CASE STUDY

Gregory de Boer
University of Leeds
MTC (Part of HVM Catapult)

The Challenge

Orthopaedic joint replacements, such as hip and knee bearings, operate under complex loading and motion conditions where maintaining effective lubrication is critical to reducing friction, minimising wear, and extending implant lifespan. However, the lubrication mechanisms within these bearings are not fully understood because they occur across multiple length scales and involve interactions between surface topography, material properties, contact mechanics, and fluid film behaviour. Existing modelling approaches often focus on a single scale or lubrication regime, limiting their ability to accurately predict real-world bearing performance, particularly under mixed lubrication conditions where both fluid film lubrication and surface contact occur simultaneously.

This creates a significant challenge for the design and optimisation of orthopaedic bearings. There is currently a lack of validated multiscale modelling frameworks capable of reliably simulating lubrication behaviour across the wide range of operating conditions experienced in vivo. Furthermore, while experimental tribology testing can provide valuable insight into bearing performance, there remains uncertainty regarding how these data should be used to validate and improve predictive computational models. At the same time, emerging surface engineering techniques such as laser texturing offer potential benefits for lubrication and wear reduction, yet the influence of specific texture features on bearing performance is not sufficiently understood. As a result, the development of surface features remains largely reliant on costly and time-consuming experimental iteration.

The project therefore addressed the need for a validated multiscale mixed lubrication framework that can accurately predict orthopaedic bearing performance and enable rapid in-silico evaluation of surface texture designs, supporting a more efficient and evidence-based approach to next-generation implant development.

Innovation
Launchpad
Network+

Innovation

This project delivered an innovative framework for understanding, predicting, and improving the lubrication and wear performance of orthopaedic bearings through the integration of advanced computational modelling and experimental validation.

The primary innovation was the development of a multiscale modelling framework capable of representing mixed lubrication conditions within orthopaedic bearing contacts. To achieve this, the project established the requirements for coupling key physical phenomena, including thin film fluid flow and contact mechanics, within a single computational environment. Appropriate numerical methods were implemented alongside realistic orthopaedic bearing geometries, creating a platform capable of investigating the complex interactions that govern friction and wear in joint replacements.

To ensure that the model produced meaningful and reliable predictions, the project also generated dedicated experimental datasets for validation. Tribological tests were designed to replicate the loading and motion conditions experienced by orthopaedic bearings in the body, allowing direct comparison between experimental measurements and model outputs. These datasets included bearings with laser-textured surfaces, enabling the quantitative assessment of how different surface features influence lubrication behaviour, friction, and wear performance.

Building on the combined modelling and experimental capabilities, the project investigated the use of laser surface texturing as a means of enhancing bearing performance. A range of texture geometries and features were evaluated within the modelling framework to identify characteristics associated with beneficial or detrimental tribological behaviour. While full optimisation, manufacture, and validation of texture designs was not completed, the project successfully quantified specific texture features that promote improved lubrication and reduced wear, providing a foundation for future in-silico surface design approaches in orthopaedic implants.

Result

The project generated significant advances in the understanding and prediction of lubrication and wear within orthopaedic bearings. The principal research outcome was the successful development and deployment of a multiscale mixed lubrication modelling framework based on Heterogeneous Multiscale Methods (HMM). Building on previous work that was limited to full-film lubrication, the new approach enables the simulation of operating conditions where surface asperity contact occurs, allowing investigation of higher load-bearing scenarios that are more representative of real orthopaedic applications. This represents an important step forward in the predictive capability of tribological modelling.

The research findings have already demonstrated strong academic advancement. Two conference papers were presented at the 2025 Leeds-Lyon Symposium on Tribology, showcasing both the methodological developments in mixed lubrication modelling and the application of the framework to orthopaedic bearing contacts. In addition, the core modelling research is currently under review for publication in the Journal of Engineering Tribology, while further outputs are planned through additional journal articles and presentations, including dissemination at the World Tribology Congress 2026.

Experimentally, the project produced a unique validation dataset quantifying the frictional performance of laser-textured ball bearing surfaces across a range of loading conditions and texture orientations. These data provide the first stage of direct validation for the multiscale model and establish clear relationships between surface texture characteristics and frictional behaviour. Beyond research outputs, the project also delivered a dedicated training workshop on multiscale lubrication modelling and HMM techniques, supporting knowledge transfer and encouraging industrial adoption of the methods developed.

Impact

The impact of this project extends beyond the development of a new tribological modelling tool and has the potential to influence how advanced engineering surfaces and bearing systems are designed across multiple sectors. By delivering a validated multiscale mixed lubrication framework, the project provides a route to reduce reliance on costly and time-consuming experimental trial-and-error approaches, enabling engineers to evaluate surface designs and operating conditions virtually before physical manufacture. This has the potential to accelerate innovation, reduce development costs, and improve confidence in the performance of next-generation bearing systems.

Within the manufacturing and medical engineering sectors, the framework offers a new capability for the design of orthopaedic bearings and engineered surfaces. By combining predictive modelling with laser surface texturing technologies, designers can move towards evidence-based, simulation-led optimisation of implant surfaces, improving lubrication performance and reducing wear. In the longer term, this could contribute to longer-lasting orthopaedic implants, fewer revision surgeries, and more personalised device designs that better reflect the needs of diverse patient populations. The ability to investigate operating conditions beyond current testing standards also creates opportunities to assess underrepresented patient groups and patient-specific devices with greater realism.

The project has also established a pathway for industrial adoption through knowledge transfer activities within the Manufacturing Technology Centre and engagement with major industrial stakeholders, including bearing manufacturers and orthopaedic device companies. Beyond tribology, the underlying multiscale methods have significant potential in areas such as additive manufacturing, biomaterials, metastructures, and thermal systems. As a result, the project serves as a platform for future collaborative research, industrial innovation, and funding opportunities, ensuring that the benefits of the work can be translated into practical engineering solutions across a wide range of applications.

MTC (Part of HVM Catapult)

"The recent technical work has provided leadership with a clearer strategic perspective on how tribology and multiscale modelling can strengthen the MTC long term position across key sectors. The University of Leeds demonstrated that the methodology is highly adaptable, extending beyond tribology to act as a multidisciplinary framework linking product performance, materials behaviour and manufacturing processes. The Research in Residence programme structured tribology at system level, connecting component interactions to predict wear, lubrication and surface behaviour with improved accuracy." - **Dr Gajarajan Sivayogan, Advanced Research Engineer at MTC.**

Gregory de Boer

"This project has demonstrated how advanced multiscale modelling can be used to tackle one of the key challenges in orthopaedic bearing design: understanding and predicting lubrication and wear under realistic operating conditions. By developing a novel mixed lubrication framework based on Heterogeneous Multiscale Methods, and supporting it with targeted experimental validation, we have created a foundation for simulation-led design of next-generation bearing surfaces. Ultimately, this has the potential to reduce development time and cost, improve implant performance and longevity, and enable a more efficient, evidence-based approach to engineering design across tribology and other sectors where multiscale phenomena govern performance."

mtc where progress happens

UK Research and Innovation