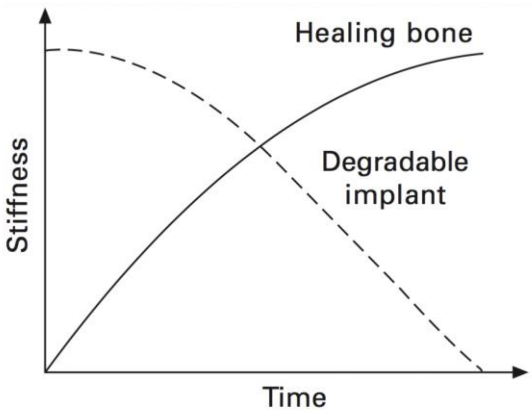
Implant and forget

In many cases, the currently available metal implants for the fixation of fractured bones have to be removed after complete fracture healing because of soft tissue irritations, potential infections and, in case of children, the ongoing growth of patients.

Even without acute medical conditions, implants are frequently removed. In a recent survey, almost 40% of the interviewed surgeons agreed or strongly agreed that ”Orthopedic implants must be removed in younger patients (<40 years of age), even if they cause no problems”. This is because for younger patients, a non-negligible probability of refracture at a later point in time exists. In such cases, fracture treatment often presents additional difficulties.

Surgeries for implant removal could be avoided with the use of a material that degrades gradually and continues to absorb in vivo. However, the total elimination of the implant material and any side products is important.

At the moment, the most promising candidates to replace current non-degradable implant materials are magnesium-based alloys. These feature sufficient mechanical strength, a low Young’s modulus, excellent biocompatibility, and exhibit strong corrosion tendencies in aqueous environments. Corrosion, often avoided as much as possible in engineering sciences, is desirable when it leads to the safe degradation of metallic implants.



Magnesium and its alloys possess excellent mechanical properties, biological acceptance and are therefore promising as implanted material. Essential for their applicability is a sufficient load-bearing capacity for a clinically relevant time frame, directly linked to a reliable degradation rate and good bone ingrowth.

Magnesium is an abundant element in the human body, with hundreds of enzymes requiring magnesium ions to function. About 25 g of magnesium can be found in the body and approximately 50% is present in bones. It plays a large role in the formation of bone tissue by influencing the activity of osteoblasts and osteoclasts. Furthermore, several studies have reported a positive relationship between magnesium intake and bone density. Magnesium deficiency, on the other hand, may be a factor in osteoporosis.

The recommended daily dose of elemental magnesium ranges from 30 mg (infant) to 420 mg (adult). Excessive magnesium intake from food does not pose any health risks as it can be safely eliminated by the kidneys and excreted in urine. However, high doses of magnesium from supplements have reportedly caused diarrhea, nausea, and abdominal cramping. Only extremely high dosages (typically more than 5,000 mg per day) have been associated with toxicity.

Magnesiums degrades in vivo because of its low corrosion potential and resulting susceptibility to corrosive tendencies in aqueous solutions. It reacts with water in the form of an anodic and cathodic reaction according to the formula:

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$$

Hydrogen in vivo is not considered harmful, but is not desirable either. It is inextricably linked with the degradation of magnesium and cannot be avoided. Excessively high degradation rates can produce gas cavities, which may result in soft tissue swelling. According to existing knowledge, hydrogen inside gas cavities diffuses through soft tissue very quickly but is replaced by other gases (most notable: carbon dioxide). These gas molecules are also carried away by blood and diffuse without causing damage after some weeks. However, for a clinically acceptable implant, gas cavities are unacceptable. Therefore, the degradation rate and the accompanied hydrogen evolution must be engineered as sufficiently low as to prevent gas cavities during degradation.

By alloying magnesium with suitable other elements, mechanical strength and degradation characteristic of the material can be optimized. Another way to slow down the degradation kinetics is the usage of extremely pure material.

ETH Zurich’s Laboratory of Metal Physics and Technology developed a distillation process that alloys to produce extrahigh-purified magnesium with remaining other elements in the range of a few parts per million. This base material is then combined with little quantities of likewise pure zinc and calcium to an alloy that features high strength and optimal degradation speed. Currently, such implants made of this extrahigh-purified magnesium alloys are intensively tested in vitro, and also in first clinical trials for the treatment of a variety of potential fracture types.

Biodegradable Magnesium Implants - ETH Zurich Pavilion in Davos

See the implants and the ultrahigh purified magnesium raw material on display and speak directly with the researchers at the ETH Zurich Pavilion in Davos during the 2019 World Economic Forum’s Annual Meeting.

Design team / bios / publications

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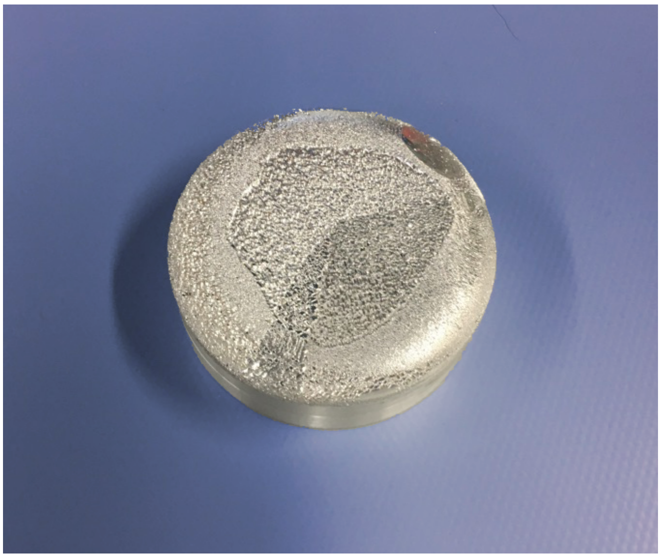
References

ETH Zürich Laboratory of Metal Physics and Technology

http://www.metphys.mat.ethz.ch/research/metallic-biomaterials.html

Images and video material



Ultra-high-purified magnesium after distillation

Hand made of polyurethane with finger implants made of a biodegradable magnesium-zinc-calcium alloy