## Fracture mechanics of metallic biomaterials

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Trzebnica, 3-6 th September 2013

13th Summer School on Fracture Mechanics

Fracture Mechanics of Metallic Biomaterials

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**Metallic Biomaterials** 

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#### Outline:

- Metallic Biomaterials
- Titanium Alloys
  - FM testing of Ti alloys
- Magnesium Alloys
  - FM testing of Mg alloys
  - Modelling the degadation of Mg stents
- Modelling the fatigue life of Co-Cr stents
- "Real Life" (Conclusions)

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Metallic implant materials (bone replacement)

What will it be used for ?



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Permanent







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What will it be used for ?

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### Materials & Properties

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| Properties                                | Natural bone | Magnesium       | Ti alloy       |
|---|--------------|-----------------|----------------|
| Density (g/cm <sup>3</sup> )              | 1.8–2.1      | 1.74–2.0        | 4.4-4.5        |
| Elastic modulus (Gpa)                     | 3–20         | 41–45           | 110-117        |
| Compressive yield strength (Mpa)          | 130–180      | 65–100          | 758-1117       |
| Fracture toughness (MPam <sup>1/2</sup> ) | 3–6          | 15–40           | 55-115         |
| Properties                                | Co–Cr alloy  | Stainless steel | hydroxyapatite |
| Density (g/cm <sup>3</sup> )              | 8.3–9.2      | 7.9–8.1         | 3.1            |
| Elastic modulus (Gpa)                     | 230          | 189–205         | 73–117         |
| Compressive yield strength (Mpa)          | 450–1000     | 170–310         | 600            |
| Fracture toughness (MPam <sup>1/2</sup> ) | N/A          | 50–200          | 0.7            |

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#### Magnesium in orthopaedics



both pictures: courtesy F. Witte



bone fixation using Mg

The good news: Magnesium corrodes !

Degrading magnesium enhances the formation of new bone material !

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#### SRµCT)\*of Mg implants



Mg implant corrodes in direct contact to surrounding bone four weeks after operation

3D view of corroding Mg implant in rabbit condyl 12 weeks after operation (red dyed: corroded Mg alloy)

#### In-vivo degradation of Mg implants

): high-resolution micro computed tomography ( $\mu$ CT) based on synchrotron radiation

F. Witte, H.-A. Crostack, J. Nellesen, J. Fischer, F. Beckmann, In-vivo Degradation Kinetic of Magnesium Implants, HASYLAB, Annual Report 2003 <sup>14</sup> 13<sup>th</sup> Summer School on Fracture Mechanics Wroclaw, 3 – 6 September 2013 Wolfgang Dietzel, HZG

# Implants made from magnesium alloys





Stents adjustable degradation rate uniform corrosion



Nerve conduits: forming adjustable degradation rate www.microfab.com courtesy: N. Hort, HZG

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Cruciate ligament: mechanical stability 6 months



Lumbar interbody fusion: adjustable degradation rate uniform corrosion, porosity?

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Osteosarcoma refilling

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Bone filling applications (dental / orthopedic):

adjustable degradation rate

mechanical stability





CF testing of tubes for manufacturing stents in enviroment (material WE43)

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courtesy: Marrey, Burgermeister, Grishaber and Ritchie; Fatigue and life prediction for cobalt chromium stents: A fracture mechanics analysis, 25 Biomaterials 27 (2006) 1988-2000 13th Summer School on Fracture Mechanics Wroclaw, 3 - 6 September 2013

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FE mesh and stress distribution in MPa for a 30  $\mu m$  corner flaw during the recoil load step

Variation in fatigue-crack growth rates for L-605 alloy under simulated physiological conditions

courtesy: Marrey, Burgermeister, Grishaber and Ritchie; Fatigue and life prediction for cobalt chromium stents: A fracture mechanics analysis, Biomaterials 27 (2006) 1988–2000

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