摩擦学在人工关节的设计及未来发展思考

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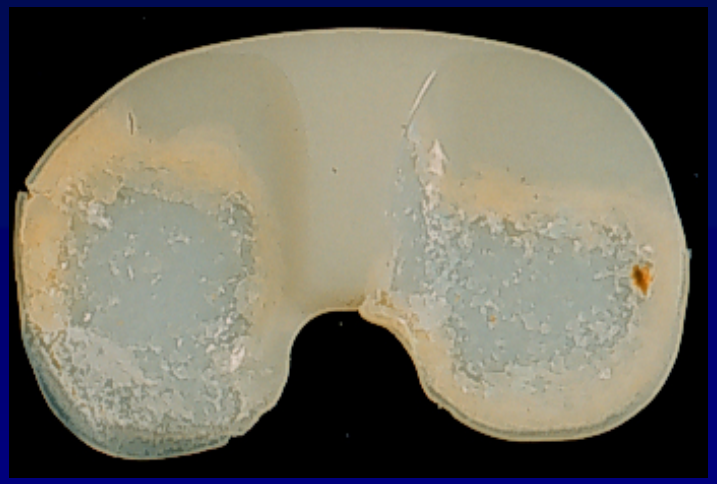
Outline:

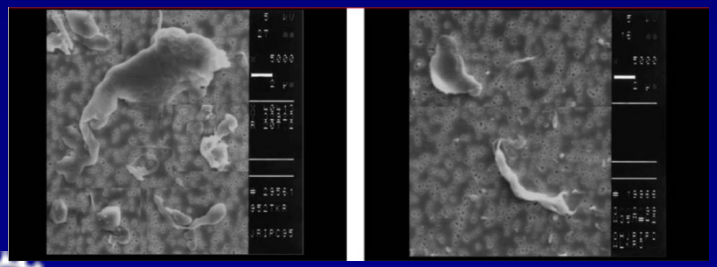
1. Major clinical problems
2. Tribology: basic principles
3. Case studies:
   - Diameter in the hip joint: large or small ?
   - Metal-on-metal joints: why some failed ?
4. Future developments

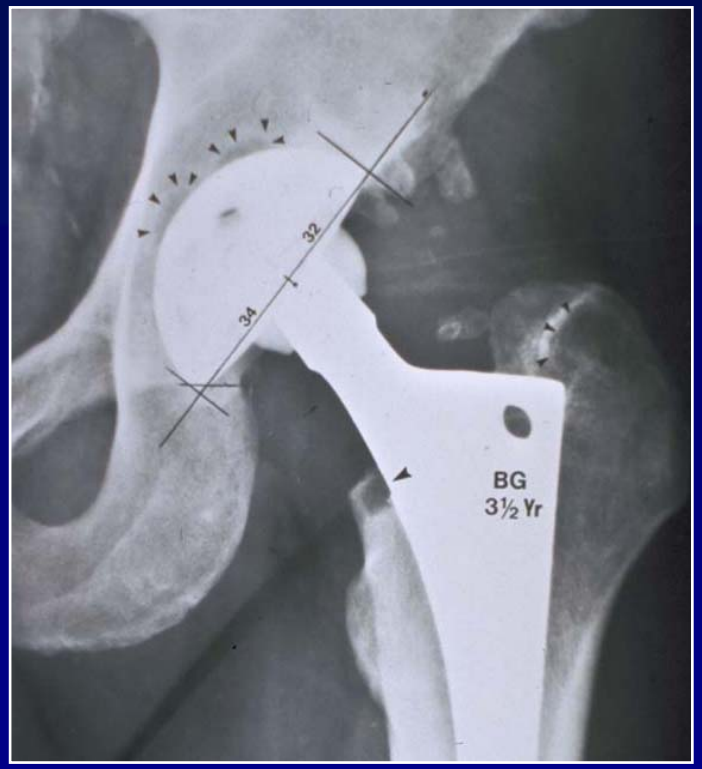
Introduction:

Major Clinical Problems

- *Wear debris* induced osteolysis and loosening







Introduction:

Major Clinical Problems

- Metallic *wear debris* and ions and pseudotumour

Introduction:

Major Clinical Problems

- Fracture/Loss of *lubrication* and squeaking

Introduction:

Major Clinical Problems

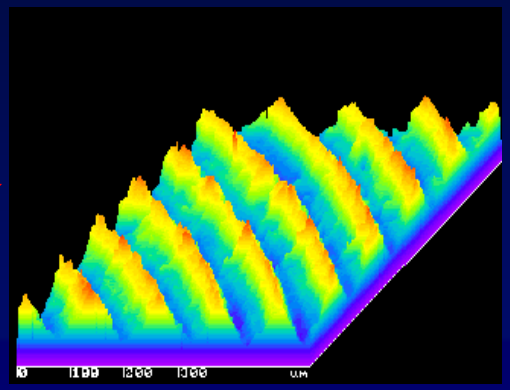
- Tribology (摩擦学) of Bearing Surfaces
- Study of friction, wear and lubrication, and design of bearings, science of interacting surfaces in relative motion

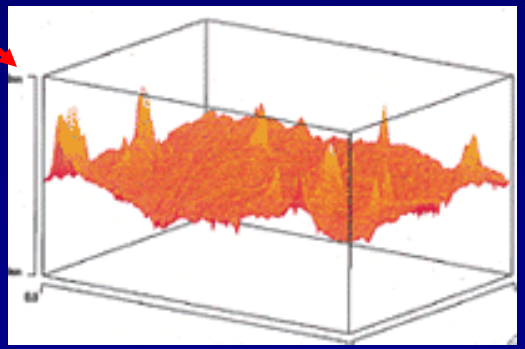
Introduction:

Basic Principles of Tribology

- All surfaces are rough
- Synovial fluid/pseudo-synovial fluid

(www.sinohotel.com/images/travel/category/16.jpg)

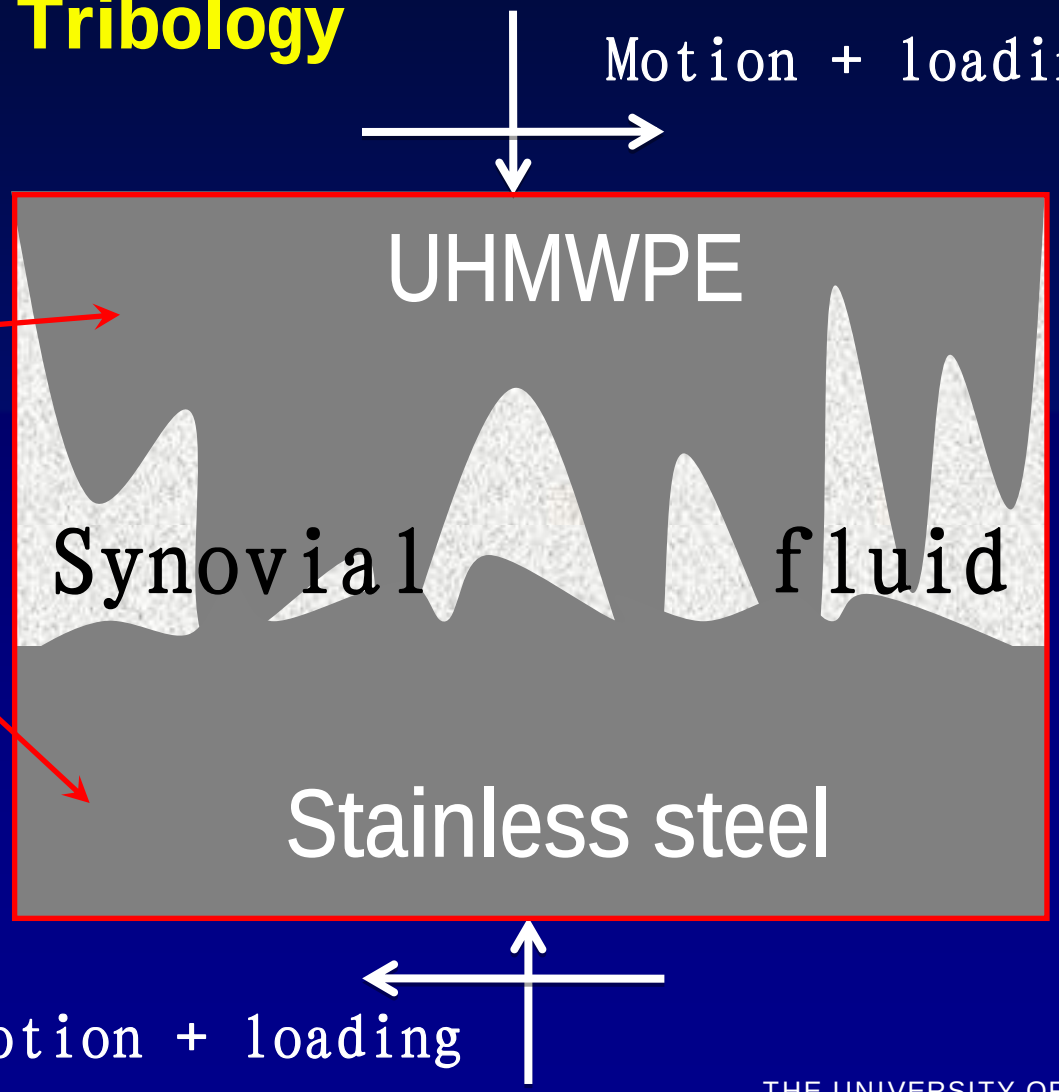




- Artificial joints mainly support load + provide motion

Introduction:

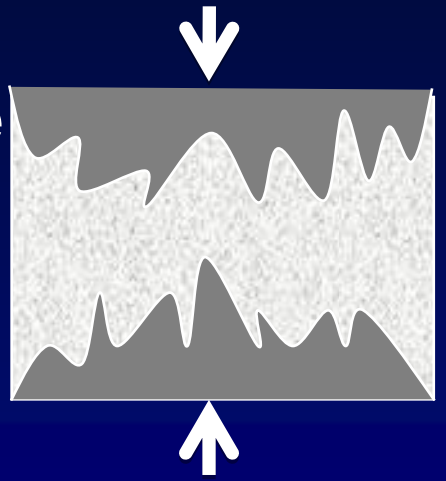
Basic Principles of Tribology



Introduction:

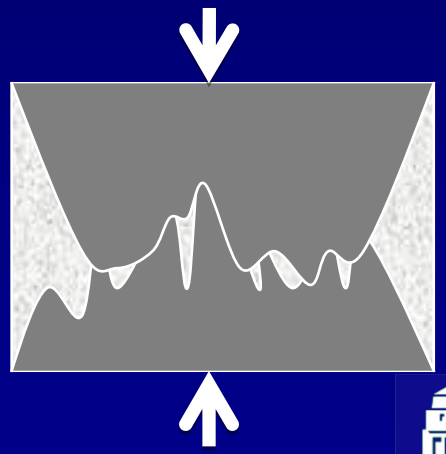
Basic Principles of Tribology

- Fluid film lubrication: two surfaces are completely separated by synovial fluid



Wear ~ 0

- Boundary lubrication: two surfaces are mainly in direct contact



Wear $\propto$ contact area x sliding distance

Diameter of Artificial Hip Joint:

UHMWPE Hips

- **UHMWPE roughness↑**
- **Roughness >> synovial film**
- **Boundary lubrication**
- **Wear**

Wear ∝ contact area x sliding distance

Diameter of Artificial Hip Joint:

UHMWPE Hips

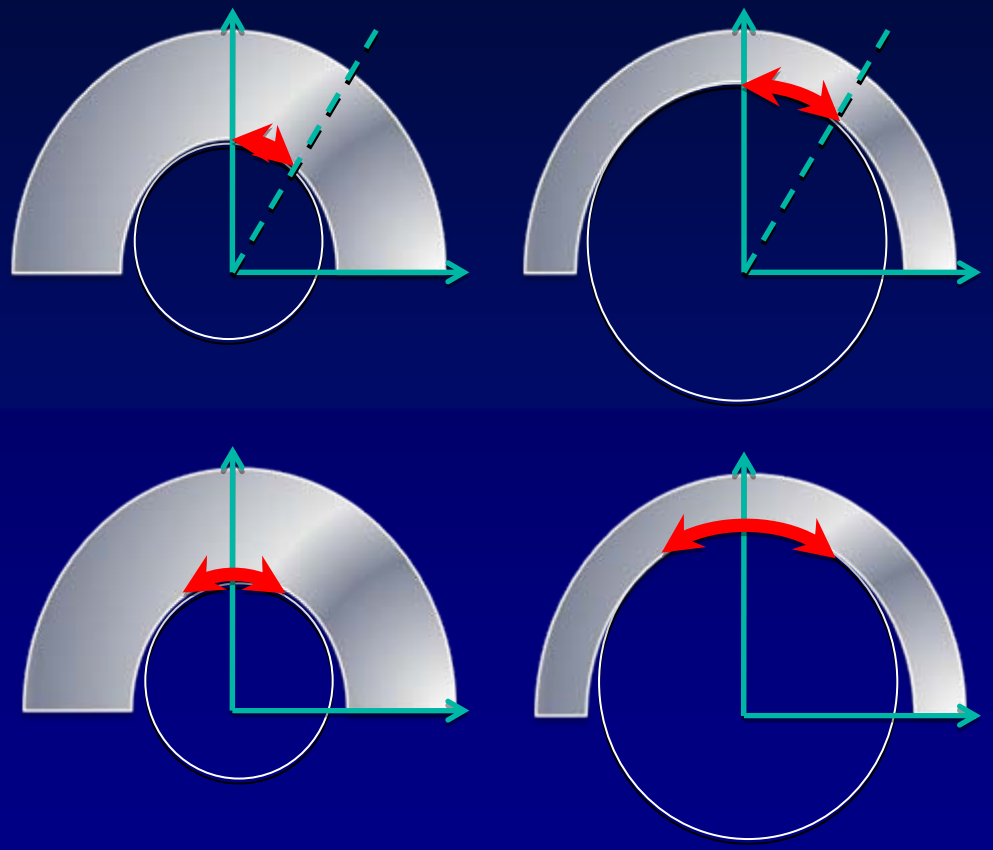
- **Diameter ↑ sliding distance ↑**

+

- **Diameter ↑ contact area: ↑**

↓

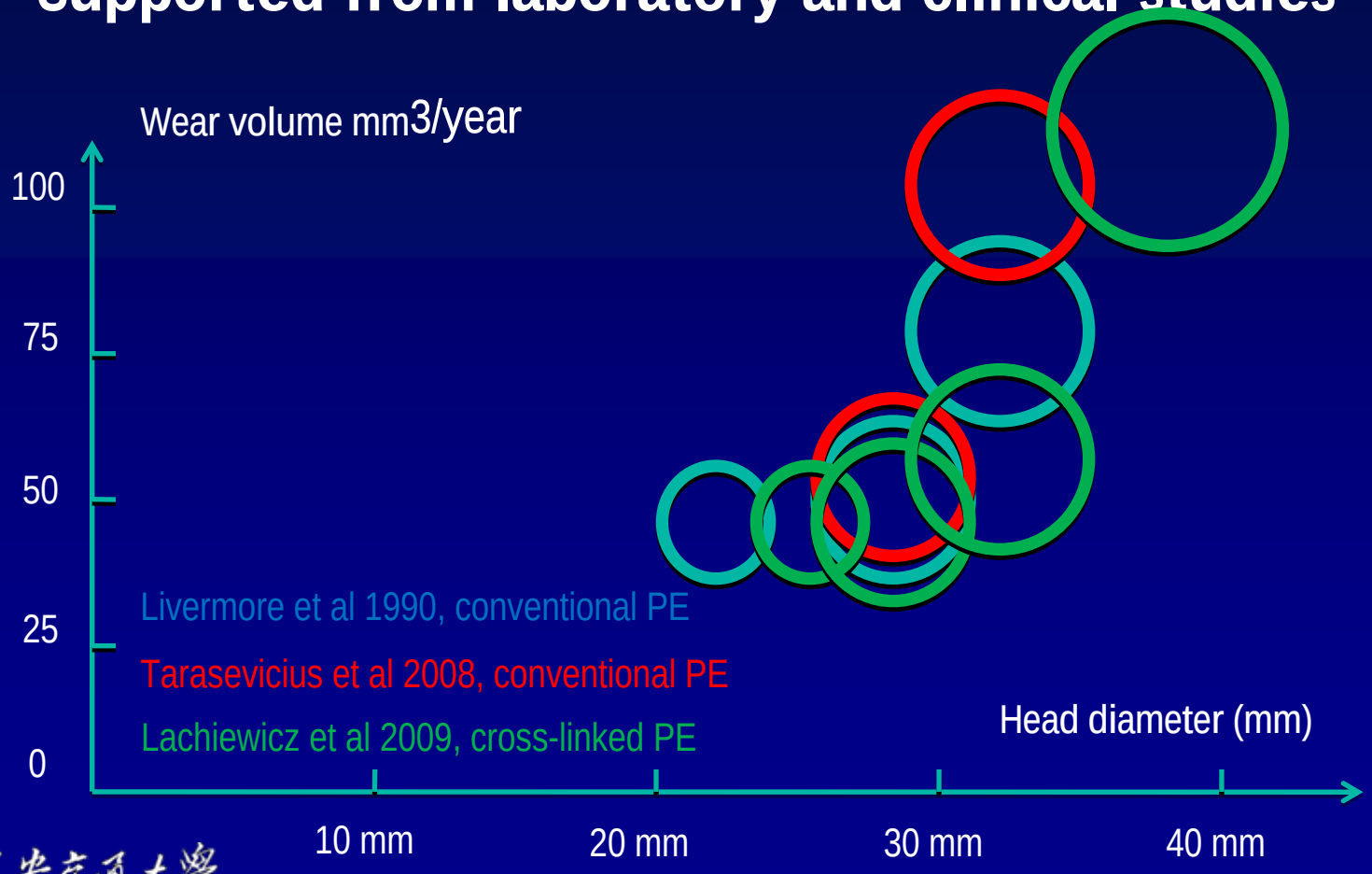
Wear ↑↑



Diameter of Artificial Hip Joint:

UHMWPE Hips

- **Supported from laboratory and clinical studies**



Diameter of Artificial Hip Joint:

Metal-on-Metal Hips

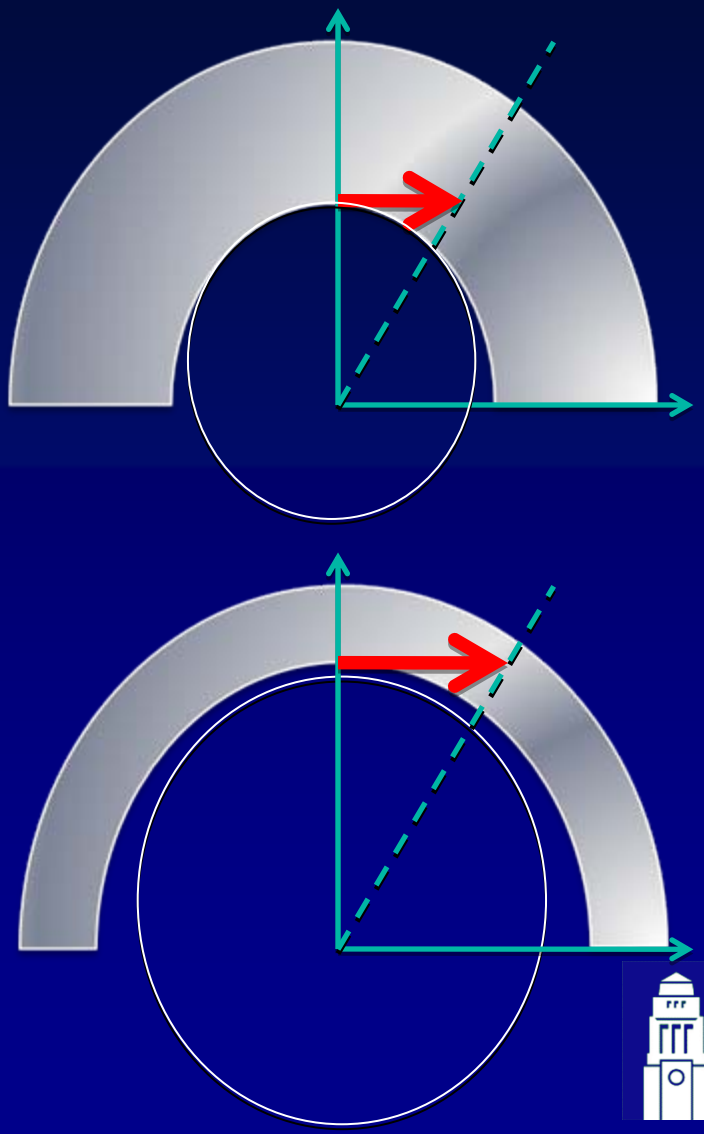
- With improved manufacturing, roughness ↓ and accuracy ↑
- High carbon CoCr
- Adequate/optimised clearance
- Clamping and loosening ↓
- Introduced extensively into clinics since 1980s

Diameter?

Diameter of Artificial Hip Joint:

Metal-on-Metal Hips

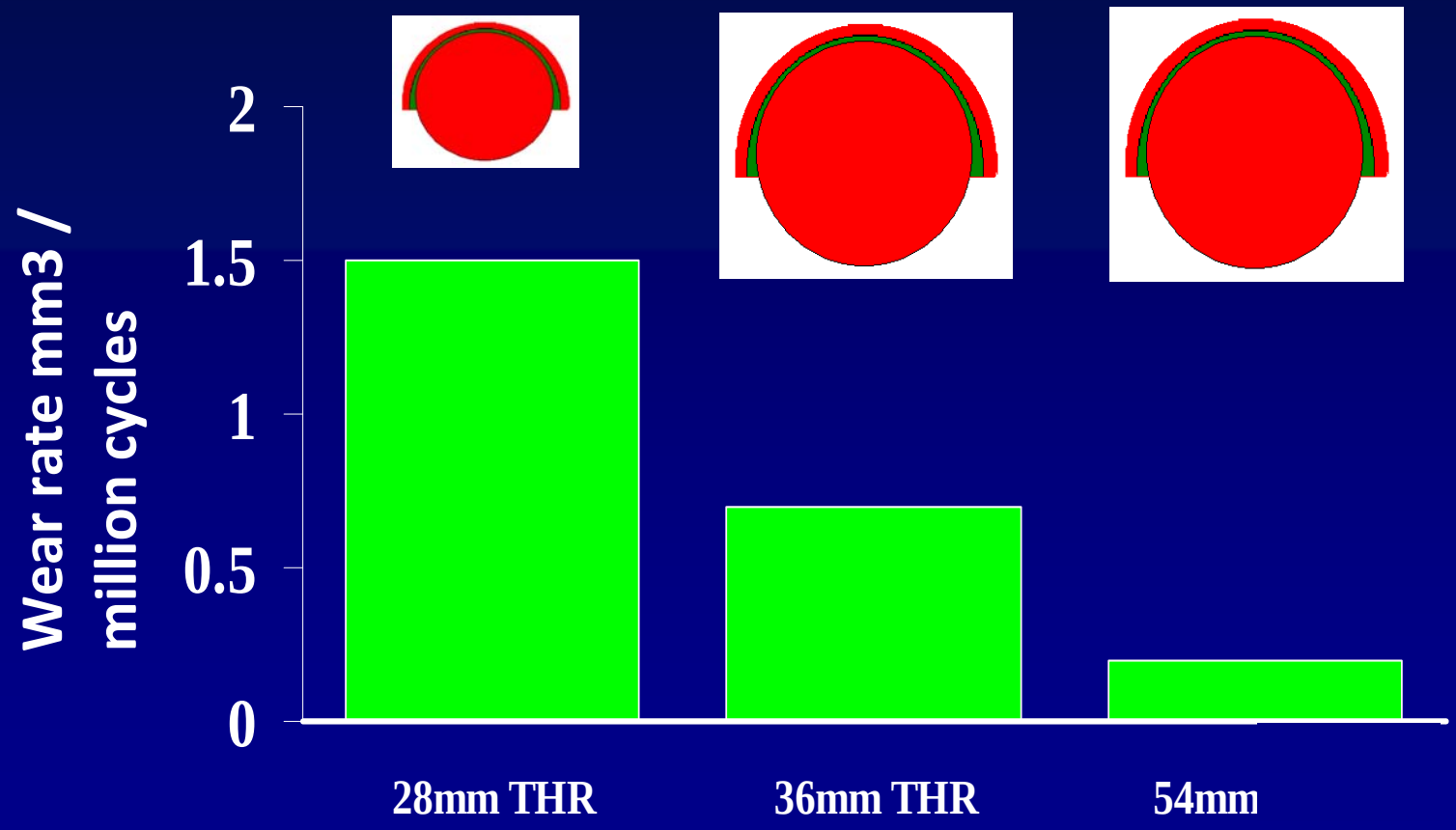
- Increase in diameter increases sliding velocity ↑
- Synovial film ↑
- Improves lubrication √
- Sliding distance increased but small effect on wear



Wear ↓

Diameter of Artificial Hip Joint:

Metal-on-Metal Hips



Fisher et al CORR 2006

Diameter of Artificial Hip Joint:

- **UHMWPE hip: large diameter increases sliding distance and increases wear:**

  Diameter: small

- **MOM hip: large diameter improves lubrication and reduces wear**

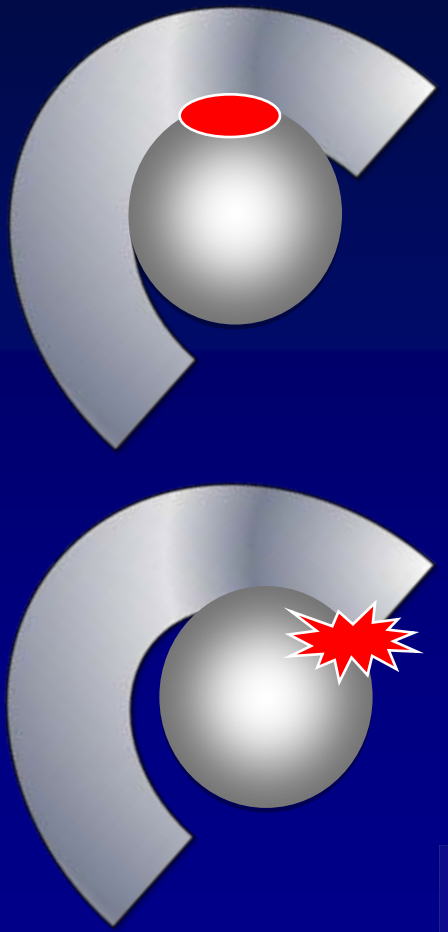
  Diameter: large

Metal-on-Metal Hip Joints:

Importance of Contact Mechanics

- Fluid film lubrication depends on ideal contact conditions

Wear ↓

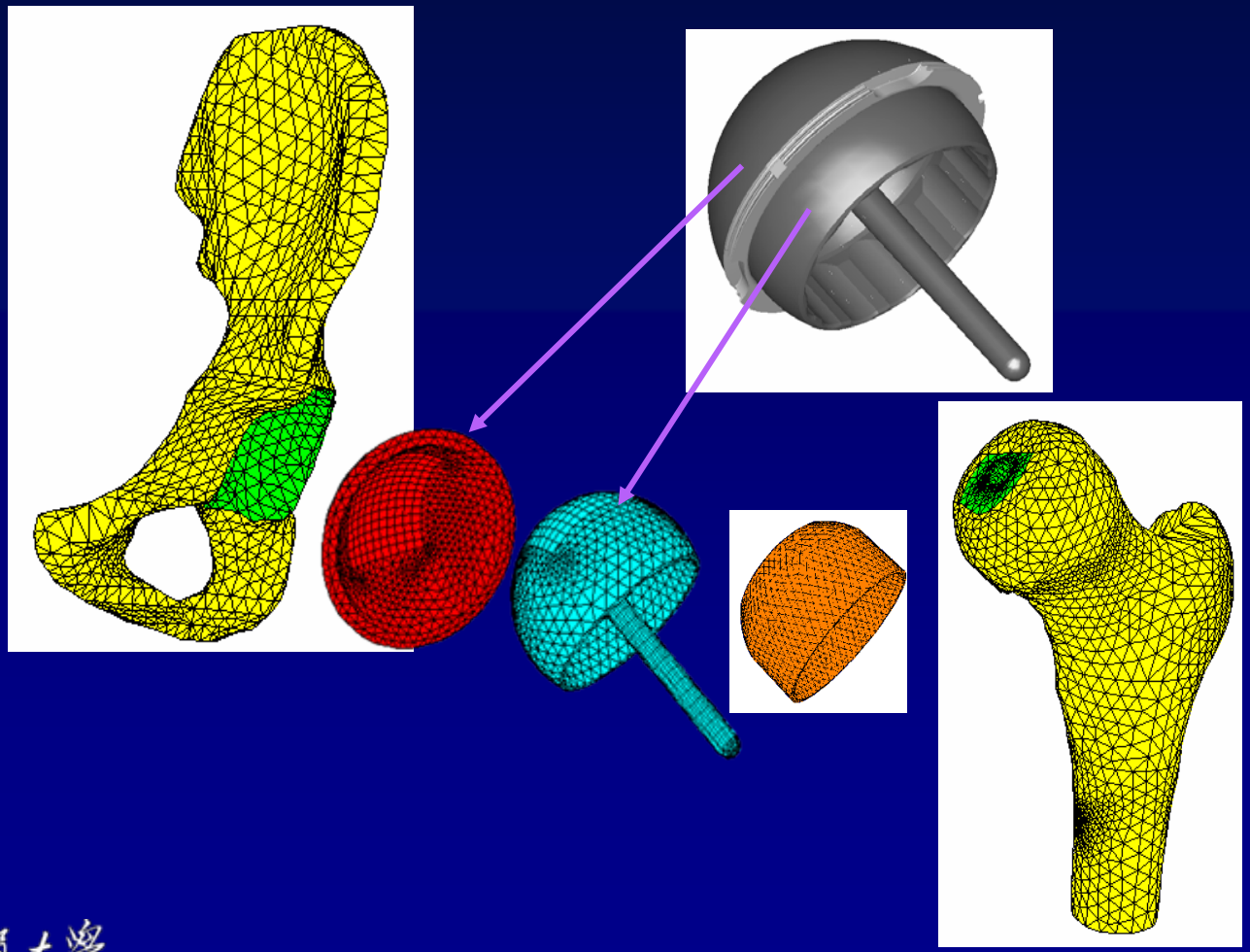


- Adverse contact conditions: edge loading
- Blocks lubricant entry/lubrication ↓
- Stress concentration

Wear ↑↑

Metal-on-Metal Hip Joints:

Contact Mechanics Modelling (finite element model)



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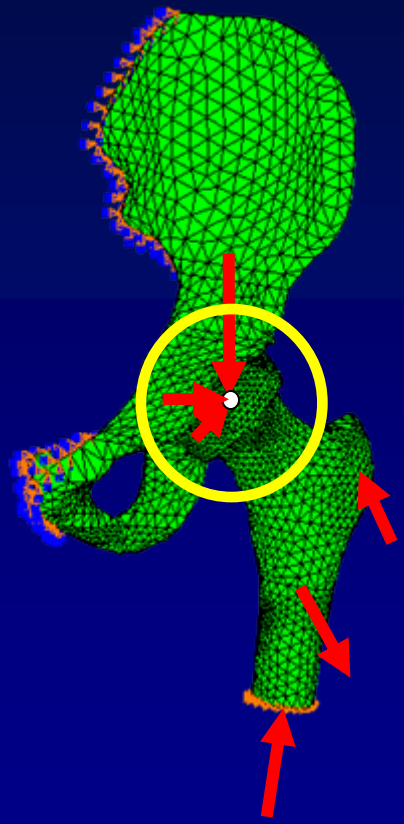


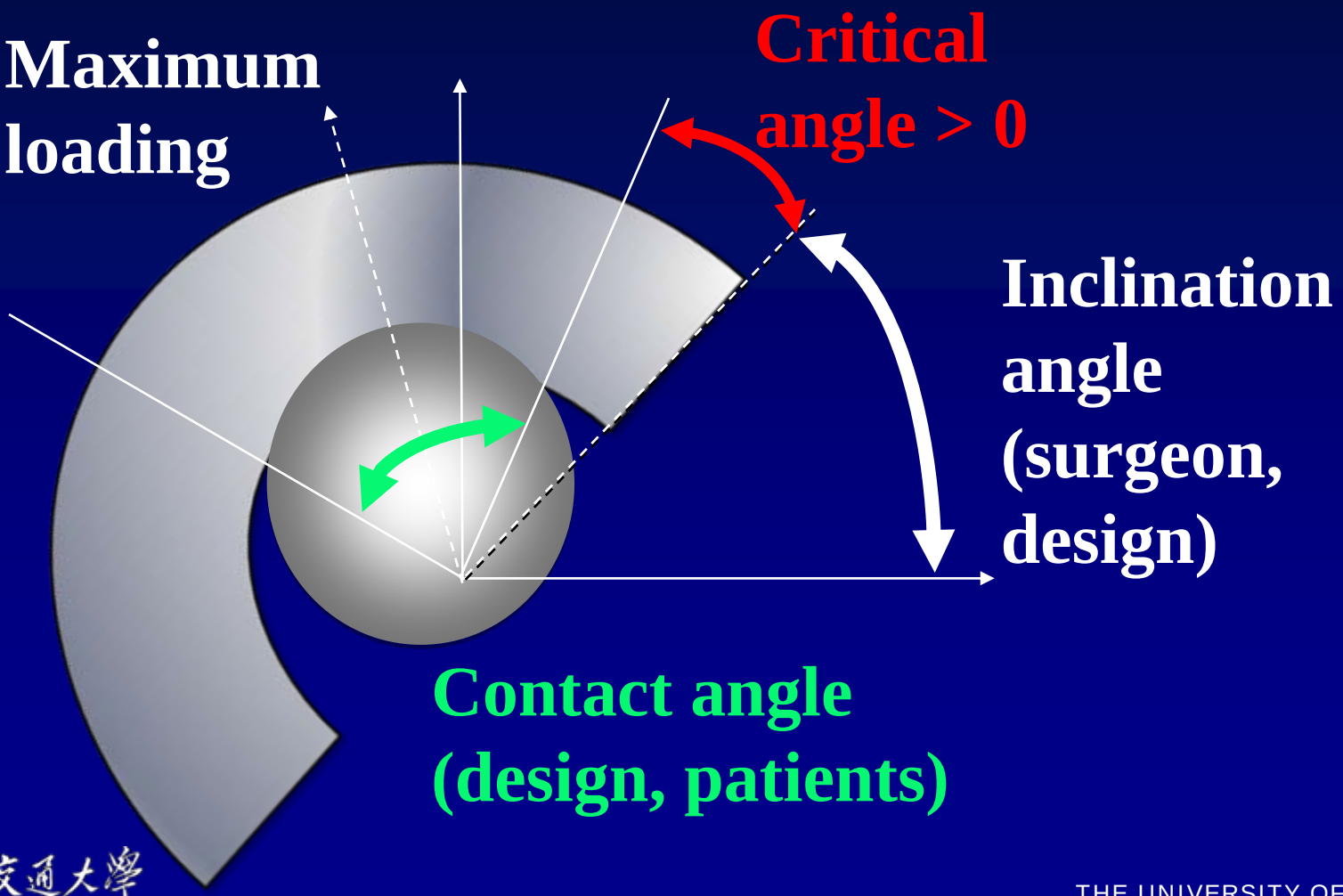
Abductors

Vastus lateralis

Subtrochanteric force

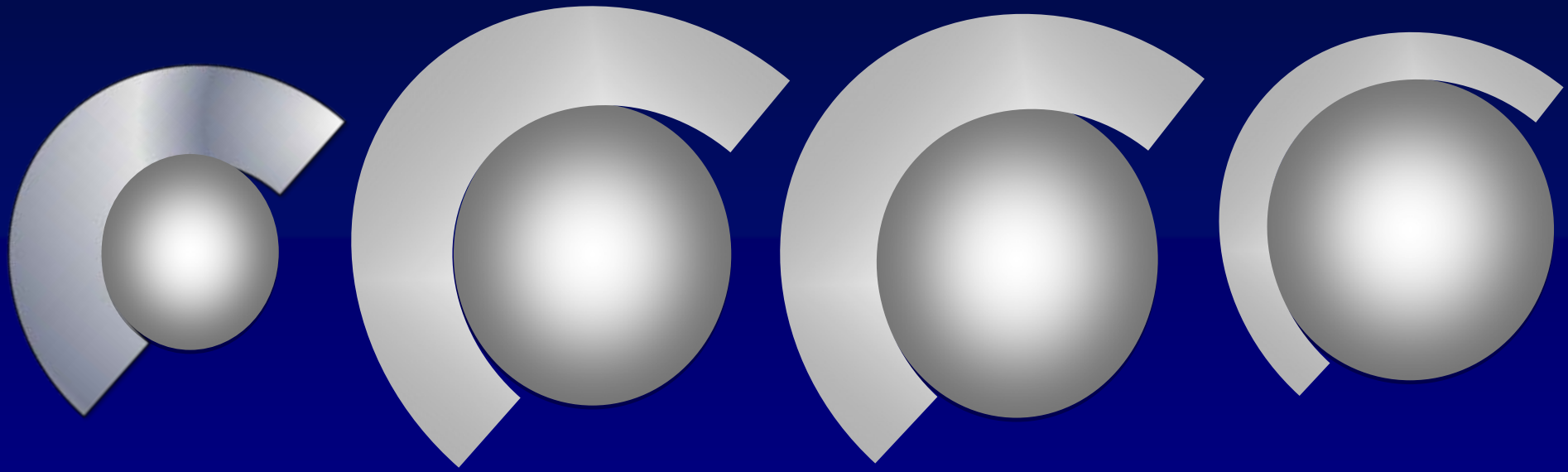
Metal-on-Metal Hip Joints:

Contact Mechanics Modelling



Metal-on-Metal Hip Joints:

Different MOM Hip Designs



28 mm THR | 50 mm SR | 50 mm SR Reduced clearance | 50 mm SR Reduced thickness

Lubrication ↑

Bone ↓

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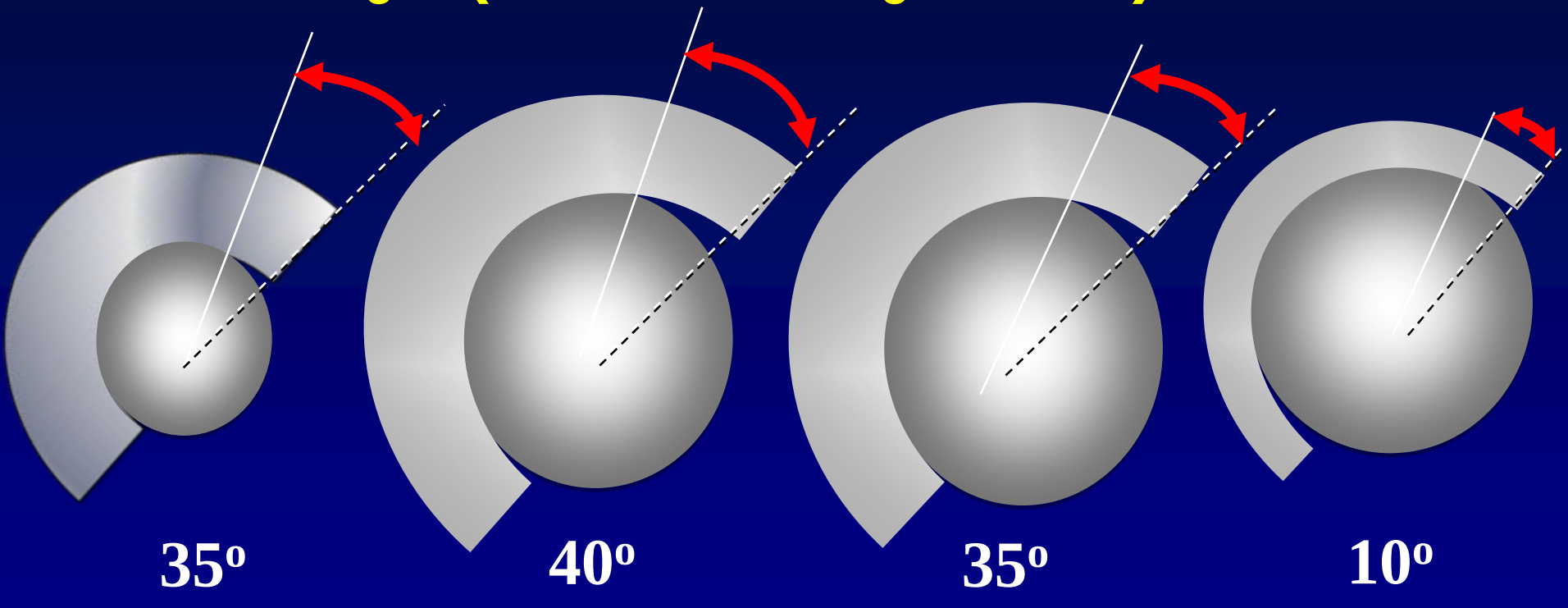
Metal-on-Metal Hip Joints:

Critical Angle (inclination angle = 45^{o})



If inclination angle becomes 55^{o}, reduced clearance/thickness cup will lead to edge contact

Metal-on-Metal Hip Joints:

Metal-on-Metal Hip Joints

- Problems are design specific
  - Thickness
  - Clearance
- It is important to optimise tribology
  - Promote lubrication
  - Avoid edge loading

Future Developments:

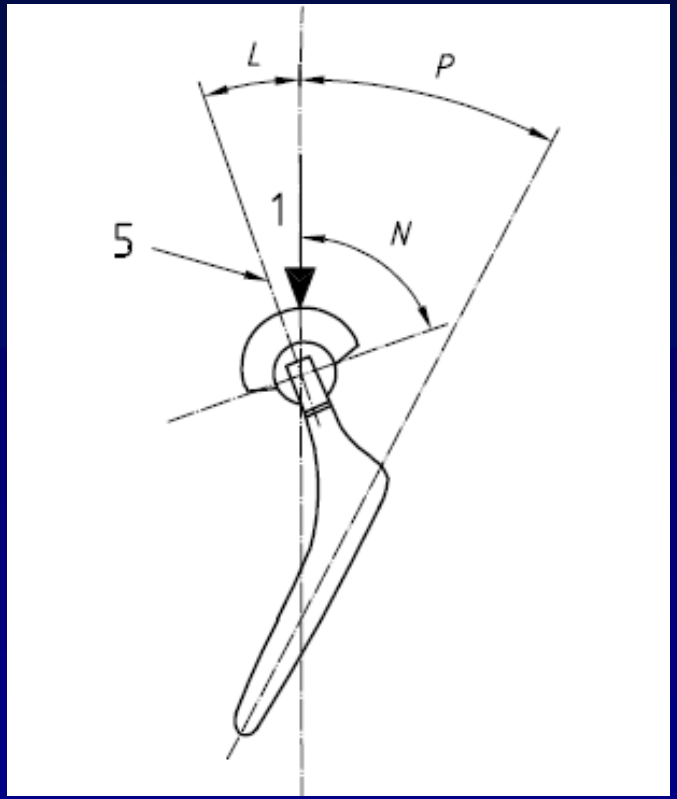
- **Pre-clinical testing:**
- **Reduce risks**
- **Short-term simulation: long-term outcomes**
- **Reduce costs associated with;**
  - **Manufacturing**
  - **Clinical re-calls**
  - **Revision!**

Future Developments:

- **Current wear simulator testing:**
- **ISO standards**
  - **Hip: ISO 14242-1/2**
  - **Knee: ISO 14243-1/2/3**
  - **Spine: ISO 18192-1**
- **Regulatory requirements**
  - **CE marking (Design Examination Certificate)**
  - **FDA (510k)**
  - **SFDA ?**

Future Developments:

- **Benchmarking under ideal conditions (ISO): hip**
  - **Loading through the centre of the cup and the head**
  - **Position of the cup: 60 degrees to the loading axis**



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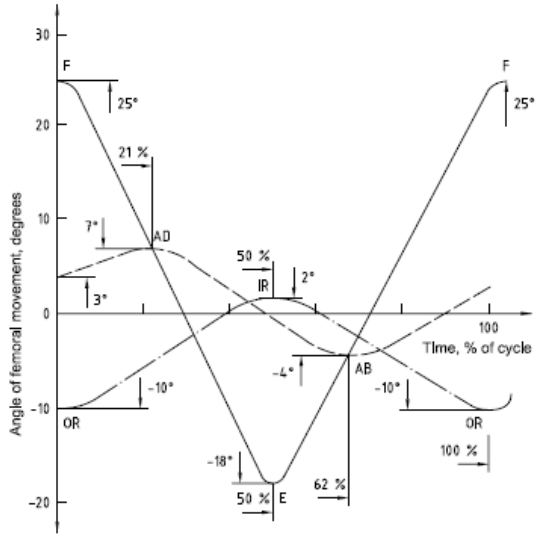
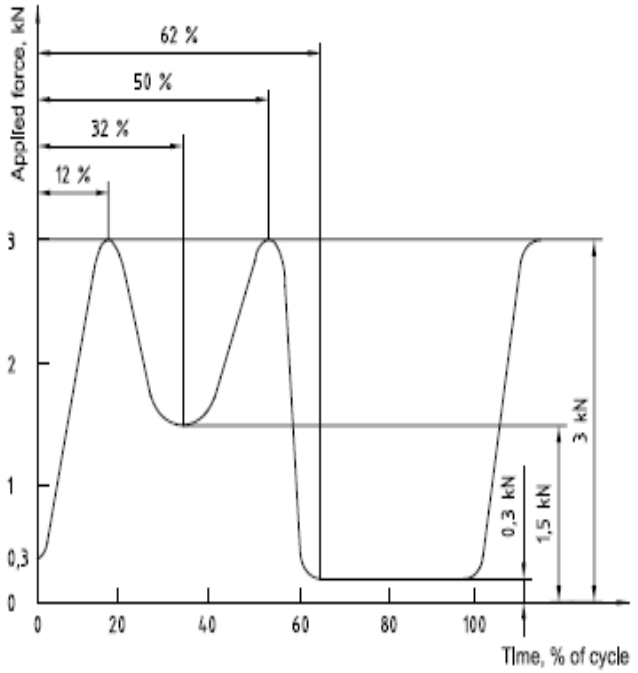


Key

AB - Abduction
AD - Adduction
E - Extension
F - Flexion
IR - Inward rotation
OR - Outward rotation

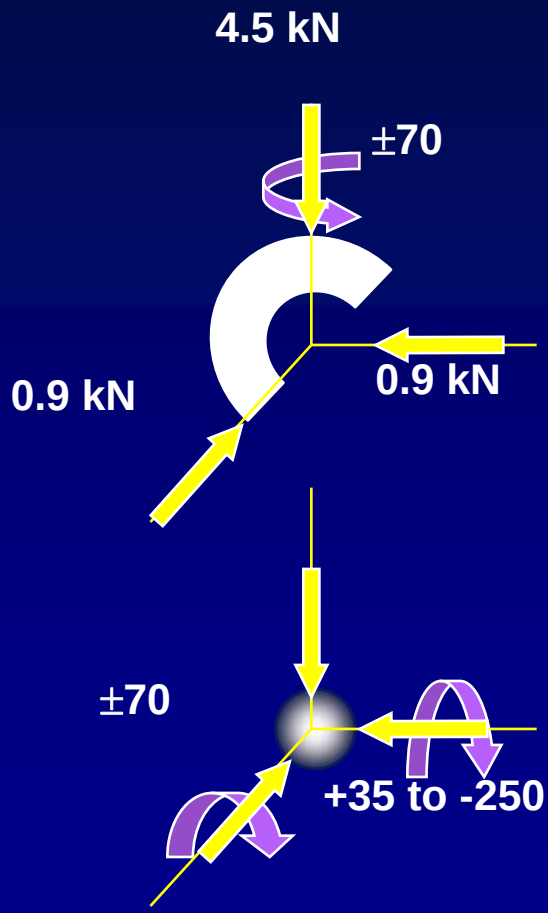
Time, % of cycle ± 1 %	0	21	50	62	100
Angle of flexion (+) or extension (–) ° ± 3 °	25		– 18		25
Angle of adduction (+) or abduction (–) ± 3 °	3	7		– 4	3
Angle of inward (+) or outward (–) rotation ± 3 °	– 10		2		– 10



Time, % of cycle (± 3 %)	0	12	32	50	62	100
Applied force, kN (± 90 N)	0,3	3,0	1,5	3,0	0,3	0,3

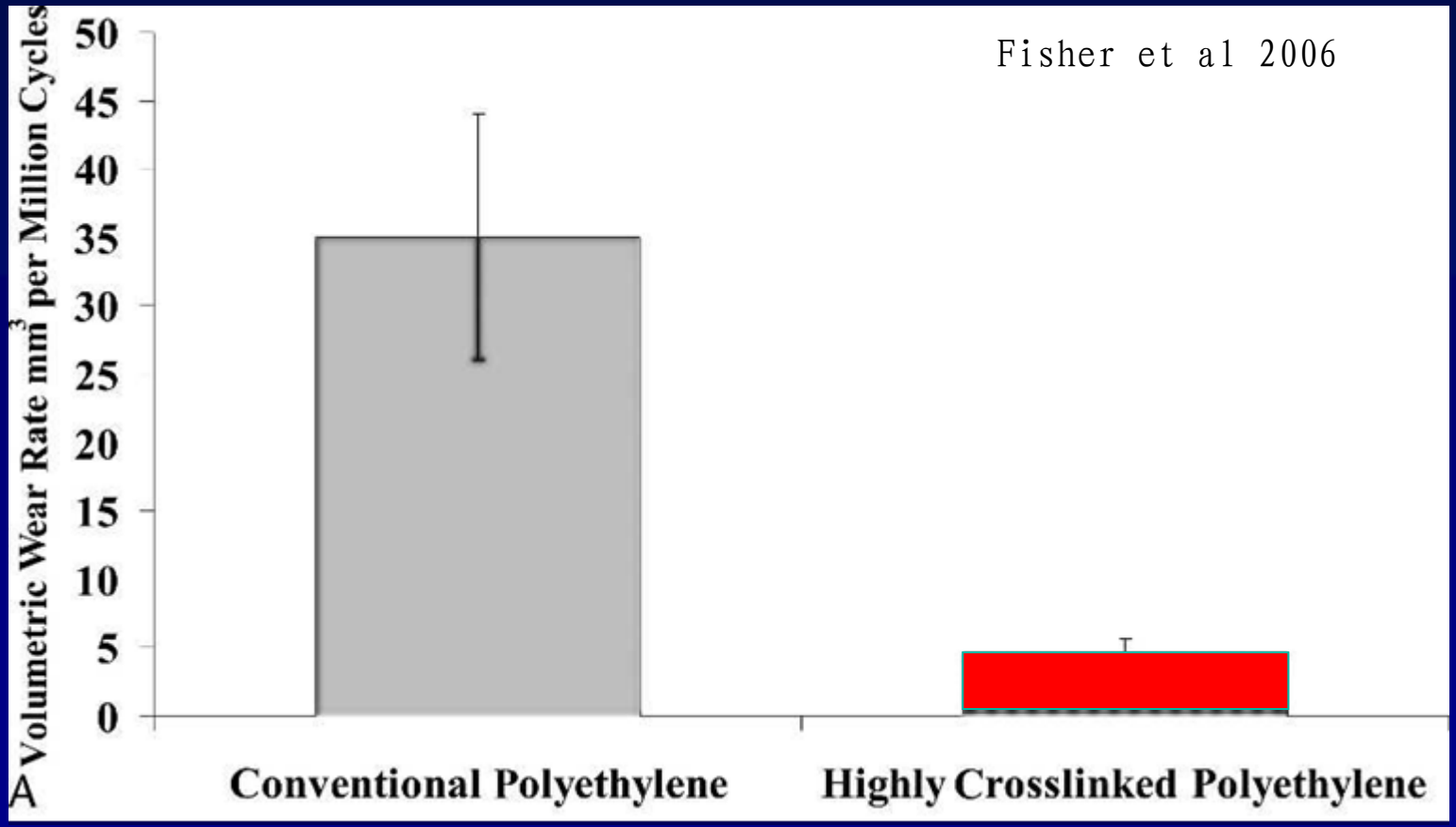
Future Developments:

- **Current wear simulator testing: hip**



Future Developments:

- **Introduction of new bearing surfaces: hip**



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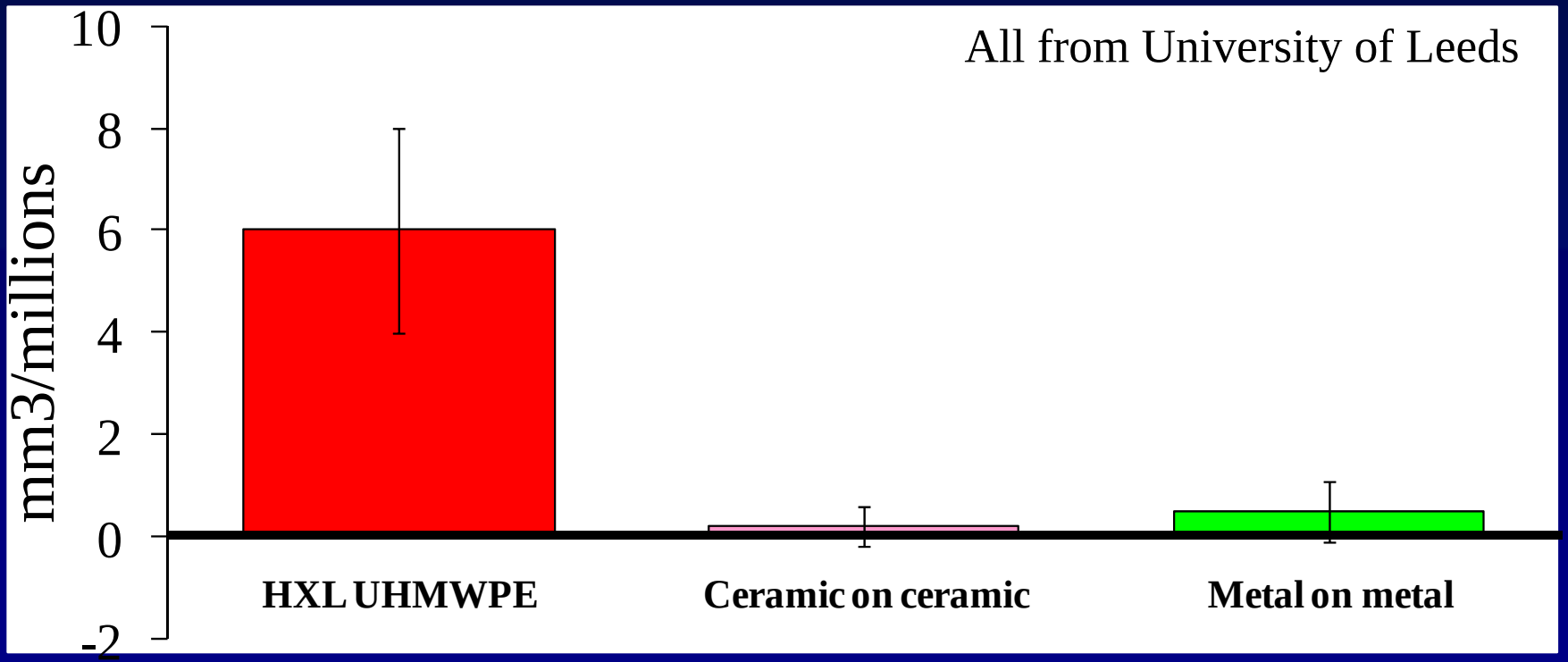

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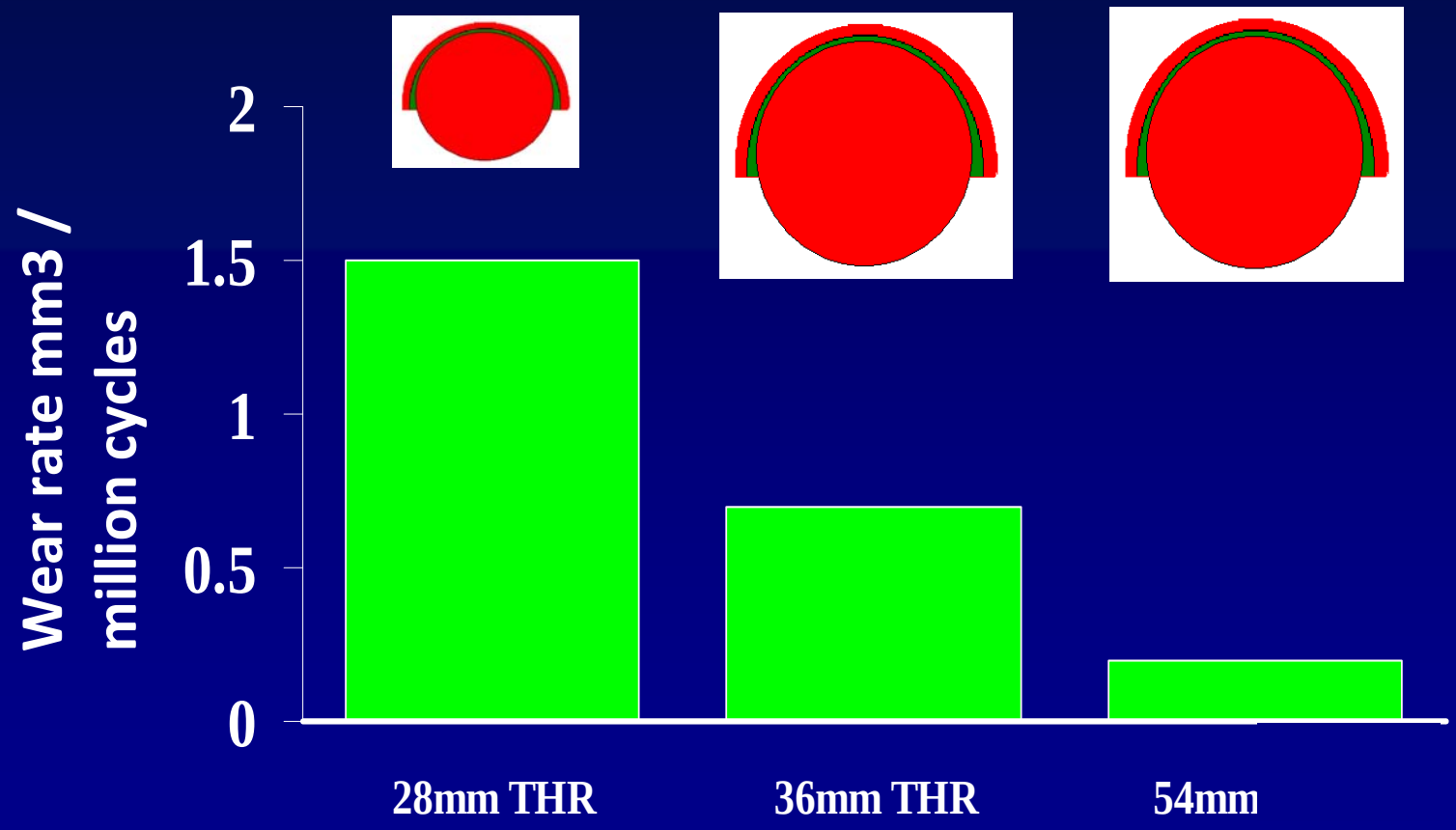
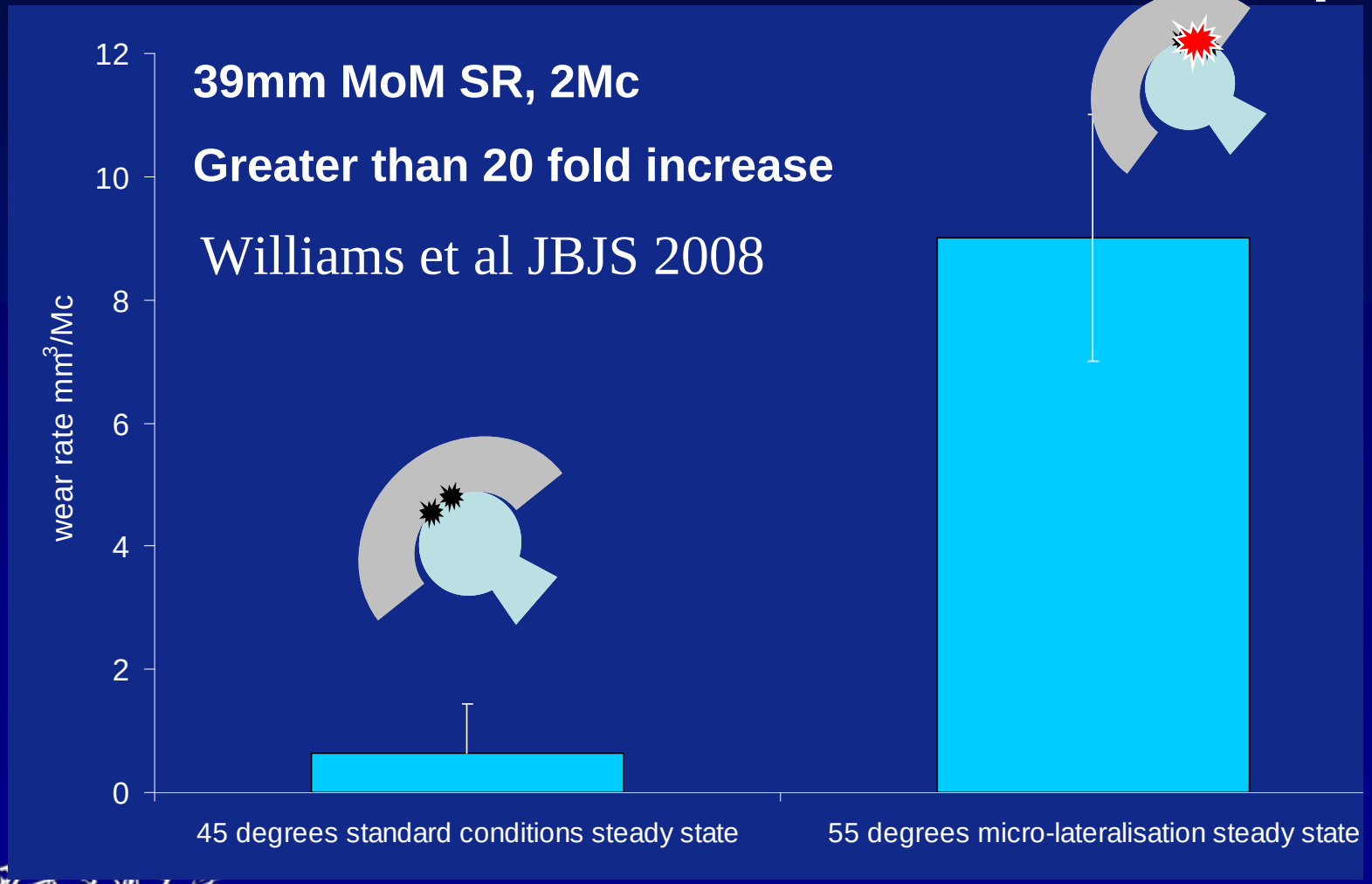


Fisher et al CORR 2006

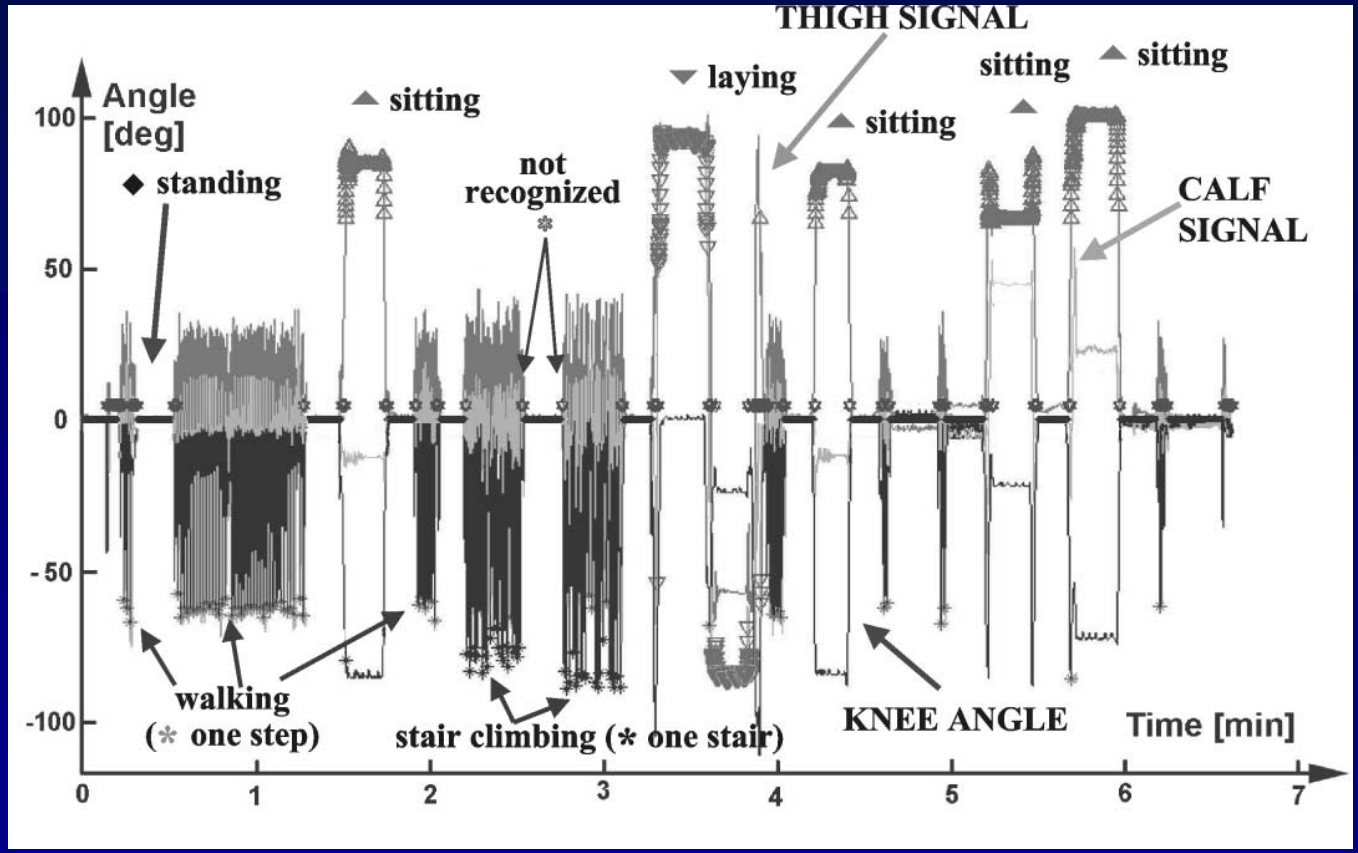
Future Developments:

- **Problems with Current Simulator testing: hip**



Future Developments:

- **Patient activities**



Morlock et al J Biomech 2001

Future Developments:

- **Patient activities**

Future Developments:

- **Importance of principles of tribology & freedom for clinicians**
- **Importance of joint simulation as part of pre-clinical testing**
- **Focus on the failure/mitigation and achieve extreme reliability**
- **Close collaborations between engineers and clinicians**
- **Importance of establishment of a pre-clinical testing platform**

http://www.maitrise-orthop.com

Thank you!

Co-authors

J. Fisher and E. Ingham (Leeds)

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