Title: Computational optimization and biodegradation of 3D-printed patient-specific acetabular implants

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Introduction: 3D-printed orthopedic implants have been gaining popularity in recent years due to the control this manufacturing technique gives the designer over the different design aspects of the implant. This technique allows us to manufacture implants with material properties similar to bone, giving the implant designer the opportunity to address one of the main complications experienced after total hip arthroplasty (THA), i.e. aseptic loosening of the implant. To restore proper function after implant loosening, the implant needs to be replaced. During these revision surgeries, some extra bone is removed along with the implant, further increasing the already present defects, and making it harder to achieve proper mechanical stability with the revision implant. A possible way to limit the increasing loss of bone is the use of biodegradable orthopedic implants that optimize long-term implant stability. These implants need to both optimize the implant such that stress shielding is minimized, and tune the implant degradation rate such that newly formed bone is able to replace the degrading metal in order to maintain a proper bone-implant contact. The hope is that such (partly) degradable implants will lead to a reduction in the size of the bone defects over time, making possible future revisions less likely and less complex.

Methods: We focused on improving the long-term implant stability of patient-specific acetabular implants for large bone defects and the modeling of their biodegradable behavior. To improve long-term implant stability we implemented a topology optimization approach. A patient-specific finite element model of the hip joint with and without implant was derived from CT-scans to evaluate the performance of the designs during the optimization routine. To evaluate the biodegradation behavior, a quantitative mathematical model was developed to assess the degradation rates of the biodegradable part of the implant (see fig. 1). Currently, the biodegradation model has been implemented for magnesium (Mg) implants as a first proof of concept.

Results: For a first test case, an optimized implant was found with stress shielding levels below 20% in most regions. The highest stress shielding levels were found at the bone implant interface. The biodegradation model has been validated using experimental data, which includes immersion tests of simple scaffolds created from Commercial Pure Mg. The mass loss of the scaffold is about 0.8 mg/cm^2 for the first day of immersion in simulated body fluid (SBF) solution. After the formation of a protective film on the surface of the simple scaffold, the degradation rate starts to slow down.

Discussion: Initial results presented serve as a proof of concept of the developed computational framework for the implant optimization and the implant biodegradation behavior. Currently, timing calibration, benchmarking and validation are taking place.

Conclusion: Reducing implant-induced stress shielding, obtaining a better implant integration and reduction of bone defects, by allowing for bone to partially replace the implant over time, are crucial design factors for large bone defect implants. In this research, we have developed in-silico models to investigate these factors. Once validated and coupled, the models will serve as an important tool to find the appropriate biodegradable implant designs and biodegradable metal properties for THA applications, that improve current implant lifetime while ensuring proper mechanical functioning.

Images:

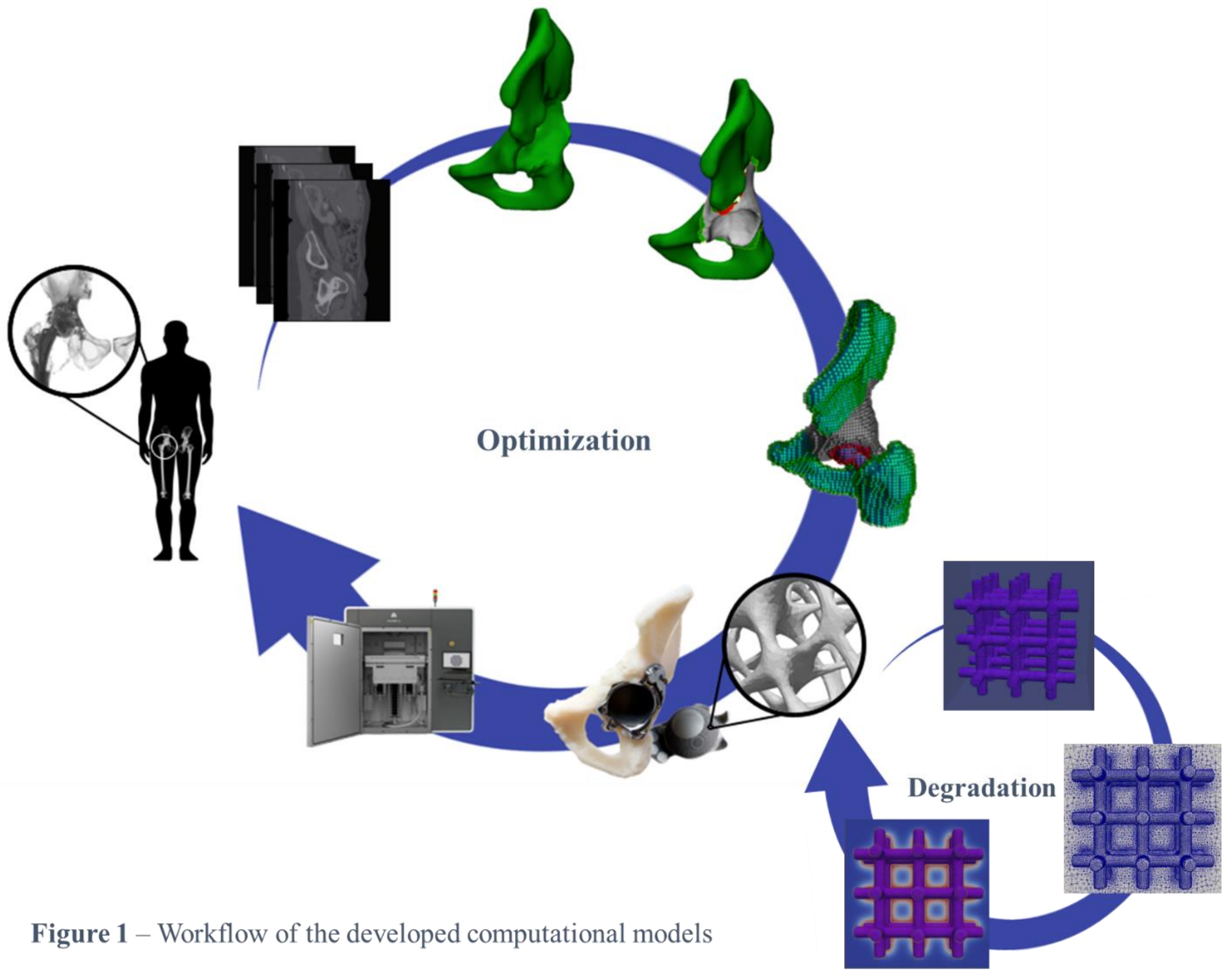

Figure 1 – Workflow of the developed computational models