Finite element modeling to investigate the mechanical behavior of biodegradable stents

Nic Debusschere[1], Matthieu De Beule[1], Patrick Segers[1], Peter Dubruel[2], Benedict Verhegghe[1]

[1]IBiTech-bioMMeda, Ghent University, Ghent, Belgium

[2]PBM, Ghent University, Ghent, Belgium

Introduction

Biodegradable stents have the potential to avoid long-term complications of conventional stents such as in-stent restenosis and late stent thrombosis, and could allow for a restoration of vasomotion and vessel growth which makes them suitable for e.g. paediatric applications [1]. To investigate the mechanics of this new type of stent via finite element simulations, we developed a numerical framework based on continuum damage mechanics, that is able to incorporate the stent's complex time-varying material properties. As a proof of concept, we set up a virtual bench test to compare the mechanical behavior of a biocorrodible magnesium stent and a bioresorbable polymeric polylactic acid (PLA) stent.

Methods

We used the pyFormex mesh designer (in-house developed open source software) to create generic finite element models of both a biocorrodible magnesium and a bioresorbable PLA stent which were virtually compressed at different degradation times to obtain their evolving radial strengths. Material models for magnesium stress and pitting corrosion and hydrolytic degradation of polyesters were implemented as user subroutines to be compatible with the finite element solver Abaqus/Standard (Dassault Systèmes, Providence, USA). Material parameters and degradation constants were obtained by fitting of the degradation dependent stress-strain curves for PLA and magnesium alloy AZ31 (data obtained from literature [2; 3]).

Results

Figure 1 plots the evolution of the radial strength of the stents as a function of degradation time. Corrosion is a surface degradation process, which initially does not affect the bulk of the material. This explaines the initial preservation of the mechanical strength of the magnesium stent. In the second phase, the stent's radial strength is rapidly diminishing because of pitting corrosion and stress corrosion. The PLA stent's hydrolytic degradation is first affecting the amorphous phase of the polymer. The decline of the stents radial strength speeds up when the loadbearing crystalline phase of the polymer starts to degrade (dashed curve).

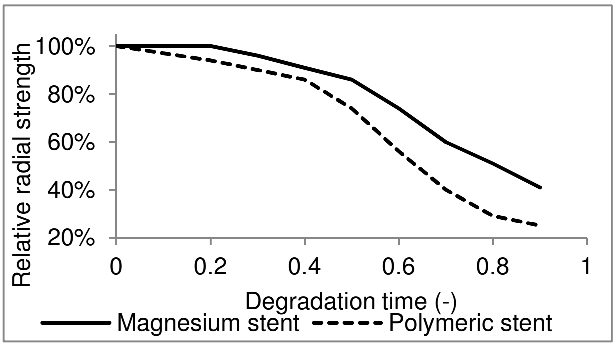

Figure 1: Evolution of the radial strength of a biocorrodible magnesium stent and a bioresorbable PLA stent as a function of time

Conclusions

Material models for metal corrosion and polymer degradation were implemented to investigate the evolution of the radial strength of a magnesium stent and a PLA stent within a finite element simulation framework. Using continuum damage mechanics, we are able to project micro-scale physical phenomena onto the macro-scale stent behavior. This proof of concept research will however need further experimental validation to lead to clinically relevant information.

References

[1] Ormiston JA, Serruys PW, Bioabsorbable coronary stents, *Circulation. Cardiovascular interventions*, 2: 255-60, 2009.
[2] Grogan JA, O'Brien BJ, Leen SB, McHugh PE, A corrosion model for bioabsorbable metallic stents, *Acta biomaterialia*, 7:3523-33
[3] Gastaldi D, Sassi V, Petrini L, Vedani M, Trasatti S, Migliavacca F, Continuum damage model for bioresorbable magnesium alloy devices - Application to coronary stents, *Journal of the mechanical behavior of biomedical materials*, 4:352-65