Title: Metal Foam - Biocement Composites: mechanical and biological properties and perspectives for bone implant design

Authors:

Berthold Nies, Stefan Glorius, Sophie Rößler – InnoTERE GmbH, Dresden

Günter Stephani, Peter Quadbeck, Ralf Hauser – FhG IFAM Dresden

Jörg Adler, Gisela Standke – FhG IKTS Dresden

Michael Gelinsky, Dieter Scharnweber, Anja Lode, Jana Farack, Cornelia Wolf-Brandstetter – TU-Dresden

Several approaches for the development of highly porous metal structures with the intended application as bone implant materials have been published in recent years and some of them have reached the stage of commercial products. There is however always a conflict of interests between highly open pore structures and sufficient mechanical strength in order to be applicable in significantly loaded bone defect sites. The aspect of stress shielding remains a still unsolved issue if the bone implant retains a constant strength over time. In our developmental approach we therefore combined highly open porous metal sponges with high strength resorbable mineral bone cements in order to obtain metal/mineral composite materials with very high initial load bearing capability. As the selected mineral bone cements are bioactive and resorbable, they are considered to support bony integration. By gradual replacement of the cement matrix with newly formed bone the implant shall be finally converted into a biohybrid composite of metal foam and bone.

In the present study metal sponges were prepared from stainless steel, iron and titanium alloy (Ti6Al4V) with an open porosity of 85 % and a pore size of 45 ppi each. In all metal sponges the pore structure was 100 % interconnecting. Cylinders of metal sponges were 10 mm in Ø and 5 mm or 20 mm in length for biological or mechanical testing, respectively. The metal sponges were either coated with a brushite ($CaHPO_4$) layer or filled completely with mineral bone cements. The latter was either calcium phosphate cement (CPC) prepared from α-TCP, $CaHPO_4$, $CaCO_3$ and pHA (precipitated hydroxyapatite) with Na_2HPO_4 as setting accelerator or magnesium calcium phosphate cement (MgCPC) with $(NH_4)_2HPO_4$ solution as setting liquid. Cement slurry was infiltrated into the sponges and cured. Complete filling was monitored by weighing all samples and by inspecting cross sections of selected samples by electron and stereo microscopy. Compressive strength was determined with an Instron universal testing machine at a crosshead speed of 1 mm/min. Biocompatibility tests were carried out using human mesenchymal stem cells (hMSCs) of preselected donors.

Combination of open celled metal sponges with high strength mineral bone cements opens new opportunities for design of bone implants. The tested metal/mineral composites provided very high initial compression strengths, largely contributed by the respective mineral bone cements. At deformation rates destructive for the pure cements the composites retain much of their strengths, thus suggesting the application of these composites for applications with high load bearing (Fig. 1).

In cell culture experiments with hMSC all metal/mineral composite samples showed results comparable to the respective mineral bone cements. Iron sponges without cement filling showed reduced cell viability close to the metal surface. This cytotoxic surface effect could be completely avoided by coating the iron sponges with a brushite layer.

We conclude that the development of metal sponge/biocement composites for application as bone implant materials deserves further efforts and especially testing in implantation studies that are predictive for performance in clinical use.

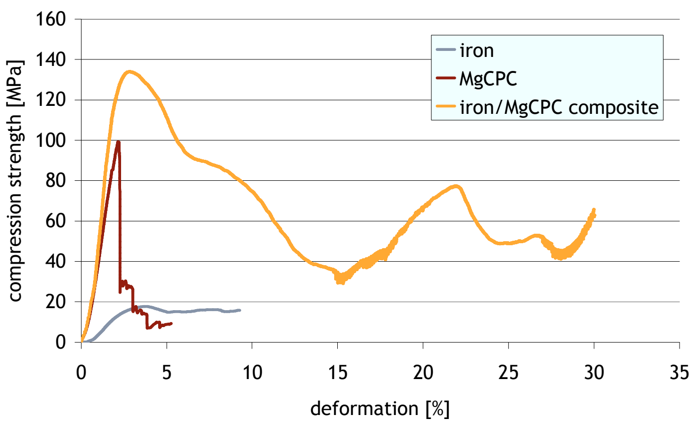

Fig 1:

Stress–strain curve of an iron/MgCPC composite and the constituent materials thereof.