Numerical simulation of biodegradation and corrosion of magnesium-based orthopedic implants

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ABSTRACT

Orthopedic implants are defined as the implants that replace or repair damaged bone, such as the implants being used in total hip arthroplasty (THA) [1]. Besides traditional approaches to produce orthopedic implants, patient-specific 3D printing has also gained great popularity in recent years. In addition to proper design, the material in which the implant is printed should be carefully chosen to prevent common postoperative problems such as allergy, implant failure, and loosening of the bond between the implant and bone [1].

Magnesium (Mg) alloys are investigated as possible biodegradable implant materials for orthopedic applications. This is mainly because of their acceptable mechanical properties (close to those of bone, which prevents stress shielding) and biocompatibility. Additionally, Mg can increase the rate of some metabolic reactions related to bone tissue growth and osteoinductivity, and as a result, is a bioactive material [1]. However, one great concern about magnesium-based implants is their high rate of corrosion in physiological conditions, which requires tuning the degradation of the implant by considering the application.

We have developed a quantitative mathematical model to simulate the degradation of magnesium-based orthopedic implants in silico (in the computer) prior to conducting any in-vitro or in-vivo experiments to tune the degradation parameters. To model the corrosion of the implant, a set of reaction-diffusion PDEs are derived from the underlying oxidation-reduction reactions, which reflect the behavior of the Mg scaffold in the presence of Chloride ions in the medium. The model captures the formation of a protective film that slows down the degradation, as well as taking into account the role of Cl^- ions on the dissolution of the formed film. The equations are implemented in FreeFem++ [2], and the finite element method is utilized to solve the equations numerically. The level set equation is solved to track the corrosion interface.

Currently, timing calibration and validation are taking place with experimental data and simple scaffold shapes. Once validated, the model will be an important tool to find the appropriate design and properties of the degradable magnesium-based implants for specific orthopaedic applications.

(a) (b)

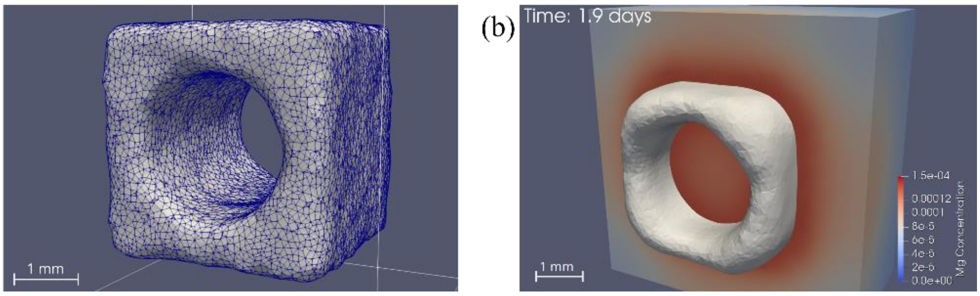

Figure Caption: a) numerical reproduction of the initial shape of the tested Mg scaffold. b) degraded shape of the scaffold, as well as the concentration of Mg, released to the surrounding medium.

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REFERENCES

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