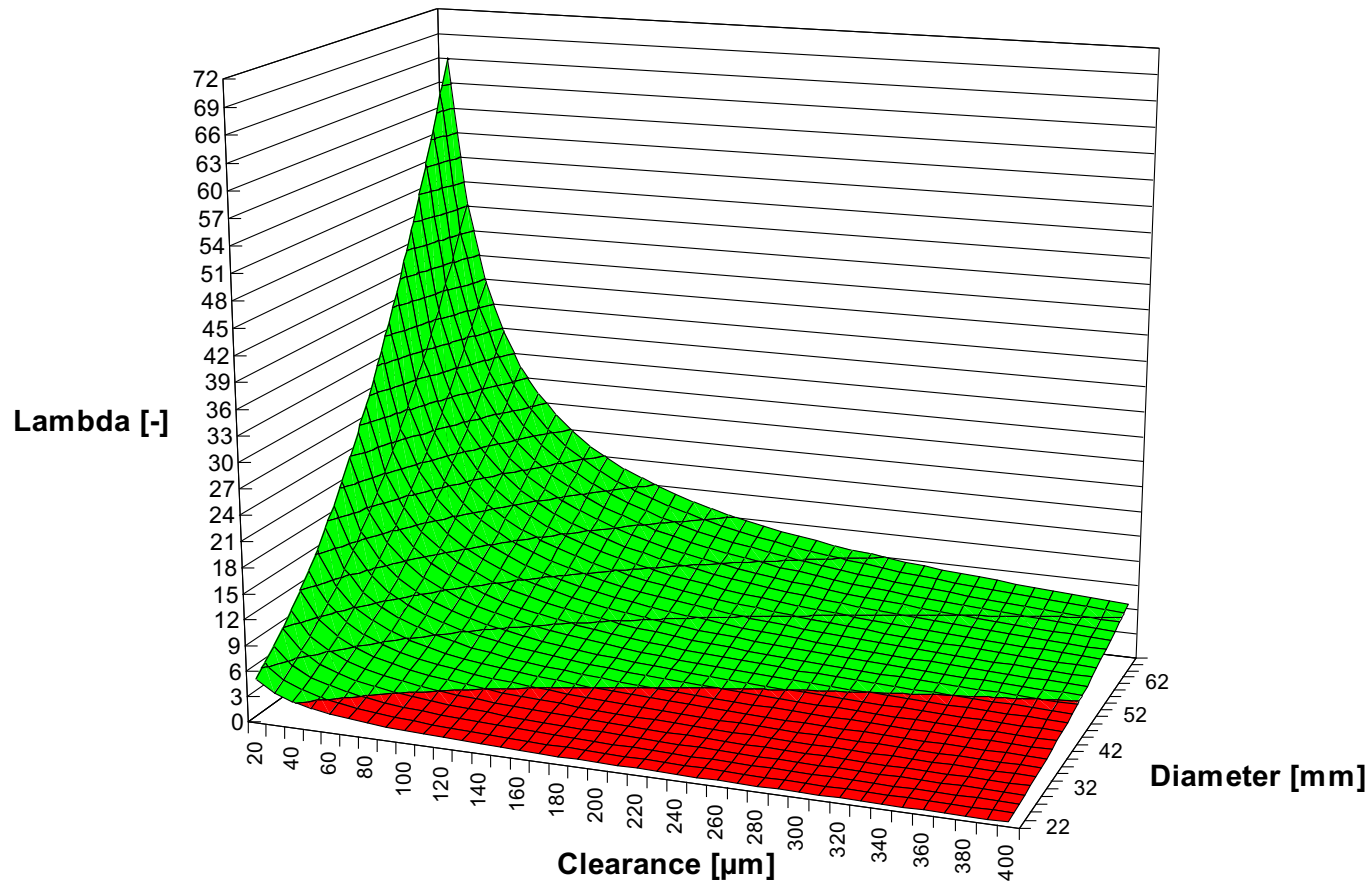
# CAST CoCrMo ALLOY



# WROUGHT CoCrMo ALLOY



# LAMBDA COEFFICIENT

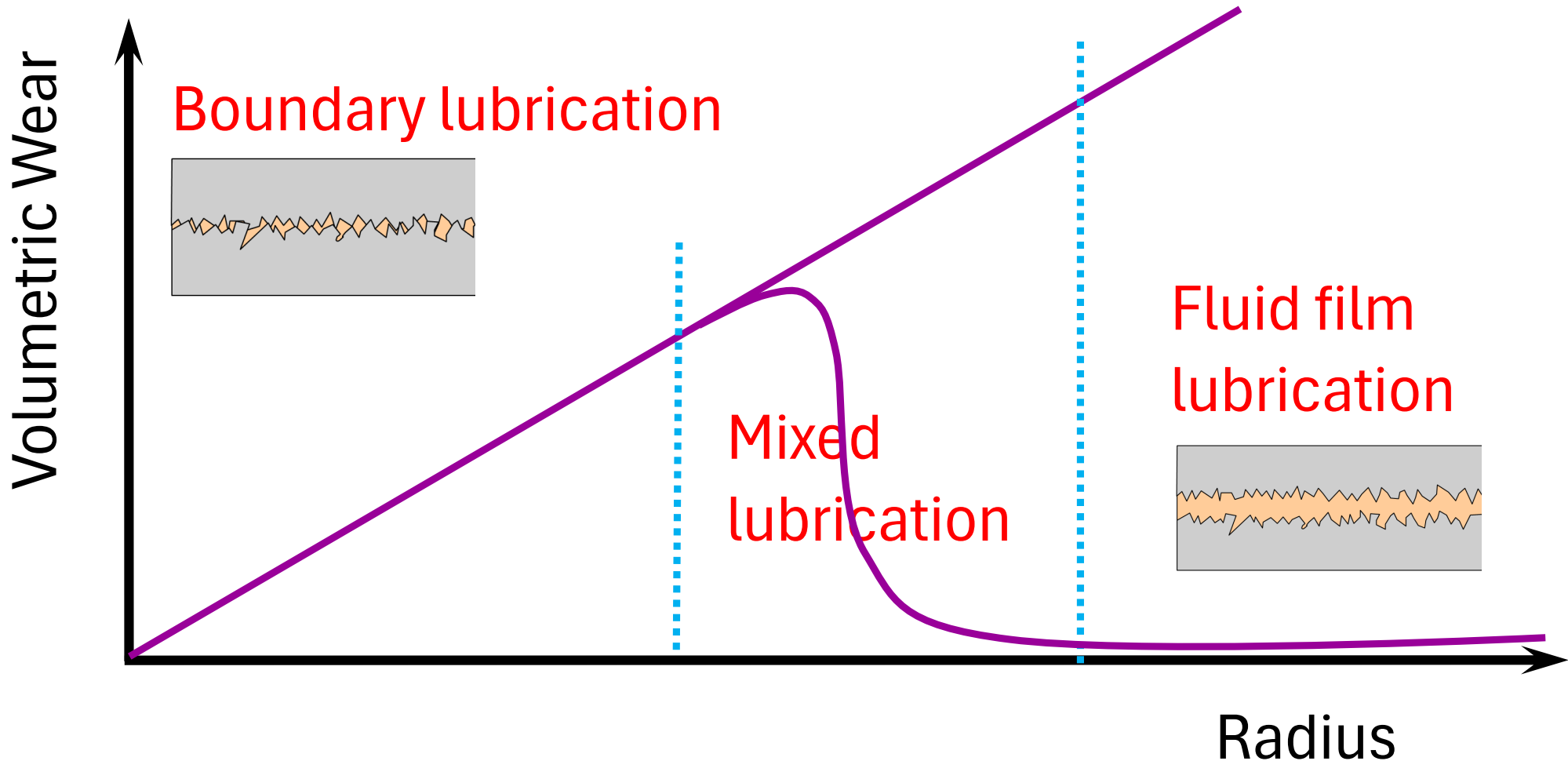


Roughness  $R_a$ : 4 nm

Roughness  $R_q$ : 5 nm

# THE EFFECT OF FEMORAL HEAD DIAMETER UPON LUBRICATION AND WEAR OF METAL-ON-METAL THR

- “This study has demonstrated that the application of sound tribological principles to prosthetic design can reduce the wear of metal-on-metal joints, using currently available materials, to a negligible level.
- S.L. Smith et al, IMechE 215, 2001, p. 1



# LARGE DIAMETER MoM BEARINGS





# THE SUNDAY TIMES

April 18, 2010

## Tumour fear over metal hip replacements

In a group of more than 1,200 patients who had hip resurfacing over an eight-year period, 4% required a further operation because of this reaction, described as "pseudotumours". The Nuffield study said 13% of women under 40 required a new operation.

Justin Cobb, professor of orthopaedic surgery at Imperial College London, said metal-on-metal hip procedures were effective and there was an adverse tissue reaction in only a small number of cases. "It's like a Formula One car. If you don't get the wheels perfectly aligned, you will shed them on the first lap," he said.

# The New York Times

---

September 15, 2011

## **Metal Hips Failing Fast, Report Says**

By **BARRY MEIER**

In a troubling development for people with all-metal artificial hips, a registry that tracks orthopedic implants in Britain reported on Thursday that the failure rate of the devices was increasing.

# Le Monde

## Après les implants mammaires, des prothèses de hanche défectueuses

Le Monde.fr avec AFP | 28.02.2012 à 13h36 • Mis à jour le 09.03.2012 à 11h53

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Imprimer

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Partager    

 Recommander

 Envoyer

 72 personnes le recommandent. [Inscription](#) pour voir ce que vos amis recommandent.

Des centaines de milliers de patients dans le monde pourraient avoir été exposés à des taux importants de métaux toxiques dus à des prothèses de hanche défectueuses, alors que le risque était connu, s'alarment, mardi 28 février, dans une enquête commune le *British Medical Journal* (BMJ) et la BBC.

# Süddeutsche Zeitung

5. März 2012 17:13 Hüftprothesen in der Kritik

## Giftige Gelenke

**Mehr als eine Million Patienten mit künstlichen Hüftgelenken sind von einem neuen Medizinskandal betroffen. Ihre Metall-Prothesen können Ionen freisetzen, die Schmerzen auslösen, Organe schädigen und das Krebsrisiko erhöhen. Skandalträchtig ist vor allem: Die Gefahren sind seit Jahrzehnten bekannt.**

Australian Orthopaedic  
Association  
National Joint  
Replacement Registry

2025 SUPPLEMENTARY REPORT

Metal/Metal  
Bearing Surface in  
Total Conventional  
Hip Arthroplasty

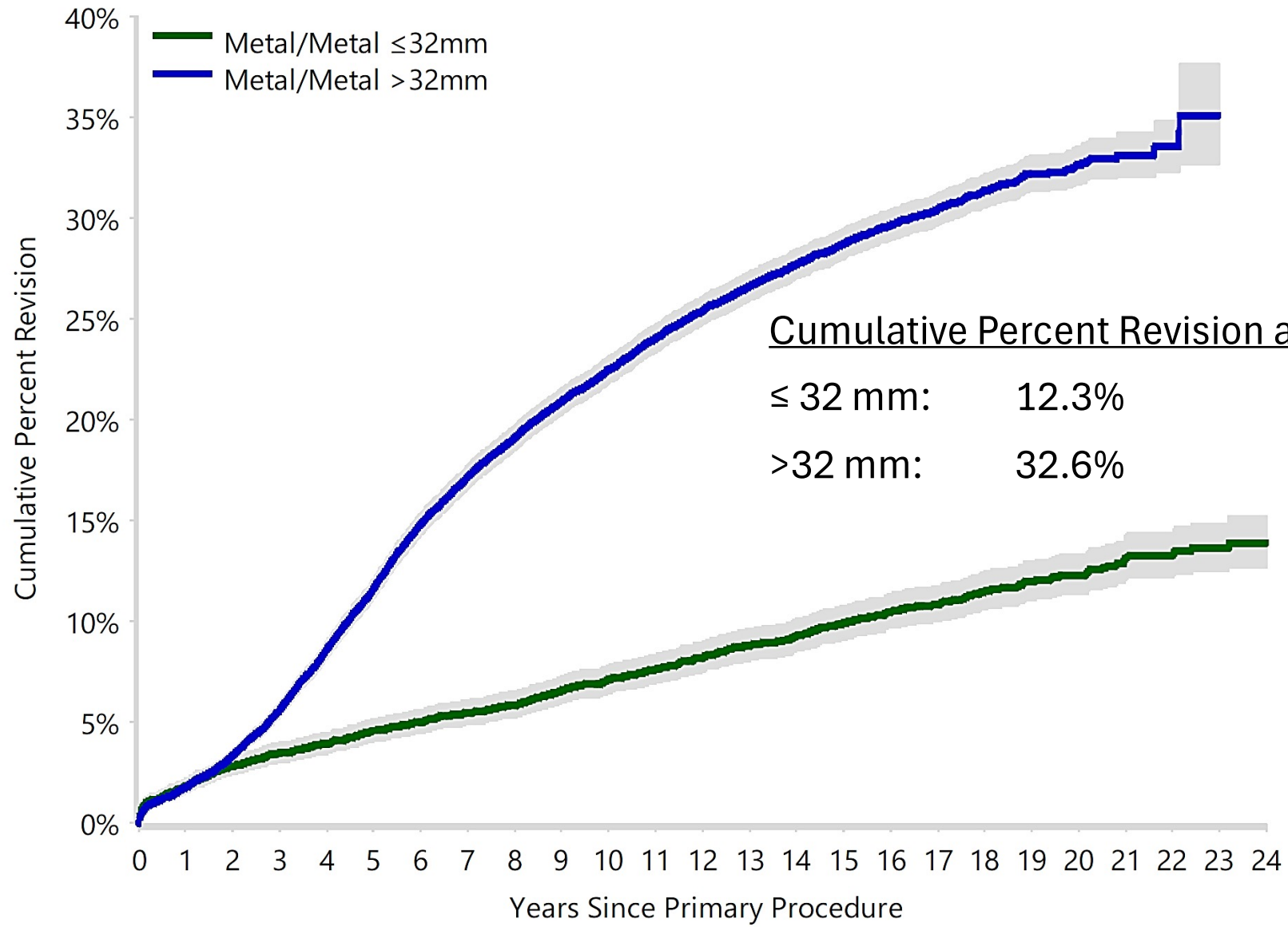


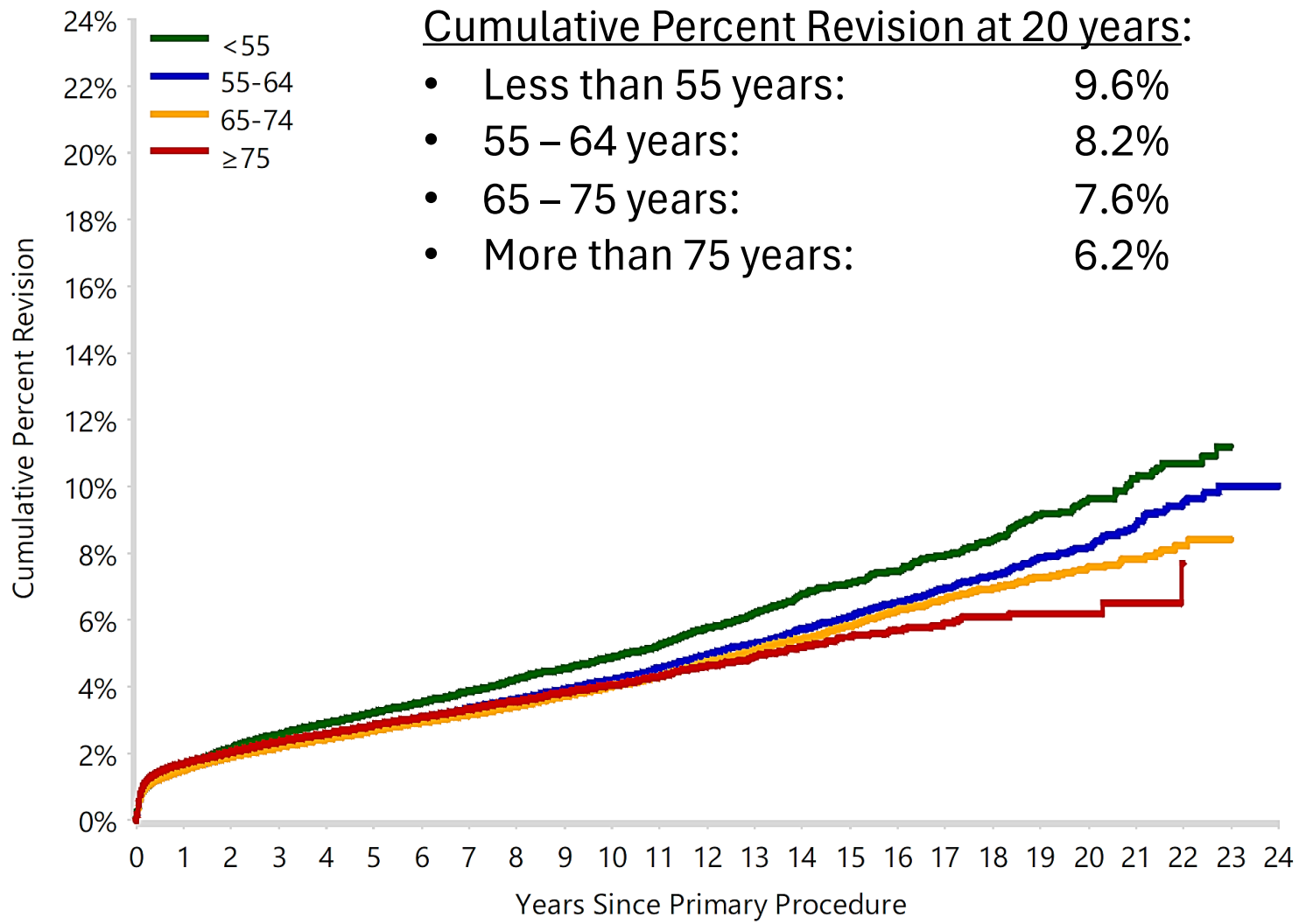
Australian  
Orthopaedic  
Association  
National  
Joint  
Replacement  
Registry

<https://doi.org/10.25310/XWDY3281>

# AUSTRALIAN REGISTRY 2025

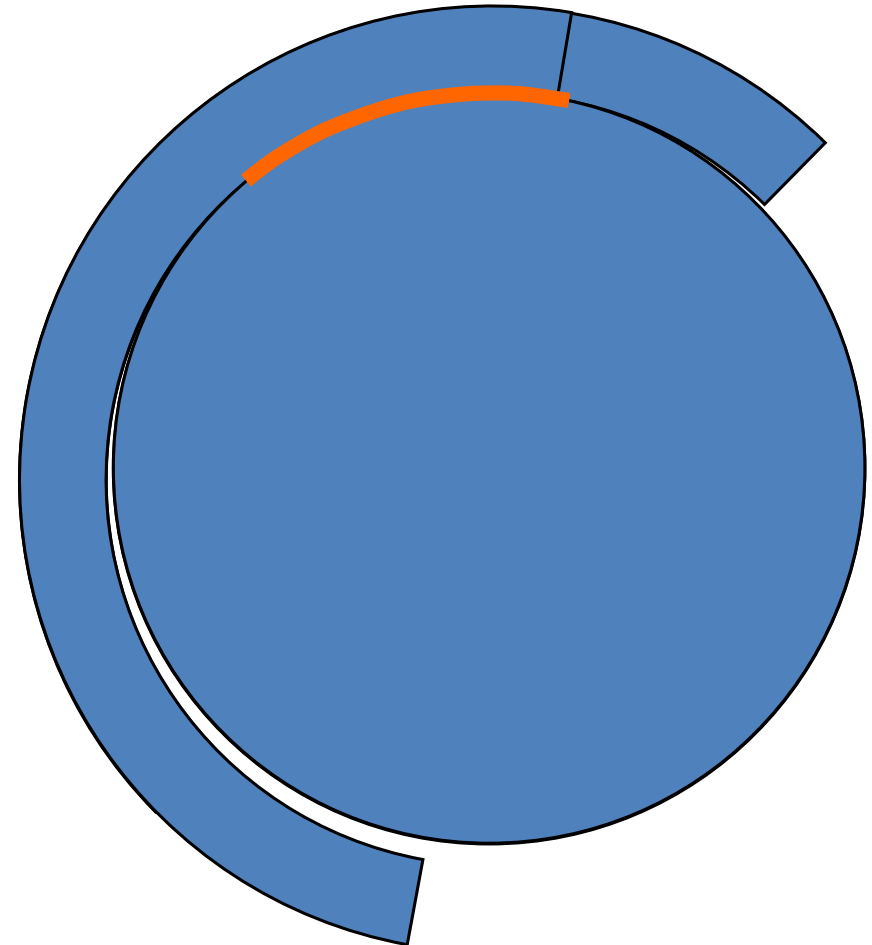
Figure MM2:  
Cumulative Percent Revision of  
Metal/Metal Primary Total  
Conventional Hip Replacement  
by Head Size





# LARGE DIAMETER MoM BEARINGS

Loss of fluid lubrication?

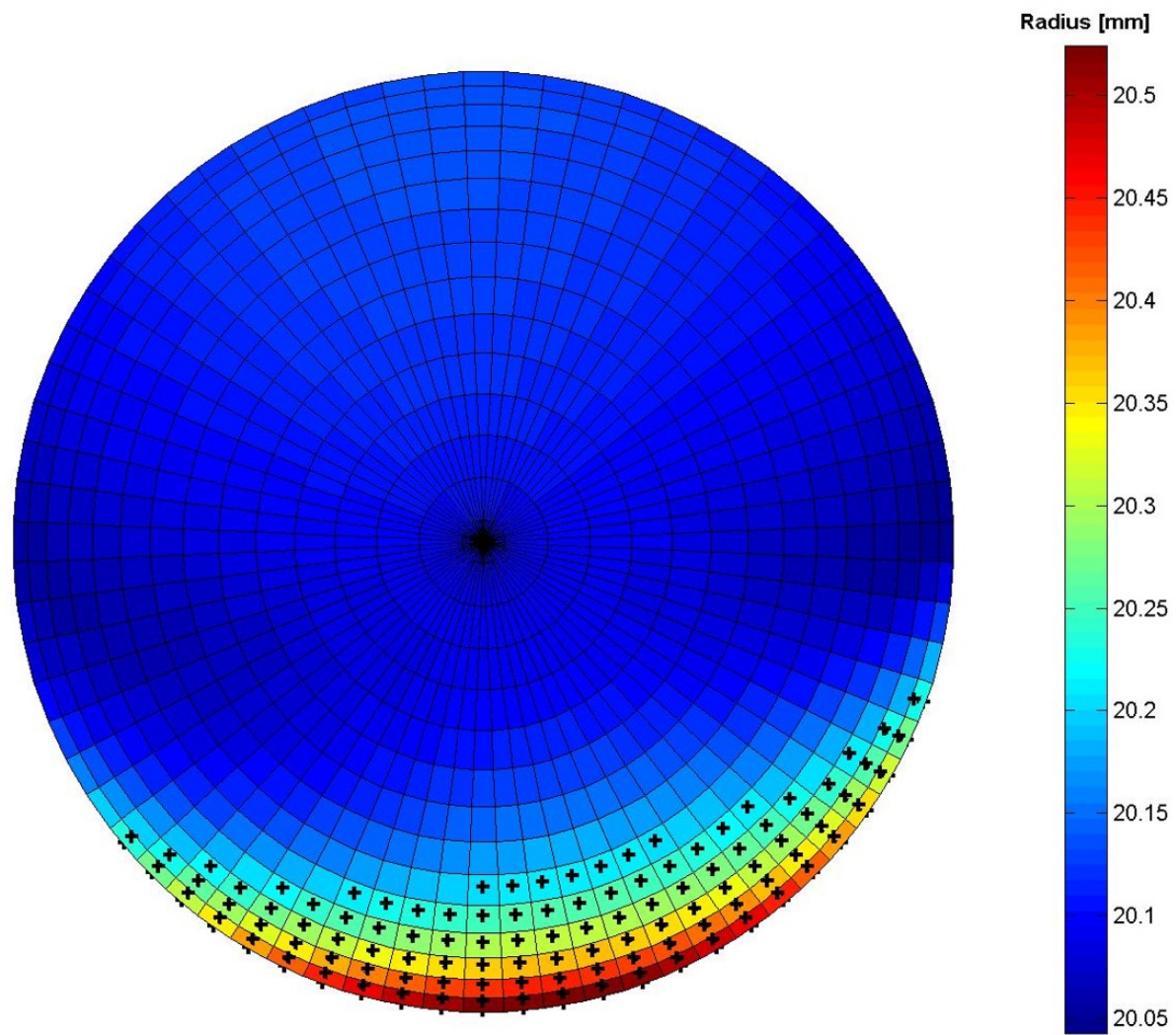


# EDGE WEAR

- 40 mm metal-on-metal bearing
- Inclination: About 55°
- Women: 48 years old
- Time in-vivo: 5.6 years





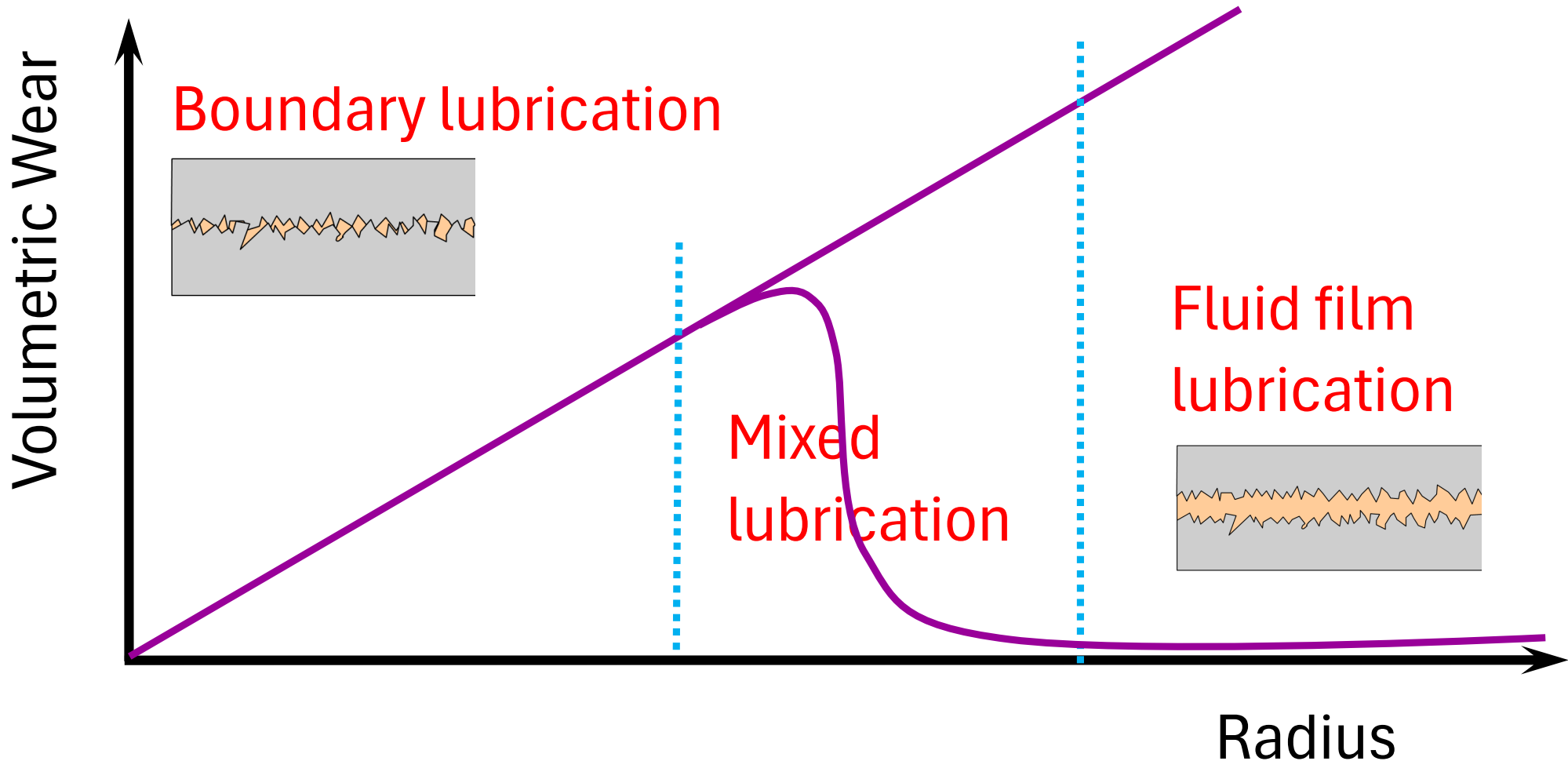


1009 points | 0 artifacts | 107 in wear zone  
Linear wear 481.1  $\mu\text{m}$  | 86.2  $\mu\text{m/a}$   
Volum. wear 51.7922  $\text{mm}^3$

# EDGE WEAR

- Volumetric wear of the head:  
58.8 mm<sup>3</sup>
- Volumetric wear of the cup:  
51.8 mm<sup>3</sup>
- Volumetric wear rate:  
19.8 mm<sup>3</sup>/year

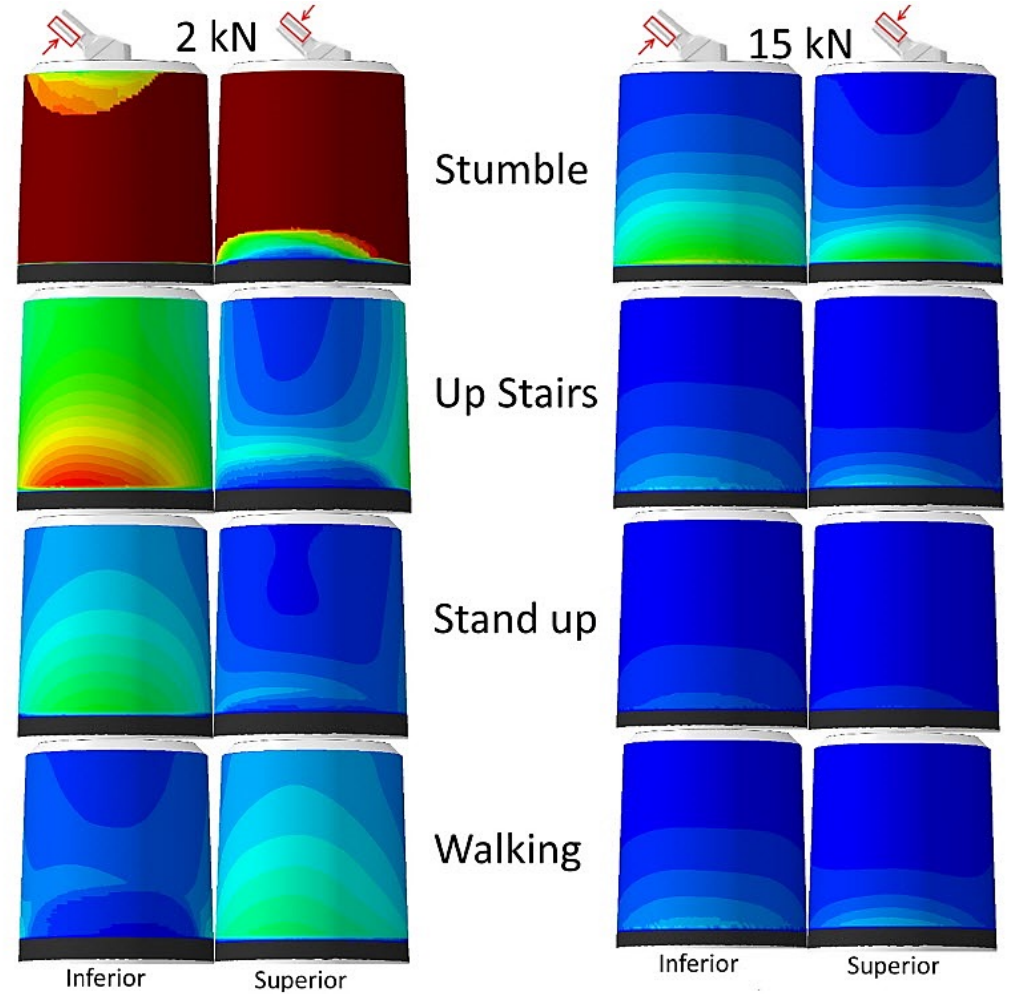
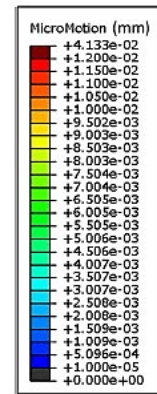




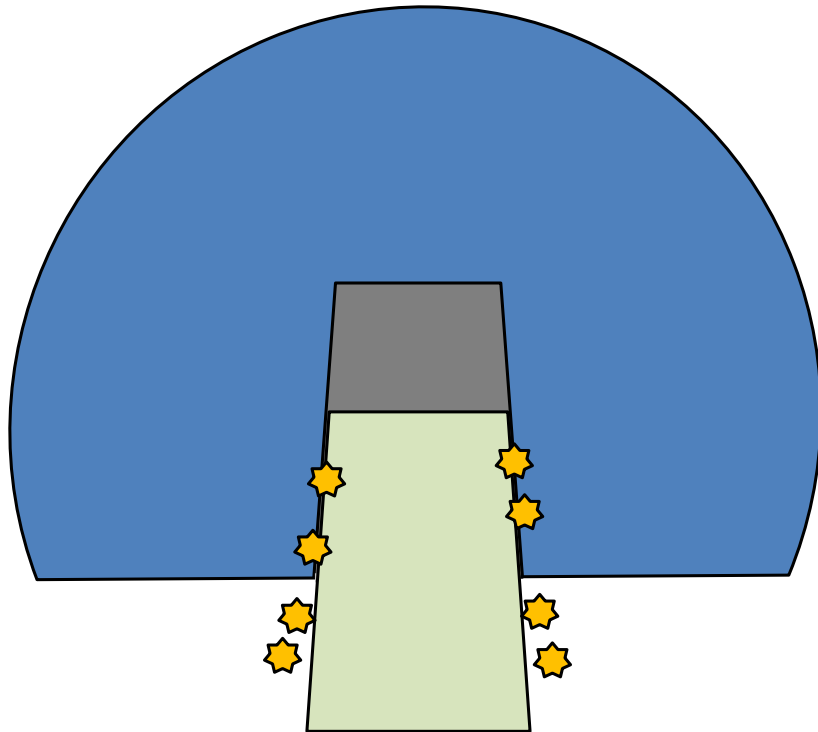
# BIOLOGIC REACTIONS

- Loss of fluid lubrication
- Without a fluid lubrication, the amount of volumetric wear / friction are increasing with large diameter bearings.

# TAPER CONNECTIONS

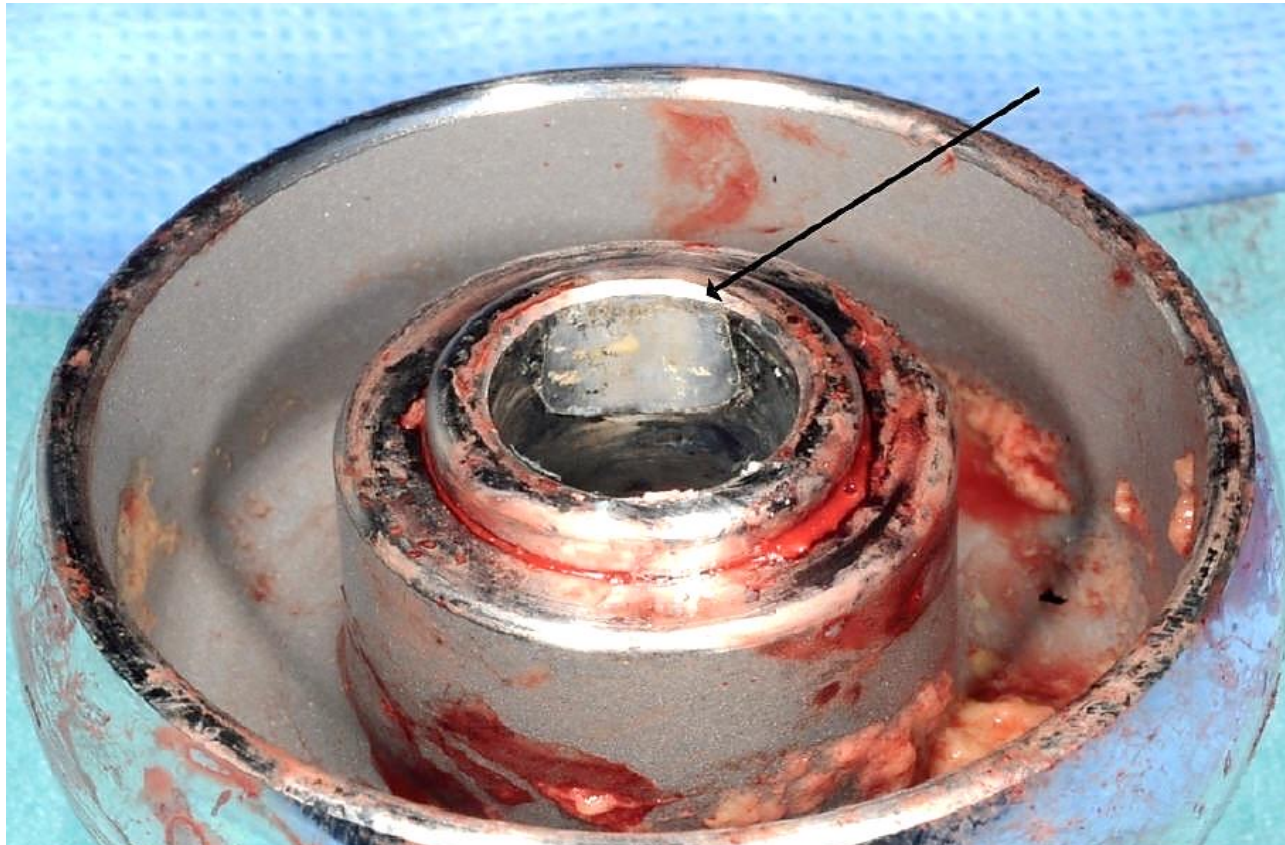


# TAPER CONNECTIONS



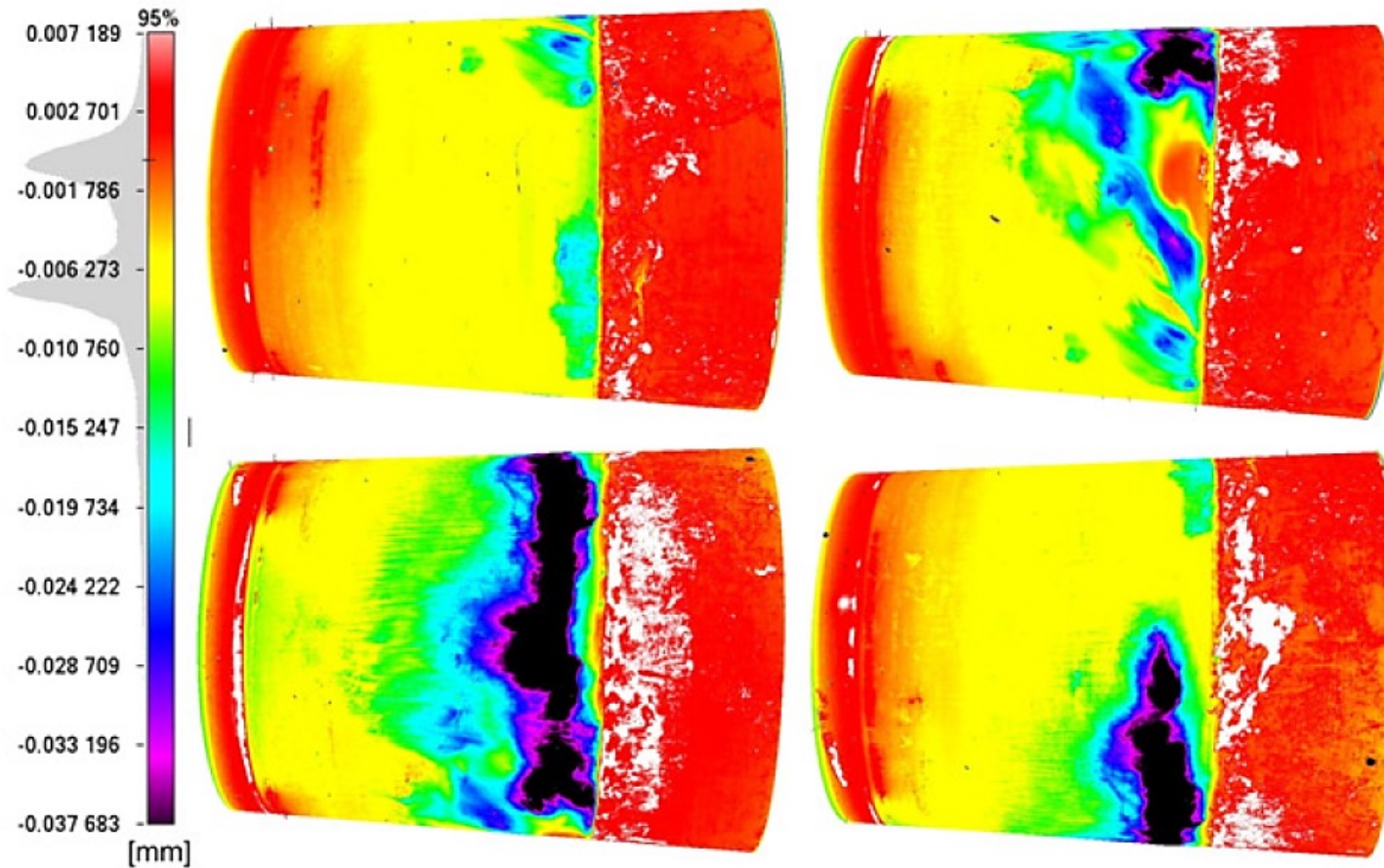
- Impaction forces
  - Mallet
  - Direction
  - Number of impacts
  - ...
- Cleanness of the taper?
- Wet or dry?
- Geometry
- Head size
- Roughness
- ...

# LARGE DIAMETER MoM BEARINGS



F.S. Haddad et al, JBJS 93B, 2011, p. 572

# LARGE DIAMETER MoP BEARINGS



R.B. Cook et al, JoA, 2013, 28, p. 1430

# SMALL DIAMETER MoP BEARINGS



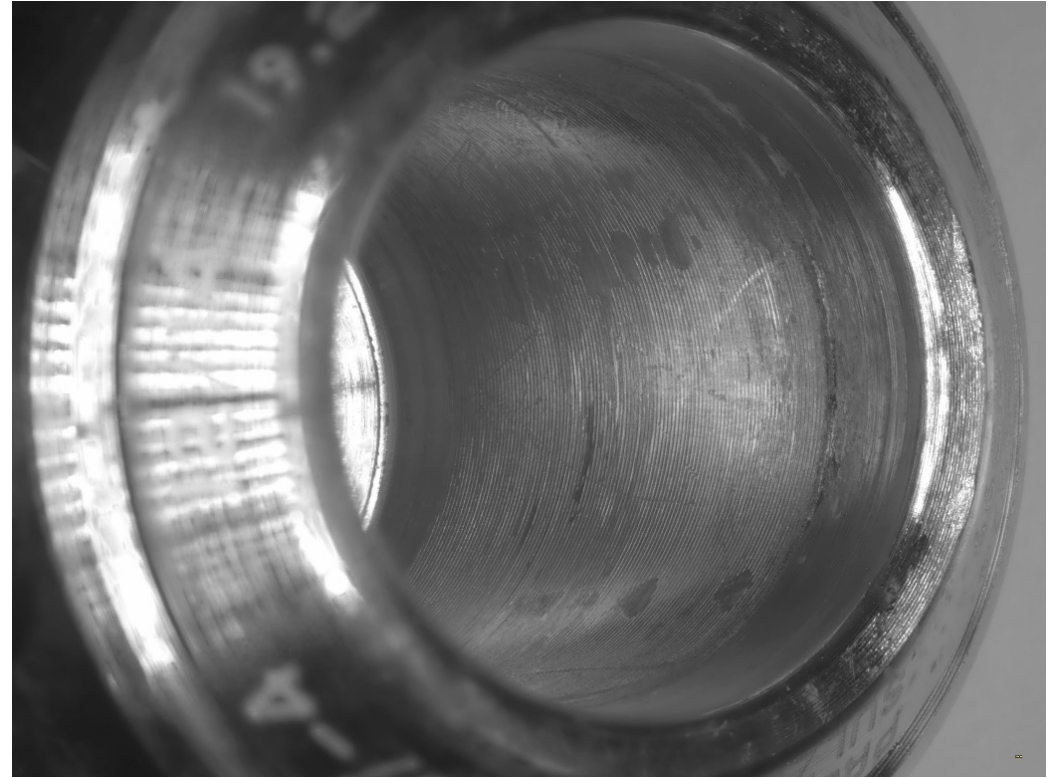
M. Kiran et al, JoA, 30, 2015, p. 277

# MODULAR NECKS



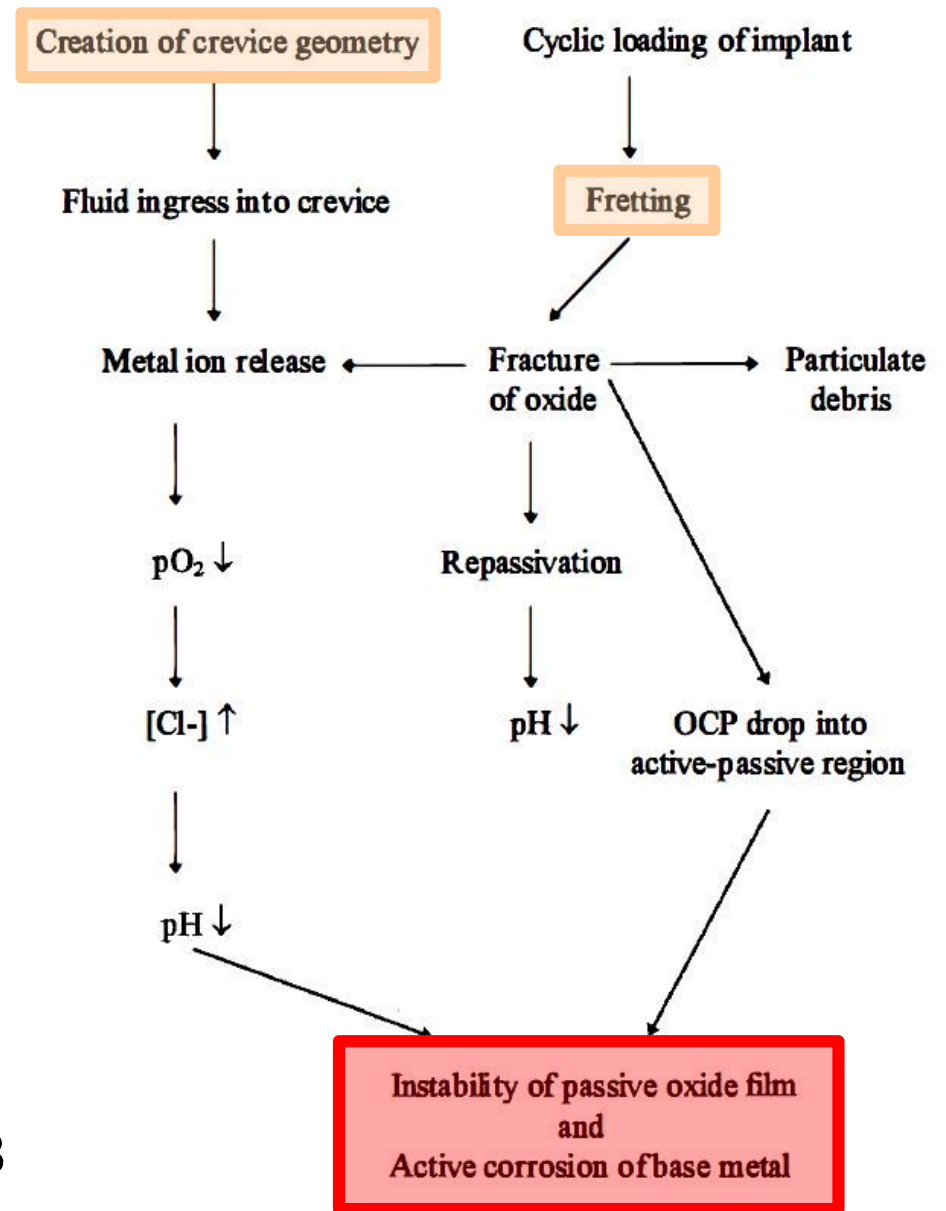
D.O. Molloy et al, JBJS, 2014, 96A, p. 488

# “IMPRINTING”



# MACC MECHANICALLY ASSISTED CREVICE CORROSION

J.L. Gilbert, JBMR, 27, 1993, p. 1533



# FRETTING CORROSION OR CREVICE CORROSION?

Angela BERMUDEZ CASTAÑEDA

Degradation of modular hip joint implants.  
A corrosion and tribocorrosion approach

Thèse N° 8591

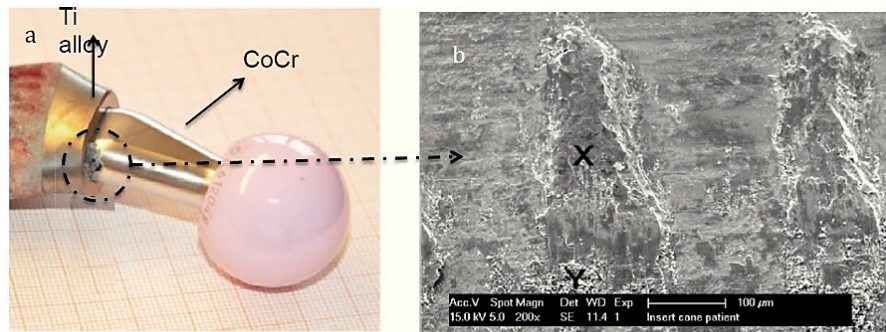


Figure 1-5. a) Modular hip joint explanted with fretting corrosion at the femoral stem-neck junction b) tribofilm found on the neck junction, image adapted from Gkagkalis et al [31].

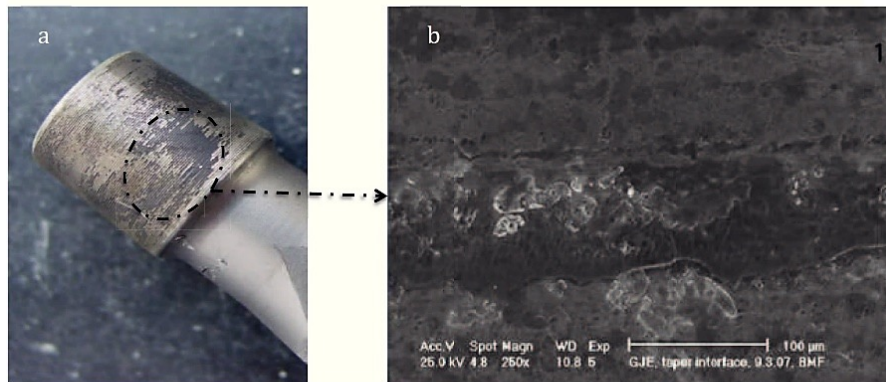


Figure 1-6. a) Tapered neck from modular hip joint implants with signs of damage, b) Scanning electron microscopy of the cone [33]

École  
Polytechnique  
Fédérale  
de Lausanne

2018



# FRETTING CORROSION OR CREVICE CORROSION?

- “Therefore, based on these results, the attention should be focus on fretting-corrosion.”
- A. Bermudez-Castañeda, Thesis 8591, EPFL, 2018

Angela BERMUDEZ CASTAÑEDA

Degradation of modular hip joint implants.  
A corrosion and tribocorrosion approach

Thèse N° 8591

École  
Polytechnique  
Fédérale  
de Lausanne

2018



Article

# A Crevice Corrosion Model for Biomedical Trunnion Geometries and Surfaces Feature

Angela Bermúdez-Castañeda <sup>1,2,\*</sup>, Anna Igual-Muñoz <sup>1</sup> and Stefano Mischler <sup>1</sup> 

<sup>1</sup> Tribology and Interfacial Chemistry Group, EPFL, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland; anna.igualmunoz@epfl.ch (A.I.-M.); stefano.mischler@epfl.ch (S.M.)

<sup>2</sup> Research Group in Sustainable Design in Mechanical Engineering, DSIM, Escuela Colombiana de Ingeniería Julio Garavito, 111166 Bogotá, Colombia

\* Correspondence: angela.bermudez@escuelaing.edu.co; Tel.: +57-305-450-7048

**Abstract:** Modular hip joint implants were introduced in arthroplasty medical procedures because they facilitate the tailoring of patients' anatomy, the use of different materials in one single configuration, as well as medical revision. However, in certain cases, such prostheses may undergo deterioration at the head–neck junctions with negative clinical consequences. Crevice-corrosion is commonly invoked as one of the degradation mechanisms acting at those junctions despite biomed-



Contents lists available at ScienceDirect

## The Journal of Arthroplasty

journal homepage: [www.arthroplastyjournal.org](http://www.arthroplastyjournal.org)



Proceedings of The Hip Society 2022

# Evaluation of Mechanically-Assisted Crevice Corrosion of Different Modular Dual Mobility Constructs



John R. Steele, MD <sup>a, b, 1</sup>, Aarti A. Shenoy, PhD <sup>c, \*</sup>, Ashley Pekmezian <sup>c</sup>,  
Timothy Wright, PhD <sup>c</sup>, Douglas E. Padgett, MD <sup>a</sup>



<sup>a</sup> Adult Reconstruction and Joint Replacement Division, Hospital for Special Surgery, New York, New York

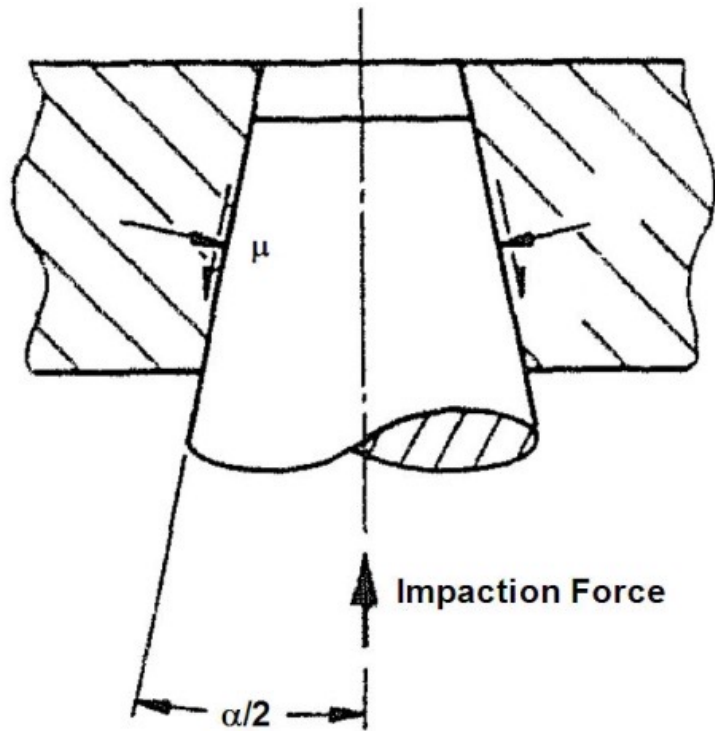
<sup>b</sup> Towson Orthopaedic Associates, Orthopaedic Institute at St. Joseph's Medical Center, Towson, Maryland

<sup>c</sup> Department of Biomechanics, Hospital for Special Surgery, New York, New York

# INFLUENCE OF ASSEMBLY PROCEDURE AND MATERIAL COMBINATION ON THE STRENGTH OF THE TAPER CONNECTION

- “A stable fixation between femoral head and endoprosthesis taper is necessary to prevent relative motions and corrosion at the taper junction.”
- A. Rehmer et al, Clin Biomech, 27, 2012, p. 77

# TAPER CONNECTIONS



$$F_{fixation} = F_{impact} \cdot \frac{\mu \cos(0.5\alpha) - \sin(0.5\alpha)}{\mu \cos(0.5\alpha) + \sin(0.5\alpha)}$$

H. Fessler et al, Journal of Engineering in Medicine, 203, 1989, p. 1

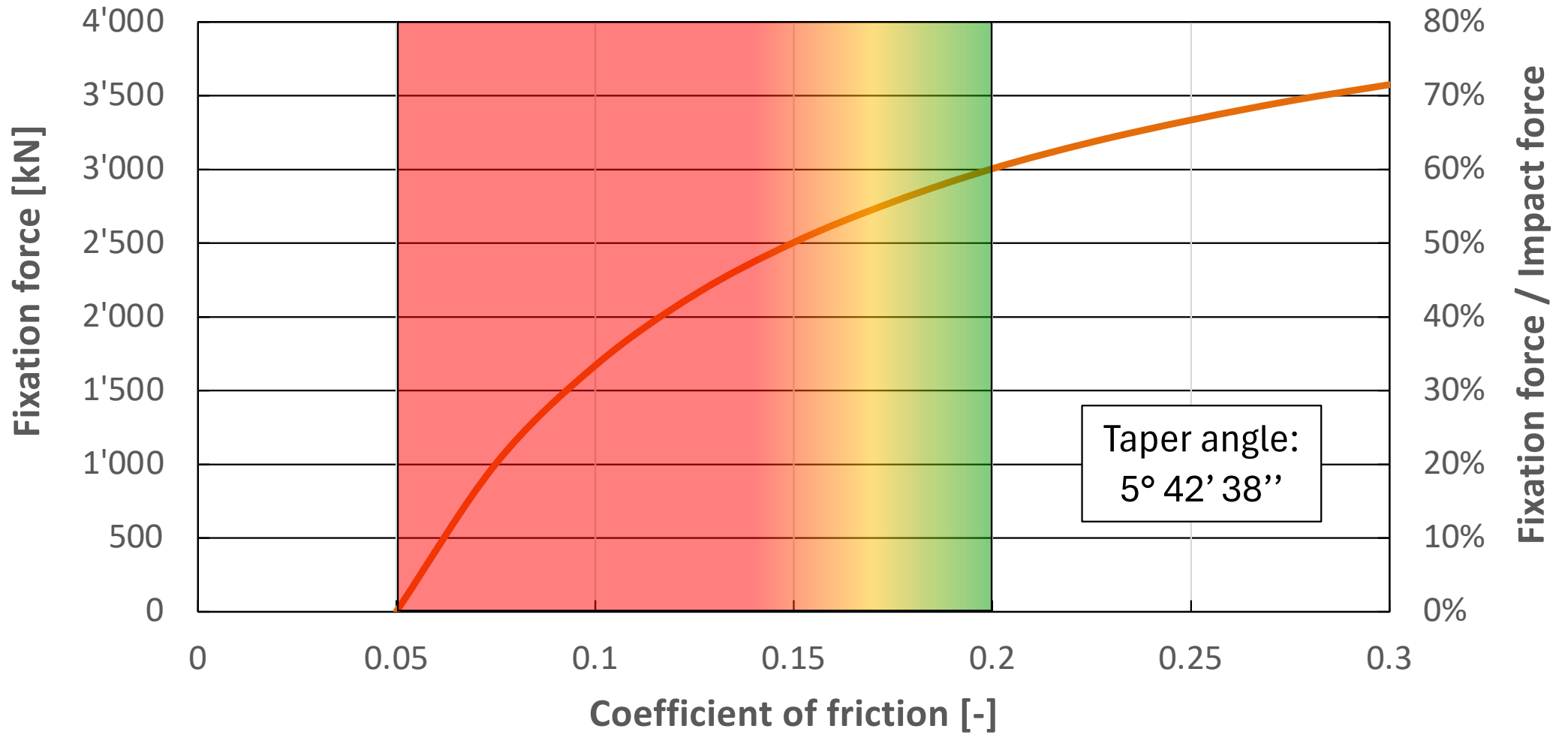
# EXPERIMENTAL MEASUREMENT OF THE COEFFICIENT OF FRICTION AT THE Ti-Ti TAPER CONNECTION

- “We found static coefficients of friction of 0.19 for the 12/14 stem-adaptor couples.”
- T. Bitter et al, JoBE, 138, 2016,

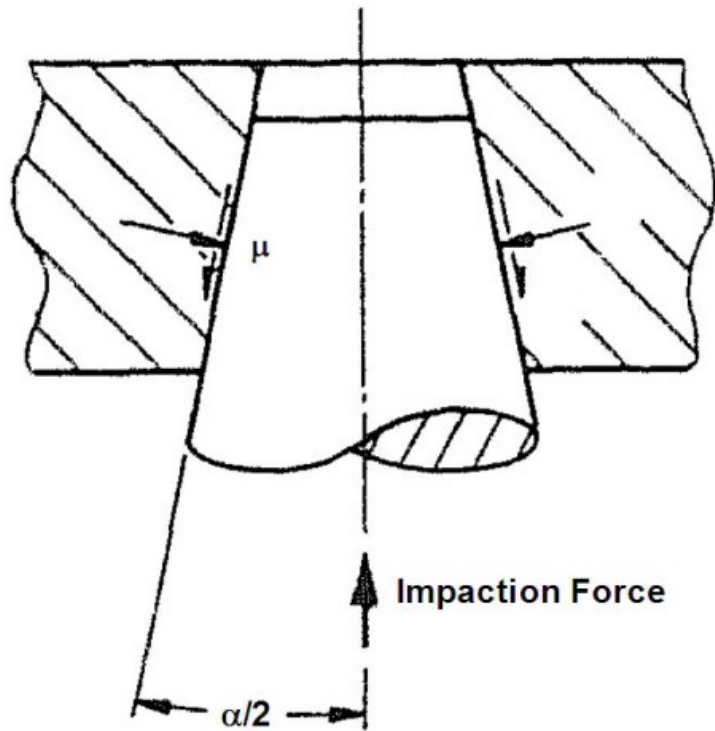
# TAPER CONNECTIONS

- Taper angle: 5° 42' 38''
- Impaction force: 5'000 N – 100%
- Dry taper → coefficient of friction 0.2  
Fixation force: 3'004 N – 60.1%
- Wet taper → coefficient of friction 0.1  
Fixation force: 1'672 N – 33.4%
- H. Fessler et al, Journal of Engineering in Medicine, 203, 1989, p. 1

# $F_{\text{IMPACT}} - 5'000 \text{ N}$



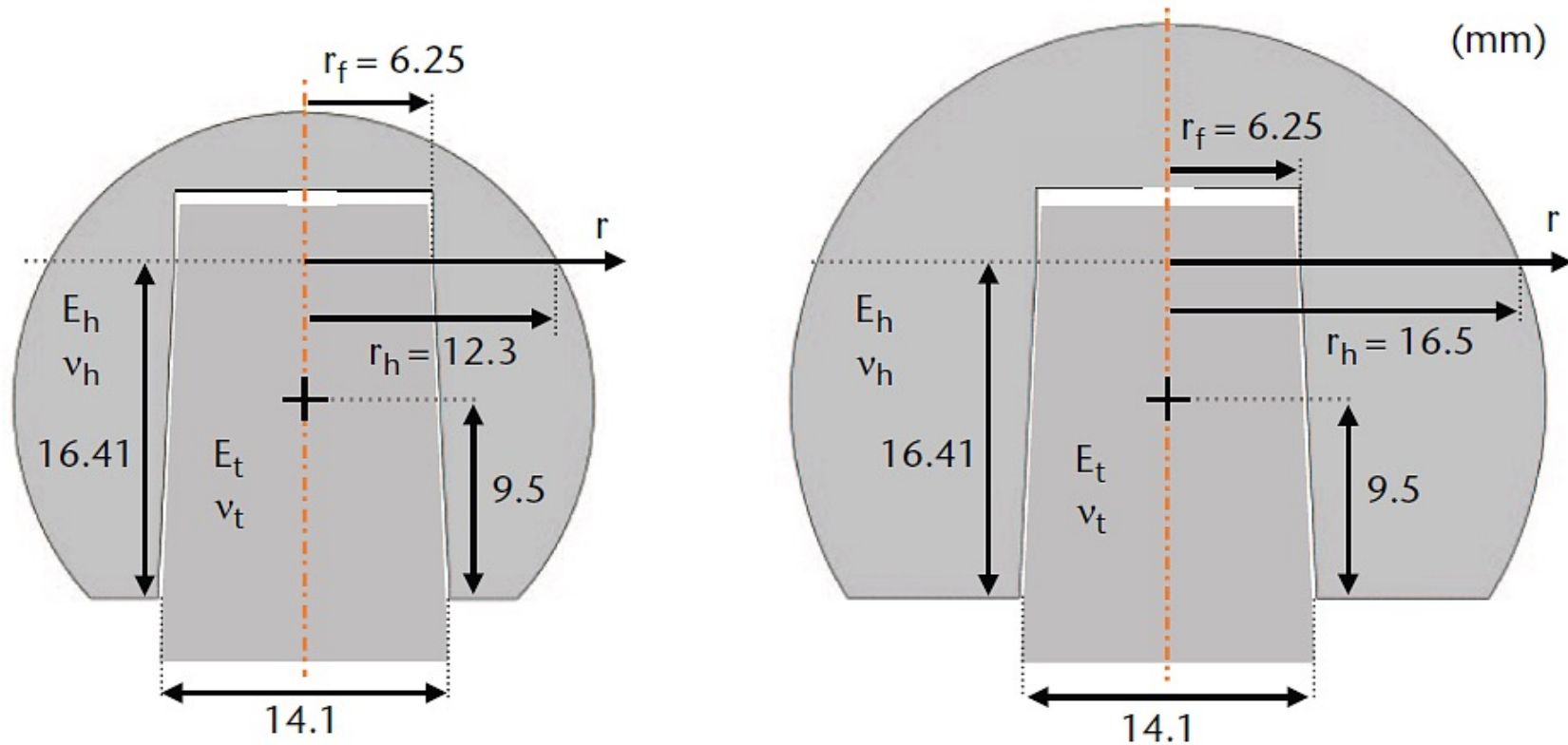
# TAPER CONNECTIONS



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H. Fessler et al, Journal of Engineering in Medicine, 203, 1989, p. 1

# TAPER CONNECTIONS



A.R. MacLeod et al, BJR, 5, 2016, p. 338

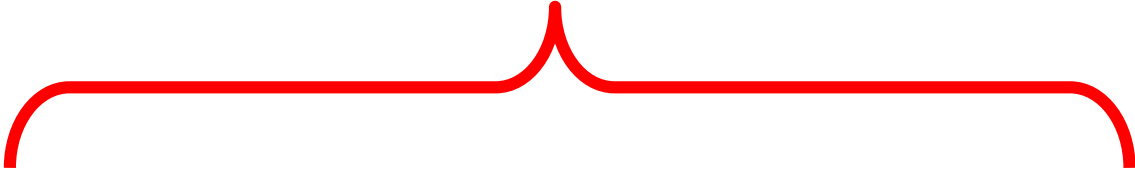
# TAPER CONNECTIONS

$$u_t = \frac{F_{impact} \left\{ \frac{r_f}{E_h} \left[ \left( \frac{r_h^2 + r_f^2}{r_h^2 - r_f^2} \right) + v_h \right] + \frac{r_f}{E_t} (1 - v_t) \right\}}{A(\sin \alpha + \mu \cos \alpha)}$$

$$F_{extract} = A(\mu \cos \alpha - \sin \alpha) \frac{E_h u_t r_f}{2r_h^2} \left( 1 - \frac{r_h^2}{r_f^2} \right)$$

# TAPER CONNECTIONS

Fessler's formula


$$F_{fixation} = F_{impact} \cdot \frac{\mu \cos(0.5\alpha) - \sin(0.5\alpha)}{\mu \cos(0.5\alpha) + \sin(0.5\alpha)} \cdot \frac{E_h r_f}{2r_h^2} \cdot \left(1 - \frac{r_h^2}{r_f^2}\right) \cdot \left[ \frac{r_f}{E_h} \left( \left\{ \frac{r_h^2 + r_f^2}{r_h^2 - r_f^2} \right\} + \nu_h \right) + \frac{r_f}{E_t} (1 - \nu_t) \right]$$

A.R. MacLeod et al, BJR, 5, 2016, p. 338

$F_{\text{IMPACT}} - 5'000 \text{ N}$

<b>Taper</b>	<b>Head Diameter</b>	<b>Coefficient of Friction</b>	<b><math>F_{\text{fixation}}</math></b>	<b><math>F_{\text{fixation}} / F_{\text{impact}}</math></b>
12/14 short	28 mm	0.20	3'855 N	77.1%
12/14 long	28 mm	0.20	3'855 N	77.1%
12/14 short	36 mm	0.20	3'986 N	79.7%
12/14 long	36 mm	0.20	3'986 N	79.7%

# $F_{\text{IMPACT}} - 5'000 \text{ N}$

<b>Taper</b>	<b>Head Diameter</b>	<b>Coefficient of Friction</b>	<b><math>F_{\text{fixation}}</math></b>	<b><math>F_{\text{fixation}} / F_{\text{impact}}</math></b>
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12/14 short	36 mm	0.20	3'986 N	79.7%
12/14 long	36 mm	0.20	3'986 N	79.7%
12/14	36 mm	0.05	8 N	0.2%
12/14	36 mm	0.10	2'219 N	44.4%
12/14	36 mm	0.15	3'324 N	66.5%

# $F_{\text{IMPACT}} - 5'000 \text{ N}$

<b>Taper</b>	<b>Head Diameter</b>	<b>Coefficient of Friction</b>	<b><math>F_{\text{fixation}}</math></b>	<b><math>F_{\text{fixation}} / F_{\text{impact}}</math></b>
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12/14	36 mm	0.10	2'219 N	44.4%
12/14	36 mm	0.15	3'324 N	66.5%
10/12	36 mm	0.20	4'035 N	80.7%
14/16	36 mm	0.20	3'930 N	78.6%

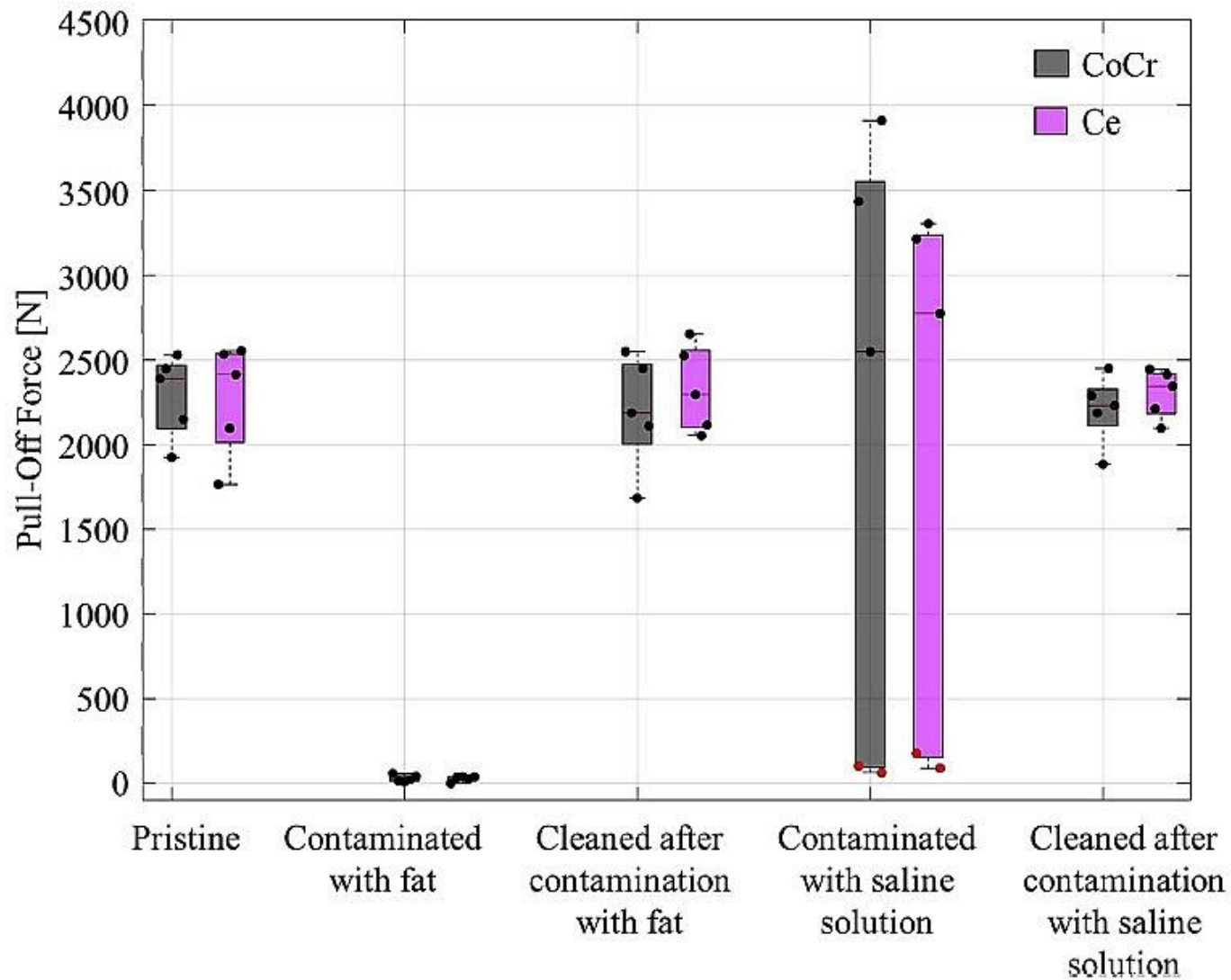
# THE INFLUENCE OF CONTAMINATION AND CLEANING ON THE STRENGTH OF MODULAR HEAD TAPER FIXATION IN THA

- “Intraoperative interface contamination of modular head-stem taper junctions of hip implants can lead to poor fixation strength, causing fretting and crevice corrosion or even stem taper fracture. Careful cleaning before assembly should help to reduce these problems.”
- A. Krull et al, JoA, 32, 2017, p. 3200

# THE INFLUENCE OF CONTAMINATION AND CLEANING ON THE STRENGTH OF MODULAR HEAD TAPER FIXATION IN THA

- “Metal or ceramic heads were impacted onto titanium alloy stem tapers with cleaned or contaminated (fat or saline solution) interfaces. The same procedure was performed after cleaning and drying the contaminated interfaces.”
- A. Krull et al, JoA, 32, 2017, p. 3200





A. Krull et al, JoA, 32, 2017, p. 3200

# THE INFLUENCE OF CONTAMINATION AND CLEANING ON THE STRENGTH OF MODULAR HEAD TAPER FIXATION IN THA

- “Cleaning of the stem taper with saline solution and drying with gauze directly before assembly allows the taper strength of the pristine components to be achieved. Not drying the taper results in a large variation in pull-off forces, emphasizing that drying is essential for sufficient and reproducible fixation strength.”
- A. Krull et al, JoA, 32, 2017, p. 3200

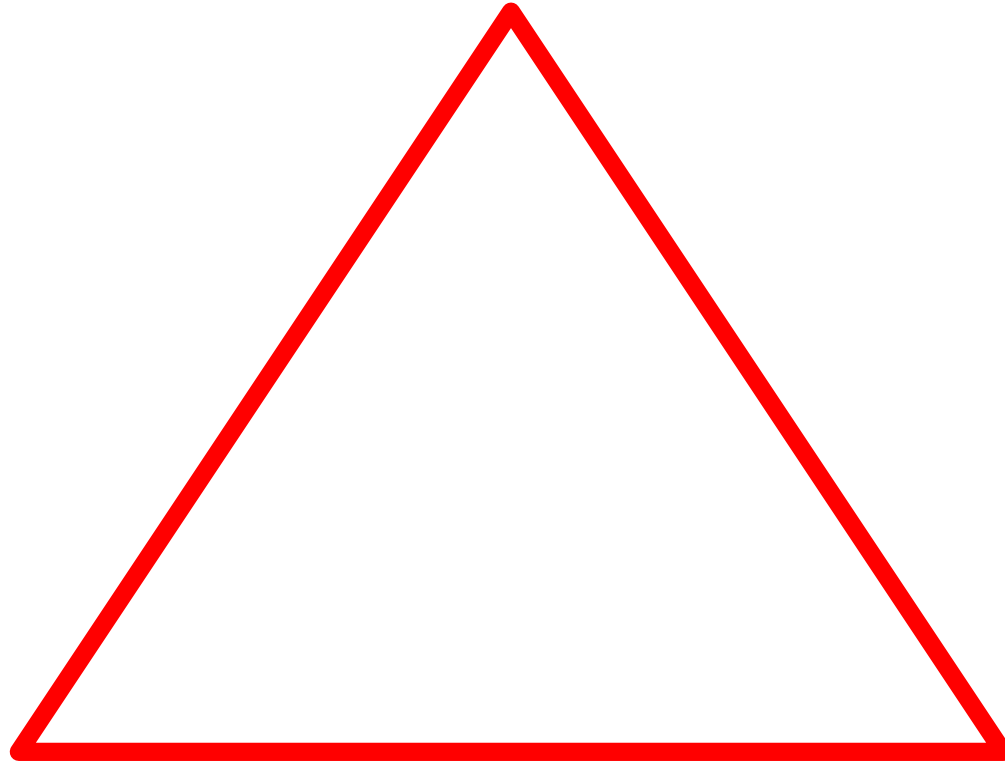
# TRIBOLOGY OF TOTAL HIP ARTHROPLASTIES

- Introduction
- Why is tribology important
- Materials
- Possible  
methodology
- Other aspects
- Conclusions

**EPFL**



Fixation  
Positioning  
Taper connection  
...



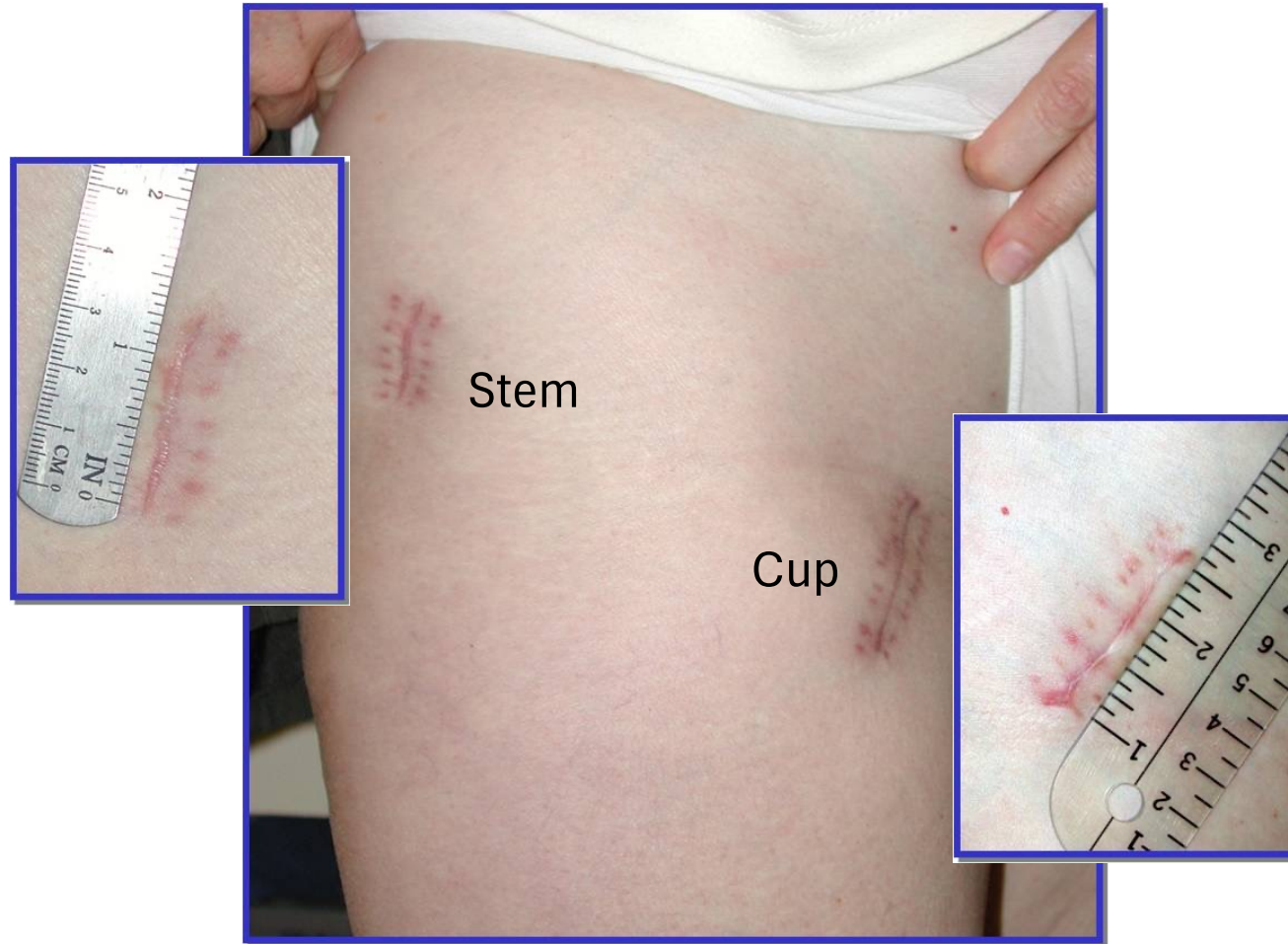
# SURGEONS



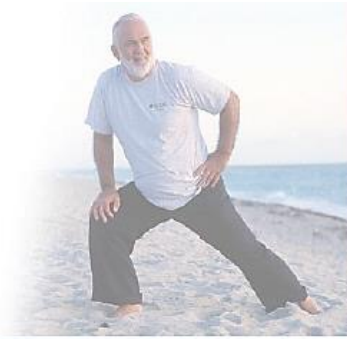
# DRIVERS



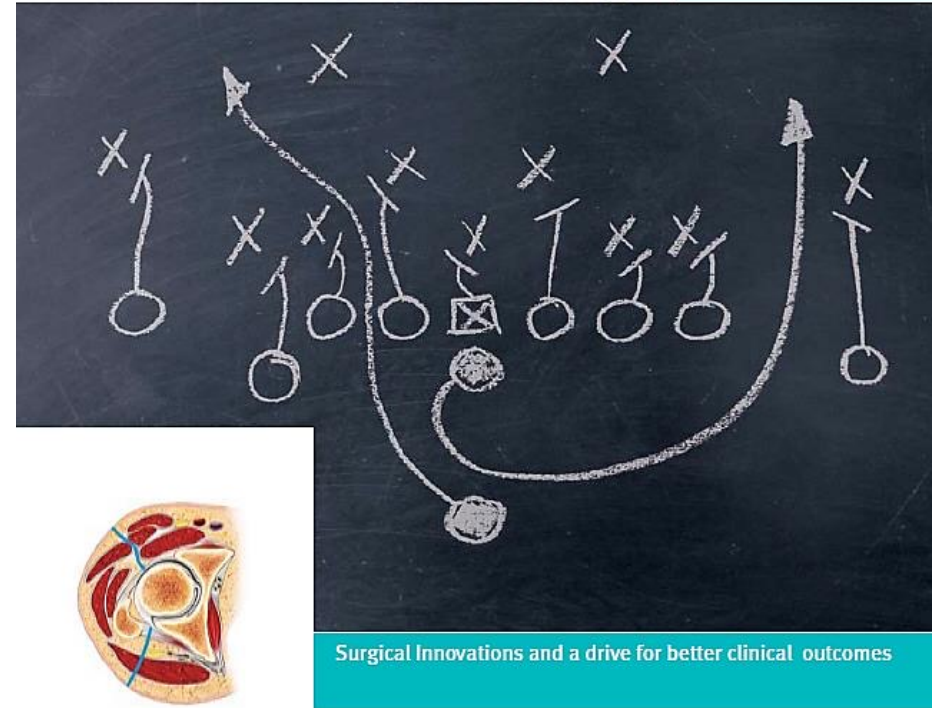
# MIS TECHNIQUE - 2-INCISION



# MIS TECHNIQUE 2-INCISION



Zimmer® MIS  
2-Incision™ Hip  
Procedure

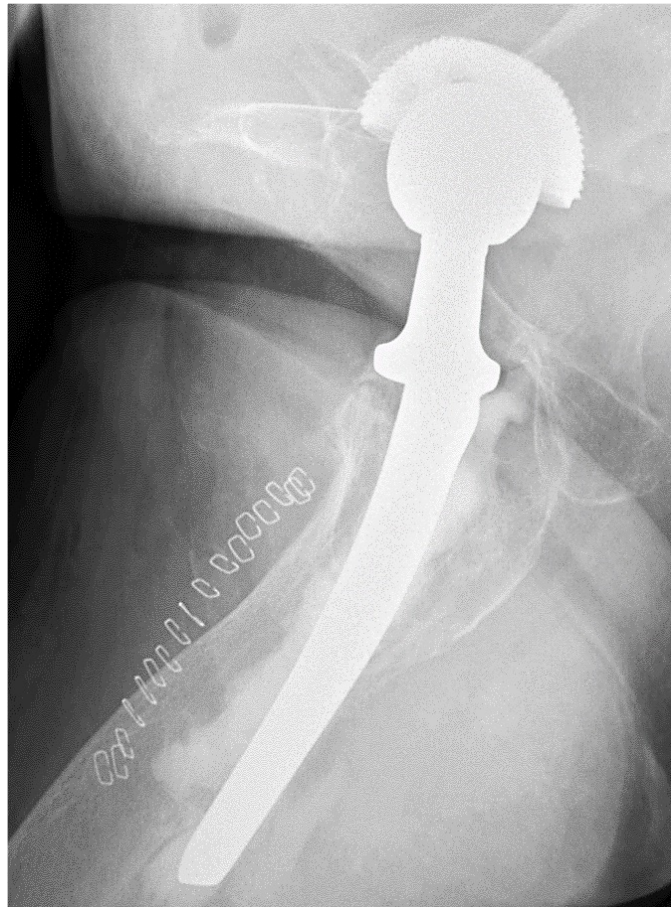
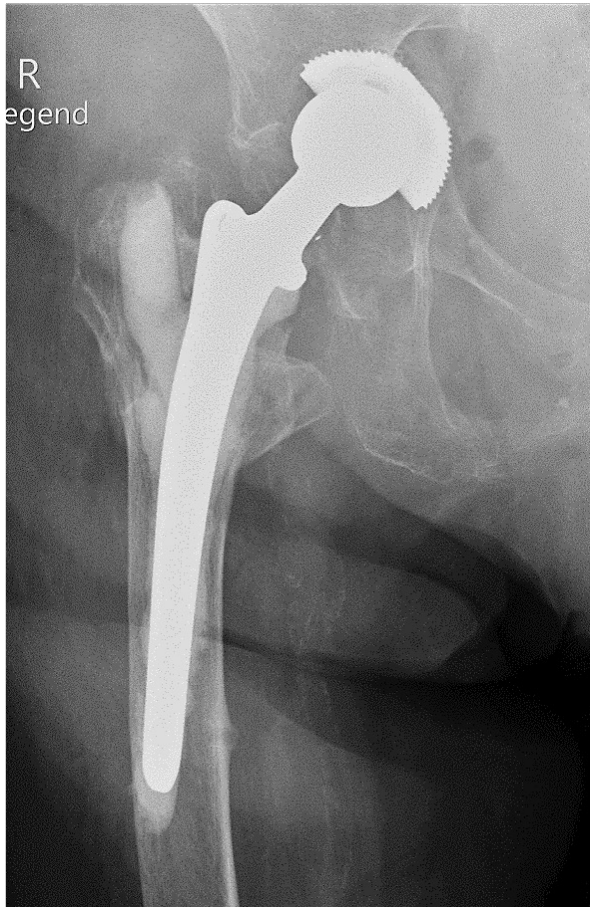


# MIS TECHNIQUE - 2-INCISION



# SURGEONS

- Surgeons may have a bad day



Courtesy of  
Prof. E. Gauthier

# SURGEONS

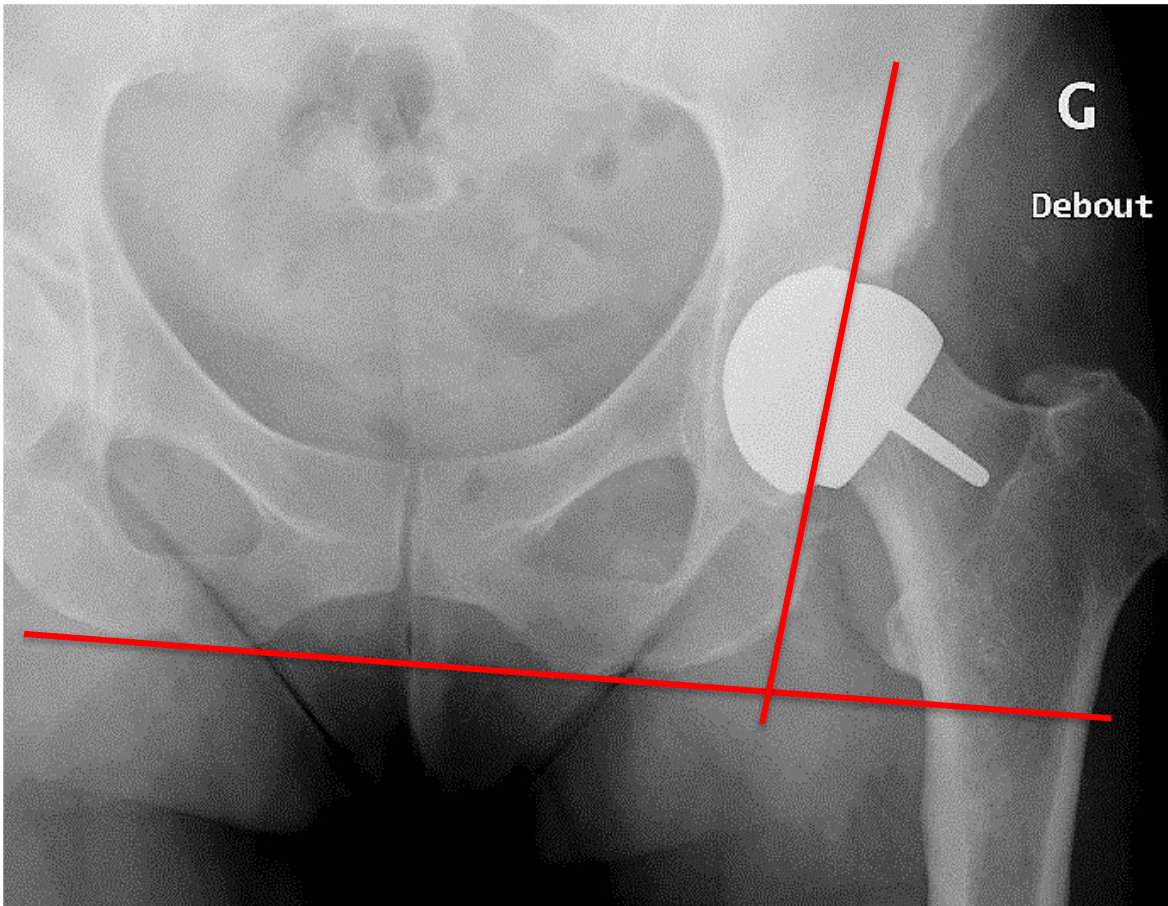
- Surgeons may have a bad day



Courtesy of  
Prof. E. Gauthier

# SURGEONS



- Surgeons may have a bad day



Courtesy of  
Prof. E. Gauthier

Clinical Research

# What Are the Relative Associations of Surgeon Performance and Prosthesis Quality With THA Revision Rates?

Wayne Hoskins MBBS(Hons), FRACS, PhD<sup>1,2</sup> , Roger Bingham MBBS, FRACS<sup>3</sup> ,  
Stephen E. Graves MBBS, DPhil(Oxon), FRACS(Orth), FAOrthA<sup>4</sup>, Dylan Harries PhD<sup>4</sup>,  
Alana R. Cuthbert BMathSc(Hons), PhD<sup>5</sup>, Sophia Corfield PhD<sup>4</sup>, Paul Smith BMBS, FRACS<sup>4</sup>,  
Kelly G. Vince MD, FRCS(C)<sup>2</sup>

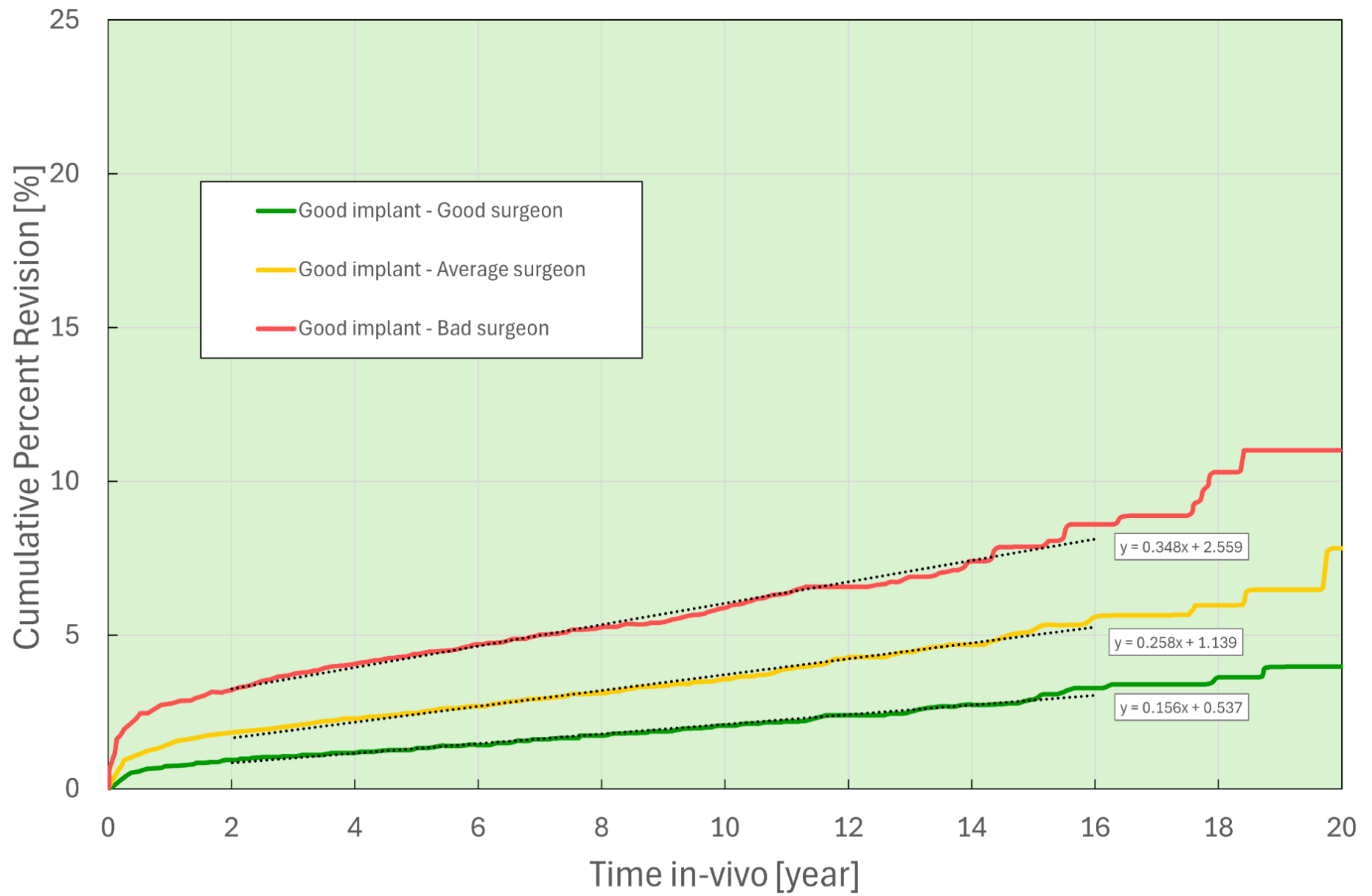
Received: 30 January 2024 / Accepted: 17 July 2024 / Published online: 6 August 2024  
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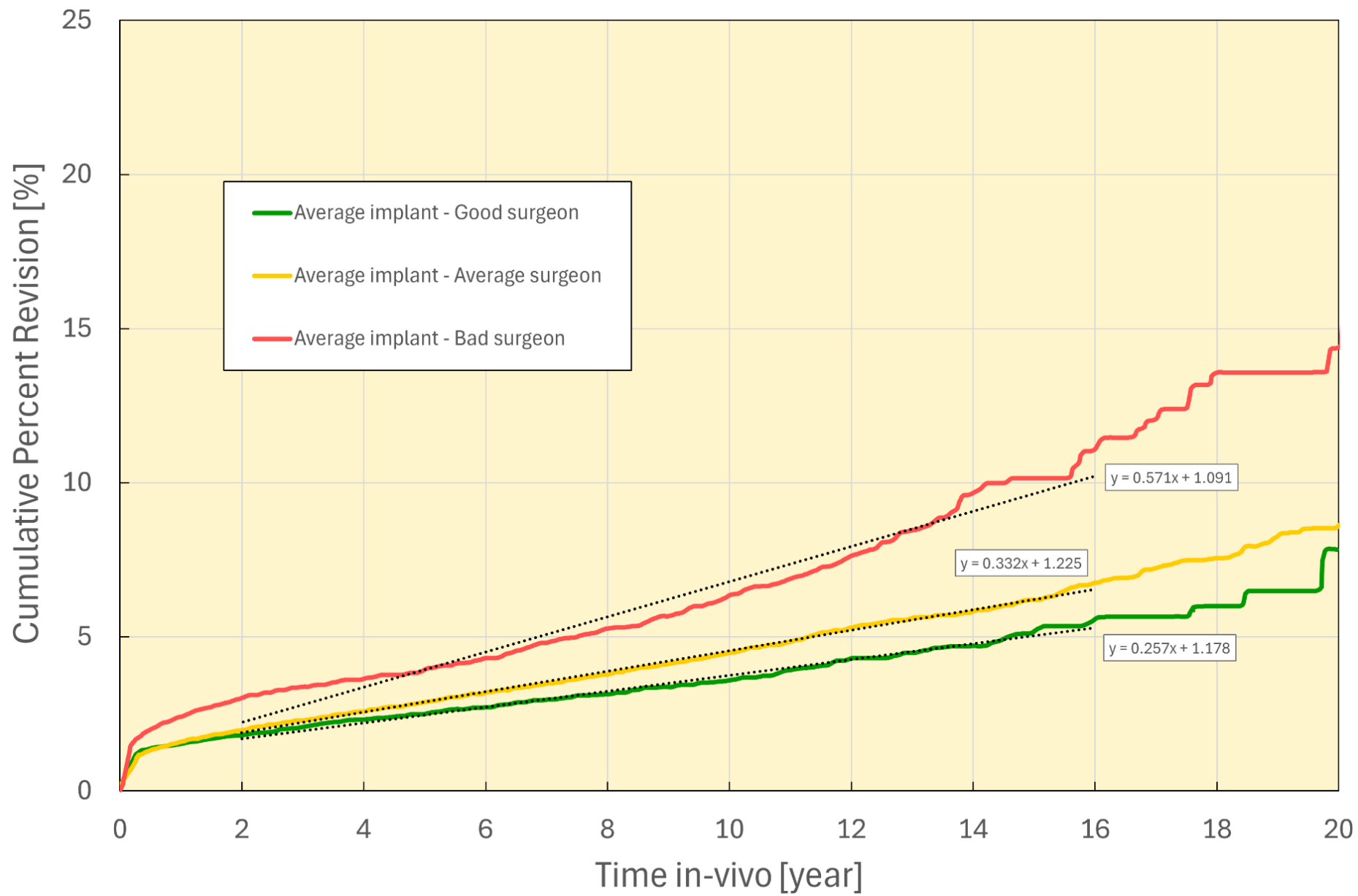
## Abstract

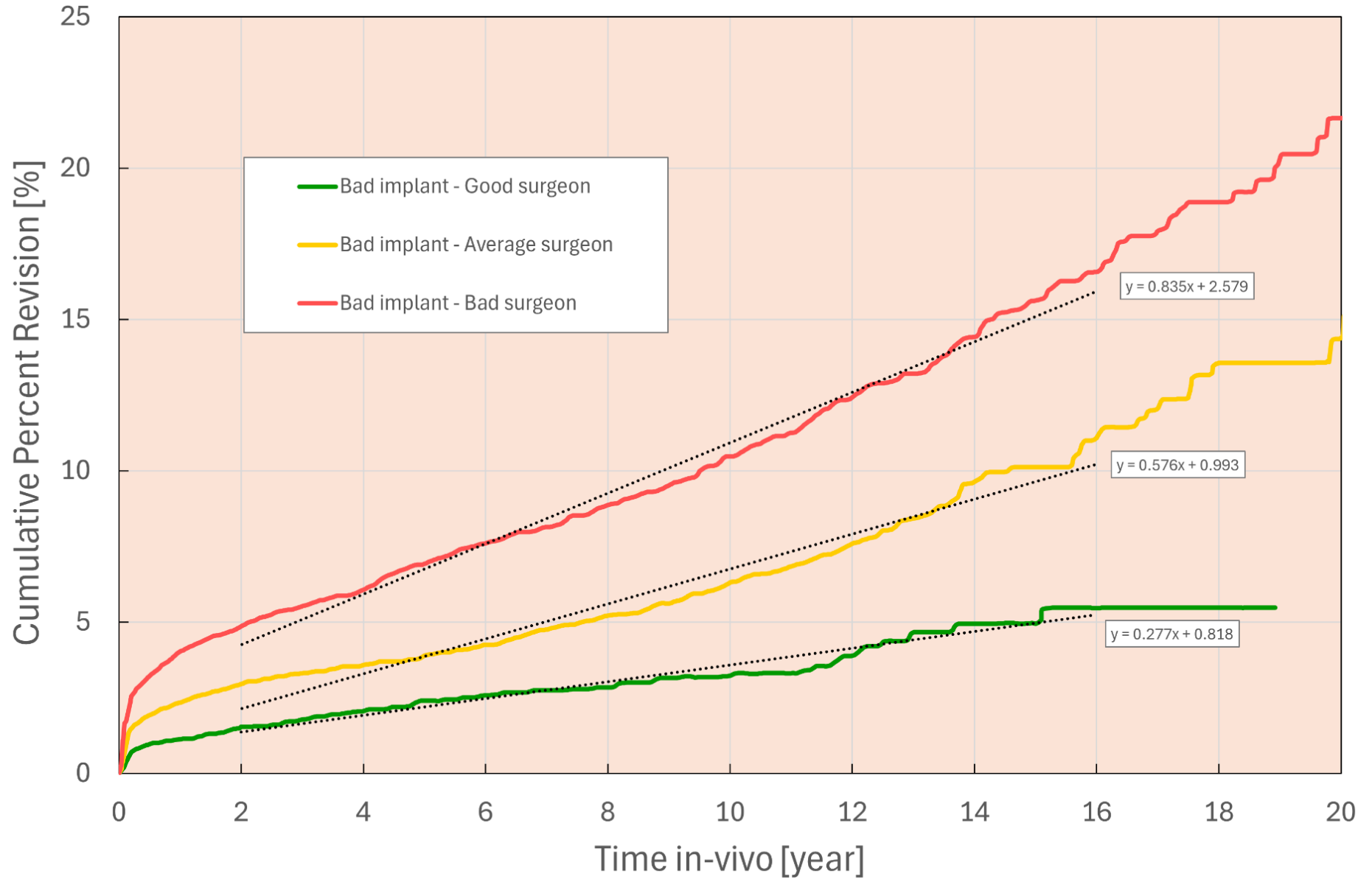
*Background* Many factors, including some related to the patient, implant selection, and the surgeon's skill and expertise, likely contribute to the risk of THA revision. However, surgeon factors have not been extensively analyzed in national joint replacement registries, and there is limited insight into their potential as a confounding variable for revision outcomes; for example, if surgeons with

higher revision rates choose more successful prostheses, would this alone reduce their revision rate?

*Questions/purposes* This study used Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) data for patients receiving primary THA for a diagnosis of osteoarthritis to answer the following questions: (1) Will the difference in revision rates among surgeons change or disappear when only







# INCREASE OF THE ANNUAL CUMULATIVE REVISION RATE

Klin Orthop Relat Res (2025) 483:237-249  
DOI 10.1097/CORR.0000000000003217

Clinical Orthopaedics  
and Related Research®  
A Publication of The Association of Bone and Joint Surgeons®

## Clinical Research

### What Are the Relative Associations of Surgeon Performance and Prosthesis Quality With THA Revision Rates?

Wayne Hoskins MBBS(Hons), FRACS, PhD<sup>1,2</sup>, Roger Bingham MBBS, FRACS<sup>3</sup>, Stephen E. Graves MBBS, DPhil(Oxon), FRACS(Orth), FAOrthA<sup>4</sup>, Dylan Harries PhD<sup>1</sup>, Alana R. Cuthbert BMathSc(Hons), PhD<sup>5</sup>, Sophia Corfield PhD<sup>1</sup>, Paul Smith MBBS, FRACS<sup>4</sup>, Kelly G. Vince MD, FRCS(C)<sup>2</sup>

Received: 30 January 2024 / Accepted: 17 July 2024 / Published online: 6 August 2024  
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#### Abstract

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		Surgeon		
		Good	Average	Bad
Implant	Good	0.156%	0.258%	0.348%
	Average	0.257%	0.332%	0.571%
	Bad	0.277%	0.576%	0.835%

# INCREASE OF THE ANNUAL CUMULATIVE REVISION RATE

Weighted average: 0.365%

		Surgeon		
		Good	Average	Bad
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Weighted average: 0.365%

		Surgeon		
		Good	Average	Bad
Implant	Good	0.156% -57.3%	0.258% -29.4%	0.348% -4.8%
	Average	0.257% -29.7%	0.332% -9.1%	0.571% 56.3%
	Bad	0.277% -24.4%	0.576% 57.6%	0.835% 128.5%

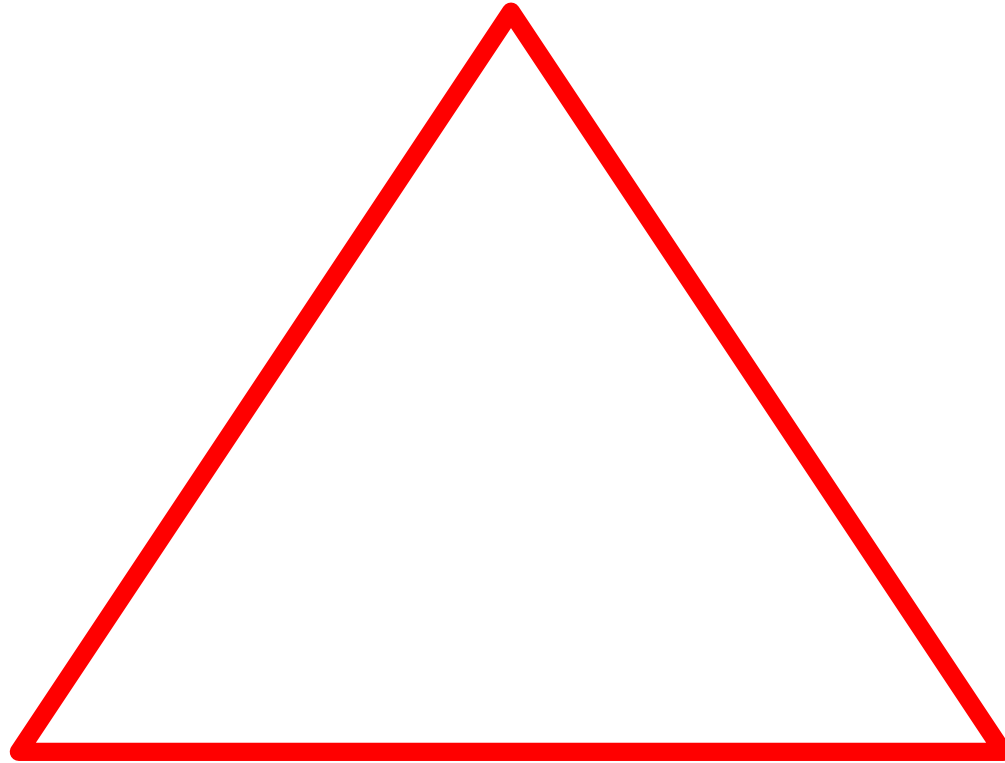
I CAN'T SAY I'M  
ENTIRELY PLEASED WITH  
MY HIP REPLACEMENT.





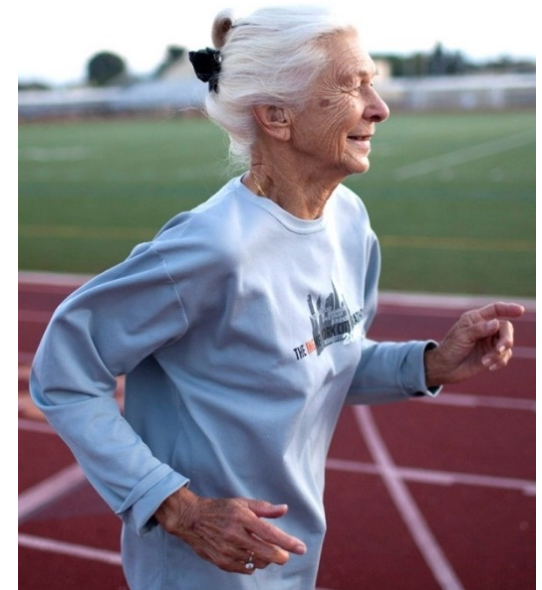
Fixation  
Positioning  
Taper connection  
...

?



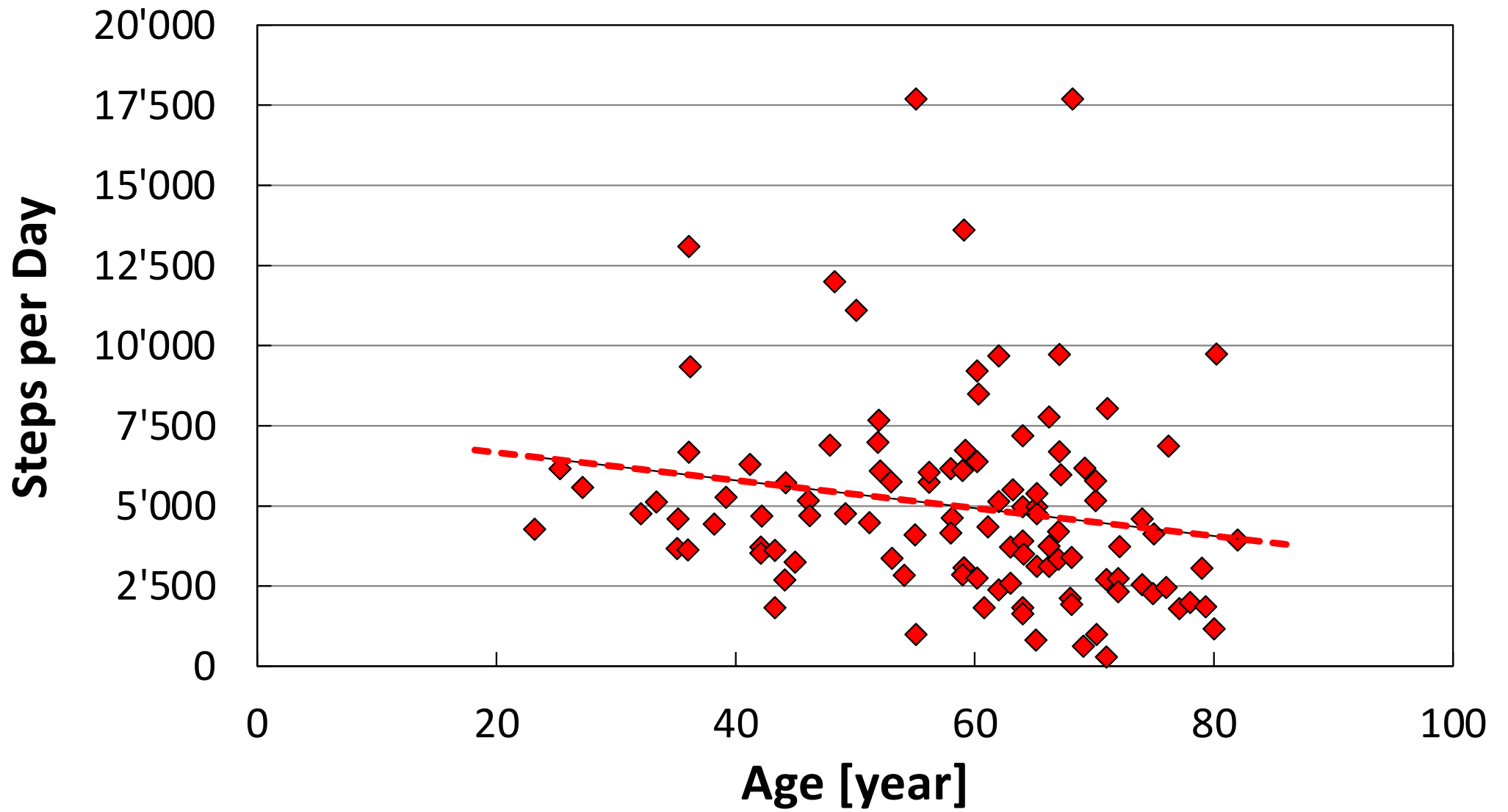
# PATIENT ACTIVITY

- As the mean age of the patients is steadily decreasing, the mean activity of the patients is increasing.



# QUANTITATIVE ASSESSMENT OF WALKING ACTIVITY AFTER TOTAL HIP OR KNEE REPLACEMENT

- “The patients averaged 4,988 steps per day, which extrapolates to approximately 1.8 million cycles per year. Average activity ranged widely from 395 to 17,718 steps per day, an approximately forty-five-fold difference.”
- T. Schmalzried et al, JBJS, 80A, 1998, p. 54



# World Masters Athletics Championships 2019

## Men 90 - 100



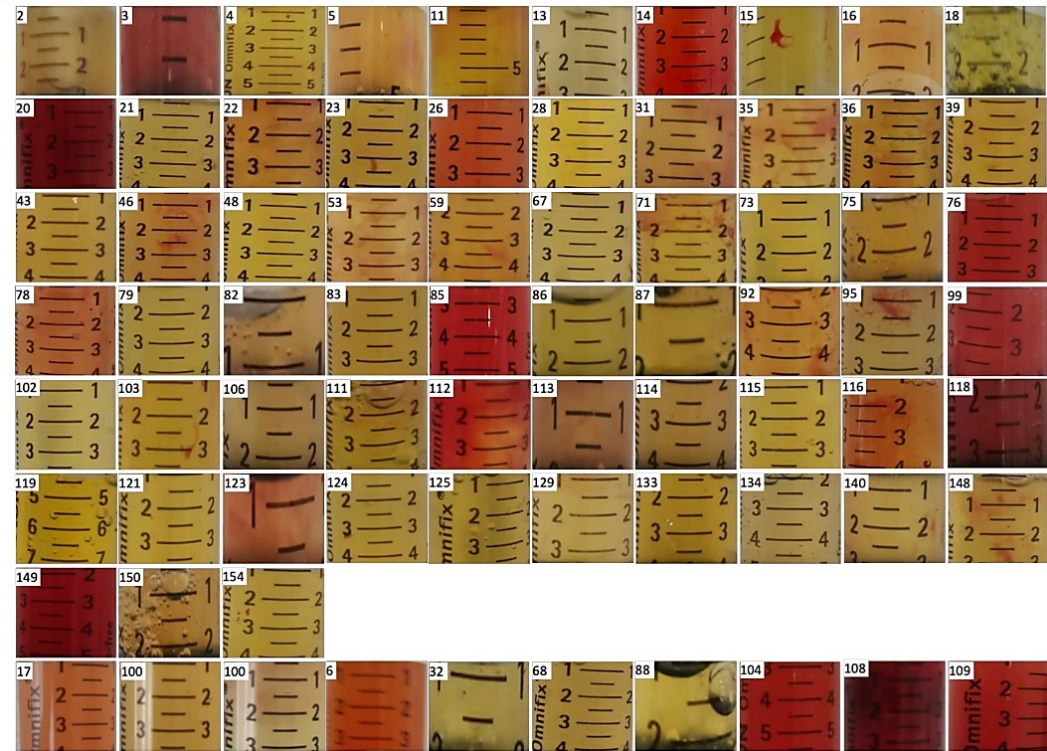
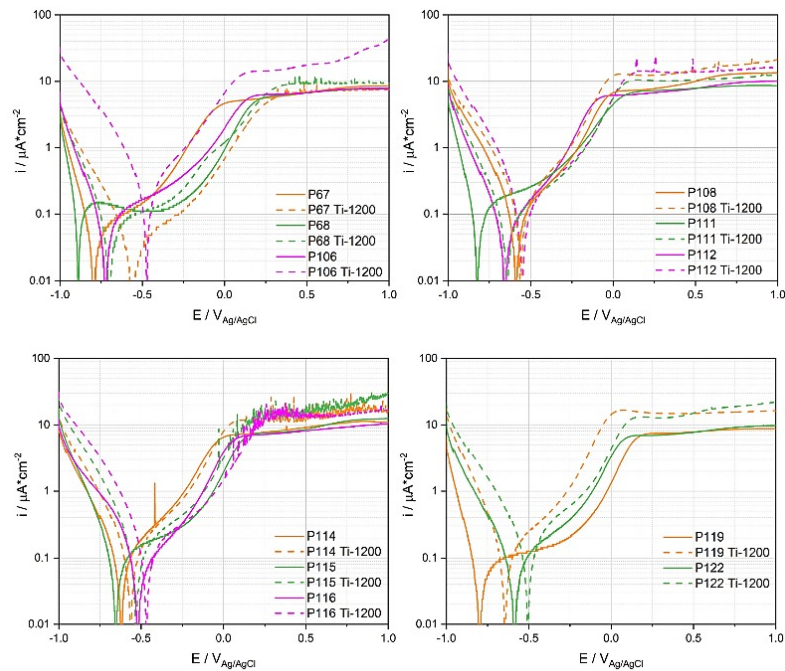
THÈSE/MÉMOIRE

# In-vivo investigation of electrochemical behavior of Ti and CoCrMo alloy in human synovial fluids

Bao, Yueyue (auteur\_e)

Lausanne : Ecole Polytechnique Fédérale de Lausanne

2023



THÈSE/MÉMOIRE

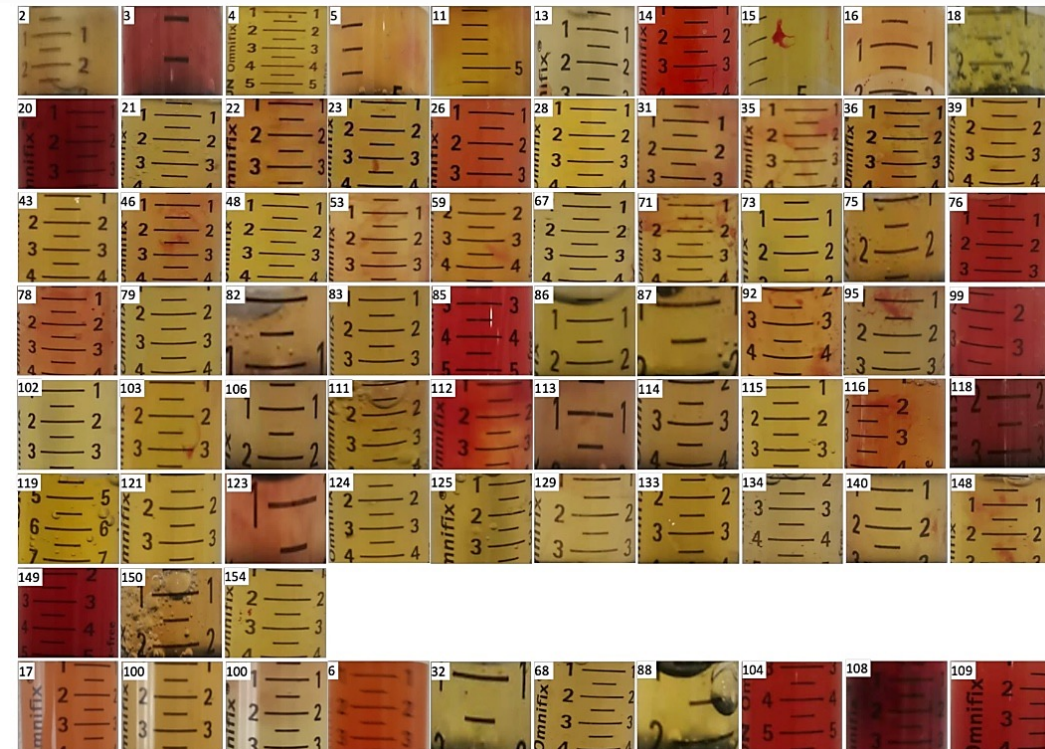
# In-vivo investigation of electrochemical behavior of Ti and CoCrMo alloy in human synovial fluids

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- “The material loss rates are patient-dependent and can be up to two orders of magnitude higher than the static corrosion rates, indicating that the nature of the patient can critically affect the degradation rate of the joint implant.





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# Electrochimica Acta

journal homepage: [www.journals.elsevier.com/electrochimica-acta](http://www.journals.elsevier.com/electrochimica-acta)



## Assessment of *in-vivo* corrosion of Ti and CoCrMo joint implants by electrochemical measurements in human synovial liquids

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### ARTICLE INFO

#### Keywords:

Human synovial fluids  
Corrosion  
Ti  
CoCrMo  
Galvanic corrosion  
Tribocorrosion

### ABSTRACT

Understanding the corrosion behavior of biomedical materials in the human body is an essential step for the development of improved materials and clinical procedures in arthroplasty. In this work, the corrosion behavior of Ti and CoCrMo alloys in human synovial fluids directly extracted from patients was investigated through an electrochemical experimental protocol, including open circuit potential (OCP), electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization measurements. The results show that the corrosion behavior of both materials largely depends on patients. The obtained corrosion rates of both materials correspond well to the metal ion release rate detected in patients with joint implants revealing the adequateness of the electrochemical experimental protocol for quantifying *in-vivo* corrosion of biomedical implants. Based on the results, no significant risk of galvanic corrosion of Ti/CoCrMo coupling is anticipated. The rates of wear-accelerated corrosion (one of the main degradation mechanisms of metallic artificial hip joints) were theoretically extracted from the present electrochemical measurements using an established tribocorrosion model. Those material loss rates are patient-dependent and can be up to two orders of magnitude higher than the static corrosion rates, indicating that the nature of the patient can critically affect the degradation rate of the joint implant.

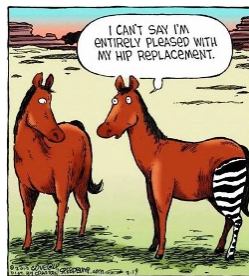
# IDENTIFICATION OF THE AT-RISK GENOTYPE FOR DEVELOPMENT OF PSEUDOTUMOURS AROUND MoM THAs

- “Among patients with a primary MoM THA, allelic variation within the HLA Class II loci may be a strong, independent risk factor associated with the need for subsequent revision surgery secondary to pseudotumour formation.”
- B.K.J. Kilb et al, CORR, 476, 2018, p. 230

# COLLABORATION



# COLLABORATION





PINNALE  
ACETABULAR CUP SYSTEM

## DePuy's Pinnacle Lawsuits

After plaintiffs lost the first bellwether trial in the DePuy Pinnacle MDL, juries awarded verdicts to the people injured by hips in the next three trials. In January 2016, a jury awarded \$502 million to five plaintiffs.

Another jury awarded \$1 billion to six plaintiffs in December 2016. The third trial resulted in a \$247 million verdict for six plaintiffs.



## Smith & Nephew

In April 2017, the Judicial Panel on Multidistrict Litigation combined 28 lawsuits over the company's BHR and R3 hip implants into a single MDL in Maryland. As of October 2017, the U.S. District Court for Maryland reported the MDL "encompasses more than 190 pending cases."

# TRIBOLOGY OF TOTAL HIP ARTHROPLASTIES

- Introduction
- Why is tribology important
- Materials
- Possible  
methodology
- Other aspects
- Conclusions

**EPFL**

# CONCLUSIONS

- Total hip prostheses is a standard operation than more than 1'500'000 operations per year
- Excellent clinical results / Operation of the century
- A good tribology is mandatory to assure good clinical results
- The in-vivo simulation is a real challenge:
  - Tribology tests allow only to exclude inappropriate solutions
  - Analytic approach may help

# CONCLUSIONS

- Surgeon are the key players in the triangle  
Implant - Surgeon - Patient
- Patients are more and more demanding
- The understanding of the patient's biology will be an important area of research in the near future
- It's a real privilege to be active in this field for more than 35 years

THANK YOU

EPFL

librairie  
la fontaine





Ortho

save

ORTHOPAEDIC  
CONSULTING