FACULTY OF MECHANICAL ENGINEERING
institute of machine and industrial design

The Effect of Synovial Fluid Constituents on Lubrication of Hip Joint Replacements

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Defense of the PhD thesis
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Institute of Machine and Industrial Design

Motivation

1848
First implants

1940
Metal head

1962
Polyethylene cup

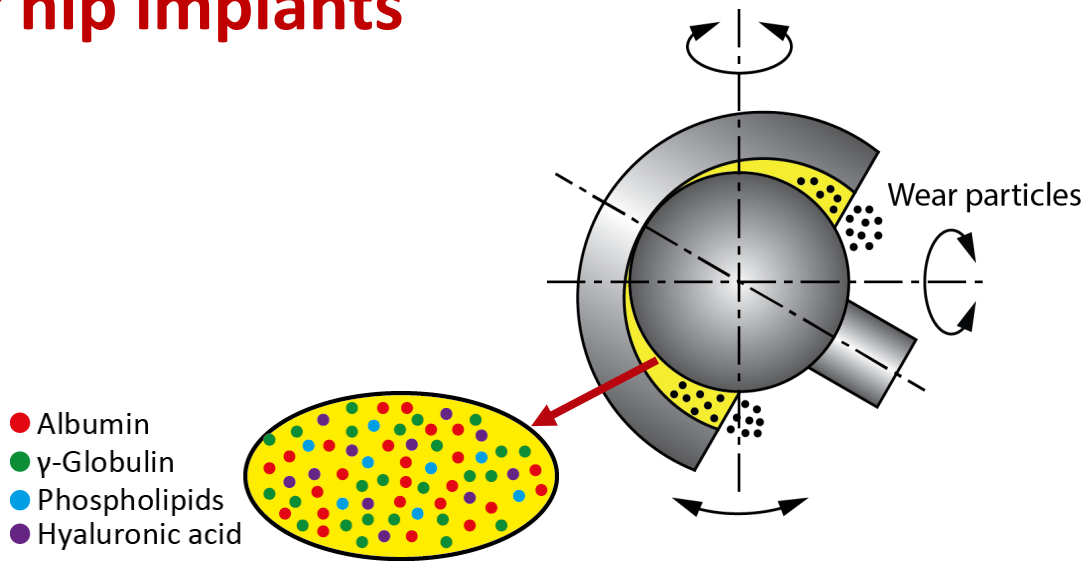
1970
Ceramic

>2000
DLC, Oxinium

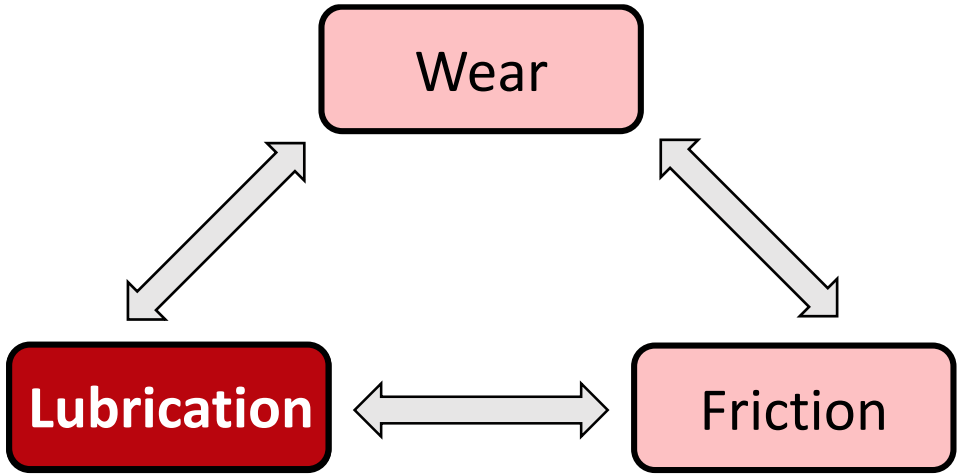
- **Total hip arthroplasty**
  - The most successful and the most applied surgery
  - 161 operations per 100 000 inhabitants in OECD in 2013 (170 per 100 000 in Czech Republic)
  - Limited service-life of implants (8 – 15 years)
  - The need of revising operations
  - Necessity of understanding the tribological performance of hip replacements

Introduction – Biotribology of hip implants

- **Revision operations**
  - 10% of total amount of surgeries
  - 2-3 times higher costs
  - Main cause
    - Aseptic loosening (osteolysis) > 50%



- Lubricant film thickness
- Protein film formation
- Role of synovial fluid constituents



Aim of the thesis

TO DEVELOP A METHODOLOGICAL APPROACH ENABLING TO ASSESS THE LUBRICANT FILM FORMATION IN HIP REPLACEMENTS, FOCUSING ON THE ROLE OF PARTICULAR PROTEINS

Introduction – Film thickness investigation in hip replacements

2009
- Mavraki and Cann – The effect of mean speed

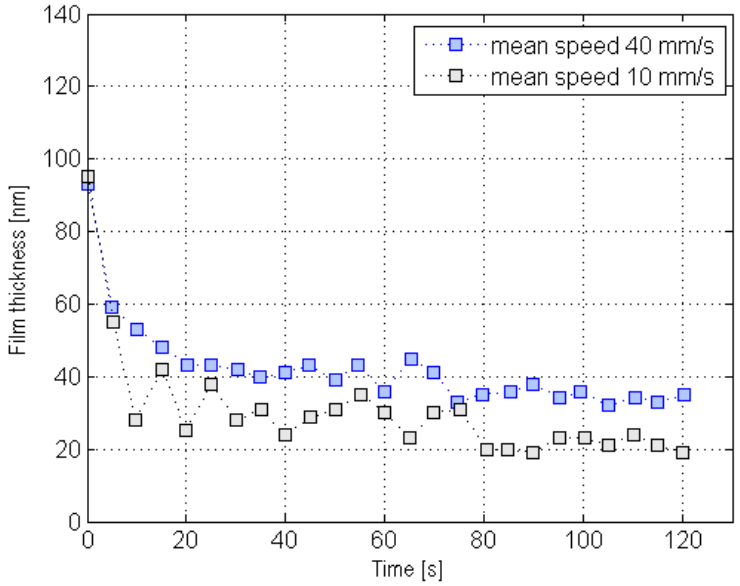
2011
- Mavraki and Cann – The effect of contact pressure and slip

2013
- Myant and Cann – Definition of „inlet phase“

2013
- Vrbka et al. – The effect of implant material

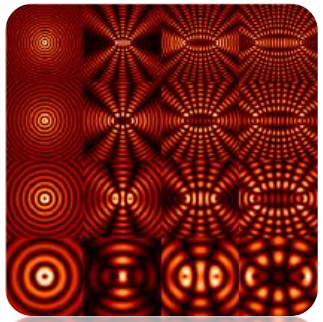
2014
- Myant and Cann – The effect of motion character

2014
- Vrbka et al. – The effect of contact conformity



Introduction – Film thickness investigation in hip replacements

- All the previous studies employed optical interferometry method

Optical interferometry			Fluorescent microscopy
	+	Lubricant film thickness	+
	+	In situ observation	+
	+	Protein film formation	+
	+	Protein adsorption	+
	−	Individual proteins separation	+
			

- Sub-aims
  - Development of fluorescent method for film thickness measurement
  - Preparation of model fluids containing fluorescently stained proteins
  - Systematic study of protein film formation under various operating conditions
  - Data analysis, results publication

Introduction – Fluorescent microscopy in tribology

1974
- Smart and Ford – Measurement of film thickness on rotating steel cylinder

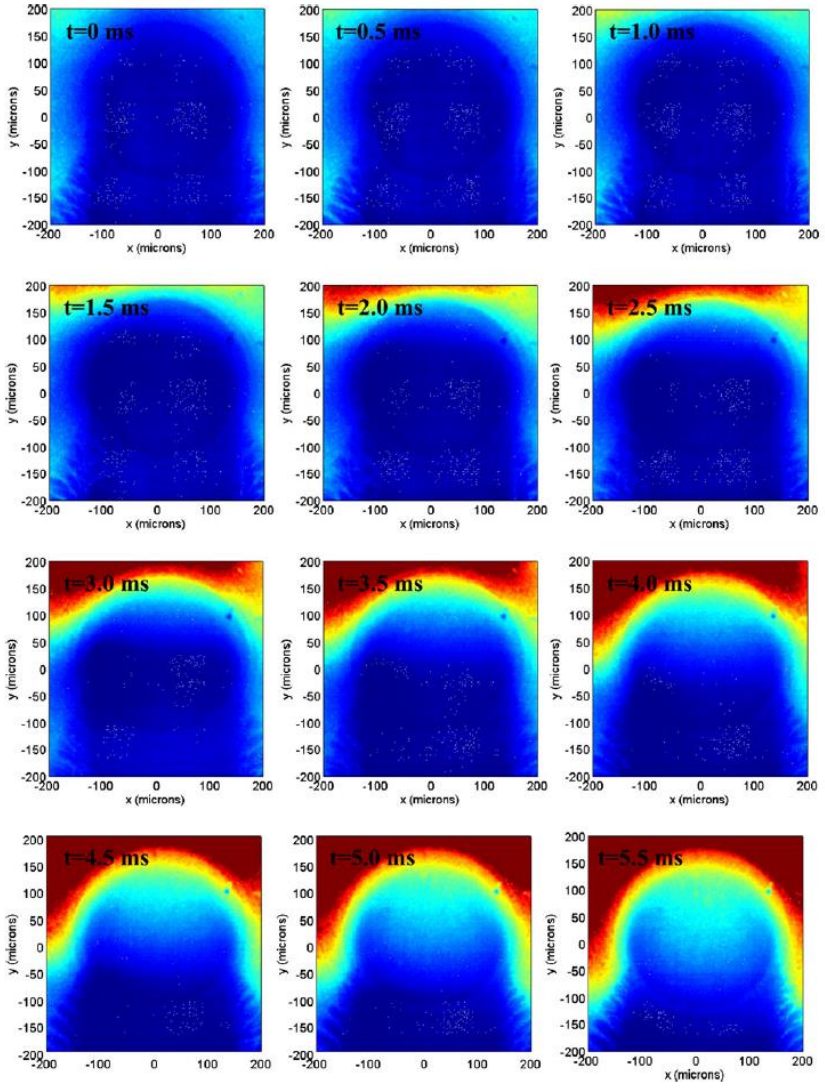
1978
- Ford and Foord – Prove of fluorescence quenching

2005
- Azushima – Prove about the linear dependence between film thickness and fluorescent intensity

2010
- Reddyhoff et al. – Determination of lubricant flow

2010
- Myant et al. – Direct measurement of film thickness in compliant contact

2013
- Ponjavic et al. – Fluorescence recovery after photobleaching (FRAP) principle for lubricant flow observation



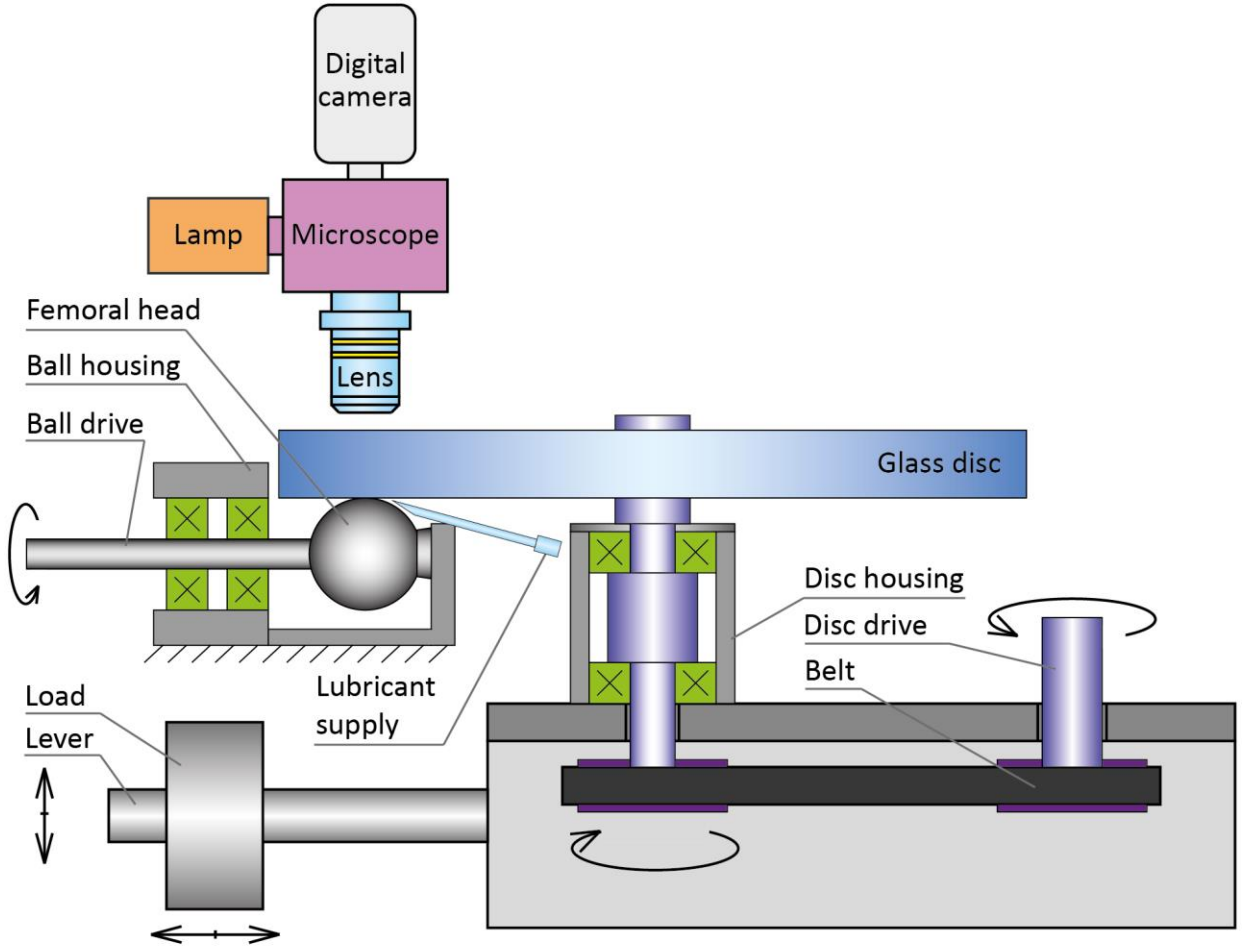
Scientific question and hypotheses

- **Scientific question**
  - How is the influence of the individual proteins on the development of lubricant film thickness within hip replacements?

- **Hypotheses**
  - The contribution of γ-globulin to film thickness is more substantial compared to albumin
  - Metal head forms thicker film
  - Level of slippage is a crucial parameter influencing protein film
  - An increase of speed causes a reduction of protein film thickness

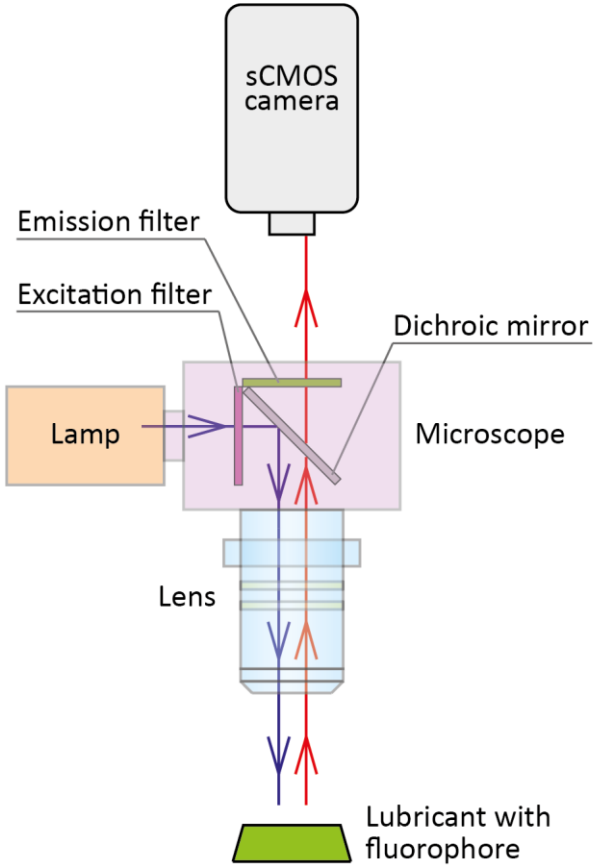
Materials and methods – Experimental device

Ball-on-disc test device



Materials and methods – Experimental methods

Fluorescent microscopy

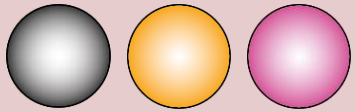
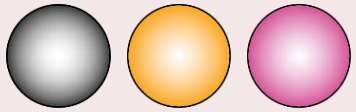
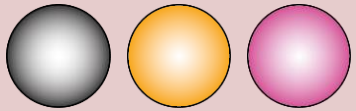


- **Limitations**
  - Light interference (all the femoral heads)
  - Fluorescence quenching (CoCrMo femoral heads)
  - Natural fluorescence (ceramic heads)

Film thickness could NOT be measured directly in the case of femoral heads by fluorescent microscopy

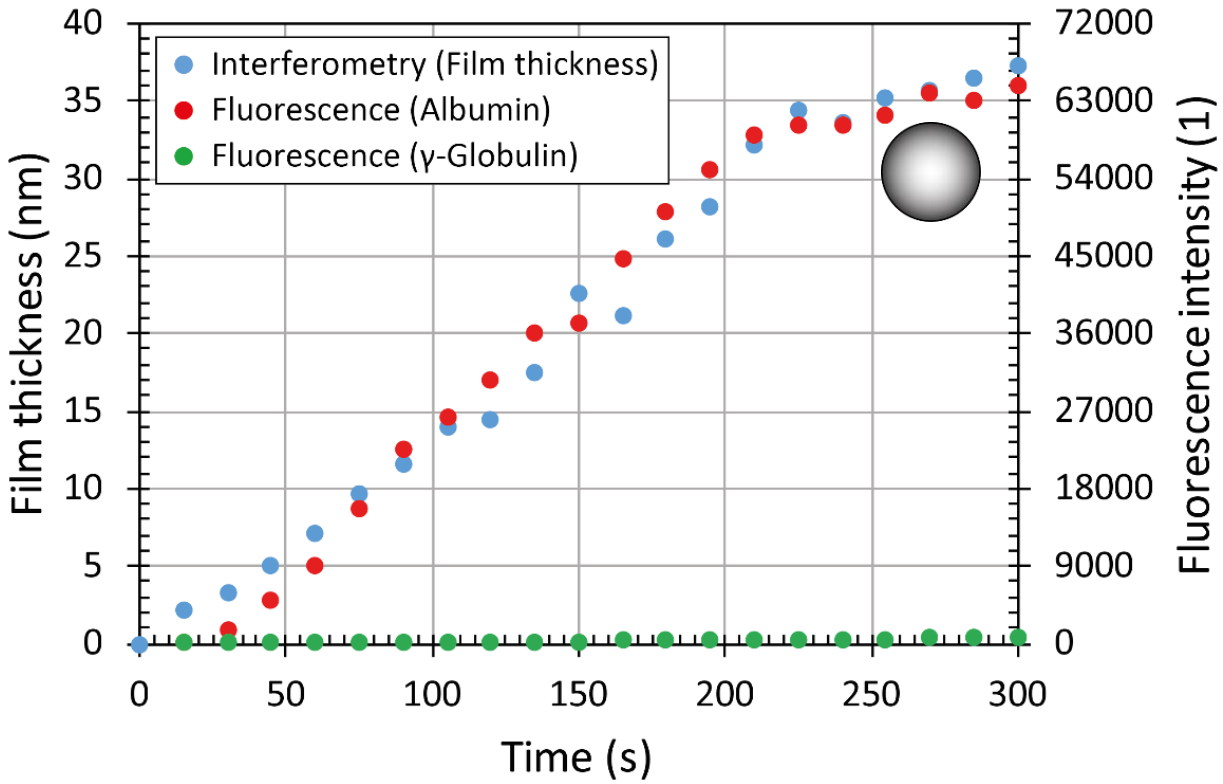
Combination of fluorescent microscopy with optical interferometry

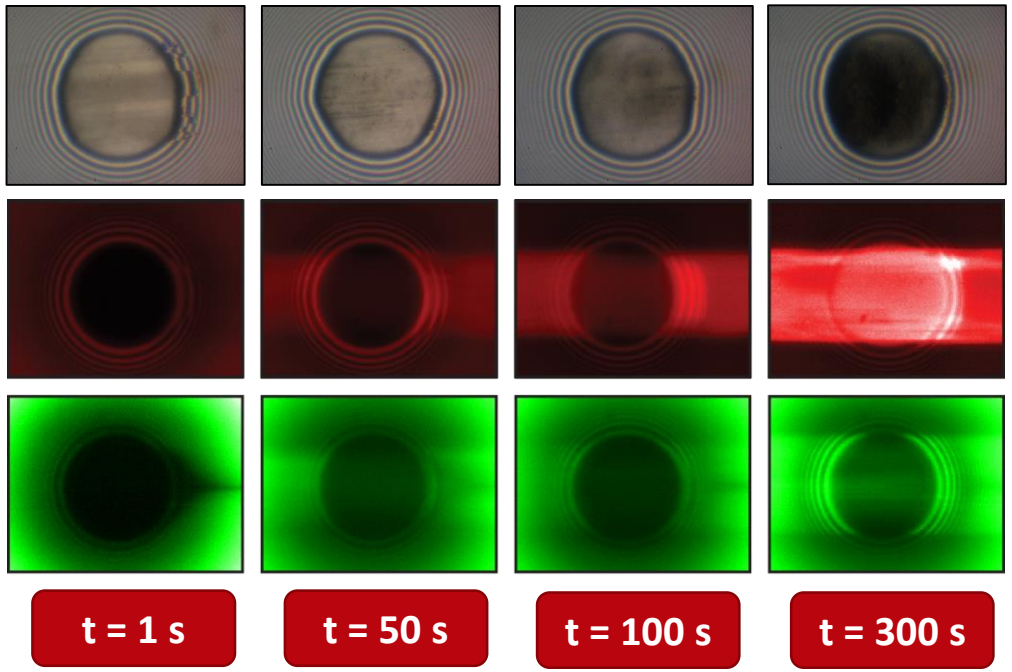
Materials and methods – Test conditions

Experimental method	Material	Slide-to-roll ratio (1)	Mean speed (mm/s)	Model fluid
Optical interferometry		0; -1.5; 1.5	5.7; 22	Albumin (A) : γ-Globulin (G) = 2 : 1
Fluorescent microscopy		0; -1.5; 1.5	5.7; 22	**LABELLED A** : Non-Labelled G = 2 : 1
Fluorescent microscopy		0; -1.5; 1.5	5.7; 22	Non-Labelled A : **LABELLED G** = 2 : 1

- Applied load: F = 5 N (p ≈ 240 – 290 MPa)
- Temperature: T = 22 °C
- Experiment duration: t = 300 s

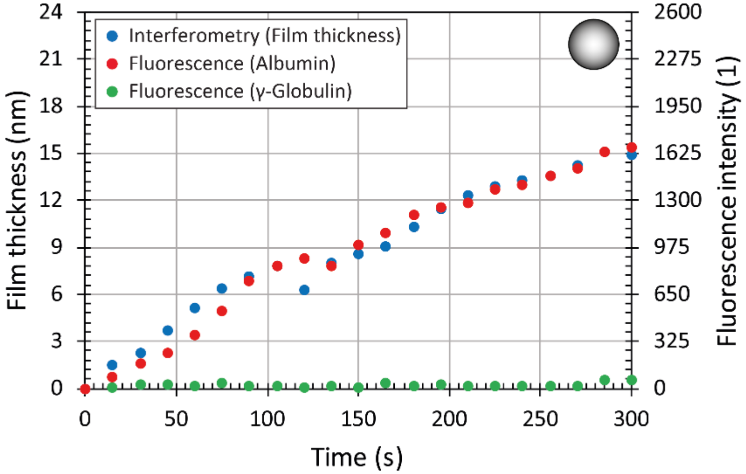
Results – metal (SRR = 0, u = 22 mm/s)

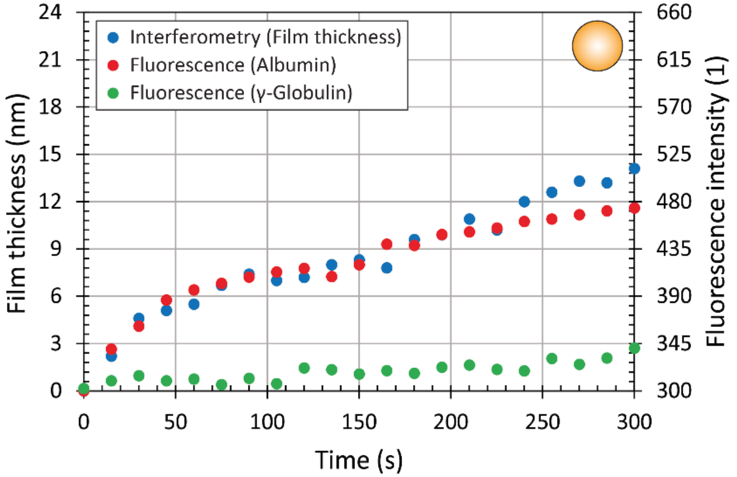


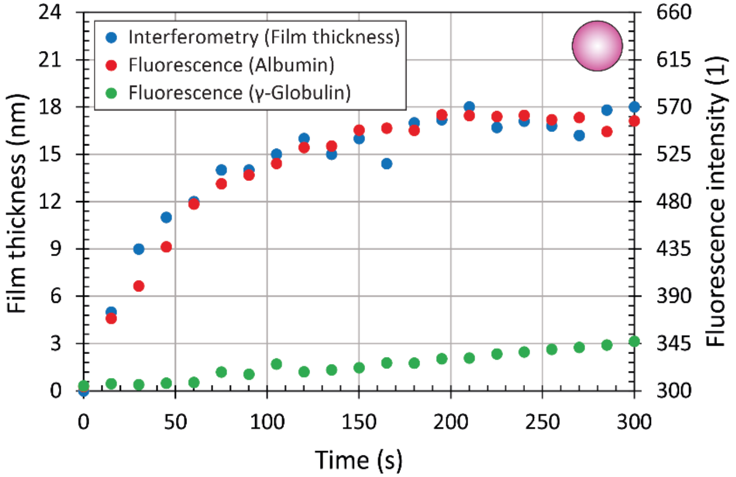


Results – The effect of material (SRR = 0)

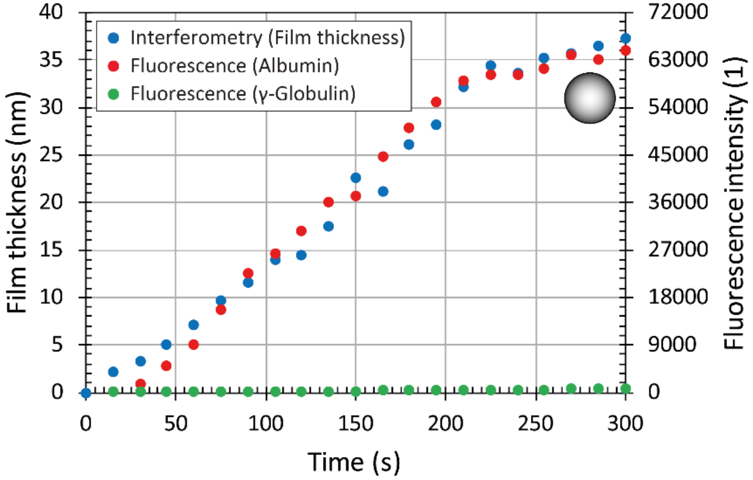
5.7 mm/s

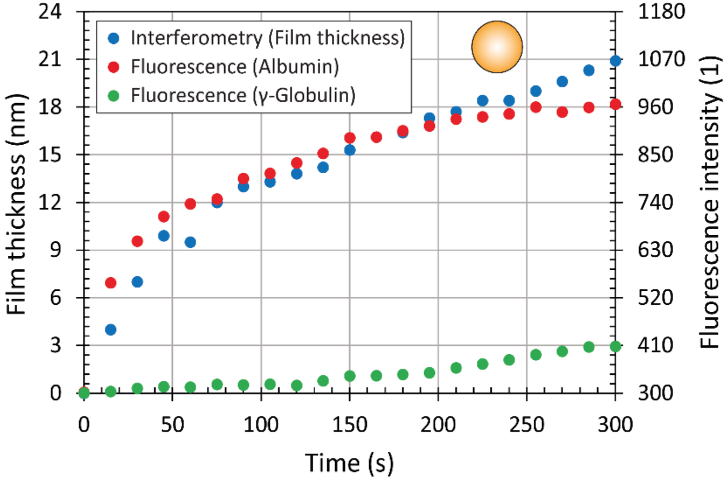


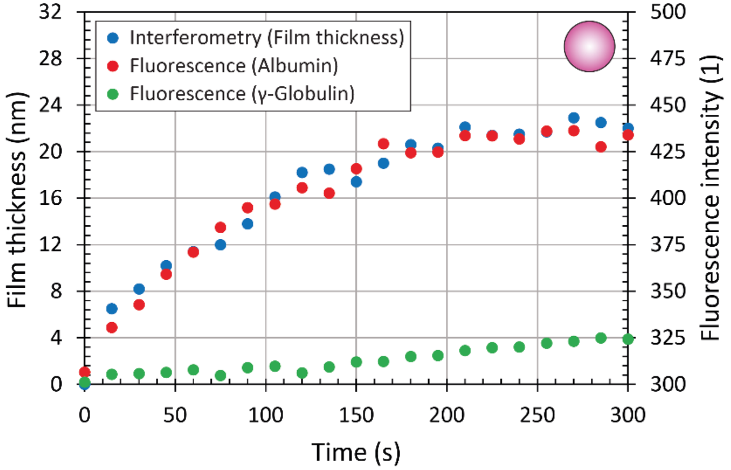




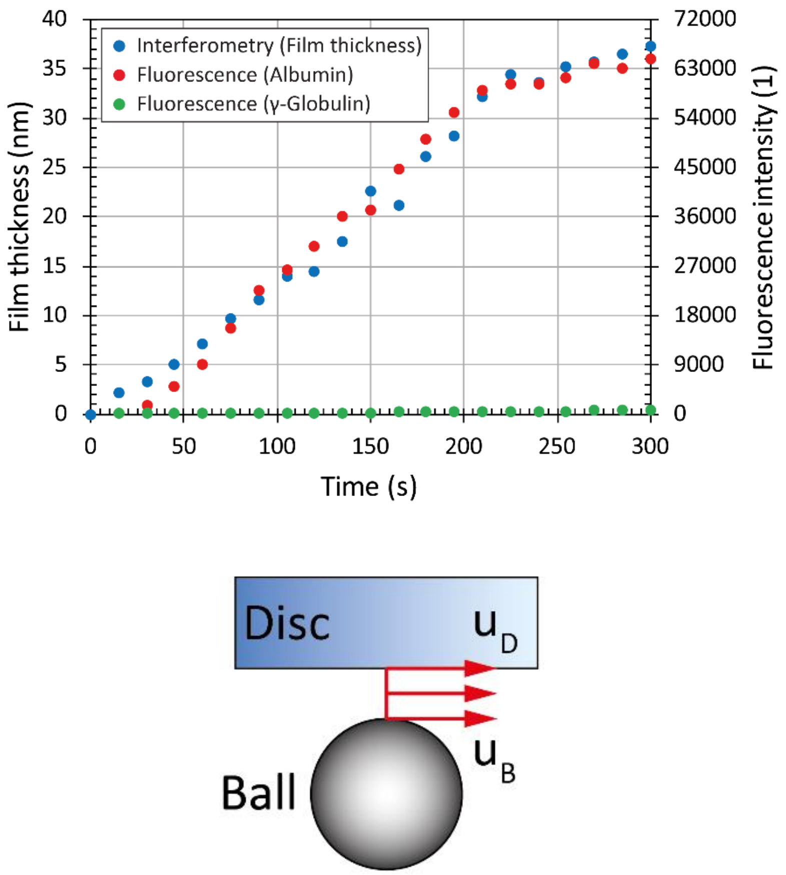
22 mm/s



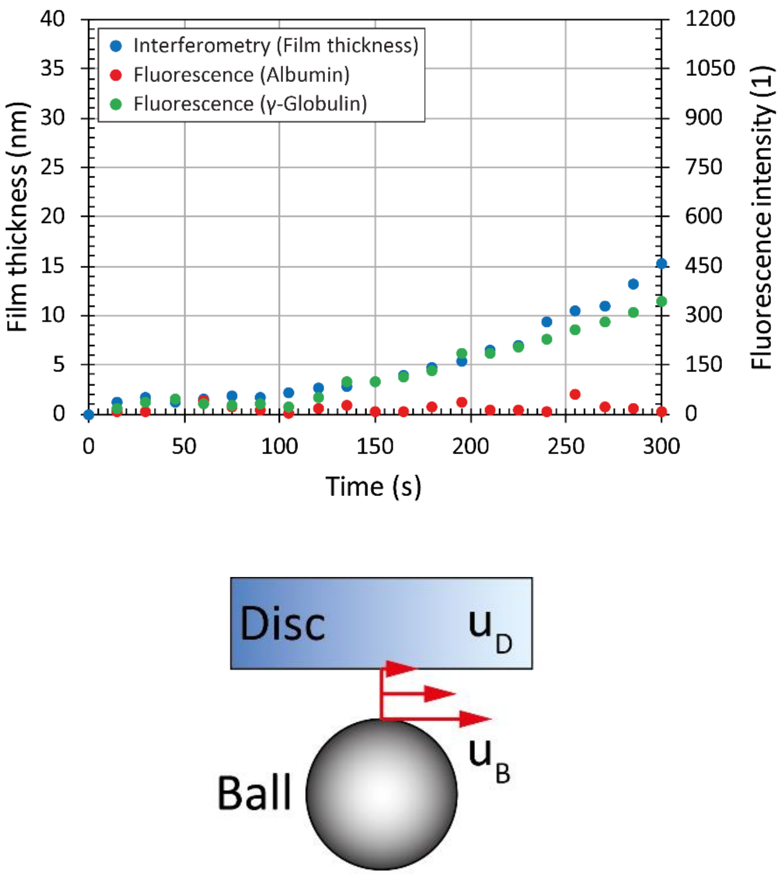




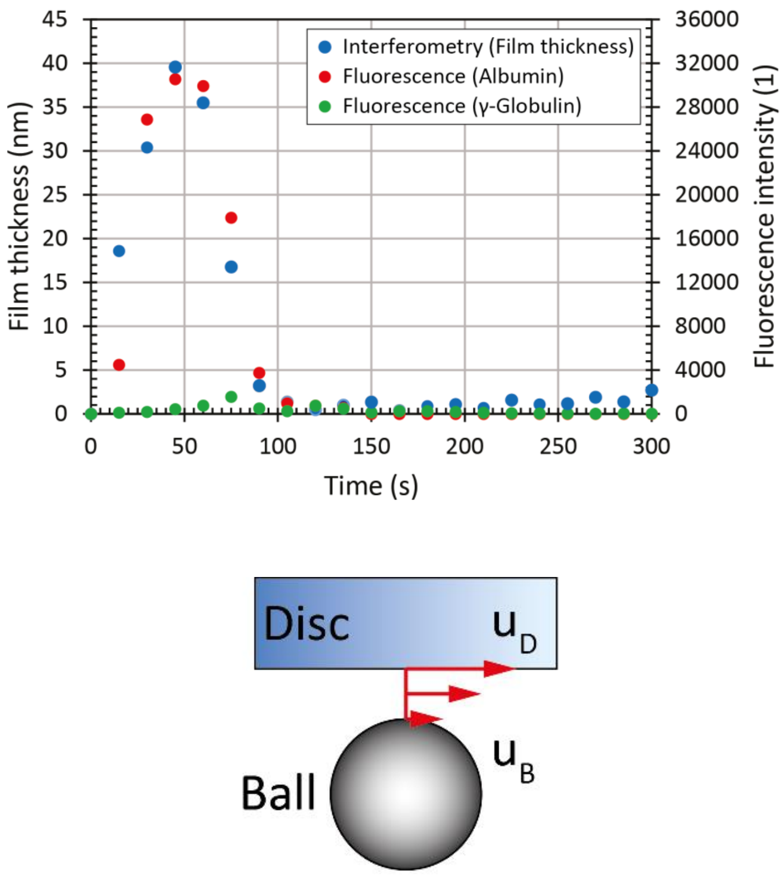
Results – The effect of SRR (metal, u = 22 mm/s)



SRR = 0; $u_D = u_B$

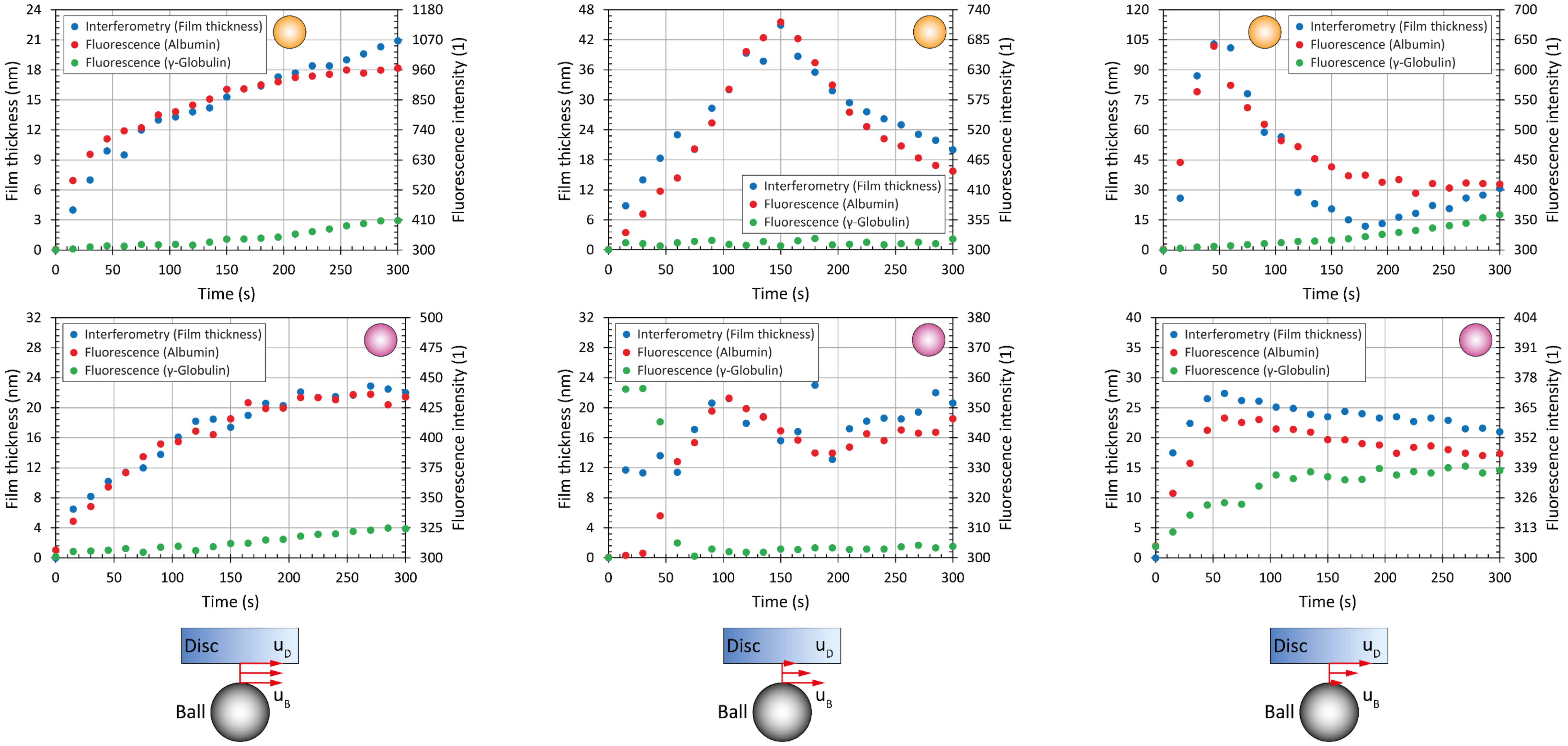


SRR = -1.5; $u_D < u_B$



SRR = 1.5; $u_D > u_B$

Results – The effect of SRR (ceramic, u = 22 mm/s)



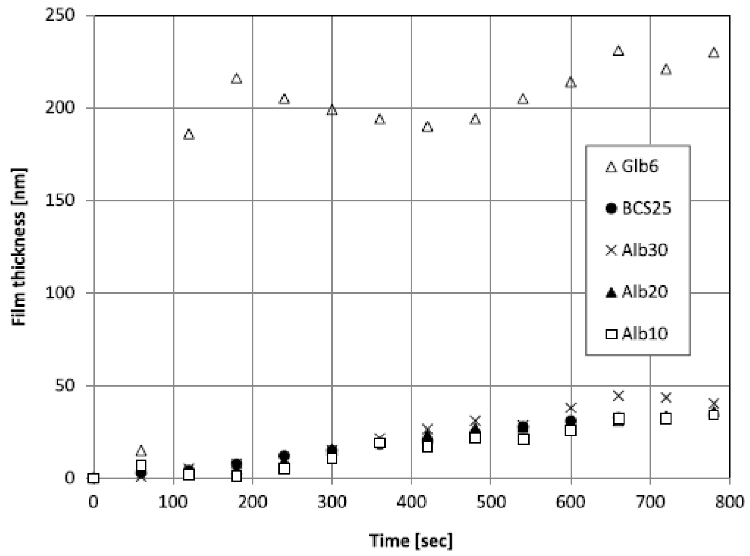
SRR = 0; $u_D = u_B$

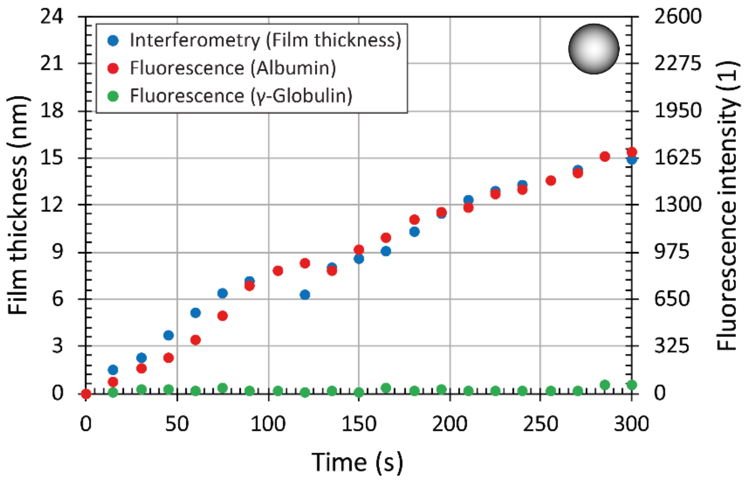
SRR = -1.5; $u_D < u_B$

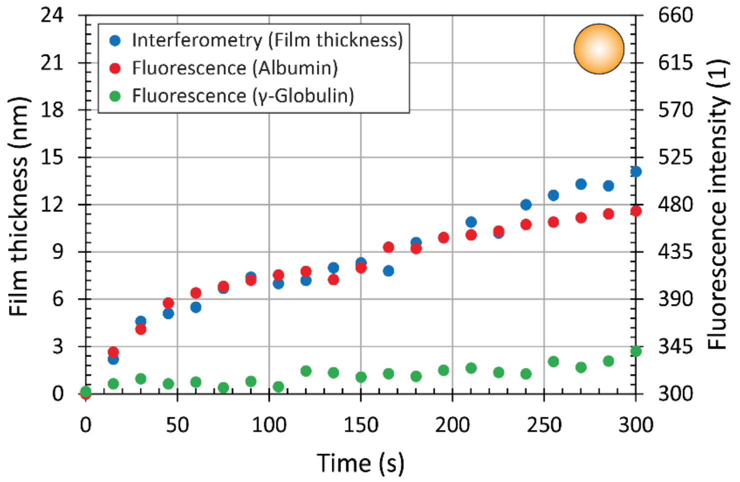
SRR = 1.5; $u_D > u_B$

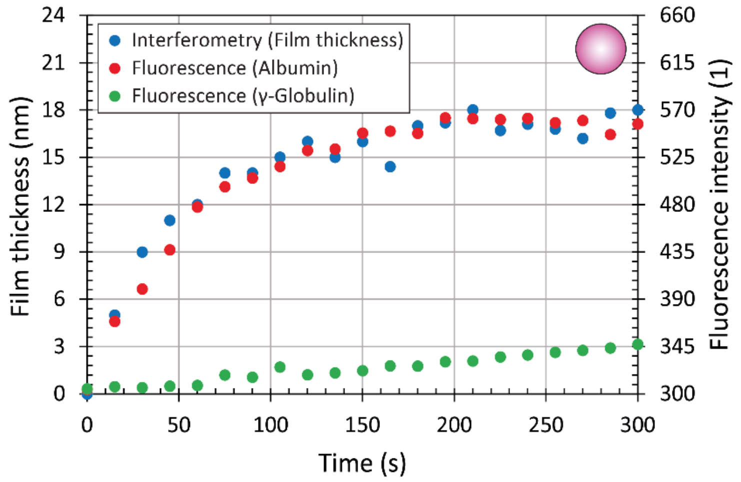
Discussion

- **Contribution of proteins**
  - γ-globulin forms thicker protein solution (*Fan et al., 2011; Myant et al., 2012; Parkes et al., 2015*)
  - The authors investigated simple protein solutions
  - Current results indicate that more important protein is albumin in most cases; therefore, complex model fluids have to be studied



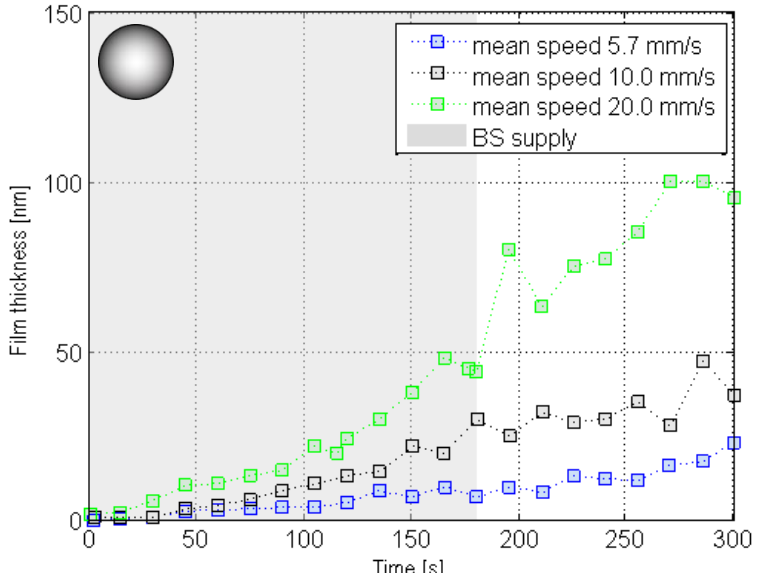


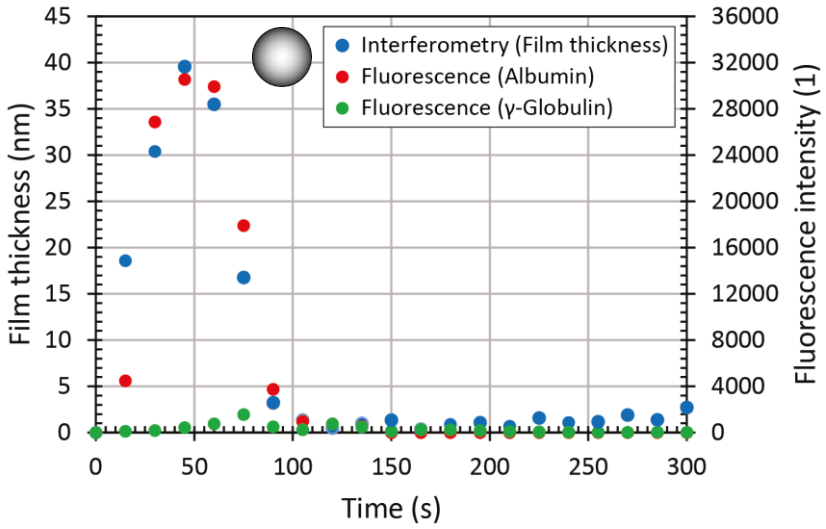


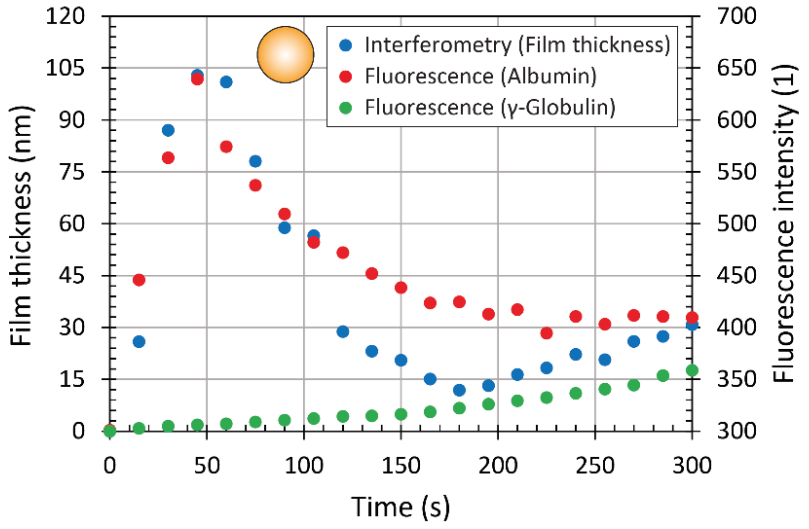


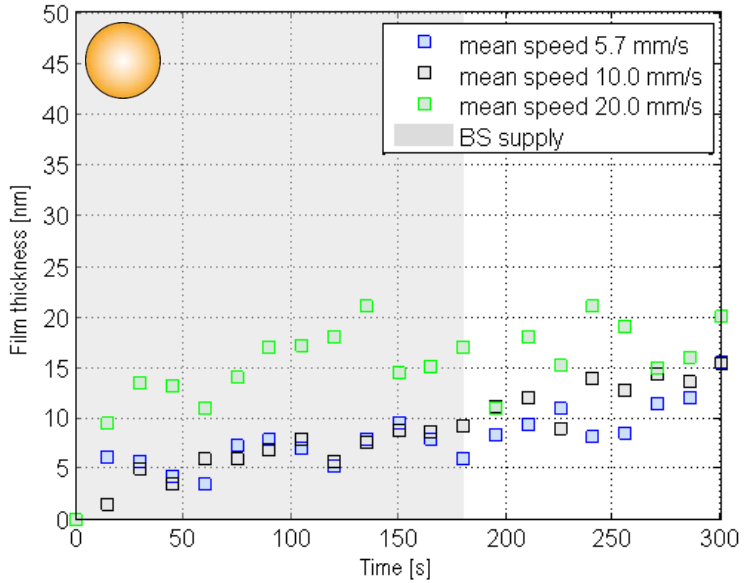
Discussion

- **The effect of material**
  - *Vrbka et al. (2013)* observed thicker protein film in the case of metal head
  - In the PhD thesis, it was found that the behaviour is complex and dependent on surface wettability, protein content, as well as kinematic conditions



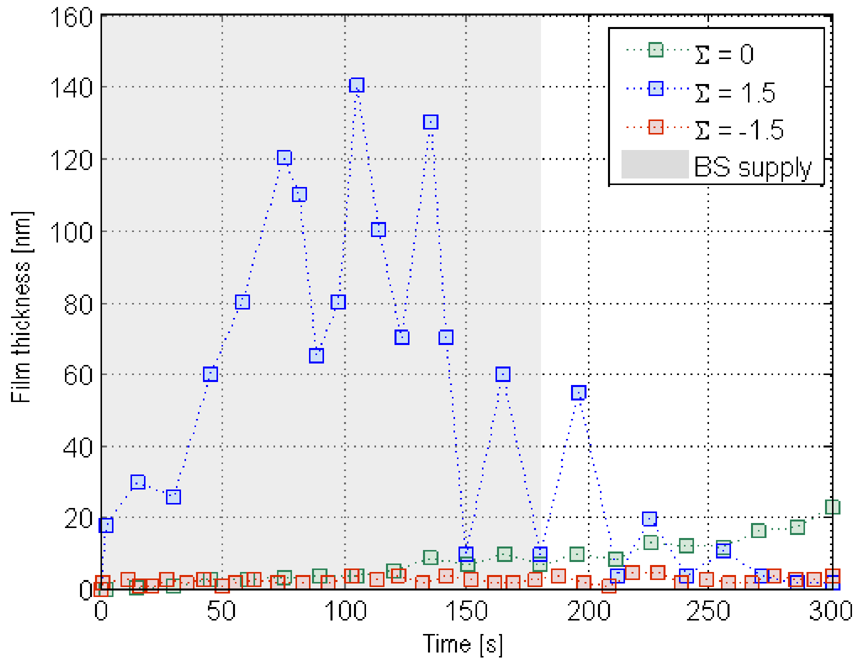


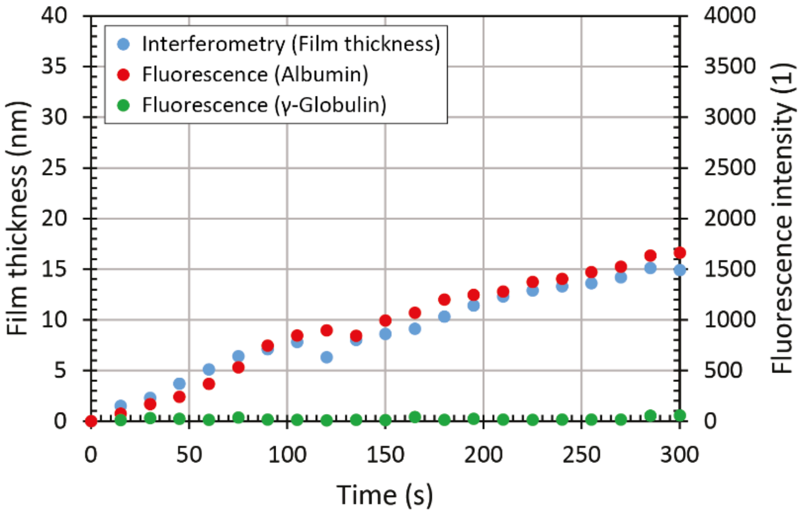


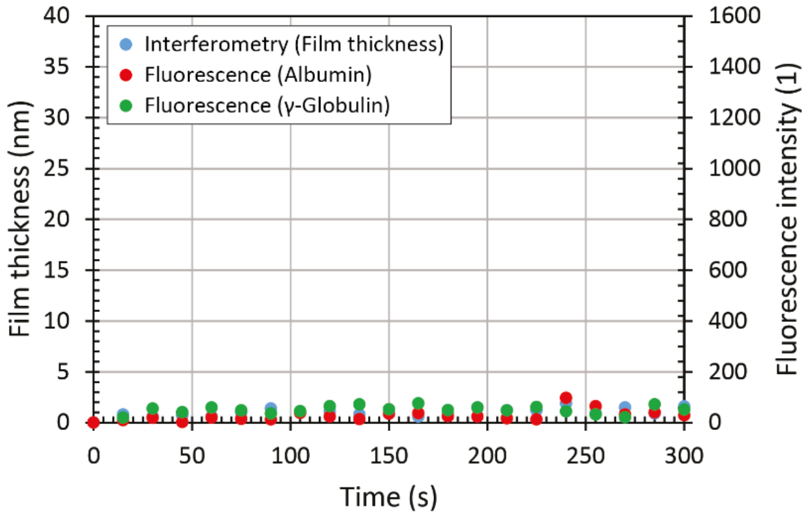


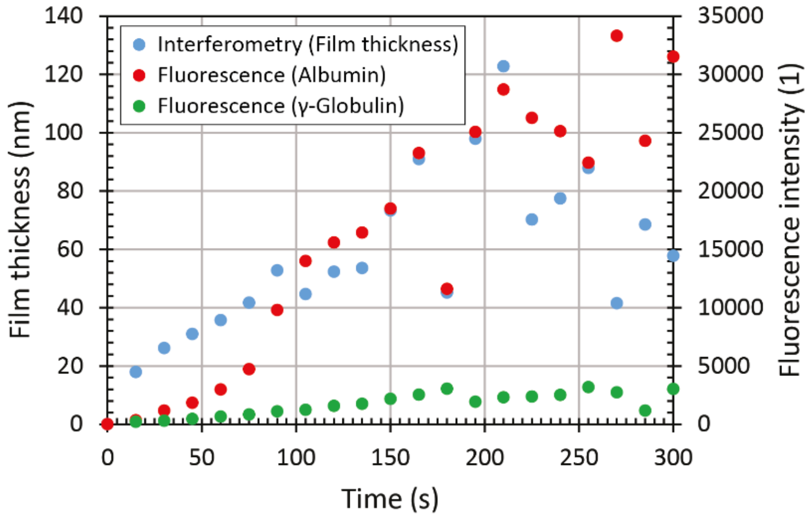
Discussion

- **The effect of kinematic conditions - slippage**
  - Considering of slippage leads to a reduction of protein film (*Mavraki and Cann, 2011*)
  - Positivity/negativity of slippage has a crucial effect on film formation (*Vrbka et al., 2014*)







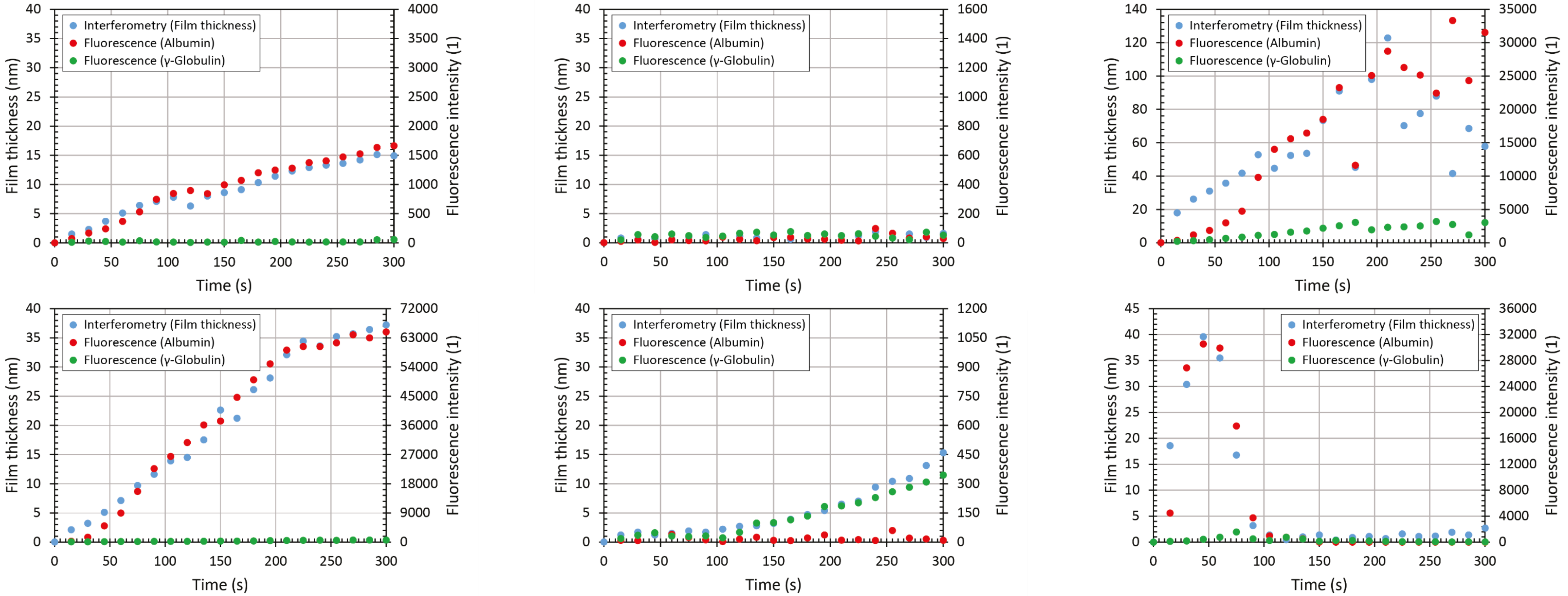


Discussion

- **The effect of kinematic conditions – mean speed**
  - An increase of speed leads to thinner protein film (*Myant and Cann, 2014*)
  - Protein film is strongly dependent on slippage; the effect of speed cannot be generalized

5.7 mm/s

22 mm/s



Conclusions – Lubrication within hip joint replacements

- Fluorescent method can help to understand the role of individual SF constituents
- Kinematic conditions have a certain effect on protein film formation
- The effect of material as well as the kinematic conditions cannot be generalized
- Under most conditions, albumin is a dominant constituent
- Simple protein solutions cannot mimic the behaviour of complex model fluids
- Interaction of proteins plays a key role in film formation process

Conclusions of the PhD thesis

- Measurement of protein film under real conformity of rubbing surfaces

- Development of fluorescent method for film thickness measurement

- Illustration of the use of fluorescent technique for the investigation of lubricant rupture ratio

- Development of methodology enabling the description of film thickness in hip replacements focusing on the role of particular proteins
  - The effect of kinematic conditions
  - The effect of material

List of publications – Publications in journals with impact factor

- KOŠŤÁL, D.; NEČAS, D.; ŠPERKA, P.; SVOBODA, P.; KŘUPKA, I.; HARTL, M. Lubricant rupture ratio at elastohydrodynamically lubricated contact outlet. *Tribology Letters*, 2015, 59(3), 1-9.
  (Journal impact factor = 1.74)
- VRBKA, M.; NEČAS, D.; BARTOŠÍK, J.; HARTL, M.; KŘUPKA, I.; GALANDÁKOVÁ, A.; GALLO, J. Determination of a friction coefficient for THA bearing couples. *Acta chirurgiae orthopaedicae et traumatologiae Cechoslovaca*, 2015, 82(5), 341-347.
  (Journal impact factor = 0.39)
- TKACHENKO, S.; NEČAS, D.; DATSKEVICH, O.; ČUPERA, J.; SPOTZ, Z.; VRBKA, M.; KULAK, L.; FORET, R. Tribological performance of Ti–Si based in situ composites. *Tribology Transactions*. 2016, 59(2), 340-351.
  (Journal impact factor = 1.35)
- NEČAS, D.; VRBKA, M.; URBAN, F.; KŘUPKA, I.; HARTL, M. The effect of lubricant constituents on lubrication mechanisms in hip joint replacements. *Journal of the Mechanical Behavior of Biomedical Materials*, 2016, 55, 295-307.
  (Journal impact factor = 2.88)
- NEČAS, D.; VRBKA, M.; KŘUPKA, I.; HARTL, M.; GALANDÁKOVÁ, A. Lubrication within hip replacements – Implication for ceramic-on-hard bearing couples. *Journal of the Mechanical Behavior of Biomedical Materials*, 2016, 61, 371-383.
  (Journal impact factor = 2.88)

List of publications

- **Papers published in peer-reviewed journals**
  - NEČAS, D.; ŠPERKA, P.; VRBKA, M.; KŘUPKA, I.; HARTL, M. Film thickness mapping in lubricated contacts using fluorescence. *MM Science Journal*, 2015, 2015(4), 821-824.
  - VRBKA, M.; NEČAS, D.; HARTL, M.; KŘUPKA, I.; URBAN, F.; GALLO, J. Visualization of lubricating films between artificial head and cup with respect to real geometry. *Biotribology*, 2015, 1-2, 61-65.

- **Papers published in conference proceedings**
  - NEČAS, D., VRBKA, M.; ŠPERKA, P.; DRUCKMÜLLER, M.; SKLÁDAL, P.; ŠTARHA, P.; KŘUPKA, I.; HARTL, M. Qualitative analysis of film thickness in rolling EHD contact by fluorescence technique. *Lecture Notes in Mechanical Engineering*, 2014, 615-622.
  - TKACHENKO, S.; NEČAS, D.; DATSKEVICH, O.; ČUPERA, J.; SPOTZ, Z.; VRBKA, M.; KULAK, L.; FORET, R. Tribological behavior of Ti– Si based in situ composites under sliding. *Metal 2014*, 2014, 2704-2709.
  - NEČAS, D., VRBKA, M.; YARIMITSU, S.; NAKASHIMA, K.; SAWAE, Y.; ŠPERKA, P.; KŘUPKA, I.; HARTL, M. Frictional properties of PVA hydrogel. *The Latest Methods of Construction Design*, 2016, 159-164.

List of publications

Conference abstracts

- VRBKA, M.; NEČAS, D.; URBAN, F.; KŘUPKA, I.; HARTL, M.; GALLO, J. A novel approach for in situ observation of lubricant film at the interface between artificial head and cup of THA. *EORS 22nd Annual Meeting*, 2014, Nantes, France.
- SAWAE, Y.; VRBKA, M.; URBAN. F.; NEČAS, D.; YARIMITSU, S.; NAKASHIMA, K.; MURAKAMI, T.; HARTL, M. Friction characterization of ceramic-on-hydrogel hip joint in pendulum test. *2nd International Conference on Biotribology*, 2014, Toronto, Canada.
- NEČAS, D.; SAWAE, Y.; YARIMITSU, S.; NAKASHIMA, K.; VRBKA, M.; HARTL, M.; MURAKAMI, T. Protein adsorbed film formation and frictional characteristics of CoCrMo-on-UHMWPE sliding pair in reciprocating sliding test. *2nd International Conference on Biotribology*, 2014, Toronto, Canada.
- NEČAS, D.; VRBKA, M.; URBAN, F.; KŘUPKA, I.; HARTL, M.; GALLO, J. Observation of lubricant film between artificial head and cup. *Tribology Frontiers Conference*, 2014, Chicago, USA.
- KOŠŤÁL, D.; NEČAS, D.; ŠPERKA, P.; SVOBODA, P.; KŘUPKA, I.; HARTL, M. Lubricant division in EHL contact outlet. *Tribology Frontiers Conference*, 2014, Chicago, USA.
- URBAN, F.; NEČAS, D.; VRBKA, M.; KŘUPKA, I.; HARTL, M.; GALLO, J. In Situ Observation of Lubricant Film within Artificial Hip Joints. *International Tribology Conference*, 2015, Tokyo, Japan.
- NEČAS, D.; VRBKA, M.; URBAN, F.; KŘUPKA, I.; HARTL, M.; GALLO, J. An experimental investigation of lubricant film formation in artificial hip joints. *The 8th International Biotribology Forum, The 36th Biotribology Symposium*, 2015, Yokohama, Japan.
- NEČAS, D.; ŠVACHOVÁ, M.; VRBKA, M.; KŘUPKA, I.; HARTL, M. The effect of albumin and γ-globulin on lubricant film formation in artificial hip joints. *The 17th Nordic Symposium on Tribology - NORDTRIB 2016*, 2016, Hämeenlinna, Finland.
- NEČAS, D.; SAWAE, Y.; FUJISAWA, T.; NAKASHIMA, K.; MORITA, T.; YAMAGUCHI, T.; VRBKA, M.; KŘUPKA, I.; HARTL, M. Influence of Protein Adsorption on Friction of Metal/UHMWPE Sliding Pair. *3rd International Conference on Biotribology*, 2016, London, UK.
- NEČAS, D.; VRBKA, M.; KŘUPKA, I.; HARTL, M. Towards Understanding the Lubrication Mechanisms Within Hip Replacements. *3rd International Conference on Biotribology*, 2016, London, UK.

Thank you for your kind attention!

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Defense of the PhD thesis
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