

THE EFFECT OF SYNOVIAL FLUID CONSTITUENTS ON FRICTION AND LUBRICATION OF ARTICULAR CARTILAGE

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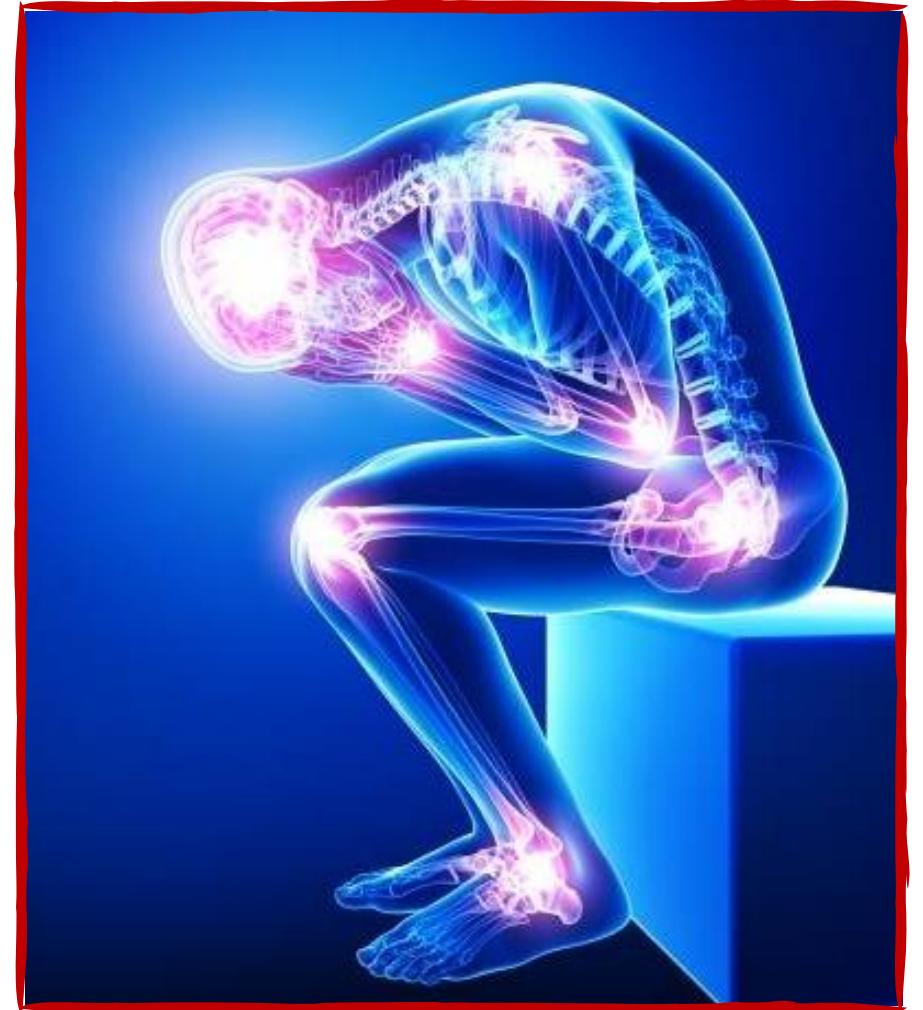
Institute of Machine and Industrial Design
Faculty of Mechanical Engineering
Brno University of Technology

Brno, 31th March 2022



Content of presentation

- Introduction and motivation
- State of the art
 - Friction, Lubrication, Visualization
- Summary of literature review
- Aim of PhD thesis
- Scientific questions, Hypotheses
- Materials and methods
 - Reciprocating tribometer and experimental methodology
- Results and discussion
- Conclusions, list of publications



Osteoarthritis

Wear of cartilage tissue

Distraction of lubrication mechanism

Increasing of friction coefficient

Changes in synovial fluid composition

Reduction of hyaluronic acid concentration



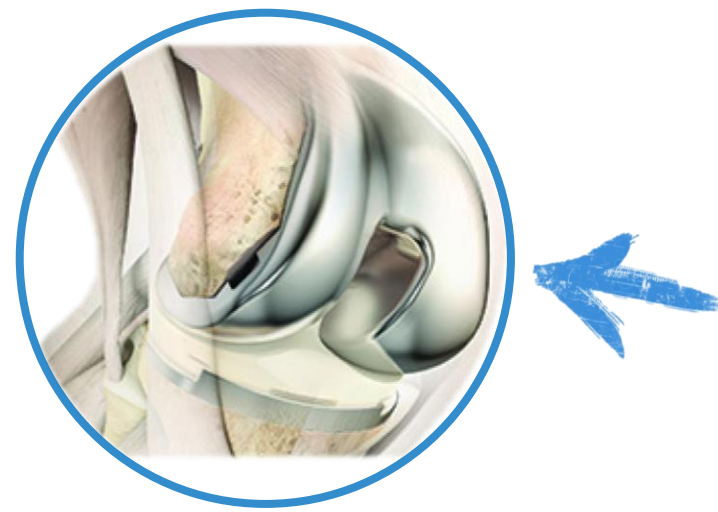
Painful movement

Movement limitations

Decline in living standard

Osteoarthritis

Total endoprosthesis

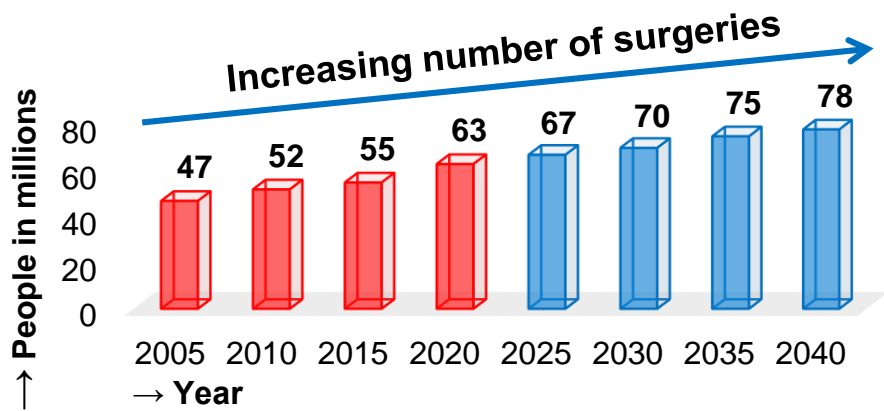


Limited longevity

Revision operations

Wear debris

Aseptic loosening



Osteoarthritis

Total endoprosthesis

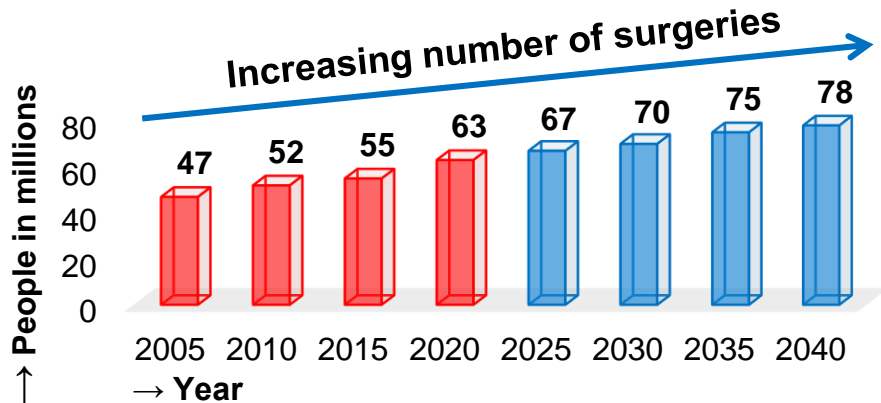


Viscosupplementation



Non-invasive treatment

Intra-articular injection with hyaluronic acid



Osteoarthritis

Reduction of inflammation

Friction reduction

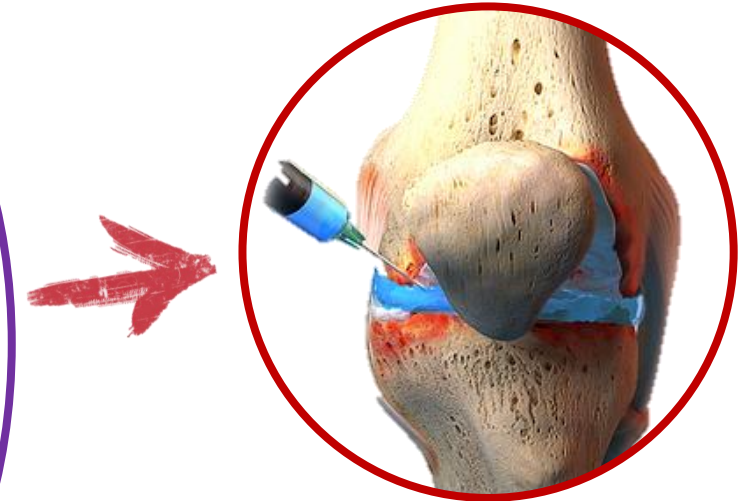
Improved lubrication processes

Hyaluronic acid supplementation

Improving the ability to absorb shocks



Viscosupplementation



Non-invasive treatment

Intra-articular injection with hyaluronic acid

Total endoprosthesis

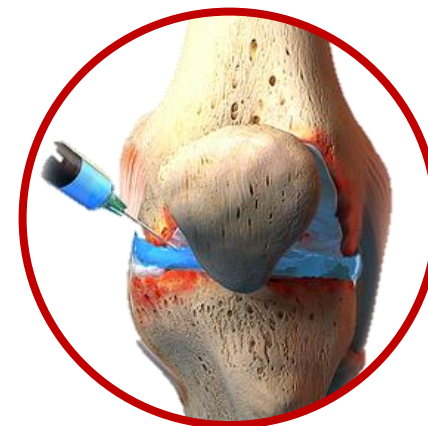


Tribology of endoprosthesis

- Many publications – well explored area
- ✓ Friction coefficient (CoF)
- ✓ Lubricating film formation



Viscosupplementation



Tribology of synovial cartilage

- Limited number of publications
- Non-verified lubrication theories
- Not completely understood

Tribology of synovial joint

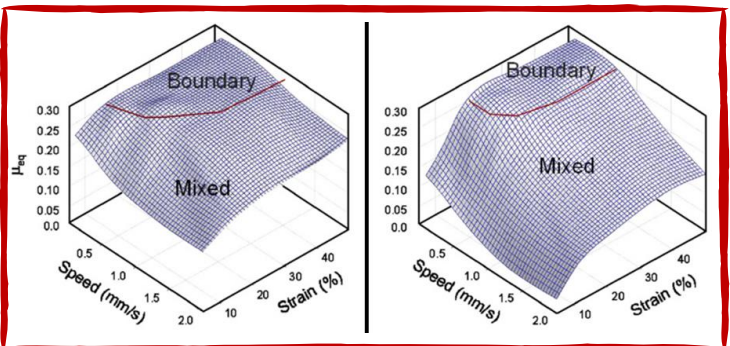
Friction in synovial joint

- Operating conditions impact
- Many publications
- Relatively well described problematics

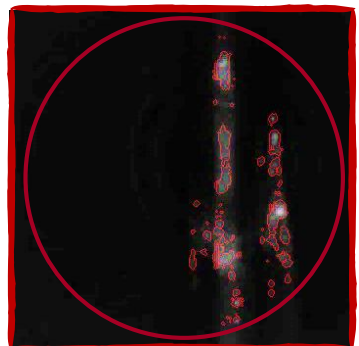


Lubricating processes in synovial joint

- Role of SF components
- Role of cartilage poreous structure
- Lubricating regimes



- Visualization of the cartilage contact - Fluorescence microscopy



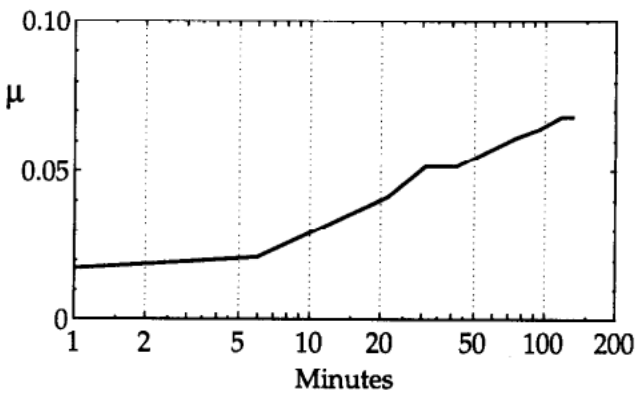
Friction in synovial joint

1994

STACHOWIAK, G.

Friction and wear changes in synovial joints

- Cartilage vs stainless steel
- Lubricant – synovial fluid



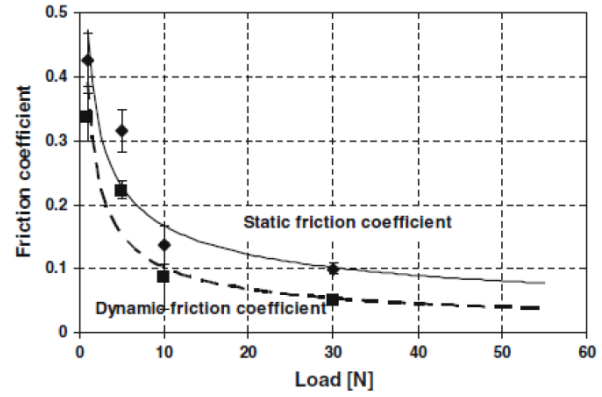
CoF between cartilage and stainless steel.

2006

MERKHER, Y. et al.

A rational human joint friction test using a human cartilage

- Tests with human cartilage
- Lubricant – synovial fluid



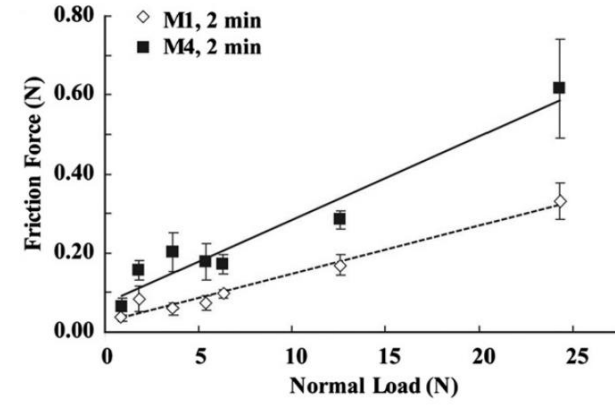
Dependency between load and CoF

2011

CHAN, S. et al.

The role of lubricant entrapment at biological interfaces ...

- Cartilage sample from high (M1) / low (M4) contact pressure



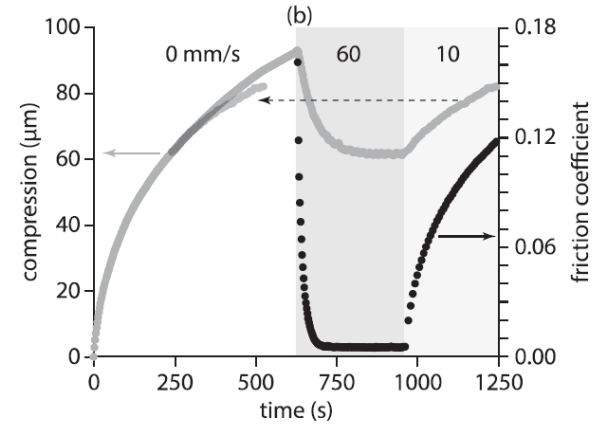
Dependency between load and CoF (M1/M4)

2016

MOORE, A. et al.

New Insights Into Joint Lubrication.

- Rehydration impact
- Cartilage vs glass plate



Tribological rehydration and recovery

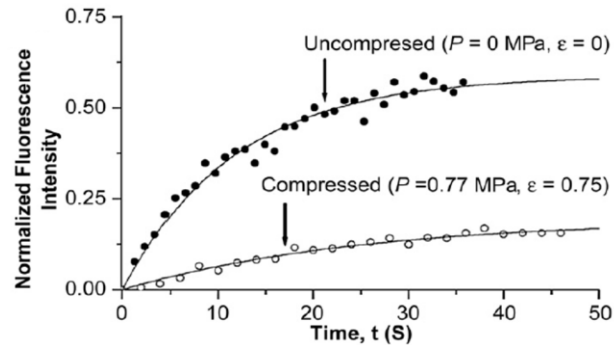
Lubricating of synovial joint

2008

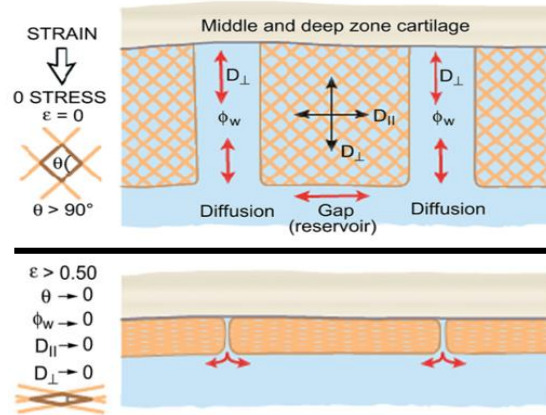
GREENE, G. et al.

Changes in pore morphology and fluid transport in compressed articular cartilage and the implications ...

- Flowing of lubricant through the cartilage porous structure
- Impact of deformation of porous structure to lubricant flowing
- Fluorescence microscopy



Recovery hydration ability of cartilage



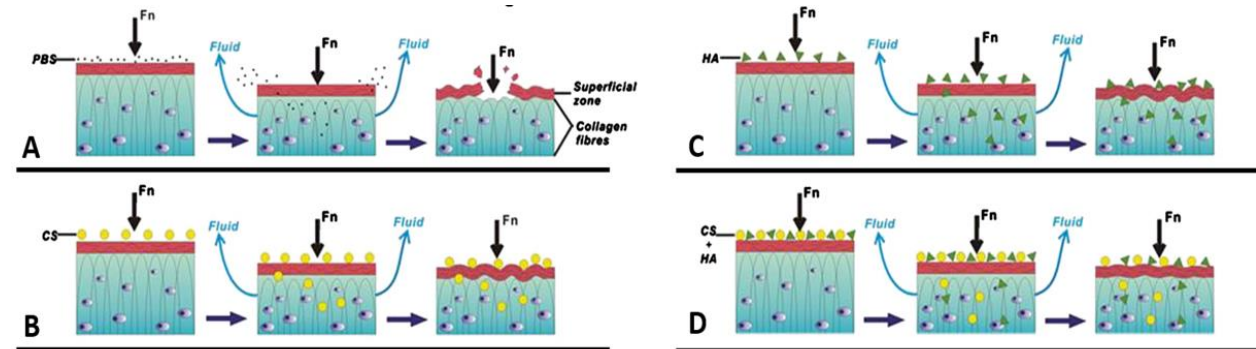
Compression of porous structure

2015

WU, T. et al.

The lubrication effect of hyaluronic acid and chondroitin sulfate on the natural temporomandibular cartilage ...

- HA Molecular weight impact
- Higher HA molecular weight = better surface protection
- Bigger particles adsorb on the cartilage surface



Physical lubrication mechanism model

Lubricating of synovial joint

2016

2017

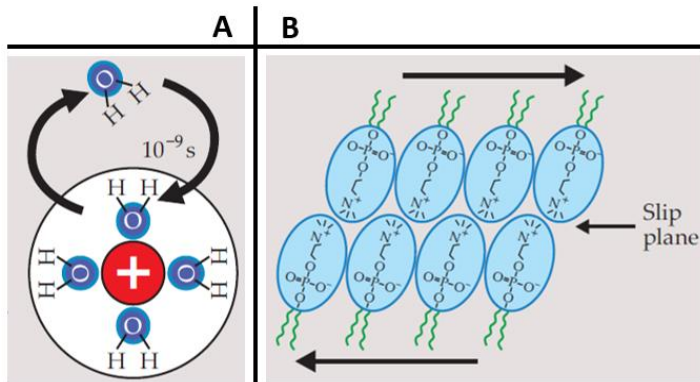
JAHN, S. et al.

MURAKAMI, T. et al.

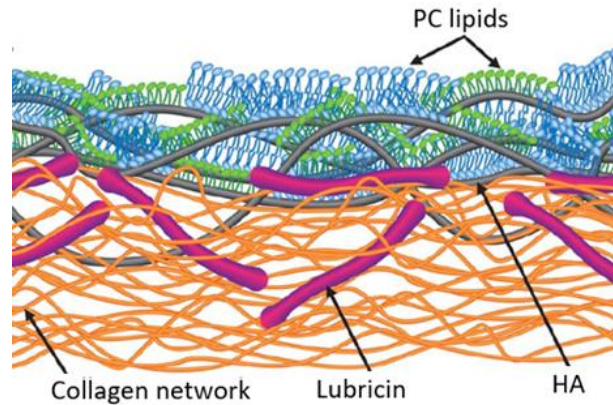
Lubrication of Articular Cartilage

Importance of adaptive multimode lubrication mechanism ...

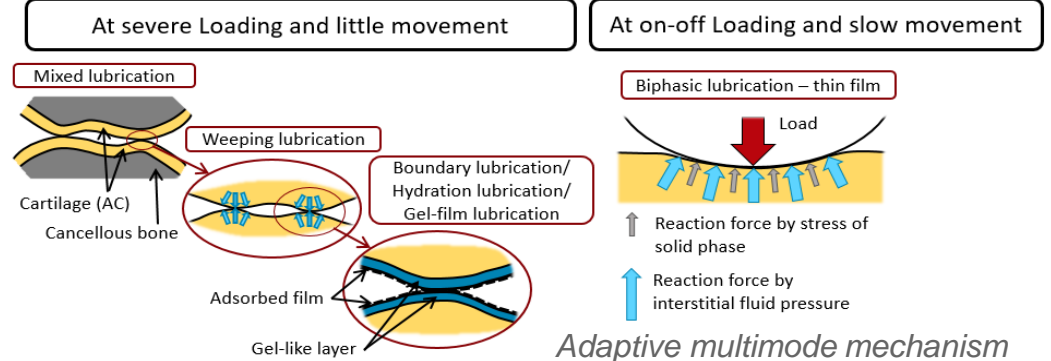
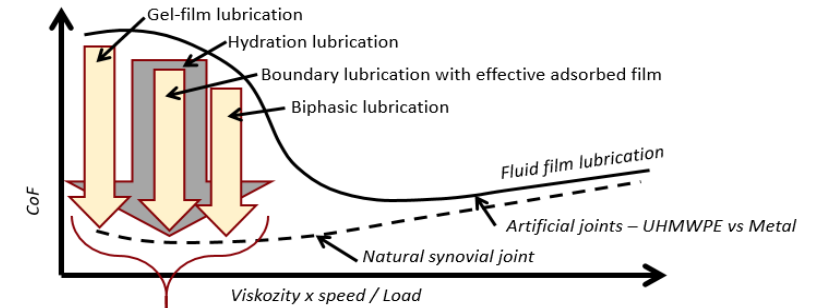
- Principle of hydration lubrication
- Mica plates – similar hydrophilicity as cartilage
- HA creates layer on the mica plate



Hydration shell – the principle of hydration lubrication



Phospholipidic bilayer



Adaptive multimode mechanism

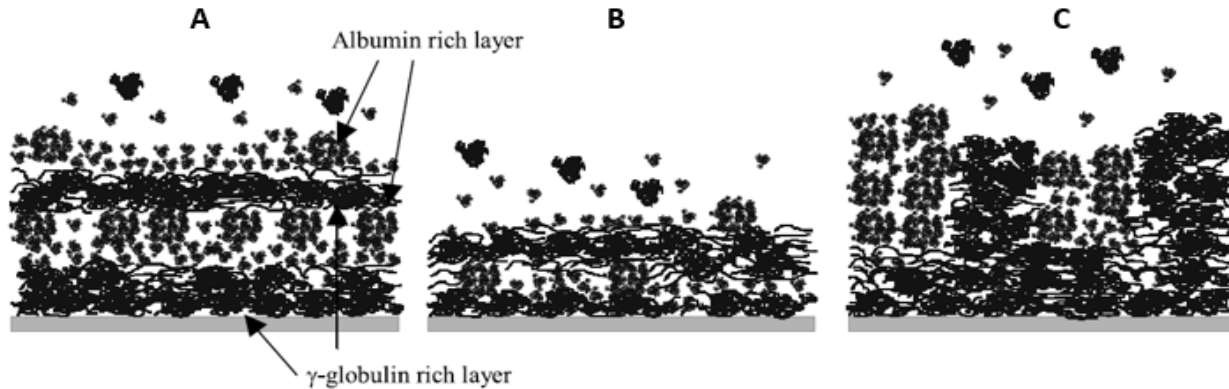
Visualization of the cartilage contact

2006

NAKASHIMA, K. et al.

Study on wear reduction mechanisms of artificial cartilage by synergistic protein boundary film formation

- PVA hydrogel contact visualization by fluorescence microscopy
- Fluorescence analysis after performing the experiment



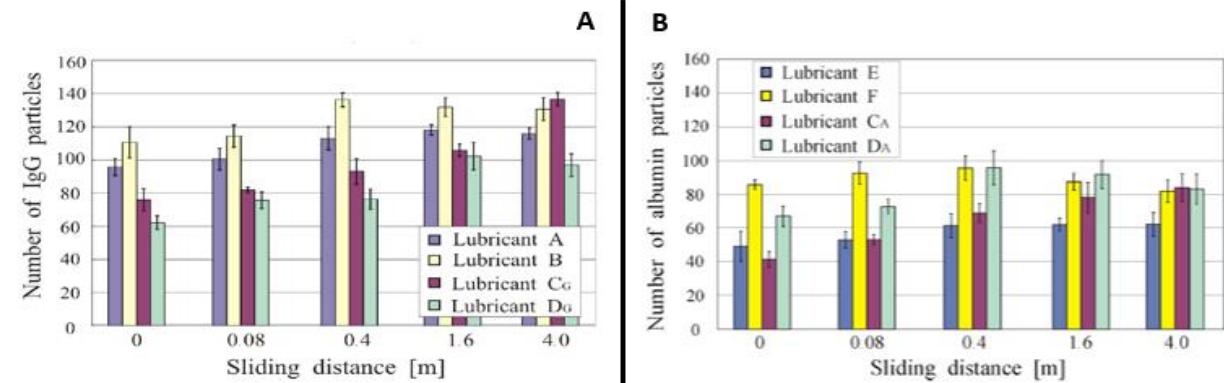
Model of lubricating film formation.

2008

YARIMITSU, S. et al.

Effects of Lubricant Composition on Adsorption Behavior of Proteins on Rubbing Surface and Stability of Protein ...

- PVA hydrogel contact visualization by fluorescence microscopy
- More complex lubricants show larger number of particles



Number of particles during friction reciprocating test.

Tribology of synovial joint

Friction in synovial joint

- Influence of operating conditions, lubricant composition, rehydration, contact pairs
- Many publications

✓ Comprehensive description of cartilage friction behaviour

Lubricating processes in synovial joint

- Limited number of studies
- Unproven theories
- Insufficiently described lubrication processes in cartilage contact

- Only post analysis of lubricating film
- Very limited number of studies – focused only on PVA hydrogel

- Comprehensive description of lubricating processes in cartilage contact
- ✗ Simultaneous friction analysis and cartilage contact visualization
- Influence of lubricant composition on lubricating film forming

Aim of PhD thesis

The aim of this PhD thesis is to describe the effect of individual components of synovial fluid on lubricating film formation in the model of synovial joint. The thesis is focused on the experimental analysis of friction coefficient and observation of adsorbed lubricating film with the use of the principle of fluorescence microscopy.

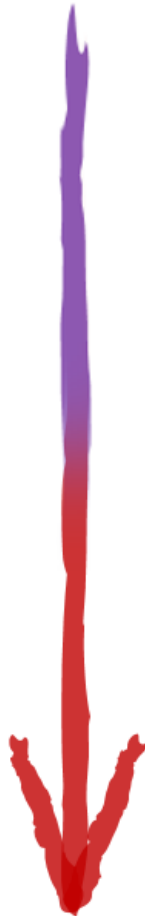
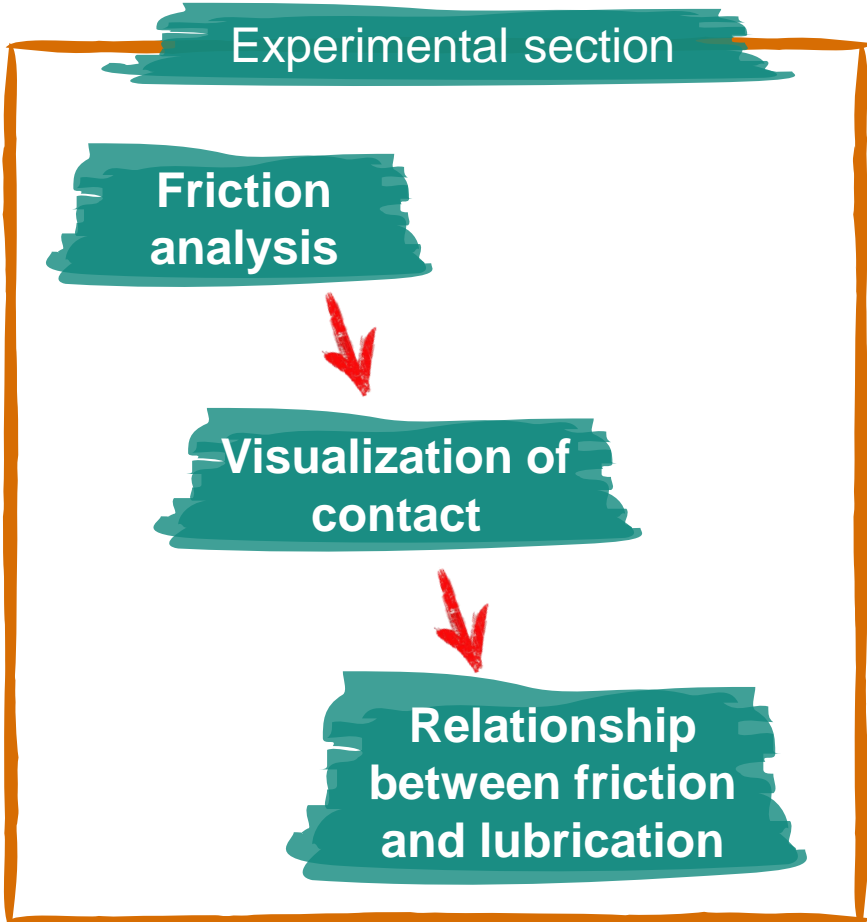
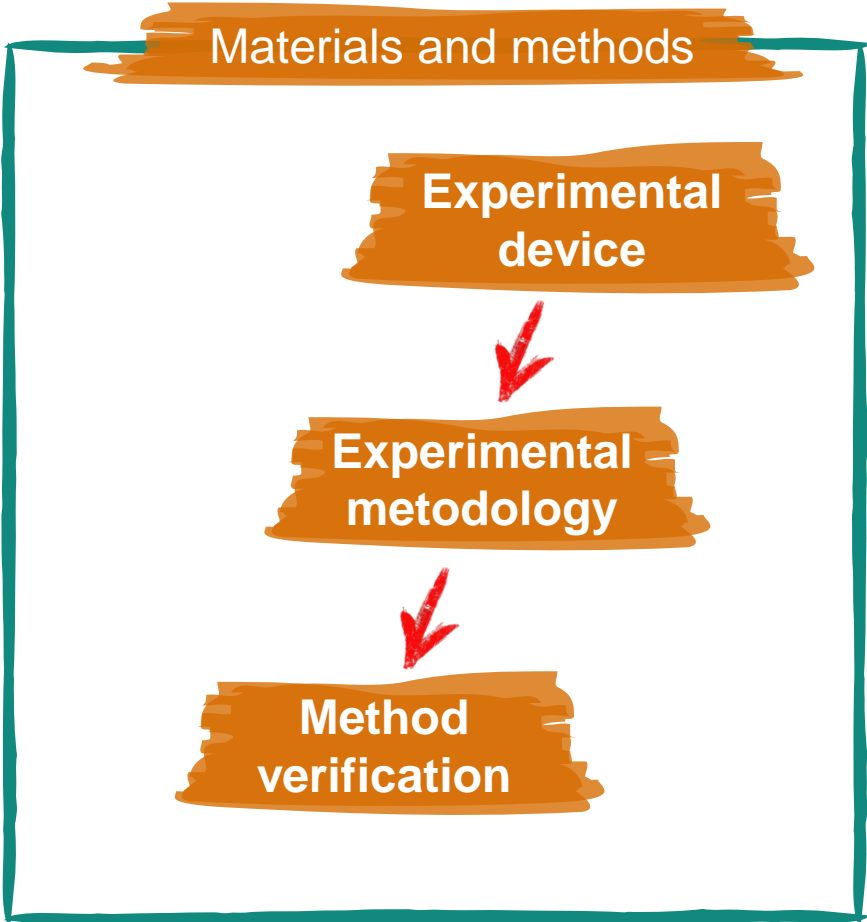
Scientific questions

- What is the influence of the individual components contained in the model synovial fluid on the lubricating film formation in the model of synovial joint?
- How is the friction coefficient affected by the number of dominant protein particles in the model of synovial joint?

Hypotheses

- A simple protein solution does not create a stable lubricating film with high friction coefficient. A combination of simple proteins causes the proteins to bind to each other. Forming of the lubricating film is mostly affected by hyaluronic acid and phospholipids; these components contribute to the stability of lubricating film and increase its thickness.
- It is expected that a higher particle count of dominant proteins component adsorbed in the contact causes a higher friction coefficient whereas the thickness and area of lubricating film increases.

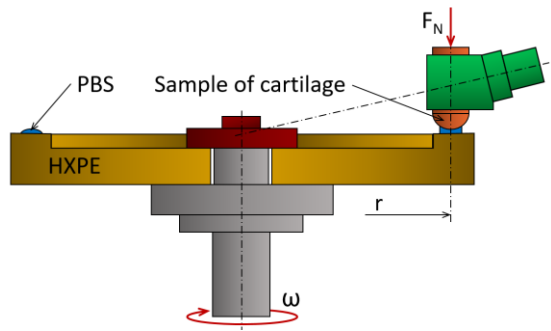
State of art



Aim of PhD thesis

Experimental devices

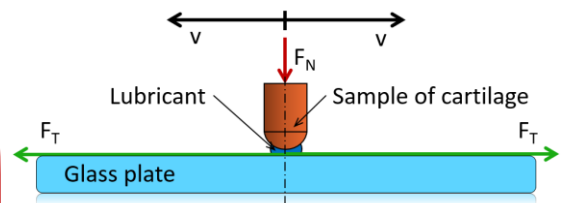
Mini Traction Machine (MTM)



Verification of cartilage sample storing method

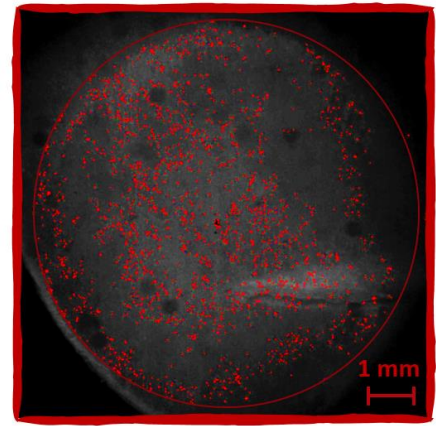
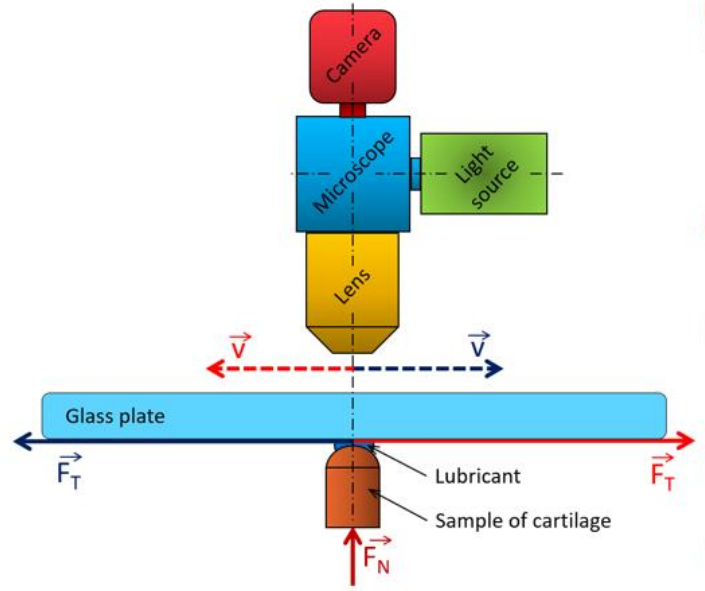
Defence of the PhD thesis

Bruker UMT TriboLAB

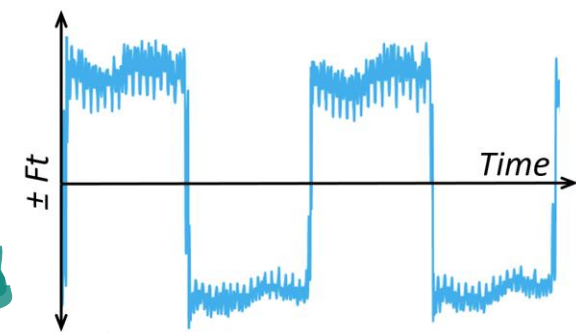


Verification of the new designed tribometer

New reciprocating tribometer



Simultaneous friction + visualization

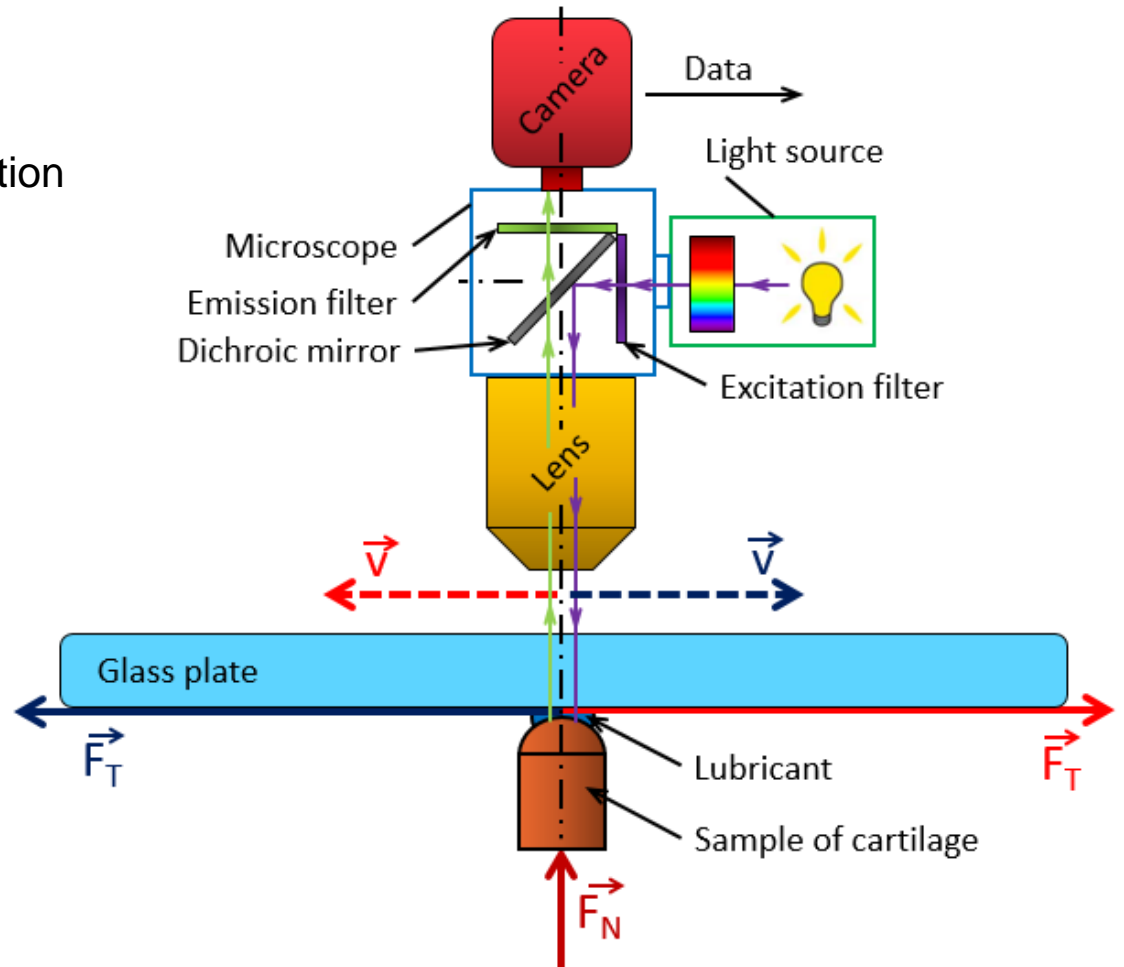


New reciprocating tribometer

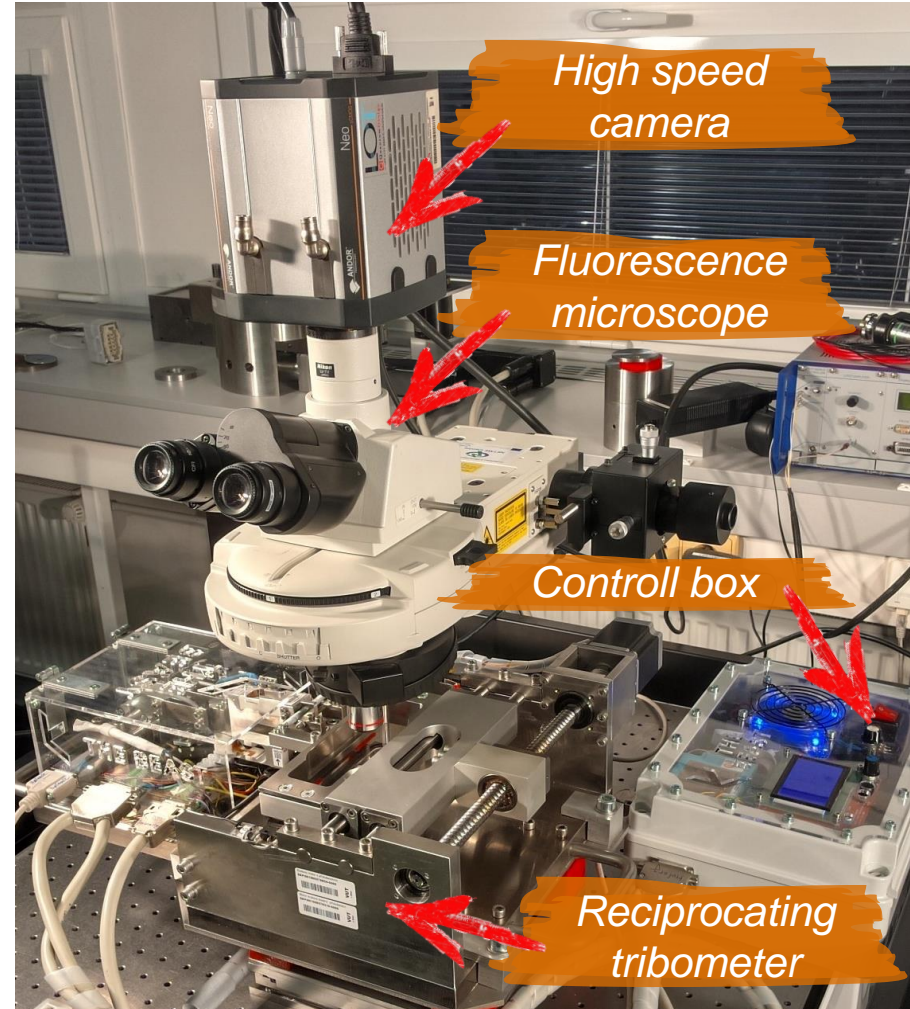
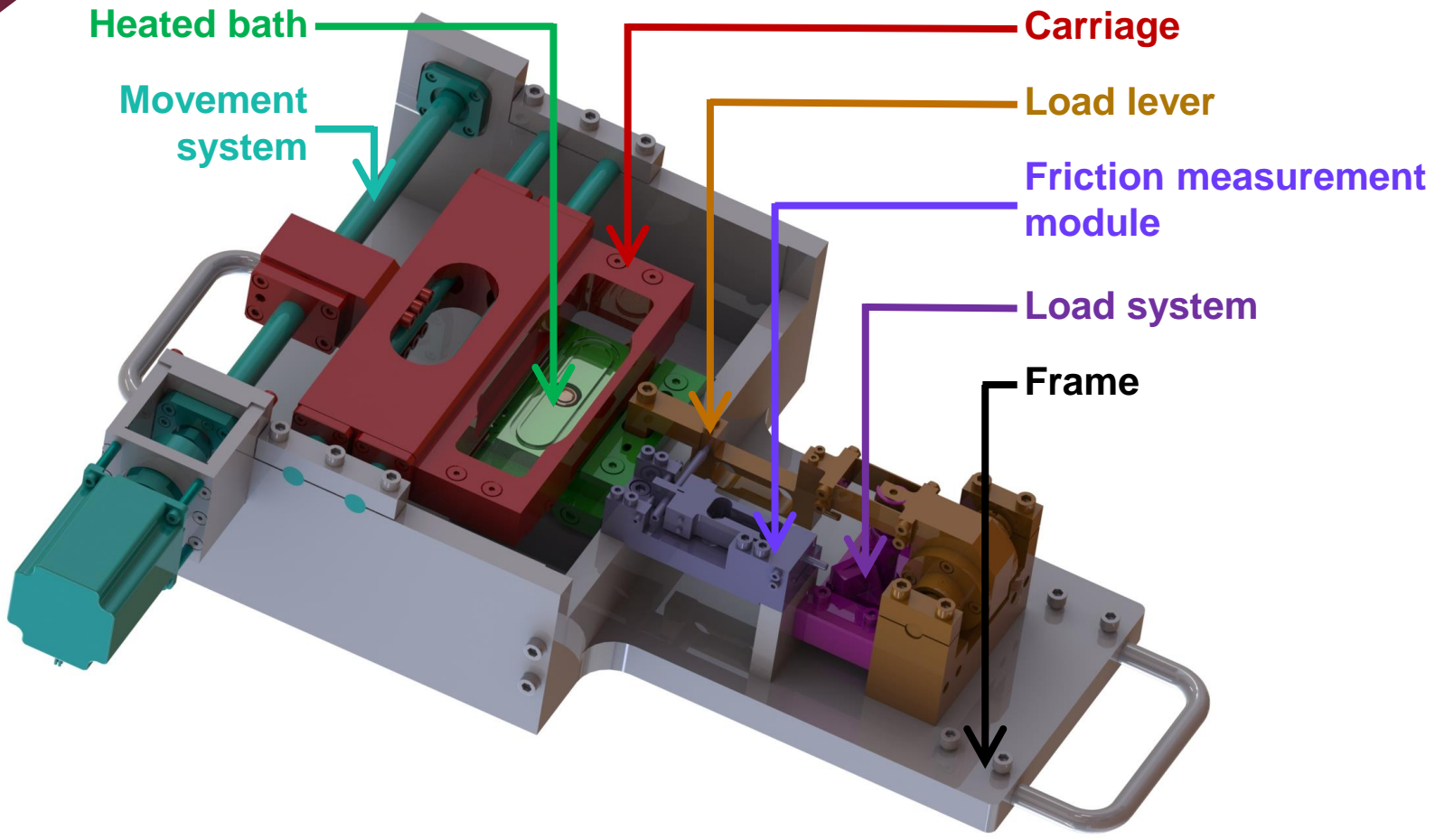
- Reciprocating pin-on-plate tribometer
- Simultaneous friction measurement and contact visualization
- Visualization method – fluorescence microscopy

Experimental conditions

- Glass plate – optical glass B270
- Pin - cartilage sample – \varnothing 9,7 mm
- Load – 10 N (approximately 0,8 MPa)
- Speed – 10 mm/s
- Stroke length – 20 mm
- Fluorescently marked lubricants



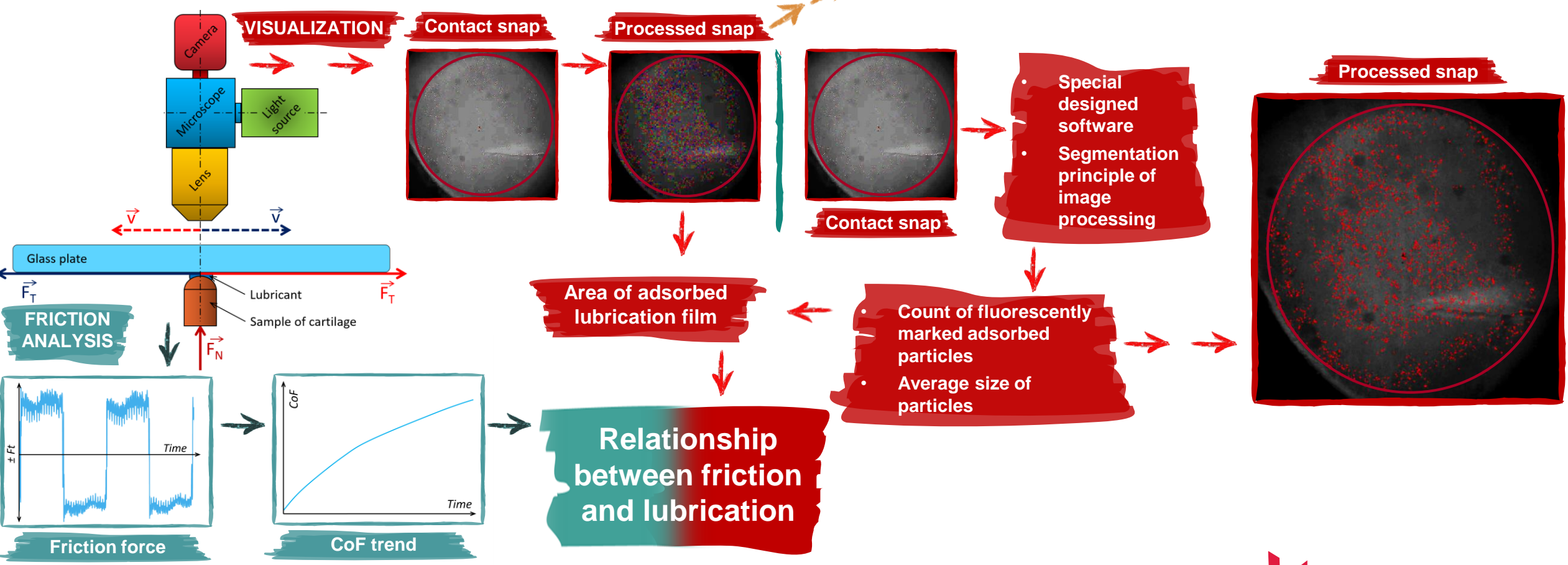
New reciprocating tribometer



Data processing

Methodology of data acquisition from the experiments

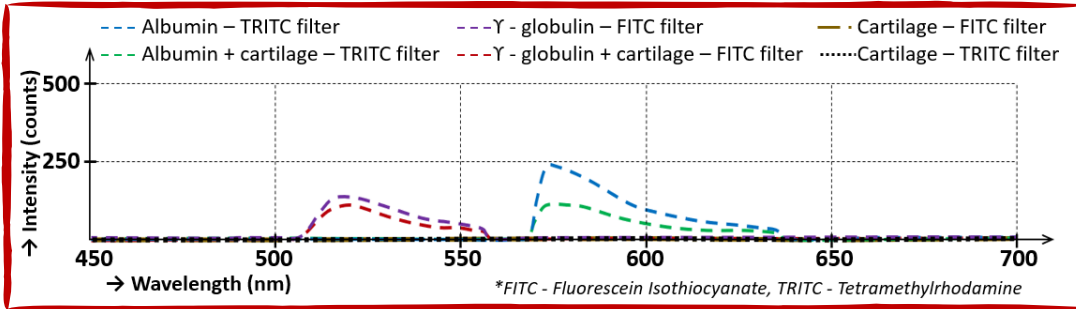
Processing algorithm of snaps



Verification of method

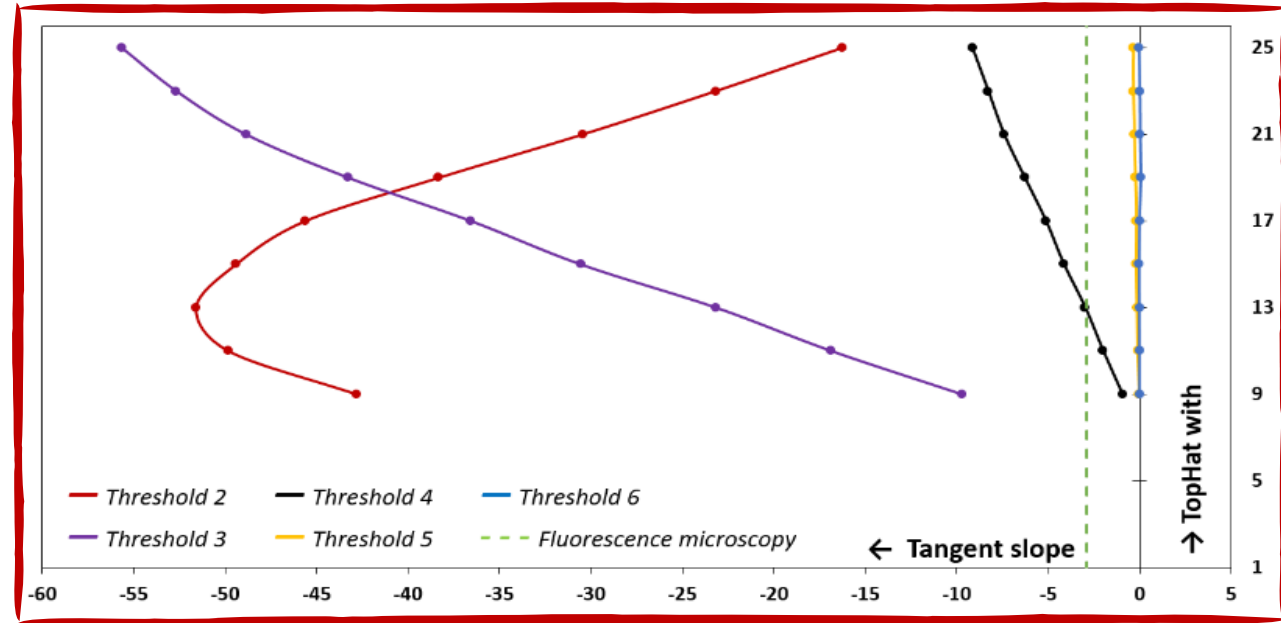
Verification of the cartilage contact

- Spectral analysis of contact with fluorescently marked lubricant



Verification the of data process

- Calibrating of new processing software (calibrating of segmentation process, threshold settings)
- Setting (calibrating) of software based on fluorescence intensity
- New Calibrating process to each cartilage sample

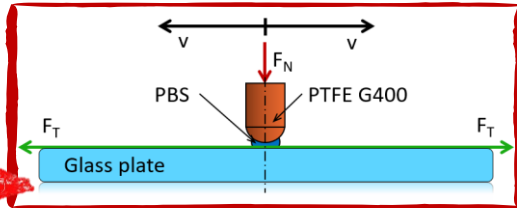
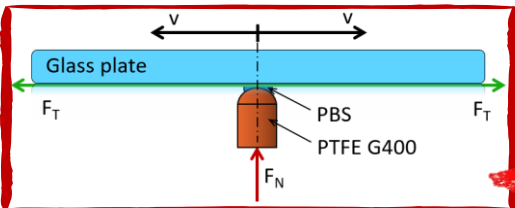


Verification and calibration of new tribometr

- The same configuration – pin-on-plate
- Comparing of friction measurement (CoF)

New reciprocating tribometer

Bruker UMT TriboLAB



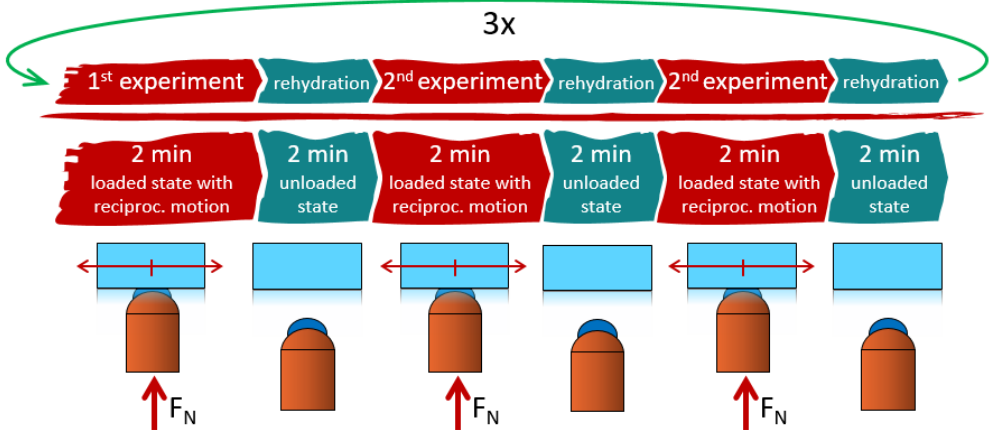
Experimental design and conditions

Cartilage sampling



- Femoral hip head of mature pigs
- Removing by ejector
- Smples – Ø 9,7 mm
- Storing in deep frozen state -20°C

Experimental design



Defence of the PhD thesis

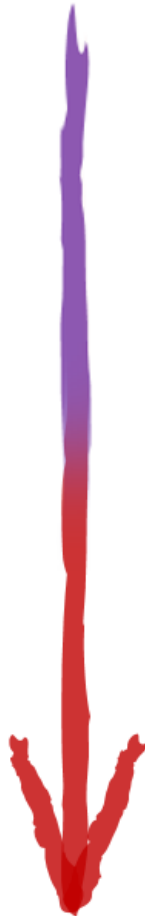
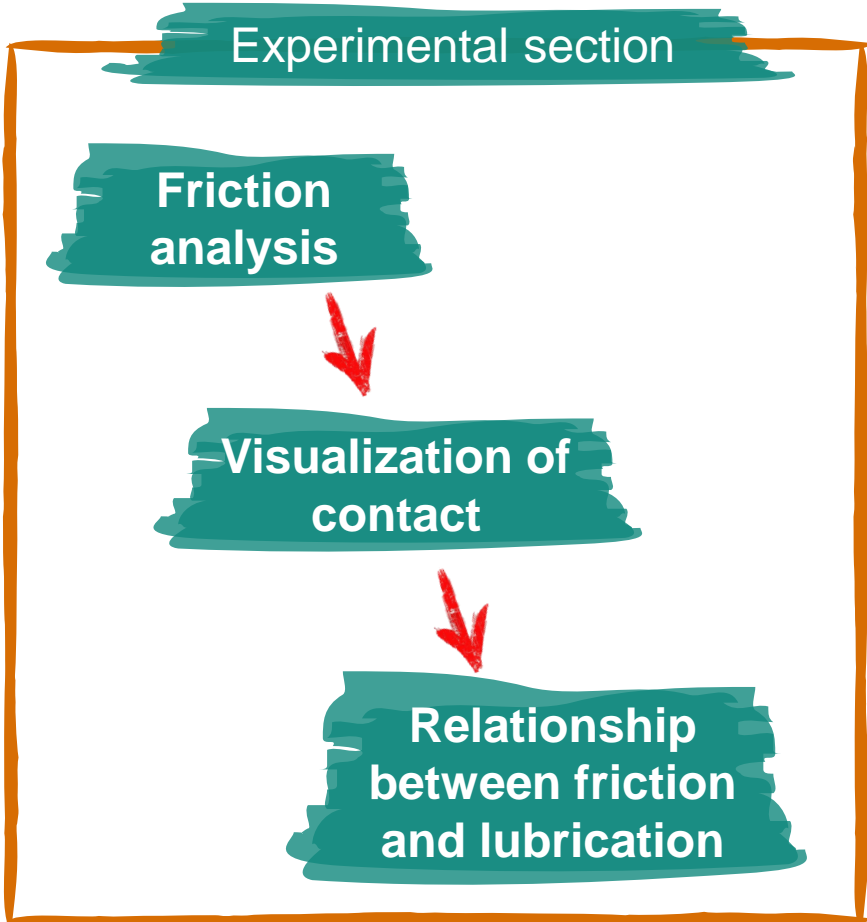
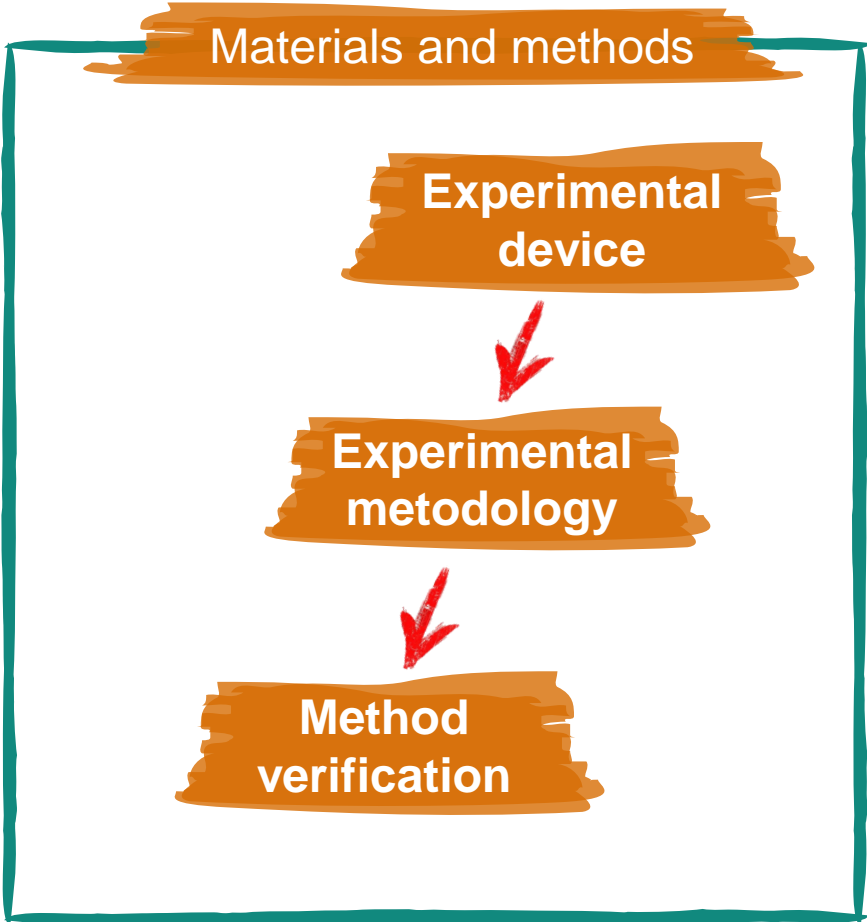
Lubricants

Lubricant label	Composition, concentration (mg/ml)				Labelled component
	Albumin	γ -globulin	HA	Phospholipids	
Lubricant 1	20	-	-	-	Albumin
Lubricant 2	20	3.6	-	-	Albumin
Lubricant 3	20	3.6	2.5	-	Albumin
Lubricant 4	20	3.6	2.5	0.15	Albumin

Experimental conditions

Load	Contact pressure	Velocity	Temperature
N	MPa	mm/s	°C
10	0.8	10	37

State of art

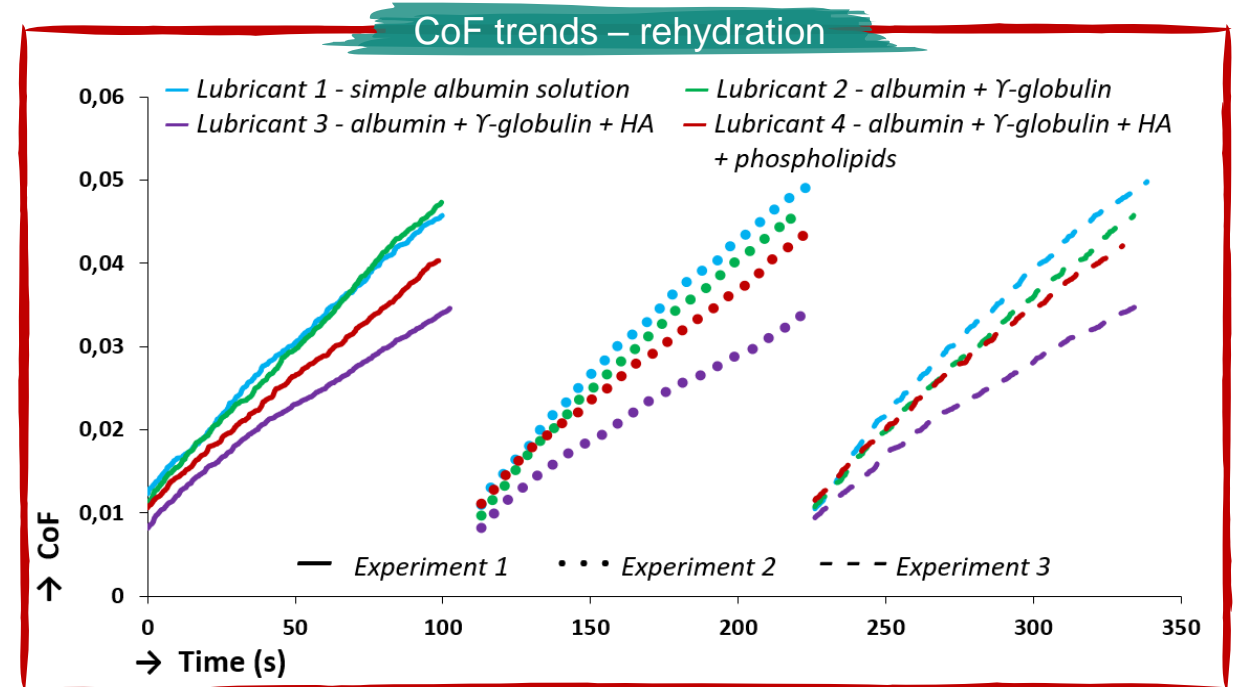


Aim of PhD thesis

Lubricating film formation - FRICTION ANALYSIS



- Simultaneous visualization and friction analysis
- Albumin protein was fluorescently marked through all experiments
- Focusing of experiments - observation of albumin proteins
- Gradually composed lubricants were used
- Rehydration process between measurements
- Load – 10N, speed – 10 mm/s
- Best frictional properties – lubricant 3 – albumin + γ -globulin + HA



Lubricating film formation - VISUALIZATION

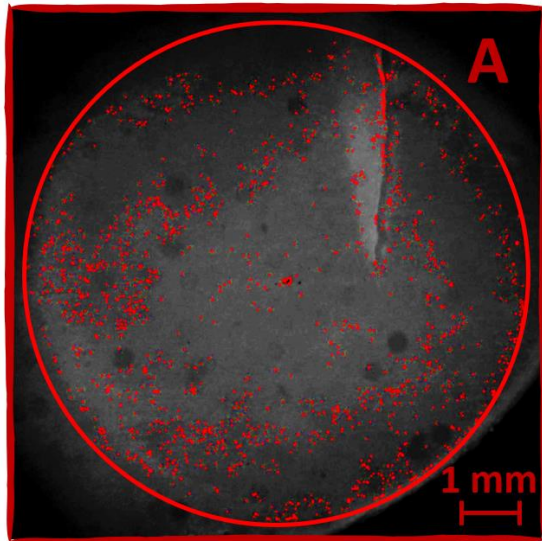
Visualization

Record of contact area

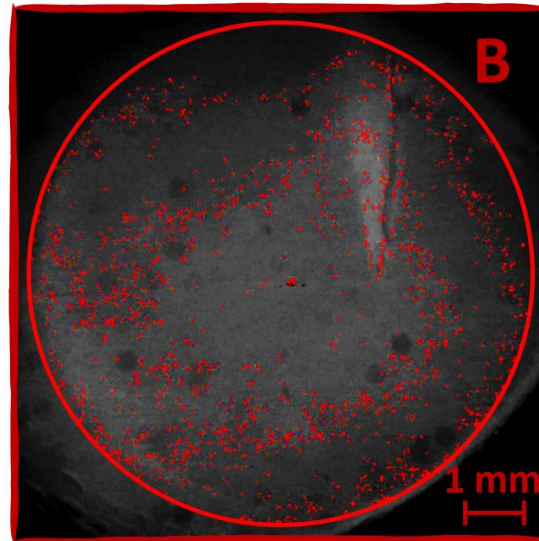
Particles count

Average size of particles

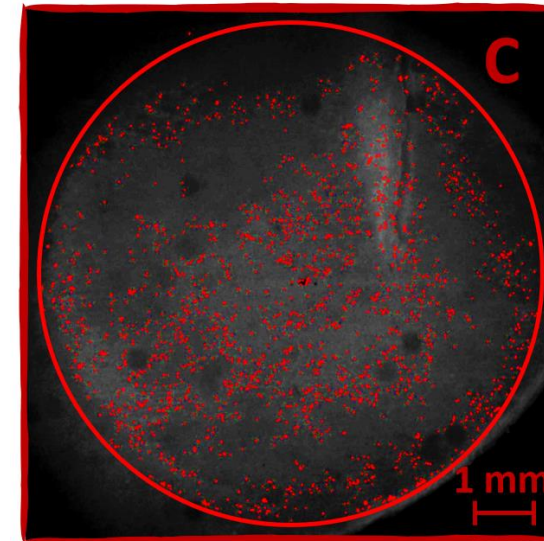
Area of adsorbed lubrication film



t = 0 s
Particles count: 1579
Average size of particles: 1



t = 25 s
Particles count: 1686
Average size of particles: 1



t = 100 s
Particles count: 2164
Average size of particles: 1

Lubricating film formation - VISUALIZATION

Visualization

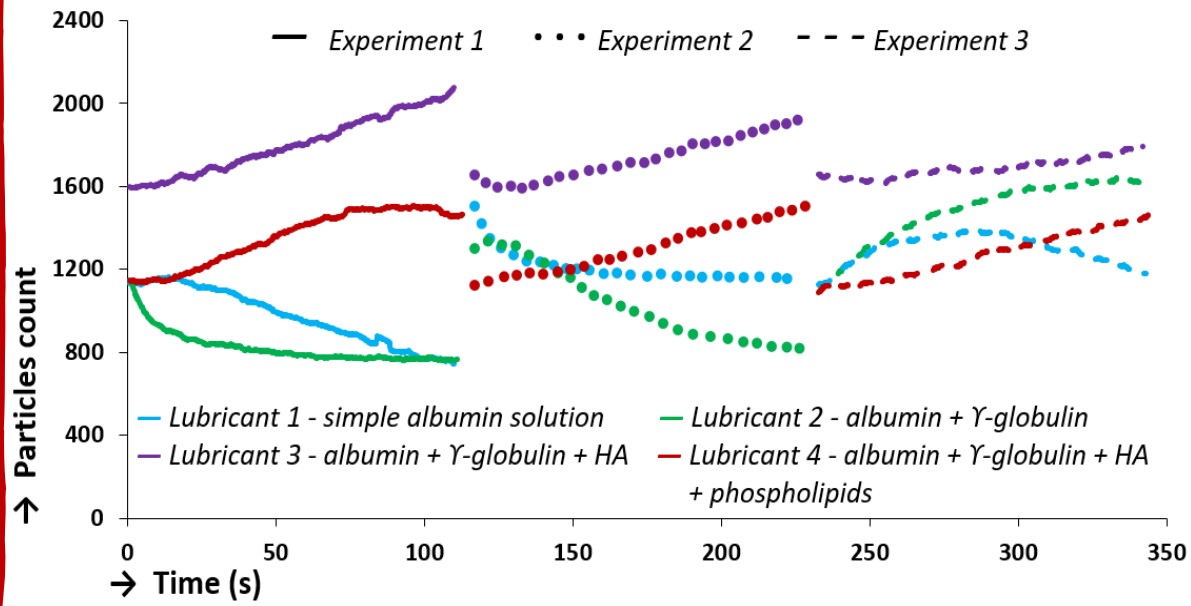
Record of contact area

Particles count

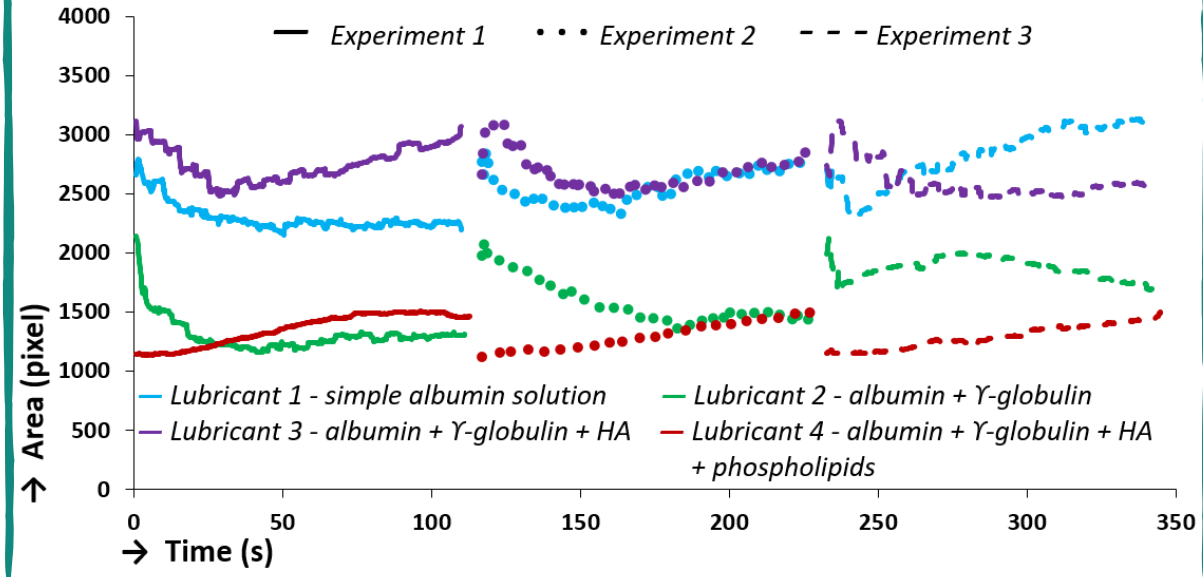
Average size of particles

Area of adsorbed lubrication film

Particles count in the contact

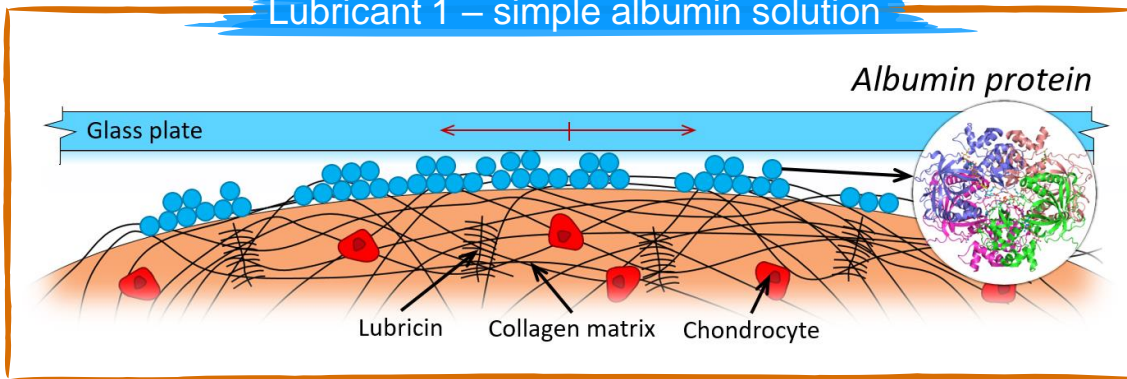


Area of adsorbed lubrication film created by albumin

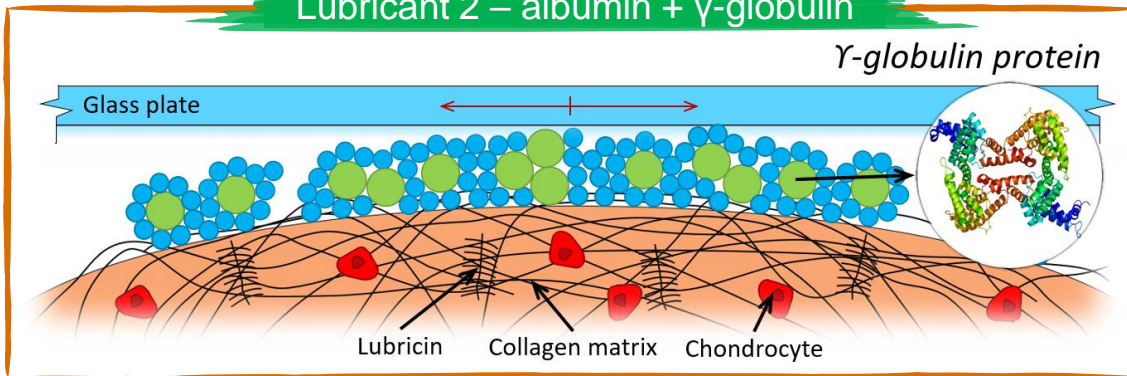


Lubricating film formation – RELATIONSHIP BETWEEN FRICTION ON LUBRICATION

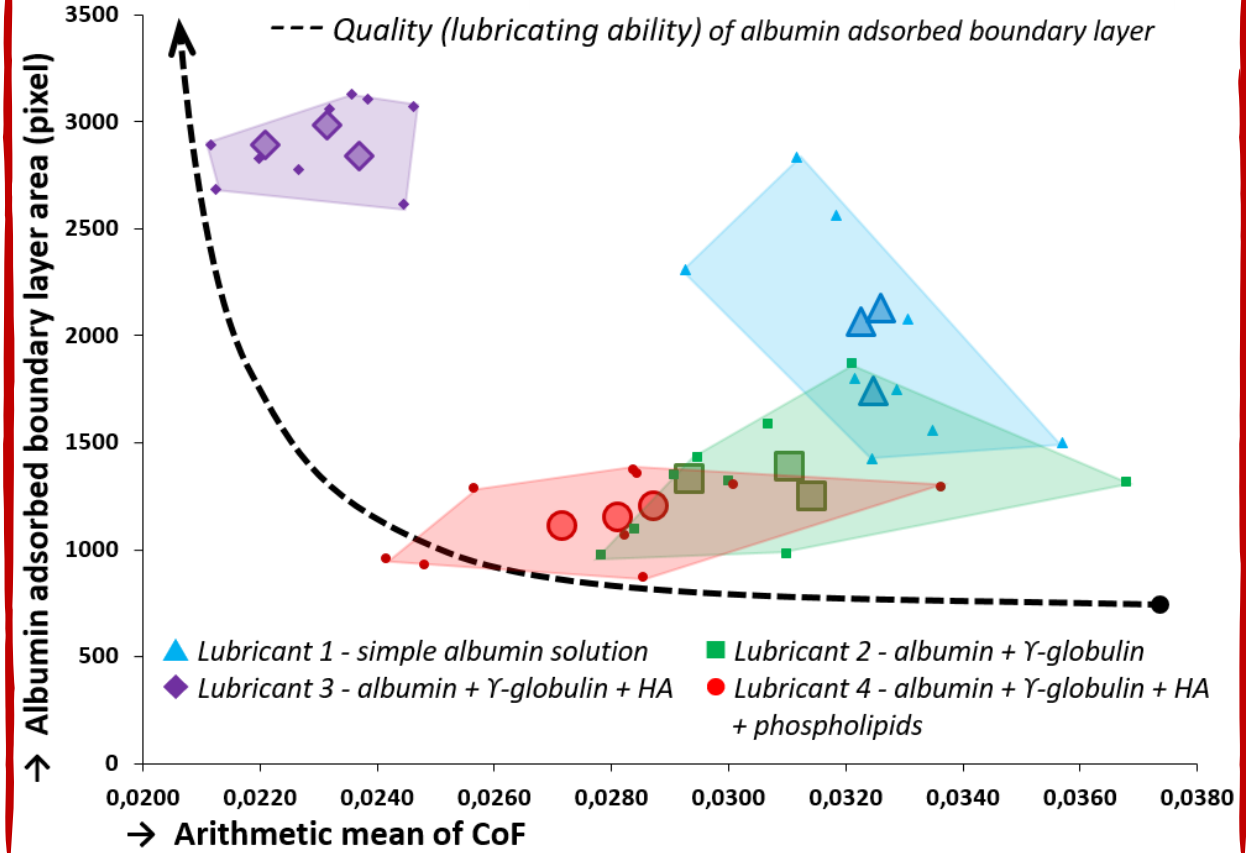
Lubricant 1 – simple albumin solution



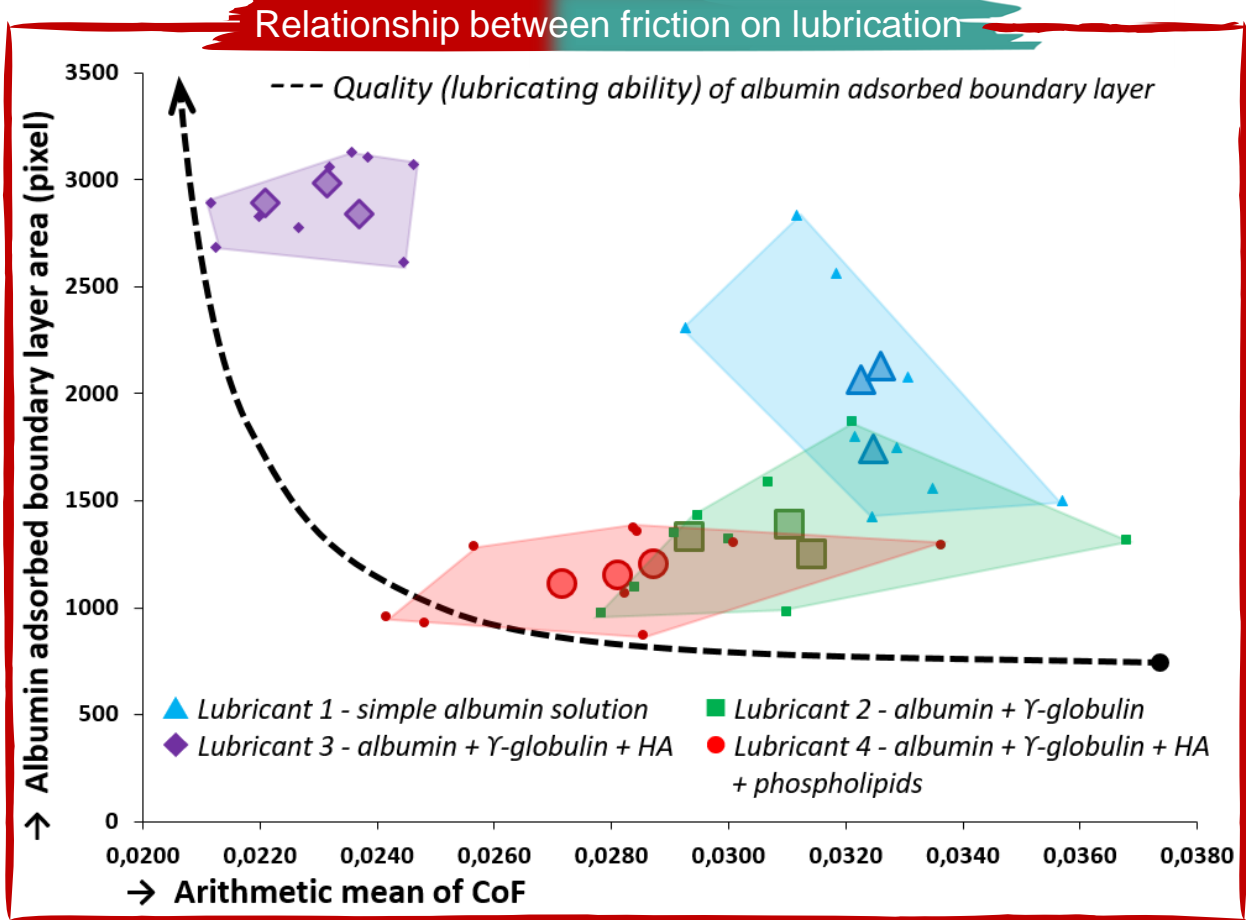
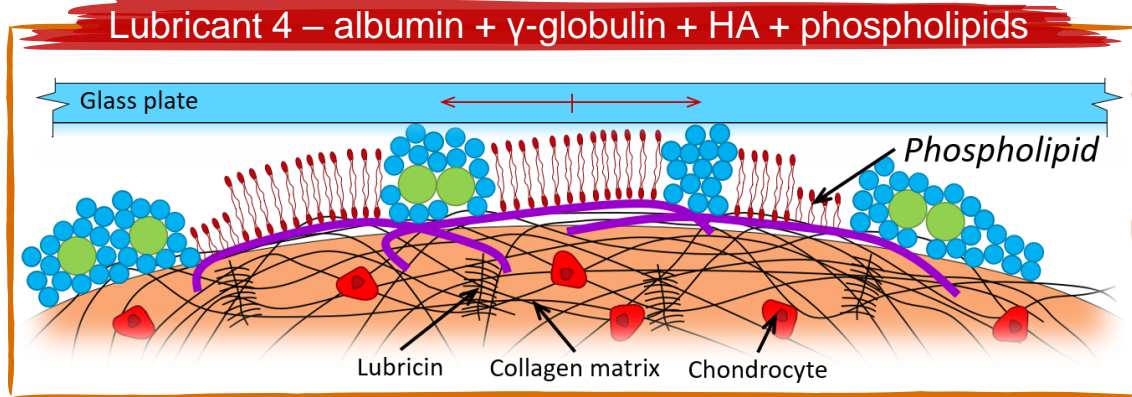
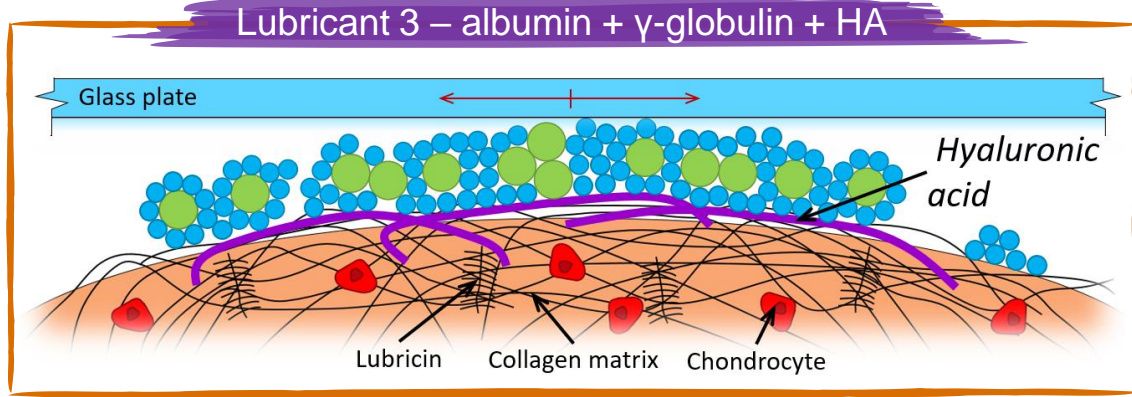
Lubricant 2 – albumin + γ -globulin



Relationship between friction on lubrication



Lubricating film formation – RELATIONSHIP BETWEEN FRICTION ON LUBRICATION



Sumarization of scientific questions and hypothesis

H1: A simple protein solution does not create a stable lubricating film with high friction coefficient. A combination of simple proteins causes the proteins to bind to each other. Forming of the lubricating film is mostly affected by hyaluronic acid and phospholipids; these components contribute to the stability of lubricating film and increase its thickness.

- The simple albumin solution does not create a stable lubrication film
- The mixture of proteins causes the binding of proteins to each other
- The forming of the lubricating film is mostly affected by hyaluronic acid
- The HA causes larger area of adsorbed film and noticeable reduction of friction
- Only the complex lubricants create stable adsorbed film - increasing of adsorbed film area during the experiment

**HYPOTHESIS WAS
NOT FALSIFIED
WHITIN THIS THESIS**

H2: It is expected that a higher particle count of dominant proteins component adsorbed in the contact causes a higher friction coefficient whereas the thickness and area of lubricating film increases.

- The best frictional properties were observed for the lubricant consists proteins and HA
- The largest area of adsorbed film was observed for the lubricant consists proteins and HA
- The simple albumin solution showed a larger adsorbed film than the mixture of proteins
- The mixture of proteins gives better values of friction coefficient

**HYPOTHESIS WAS
FALSIFIED WHITIN
THIS THESIS**

Thesis layout

Introducing the newly developed tribometer

Introducing the experimental methodology and data processing

Role of albumin in adsorbed film formation in cartilage contact

Tribology in Industry

2019

Materials

2020

JESTECH

2022

Visualization of Lubrication Film in Model of Synovial Joint

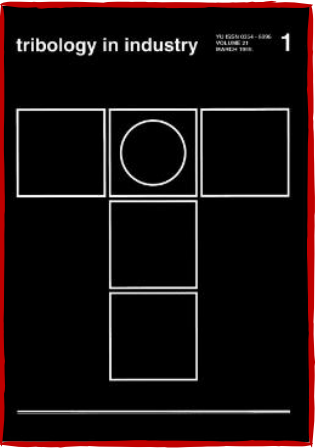
Biotribology of Synovial Cartilage: A New Method for Visualization ...

Biotribology of synovial cartilage: Role of albumin in adsorbed film ...

CiteScore = 1.09
Author's contribution: 70%

Journal impact factor = 3.06
CiteScore = 3.26, Quartile Q2
Author's contribution: 50%

Journal impact factor = 4.36
CiteScore = 9.00, Quartile Q2
Author's contribution: 70%



List of publication

Journals with impact factor

ČÍPEK, P.; VRBKA, M.; REBENDA, D.; NEČAS, D.; KŘUPKA, I. Biotribology of Synovial Cartilage: A New Method for Visualization of Lubricating Film and Simultaneous Measurement of the Friction Coefficient. *Materials*, 2020, **13**(9), 1-20. ISSN: 1996-1944.

REBENDA, D.; VRBKA, M.; ČÍPEK, P.; TOROPITSYN, E.; NEČAS, D.; PRAVDA, M.; HARTL, M. On the Dependence of Rheology of Hyaluronic Acid Solutions and Frictional Behaviour of Articular Cartilage. *Materials*, 2020, **13**(11), 1-14. ISSN: 1996-1944.

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REBENDA, D.; VRBKA, M.; NEČAS, D.; TOROPITSYN, E.; YARIMITSU, S.; ČÍPEK, P.; PRAVDA, M.; HARTL, M. Rheological and frictional analysis of viscosupplements towards improved lubrication of human joints. *Tribology International*, 2021, **160**: 107030. ISSN: 0301679X

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THANK YOU FOR YOUR ATTENTION

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