INSTITUTE OF **MACHINE**
AND **INDUSTRIAL DESIGN**

TFME

Faculty of Mechanical Engineering
Brno University of Technology

Review of Doctoral Thesis

1. PhD candidate
Ing. Lukáš Odehnal / Lukas.Odehnal@vut.cz
2. Name of PhD programme
Design and Process Engineering
3. Title of PhD thesis
Tribological Processes of an Additively Manufactured Small Joint Implant under Simulated Conditions

4. Principal supervisor
prof. Ing. Martin Vrbka, Ph.D. / Martin.Vrbka@vut.cz
5. Co-supervisor
Ing. Matúš Ranuša, Ph.D./ Matus.Ranusa@vut.cz

6. Reviewer
Prof. Nazanin Emami/ nazanin.emami@ltu.se
Luleå University of Technology

7. Overview of the scope of PhD thesis[1]
Very good
The dissertation systematically investigates the tribological behaviour of additively manufactured Ti6Al4V for small joint implant applications, with particular focus on the first metatarsophalangeal (1.MTP) joint, where boundary and mixed lubrication regimes dominate. The work is structured around four peer-reviewed publications that progress logically from a baseline comparison of conventionally manufactured Ti6Al4V and CoCr30Mo6, through laser-textured surfaces with electrochemical finishing, to additively manufactured Ti6Al4V with controlled built-in surface structures (homogeneous, grid, line), and concludes with long-term wear validation against UHMWPE. The methodology combines colourimetric interferometry, fluorescence microscopy of fluorescently labelled model synovial fluid constituents, optical profilometry, and SEM/EDS/FIB/STEM subsurface analysis on a custom-built reciprocating wear simulator. The principal scientific achievement is the demonstration that AM Ti6Al4V with a targeted grid surface structure outperforms conventional CoCr30Mo6 in long-term UHMWPE wear, retains synovial fluid constituents within the contact area, and develops a stable nanograin and amorphous oxide near-surface layer that supports lubrication.

8. Significance of the topic and clarity of problem statement

[1] Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

Very good
The topic addresses a clinically relevant and scientifically underexplored problem. Small joint arthroplasty, including the first metatarsophalangeal joint, is becoming increasingly important due to demographic ageing and the limitations of existing implant designs, yet the tribology of small joint implants has received considerably less attention than that of hip and knee replacements. The thesis correctly identifies that small joints operate predominantly under boundary or mixed lubrication, where surface design and synovial fluid interactions dominate over bulk material properties. The choice to combine additive manufacturing — which is reshaping orthopaedic implant production — with tribological evaluation under physiologically representative lubrication is timely and well motivated. The problem statement is clearly articulated in Chapter 3, supported by an explicit set of identified knowledge gaps in Section 2.9, and translated into three precise scientific questions and testable hypotheses. The clinical, socioeconomic, and scientific motivation is convincingly presented. The framing could have been further strengthened by closer integration of biological response considerations such as debris reactivity and ion release, but the central tribological problem is significant and clearly stated.

9. Knowledge of existing literature
Very good
The literature review is comprehensive, well structured, and demonstrates a mature command of the field. It covers the historical evolution of arthroplasty, design, material classes (metallic, ceramic, polymeric), additive manufacturing routes, surface engineering and coating strategies (TiN, DLC, plasma treatments, texturing), and biotribological lubrication mechanisms, including the Protein Aggregation Lubrication framework of Myant and Cann. The discussion of synovial fluid constituents and their differential roles (albumin layering, γ-globulin/HA boundary films, phospholipid effects) is particularly well done. The review of small joint literature in Section 2.7 appropriately highlights the comparative insufficiency of published data. The analysis culminates in a clearly articulated synthesis (Section 2.8) and four explicit knowledge gaps (Section 2.9) that directly motivate the experimental approach. The reference list is current and appropriately weighted toward primary research. A more critical evaluation of methodological inconsistencies between cited tribological studies, lubricant choice, contact geometry, sliding velocity, would have further strengthened the review, but the coverage and integration are clearly above expectation.

10. Choice of methods and technical soundness
Very good
The methodological design is sound and well matched to the research questions. The candidate combines complementary techniques, colourimetric interferometry for film thickness, fluorescence microscopy with fluorescently labelled albumin, γ-globulin and hyaluronic acid for constituent retention, optical profilometry for wear quantification, and SEM/EDS/FIB/STEM for subsurface characterisation — and develops a custom long-term wear simulator with two parallel stations. The progression from optically accessible glass and PMMA counterparts to clinically relevant UHMWPE is logical and reflects a deliberate trade-off between mechanism observability and realism. Hertzian recalculation of contact pressures across material pairs and the use of a physiologically representative model synovial fluid are appropriate. Some methodological choices warrant critical discussion at the defence: the unidirectional reciprocation does not capture the multidirectional kinematics of the 1.MTP joint, the statistical foundation (n = 3 for short-term tests, n = 2 for long-term wear) introduce some reservation, and the absence of electrochemical and ion-release measurements leaves the tribocorrosion side of the problem is not addressed. Within these limitations, the experimental design and execution are technically rigorous.

11. Quality, originality and significance of the results
Very good
The results are of high quality and contain genuinely original contributions. The most striking finding is the misrepresentation of the candidate's own conservative third hypothesis: AM Ti6Al4V with a targeted grid structure not only matches but outperforms conventional CoCrMo in long-term UHMWPE wear (approximately 58 %, 34 % and 17 % lower wear rates at 100 000, 200 000 and 300 000 cycles, respectively) and shows more stable friction evolution. This challenges a long-standing assumption about Ti6Al4V's tribological inferiority for articulating surfaces. Two further findings are particularly valuable: the demonstration that surface texturing combined with electrochemical finishing can raise lubrication film thickness from approximately 60 nm to 280–320 nm, and the post-test identification of a roughly 200 nm nanograin layer and 35 nm amorphous oxide that probably underpin the observed wear stability. The use of fluorescence microscopy to track individual M-SF constituents inside the contact provides mechanistic insight rarely available in the literature. The results meaningfully advance understanding of small joint implant tribology and the functional potential of as-built AM surface morphology.

12. Quality of attached papers
Very good
The four attached papers form a coherent, progressive body of work and are of strong quality. Three are first-author contributions by the candidate (with extensive contribution) and one is a second-author contribution. Two papers are published in Q1 journals (JIF 6.9, AIS Q1) and two in Q2 journals (JIF 2.9 and 3.3). All four appear in indexed, peer-reviewed venues and have already accumulated citations, which is creditable for papers published between 2023 and 2025. The chronological sequence of the publications mirrors the logical structure of the thesis, and each paper builds methodologically and conceptually on its predecessors. Co-authorship patterns are consistent with an appropriate doctoral research environment, and the candidate's lead role in three of the four publications is well documented. The publication record clearly meets, and in scope and venue exceeds, the standard expected for a doctoral thesis in this field.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Very good
The dissertation is of very good quality and represents an independent, original contribution to the field of biotribology and additive manufacturing of orthopaedic implants. Its principal strengths are (i) a clear and well-justified scientific problem, (ii) a logical four-step experimental progression mirrored in four peer-reviewed publications, (iii) the integration of complementary measurement techniques together with a custom long-term wear simulator, (iv) a willingness to test and reverse the candidate's own hypotheses (notably Hypothesis 3), and (v) the demonstration that AM Ti6Al4V with engineered surface morphology can outperform CoCr30Mo6 over long sliding distances. The principal weaknesses are (i) the simplification of geometry and kinematics (pin-on-plate, unidirectional reciprocation, transparent counterparts in Articles 1–3), (ii) the limited statistical evaluation, (iii) the absence of tribocorrosion, ion-release and wear-debris characterisation that would be required for a full preclinical assessment, and (iv) the unaddressed fatigue implications of structuring the articulating surface of an AM component. None of these weaknesses undermines the central scientific contribution and could be planned as future research.

14. Questions and comments

The 15 questions below are organised into five thematic clusters: methodology, interpretation of results, mechanistic understanding, scientific scope, and clinical translation.

A. Methodology and experimental design

1. In Articles 1–3, the polymeric counterpart (UHMWPE) was replaced by glass or PMMA to enable optical observation. UHMWPE is several orders of magnitude softer than glass and deforms viscoelastically, entering the soft-EHL regime. To what extent do the film-thickness and protein-retention values measured against rigid transparent plates translate quantitatively to the real Ti6Al4V/UHMWPE contact? Could you quantify the expected error from this simplification?

2. The 1.MTP joint combines dorsiflexion, plantarflexion and small rotational components, yet your experiments use unidirectional reciprocation. Because the grid structure is geometrically anisotropic, how sensitive is its performance to sliding direction? Would you expect the grid advantage to persist under multidirectional or cross-shear motion, which is known to accelerate UHMWPE wear?

3. Most measurements rely on three repetitions and long-term wear tests are duplicated on two stations. The scatter in Article 1 alone (Ti6Al4V wear scar depths of 437, 583 and 984 nm) is substantial. Could you elaborate on the statistical methodology used and how you justify quantitative conclusions such as "58 % lower wear rate" from such a limited sample size?

4. The model synovial fluid composition is fixed throughout the thesis. Real post-arthroplasty synovial fluid varies widely in protein ratio, HA molecular weight and rheology. How sensitive are film thickness, PAL-type aggregation and long-term wear to realistic variations in M-SF composition? Has any additional sensitivity analysis been performed on, for example, the albumin/γ-globulin ratio?

B. Interpretation of the key results

5. The friction coefficients of Ti6Al4V and CoCr30Mo6 stabilised around 0.4, yet wear behaviour differed by an order of magnitude. What does the coefficient of friction actually measure in these boundary/mixed-lubrication regimes, and why do you continue to report it as a primary tribological descriptor if it does not discriminate between damaging and non-damaging contacts?

6. Your "insufficient separation" conclusion for Ti6Al4V depends on the 95 % separation threshold computed from surface roughness. With Ti6Al4V roughness about four times higher than CoCr30Mo6, this threshold is by definition higher. How do you rule out that the apparent separation deficit is partly an artefact of a roughness-based comparison rather than a mechanistic difference?

7. The texturing study reports film thicknesses rising from approximately 60 nm to 280–320 nm. Colourimetric interferometry measures the fluid layer, which can include protein-rich aggregates filling dimples. How do you distinguish true asperity separation from an apparent film thickness dominated by protein trapped inside the texture features themselves?

8. Hypothesis 3 was conservatively stated, and its falsification is the strongest positive claim of the thesis. Can you disentangle the relative contributions of (a) the grid topography acting as a lubricant reservoir, (b) the approximately 200 nm nanograin near-surface layer, and (c) the approximately 35 nm amorphous oxide? Which of these would survive if the grid geometry were replicated on CoCr30Mo6?

C. Mechanistic understanding

9. The grid pattern was produced by changing the hatch distance to 179 μm with 90° inter-layer rotation — parameters driven as much by printing strategy as by tribological design. Did you perform a parametric

study of spacing, aspect ratio and feature depth to demonstrate that this geometry is a tribological optimum rather than a convenient one?

10. The TEM/STEM analysis shows a roughly 200 nm nanograin layer and a 35 nm amorphous oxide after long-term testing. Were equivalent cross-sections prepared on the as-built AM pins before testing? If the nanograin layer is a consequence of tribological loading (a tribologically transformed structure), what is its predicted evolution under longer sliding distances — stable, growing, or eventually delaminating?

11. The thesis builds on the Protein Aggregation Lubrication framework but observes only random PAL-type inlet aggregation on conventional surfaces. Is the improved retention on the grid surface a genuine PAL phenomenon operating at the texture scale, or primarily mechanical entrapment in dimples that would not contribute to film formation under different kinematics? How would you design an experiment to discriminate these mechanisms?

D. Scientific scope and missing elements

12. The literature review devotes significant attention to tribocorrosion and the release of Al, V, Co and Cr ions, yet the experimental programme contains no electrochemical measurements or ion-release quantification. A structured AM surface has a larger true surface area than a polished CoCr30Mo6 surface. How confident are you that the mechanical wear advantage of AM Ti6Al4V is not partly offset by increased ion release, and what would it take to verify this?

13. AM Ti6Al4V is known for martensitic α′ microstructure, columnar prior-β grains, residual stress and lack-of-fusion defects. Adding a grid topography introduces geometric stress concentrators at the articulating surface. Have you estimated, either experimentally or via FE simulation, the fatigue performance of the grid-textured surface, and is there a risk that tribological optimisation comes at the cost of structural reliability?

14. Metallic and polymeric wear debris are the principal drivers of osteolysis. The long-term wear study quantifies UHMWPE volume loss but does not analyse debris morphology, size distribution or biological reactivity. How do you reconcile a claim of "improved preclinical performance" of AM Ti6Al4V without debris characterisation, and what would a minimum viable debris-analysis plan look like?

E. Clinical translation and future work

15. Your results demonstrate a mechanistic advantage in a simplified geometry but never reach a conforming 1.MTP configuration. (a) Which ISO/ASTM standards do you view as applicable or inappropriate for small-joint arthroplasty (ISO 14242 was written for hip, ISO 14243 for knee)? (b) What is the next experiment on your critical path — conforming simulator testing, in vitro cytocompatibility of debris, or in vivo animal model? (c) What regulatory pathway would you pursue for a patient-specific, additively manufactured 1.MTP implant?

15. Conclusion
PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES

16. Date and signature

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Faculty of Mechanical Engineering
Brno University of Technology

09/05/2026

Please note

A. *Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.*
B. *E-mail the completed form to: Klara.Javorcekova@vut.cz*

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Review of Doctoral Thesis

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5. Co-supervisor
Ing. Matúš Ranuša, Ph.D./ Matus.Ranusa@vut.cz

6. Reviewer
Prof. Jean Geringer / geringer@emse.fr
École des Mines de Saint-Étienne

7. Overview of the scope of PhD thesis[1]
Evaluate:
The thesis is by the title: TRIBOLOGICAL PROCESSES IN THE CONTACT OF SIMULATED SMALL JOINT IMPLANT MANUFACTURED BY ADDITIVE TECHNOLOGY. The main goal is to test some additive implants under tribocorrosion conditions. The author described all joints in human body. Small joint is a generic name. Such a lot of work was considered about tribological experiments. The thesis scope was to evaluate tribological performances AM Ti-6Al-4V. Scientific achievements by number of publications was right. GOOD

8. Significance of the topic and clarity of problem statement
Evaluate:
One may attempt some figures related to the typical joint, 1-MTP. One may attempt the anatomy description. One may attempt the physiological conditions as a surgeon thought. Thus, the engineers could work under the supervision of surgeons. What about the method to treat reproducibility? A the beginning, it might be impossible to control anything. After 20 minutes, after the running-in period, the stationary conditions may be reached. One may attempt these results in any tribological tests. Problem statement? It might a little bit difficult to have an insight on the best AM conditions. ACCEPTABLE

[1] Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

9. Knowledge of existing literature
Evaluate:
The authors did collaborate with some scientists from extra-Europe. One may wonder about the consideration of the attached literature. I am thinking about one in particular, Pr. M.A. Wimmer, he did a lot of advancements in tribology, wear mechanisms and many collaborators and co-workers. One may wonder why no reference did appear in the bibliography. The tribological mechanisms are described in the document. Hills and Nowell are not mentioned. K.L. Johnson was at the basement of any mechanical and physical studies. They are not mentioned. You understood a lack of fundamental authors. Forging and casting, do the author consider a difference? Unacceptable.

10. Choice of methods and technical soundness
Evaluate:
Answering some questions to guide some research investigations make sense. About the statistics, are the results considered without any statistics? About the experimental devices, may I ask you how you did calibrate the transducers? **Satisfactory**

11. Quality, originality and significance of the results
Evaluate:
The results are as the results. The tone in publications is a little bit different than in the text of Ph.D document. All combinations of materials are not new, except the AM Ti-6Al-4V. One may wonder about the method to get AM Ti-6Al-4V. I am not an expert of AM bur I know some failures, some difficulties in the field. It is weird not mentioning this statement. A huge quantity of work was achieved about tribological tests. In the document some polishing processes are described. Titanium samples are quite difficult to polish, by experience. How did you treat this issue? **Satisfactory**

12. Quality of attached papers
Evaluate:
These papers were published in A ranking journal. One might expect the quality was on according to the standards of papers. One may ask about the peer review process. The orthopedic community was not attending the conferences where the authors presented. **Satisfactory**

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Evaluate:
Strengths: quantity of tests is quite enough. Some microscopic observations were done. Weaknesses are the ones described in the document. The interests of the Ph.D document depend on the professional project in 10 years. Did the company find an interest on your work? Satisfactory

14. Questions and comments
We will consider these points during the dfense during the defense.

15. Conclusion
PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES but

16. Date and signature	
13/05/2026	Jean Geringer

Please note

A. *Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.*
B. *E-mail the completed form to: Klara.Javorcekova@vut.cz*

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Principal supervisor's final report on the PhD study

1. PhD candidate
Ing. Lukáš Odehnal / lukas.odehnal@vut.cz
2. Name of PhD programme
Design and Process Engineering
3. Title of PhD thesis
Tribological Processes of an Additively Manufactured Small Joint Implant under Simulated Conditions

4. Principal supervisor
Prof. Ing. Martin Vrbka, Ph.D. / martin.vrbka@vut.cz
5. Co-supervisor
Ing. Matúš Ranuša, Ph.D. / matus.ranusa@vut.cz

6. Stays at other institutions (min. 7 days)
06-08/2025 École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland. Research topic: Tribocorrosion Study of AM Ti6Al4V with Surface Structure and UHMWPE Interfaces Under Synovial Fluid Degradation. Supervisors: Dr. Anna Neus Igual Muñoz and Dr. Stefano Mischler.

7. Teaching activities
CAD (3CD, winter semester) Design and CAD (4KC, summer semester) Machine Design and Machine Elements (CKP, winter semester) Machine Design – Mechanical Drives (6KT, summer semester) Machine Design – Machine Elements (5KS, winter semester, student exams only)

8. List of main publications
Papers in journals with IF included in the dissertation: **Odehnal L.**, Ranuša M., Vrbka M., Křupka I., Hartl M. *Tribological Behaviour of Ti6Al4V Alloy: An Application in Small Joint Implants.* Tribology Letters 2023;71:125. (https://doi.org/10.1007/s11249-023-01795-4) Ranuša M., **Odehnal L.**, Kučera O., Nečas D., Hartl M., Křupka I., Vrbka M. *Effect of Surface Texturing on Friction and Lubrication of Ti6Al4V Biomaterials for Joint Implants.* Tribology Letters 2025;73:15. (https://doi.org/10.1007/s11249-024-01950-5)

Odehnal L., Ranuša M., Malý M., Křupka I., Koutný D., Hartl M., Vrbka M. *Tribological behaviour of additively manufactured Ti6Al4V with controlled surface structure: An application in small joint implants.* Tribology International 2025;211:110832. (https://doi.org/10.1016/j.triboint.2025.110832)

Odehnal L., Ranuša M., Čípek P., Malý M., Mazánová V., Dlouhý A., Koutný D., Hartl M., Vrbka M. *Additively manufactured Ti6Al4V with controlled surface structure as a Potential Material for Joint Implants: Long-Term Wear Performance and Durability.* Tribology International 2026;216:111599. (https://doi.org/10.1016/j.triboint.2025.111599)

9. Assessment of the supervision process

Very good

The supervision process followed the pre-set rules for PhD study. The process was based on one-month main meetings and on-demand discussions with the supervisor, co-supervisor and colleagues from the Biotribology Research Group. Cooperation was also carried out with a scientific team specialising in additive manufacturing, where the development and production of 3D-printed friction surfaces for implants were discussed. The dissertation was supported by three research projects, the most important of which was “Friction and lubrication of small joint implants produced by 3D metal printing additive technology”, funded as project No. 22-02154S by the Czech Science Foundation. The candidate was always well prepared to discuss the dissertation issues, including reflections on critical comments. He contributed new insights and ideas, particularly to the experimental part of the work. The final PhD thesis was prepared on time and of excellent quality. The PhD thesis resulted from four research papers, of which the candidate is the main author of three. The candidate attended four international conferences where he presented partial results of his research: ECOTRIB 2023 (Bari, Italy), International Conference on Tribology in Manufacturing Processes 2024 (Alcoy, Spain), Leeds-Lyon Symposium on Tribology 2024 (Lyon, France), ECOTRIB 2025 (Zurich, Switzerland). The candidate has completed one internship as part of his PhD studies (see next paragraph). The teaching activities of the candidate were focused especially on tutorials of courses of CAD, Design and CAD, Machine Design and Machine Elements, Machine Design – Mechanical Drives, and Machine Design – Machine Elements.

10. Assessment of the candidate's ability to work independently

Excellent

The candidate worked independently, based on discussions with me, the co-supervisor, and my colleagues from the Biotribology Research Group, as well as other experts in tribology, additive manufacturing, 3D printing, and material engineering. The PhD candidate was highly self-motivated and independent. I also appreciate his very precise work in the laboratory and in the process of evaluating and interpreting the measured results. I would like to highlight the candidate’s contribution to three research projects, particularly the one directly related to his dissertation, titled “Friction and lubrication of small joint implants produced by 3D metal printing additive technology”. During his final year of PhD study, the candidate participated in a three-month internship at the highly reputable workplace École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, under the supervision of Dr. Anna Neus Igual Muñoz. The primary purpose of his research stay at EPFL was to gain advanced knowledge and practical expertise in the field of tribocorrosion, which is increasingly recognised as one of the central topics within biotribology. Another goal of the mobility was to establish a platform for transferring knowledge and methodologies back to the home research group. All three high-quality publications (2xQ1, 1xQ2) in which the candidate is listed as the main author were prepared by him. The candidate was also very helpful to bachelor's and master's students, assisting them with their experimental work and the analysis of results in the field of biotribology.

11. Assessment of the contribution that the research makes to knowledge in the field
Excellent
The motivation for this dissertation comes from the fact that the Ti6Al4V alloy has long been recognised as a biomaterial with excellent biocompatibility and great potential for additive manufacturing (3D printing) of implant contact surfaces; however, its tribological behaviour has not yet been sufficiently studied. Therefore, the main aim of this dissertation was to describe the tribological behaviour of a Ti6Al4V alloy produced using 3D printing additive technology for use in small joint implants and to compare it with the conventionally used CoCrMo alloy, particularly in terms of lubricant film formation and wear durability. The PhD thesis is very well structured and is composed of four interconnected papers published in journals with impact factors: two in Tribology International (IF 6.9, Q1) and two in Tribology Letters (IF 3.3, Q2). The dissertation addresses three main scientific questions, which are answered in the three authors' papers. The research began with a comparison of conventionally manufactured Ti6Al4V and CoCrMo under model small joint conditions. This was followed by an examination of the effects of surface texturing and electrochemical polishing on lubrication formation. Subsequently, the additively manufactured Ti6Al4V with controlled surface structures produced during 3D printing was evaluated. Furthermore, long-term wear experiments involving microstructural analysis were conducted. The methodology comprised a combination of friction measurements, colourimetric interferometry, fluorescence microscopy, and advanced surface analyses. The main results showed that the tribological limitations of the Ti6Al4V alloy are not determined solely by the alloy itself, but primarily by the ability of its rubbing surface to support the formation, retention, and regeneration of a protein-rich lubricating film. Conventionally manufactured Ti6Al4V friction surfaces continued to exhibit tribological limitations, whereas specifically modified surfaces produced by 3D printing demonstrated significantly improved lubrication and wear resistance. The findings of this dissertation are of considerable value to implant manufacturers (e.g., ProSpon Company) and will subsequently be applied in further fundamental and applied research conducted by our BioTribo group.

12. Other comments
At the International Conference on Tribology in Manufacturing Processes (ICTMP), held in Alcoy, Spain, in 2024, Lukáš received Best Student Paper Award.

13. Conclusion
PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES

16. Date and signature	
04/05/2026	

Please note

A. *Evaluate categories 9 to 11 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent.*
B. *In each category 9 to 11 explain reasons for evaluation using between 100–200 words.*
C. *E-mail the completed form to: Klara.Javorcekova@vut.cz*