

## POPULAR SCIENTIFIC SUMMARY OF THE PROJECT

Total knee arthroplasty (TKA) and unicompartmental knee arthroplasty (UKA) are among the most common and successful orthopedic procedures worldwide, offering significant improvements in mobility and quality of life for patients with advanced joint degeneration. Despite the high success rates, a fraction of implants fail over time, requiring complex and costly revision surgeries. The mechanisms behind such failures are often multifactorial, involving both mechanical degradation of the implant and a biological response to wear particles released during use.

This interdisciplinary project aims to provide a comprehensive analysis of both wear mechanisms in retrieved knee implants and the associated periprosthetic tissue reactions. The research utilizes a unique collection of over 160 retrieved implants gathered since 2012 at PUMS as part of a structured retrieval program.

The study will involve detailed examination of the implants, including macroscopic assessment, surface profilometry, scanning electron microscopy (SEM), and energy-dispersive spectroscopy (EDS) to determine wear patterns and material degradation. In parallel, surrounding periprosthetic tissues will undergo enzymatic and chemical digestion to isolate wear debris (including polyethylene, metal, and ceramic particles), followed by high-resolution imaging and classification.

One of the novel aspects of the project is the implementation of artificial intelligence (AI) methods to automate the analysis of wear particles in SEM images. Using models such as MetaSAM, R-CNN, and Unet, debris will be segmented, counted, and characterized in terms of size, morphology, and distribution. To support this AI-driven workflow, a high-performance GPU (e.g., NVIDIA H100) will be integrated into the research infrastructure.

The biological response will be assessed through a combination of histological analysis (H&E), immunohistochemical staining for inflammatory markers and cytokines, and laser capture microdissection (LCM). LCM will allow researchers to isolate precise regions of tissue showing specific cellular responses, facilitating the direct correlation between particle characteristics and local immune activation.

This project is a collaboration between experts in materials science, pathology, orthopedics, and bioinformatics. It represents one of the first large-scale efforts to combine advanced imaging, AI-driven analysis, and histopathology to understand the interplay between implant wear and biological responses. The insights gained from this research may lead to improved implant materials and designs with enhanced biocompatibility and durability, ultimately reducing the incidence of revision surgeries and improving patient outcomes.