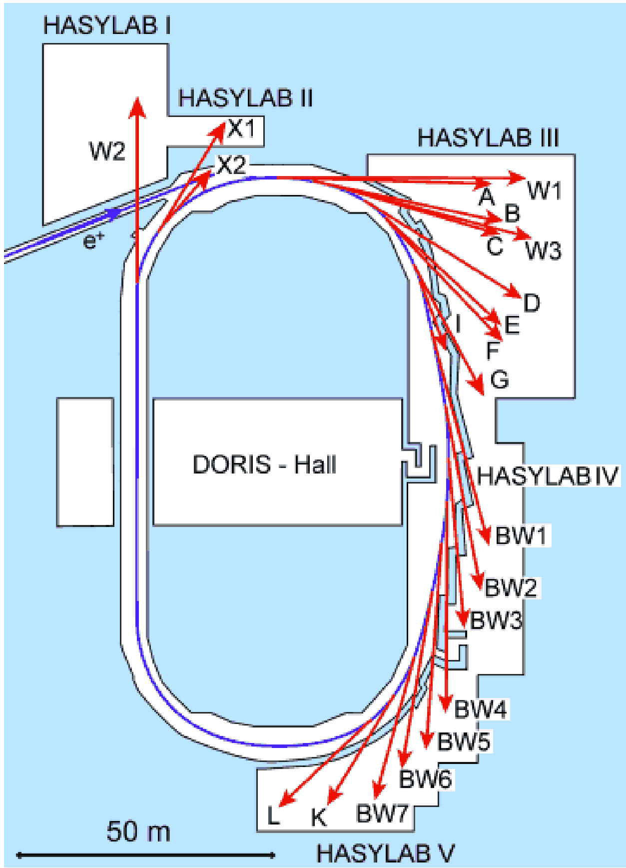
Tomographic imaging using synchrotron light: Benefit for orthopedic research

Frank Witte

Laboratory for Biomechanic and Biomaterials,
Department of Orthopaedic Surgery, Hannover Medical School

Synchrotron-radiation based computed micro-tomography



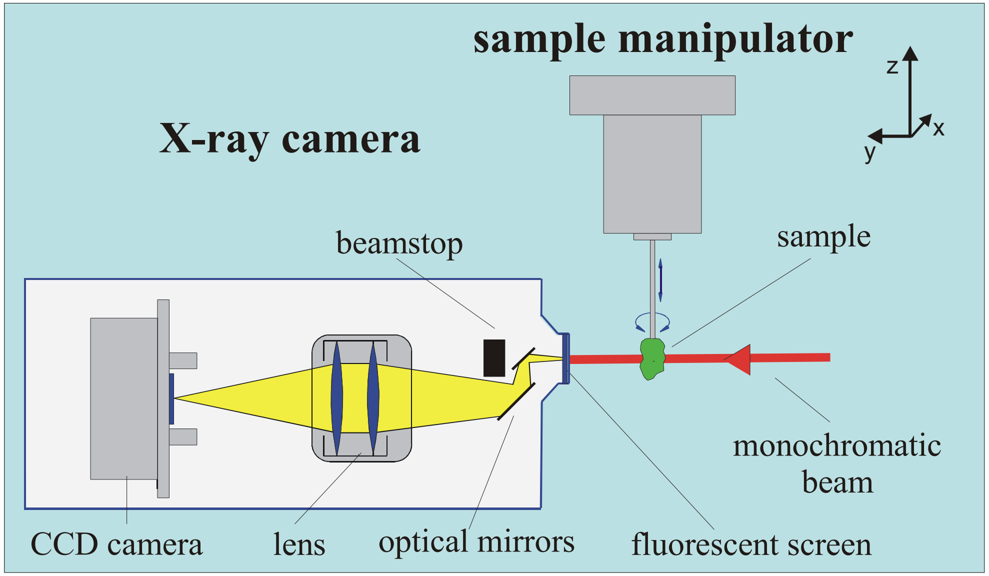
Hamburger Synchrotronstrahlungslabor

HASYLAB

- DORIS storage ring
- E=4.450 GeV Positrons
- 22 Beamlines

GKSS FORSCHUNGSZENTRUM in der HELMHOLTZ GEMEINSCHAFT e.V.

HARWI II
Felix Beckmann



Laboratory for Biomechanic and Biomaterials,
Department of Orthopaedic Surgery, Hannover Medical School

The beginning of SRµCT in biology

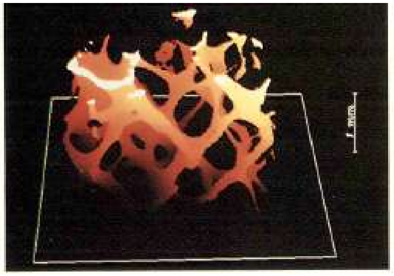
644

Nuclear Instruments and Methods in Physics Research A246 (1986) 644–648
North-Holland, Amsterdam

HIGH RESOLUTION TOMOGRAPHY WITH CHEMICAL SPECIFICITY

U. BONSE [2)], Q. JOHNSON [1)], M. NICHOLS [3)], R. NUSSHARDT [2)], S. KRASNICKI [2)*] and J. KINNEY [1)]

[1)] *Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[2)] *Institut für Physik, University of Dortmund, Dortmund, FRG*
[3)] *Sandia National Laboratory, Livermore, CA 94550, USA*



Prof. Ulrich Bonse

ELSEVIER SCIENCE IRELAND

Bone and Mineral 25 (1994) 25–38

BONE AND MINERAL

3D computed X-ray tomography of human cancellous bone at 8 μm spatial and 10^{-4} energy resolution

Ulrich Bonse*[a], Frank Busch[a], Olaf Günnewig[a], Felix Beckmann[a], Reinhard Pahl[a], Günter Delling[b], Michael Hahn[b], Walter Graeff[c]

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(Received 19 August 1993; revision received 28 October 1993; accepted 10 November 1993)

Microcallus (www.roche.com)

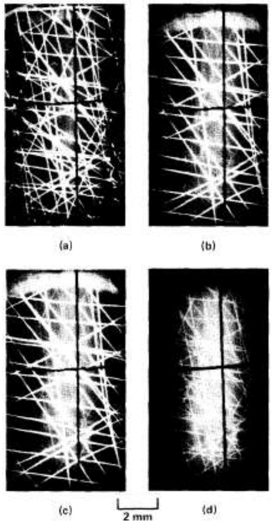

Fig. 7. (a) Web structured gaps in Cu + Ni Layers imaged at 23 eV above Cu K-edge, (b) 18 eV below Cu K-edge, (c) 26 eV above Ni K-edge, and (d) 22 eV below Ni K-edge.

SRµCT-based FEM

ELSEVIER

Journal of Biomechanics ■ (■■■■) ■■■–■■■

JOURNAL OF BIOMECHANICS

www.elsevier.com/locate/jbiomech
www.JBiomech.com

Intrinsic mechanical properties of trabecular calcaneus determined by finite-element models using 3D synchrotron microtomography

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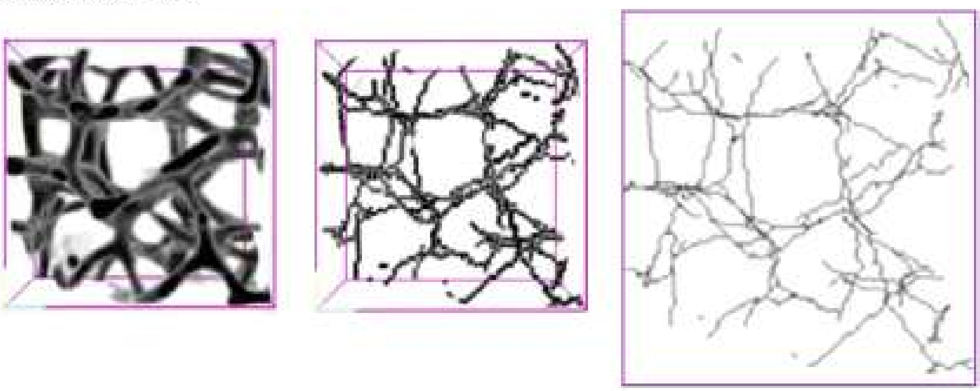
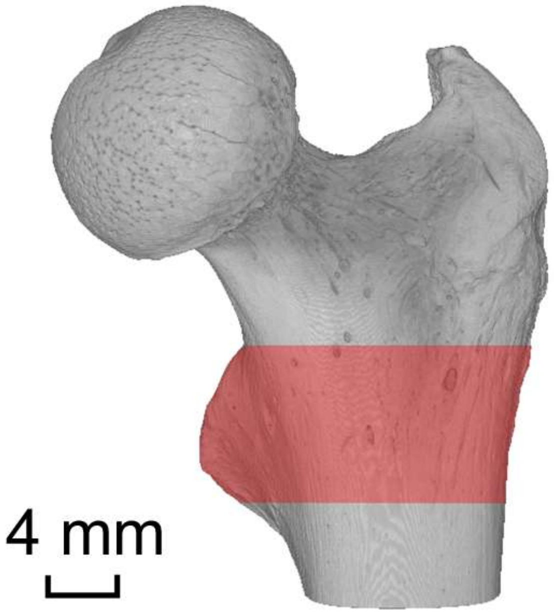
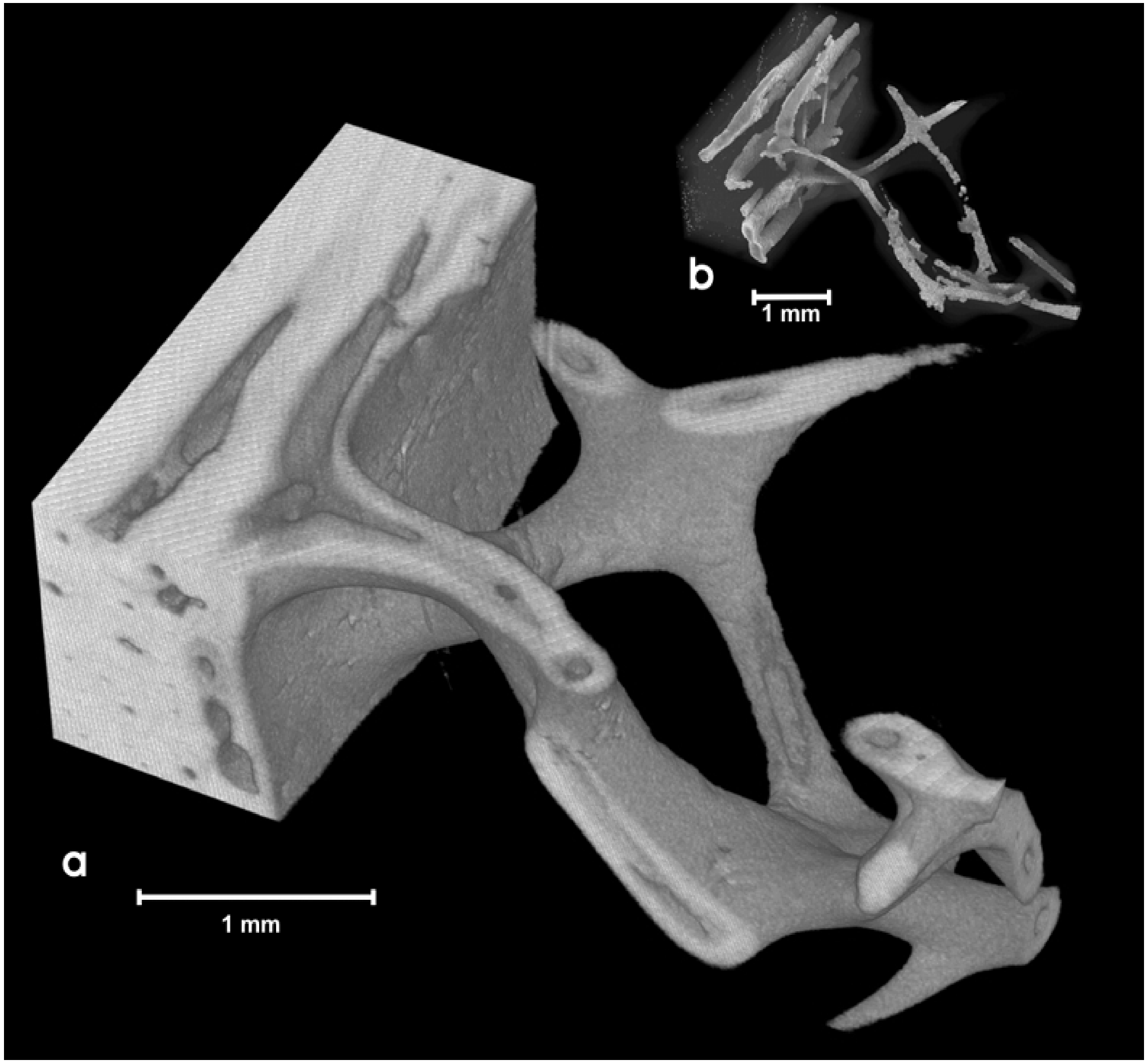
Accepted 24 October 2006



SRμCT for structural biology



Scherf H., Fischer J., Beckmann F., Witte F. SPIE 5535, 2004



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SRµCT for soft tissue imaging

Orthod Craniofacial Res **9**, 2006/199–205

ORIGINAL ARTICLE

M Dalstra
PM Cattaneo
F Beckmann

Synchrotron radiation-based microtomography of alveolar support tissues

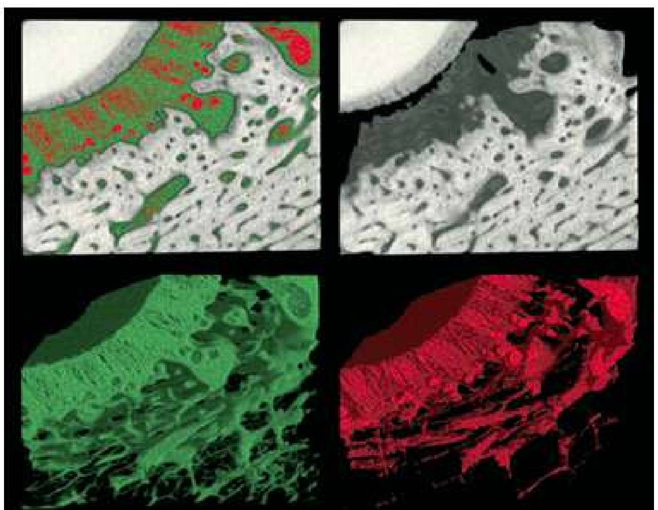

Fig. 8. 3D reconstruction of the mineralized and soft tissues in a section of the porcine sample. Note the use of false-coloring to enhance the low-density structures; green for the bone marrow and the fibers of the PDL; red for the blood vessels and interstitial tissue.

Phys. Med. Biol. **43** (1998) 2911–2923. Printed in the UK   PII: S0031-9155(98)93345-0

Feasibility study of x-ray diffraction computed tomography for medical imaging*

U Kleuker†‡, P Suortti†, W Weyrich§ and P Spanne†
† Medical Imaging Group, European Synchrotron Radiation Facility, PO Box 220, F-38043 Grenoble, France
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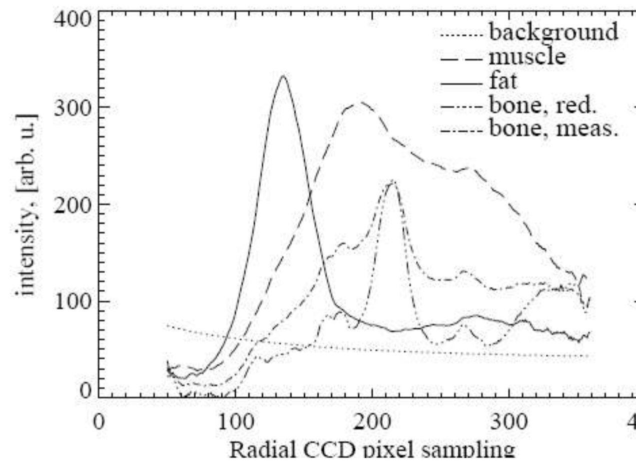
Received 16 April 1998, in final form 27 July 1998



SRµCT in tissue engineering

Microsc. Microanal. 12, 97–105, 2006
DOI: 10.1017/S1431927606060168

Microscopy AND Microanalysis

Three-Dimensional Characterization of Cell Clusters Using Synchrotron-Radiation-Based Micro-Computed Tomography

Bert Müller,[1,*] Marco Riedel,[2] Philipp J. Thurner[1,3]

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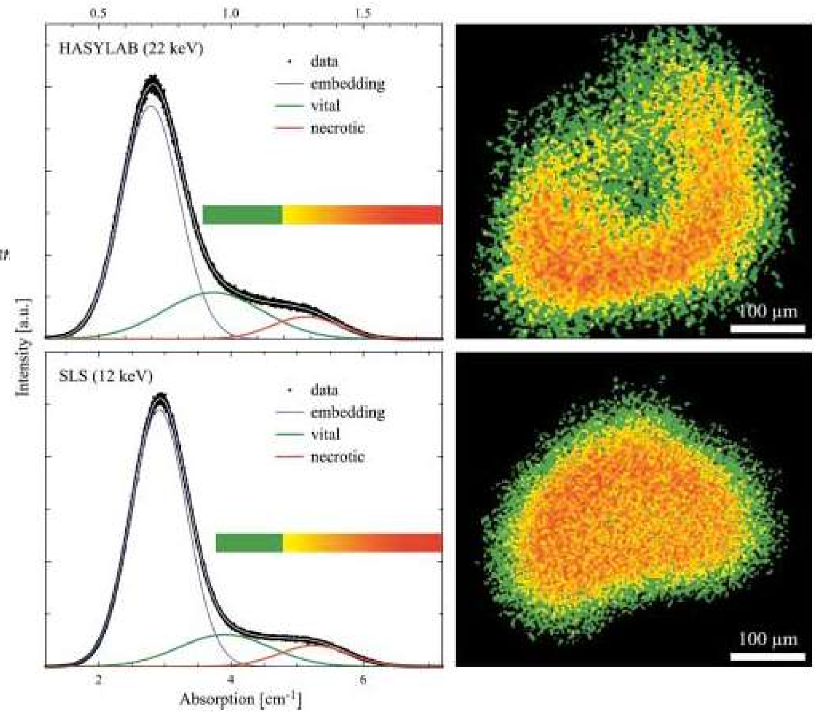

Biomaterial research using SRµCT

- Field of application
  - Structural bone analysis
  - Bone-Implant-Interface
  - Determination of degradation rates
- Mainly used modes
  - SRµCT: attenuation mode
  - SRµCT: element-specific mode

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Department of Orthopaedic Surgery, Hannover Medical School

Limitation of hard-tissue histology

1. <u>Limitation of ***biomaterial-tissue interface*** analysis</u>
   - „Wrong angle“ phenomena
   - limitation of cutting-grinding technique

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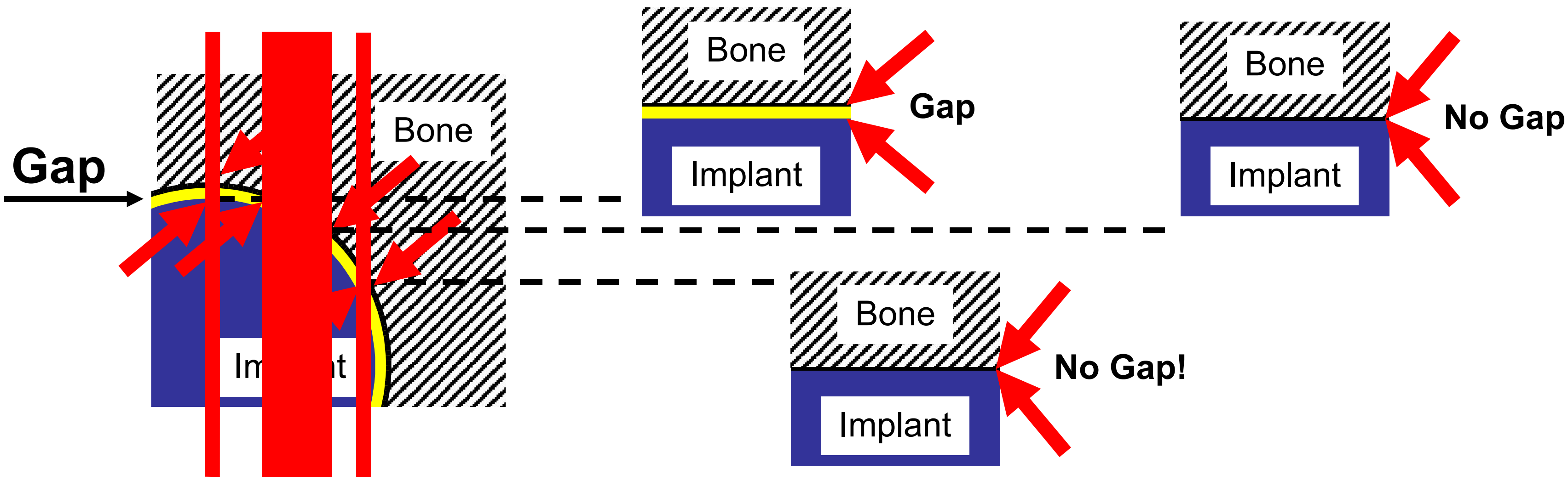
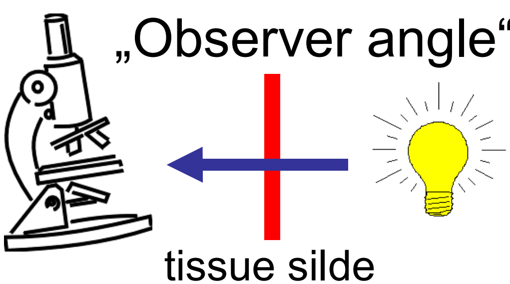
„Wrong angle“ – Phenomena

Plane of Histological sections

Appearence of Bone-Implant-Interphase





„wrong-angle“-phenomena is dependent on:

1. thickness of the histological section
2. the plane of the section (An and Friedman, 1999)

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Department of Orthopaedic Surgery, Hannover Medical School

Advantage of SRµCT

European Cells and Materials Vol. 7. 2004 (pages 42-51) ISSN 1473-2262

COMPARISON OF MICROFOCUS- AND SYNCHROTRON X-RAY TOMOGRAPHY FOR THE ANALYSIS OF OSTEOINTEGRATION AROUND TI6AL4V-IMPLANTS

R. Bernhardt[1], D. Scharnweber[1], B. Müller[2*], P. Thurner[3], H. Schliephake[4], P. Wyss[3], F. Beckmann[5], J. Goebbels[6], and H. Worch[1]

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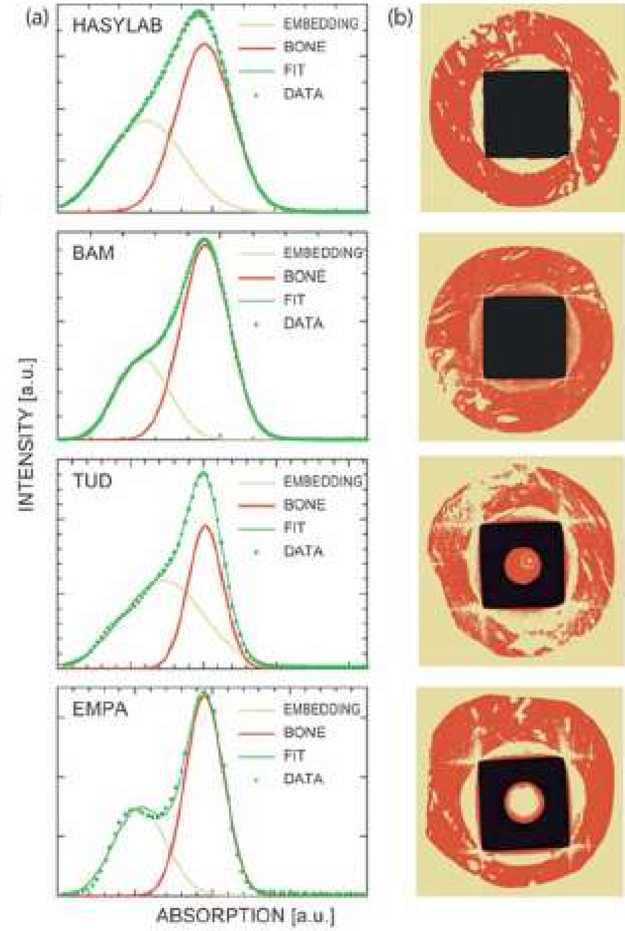

SRµCT Interface Analysis

Influence of extracellular matrix coatings on implant stability and osseointegration: An animal study

Bernd Stadlinger 1 *, Eckart Pilling 1, Matthias Huhle 1, Ronald Mai 1, Susanne Bierbaum 2, Ricardo Bernhardt 2, Dieter Scharnweber 2, Eberhard Kuhlisch 3, Ute Hempel 4, Uwe Eckelt 1

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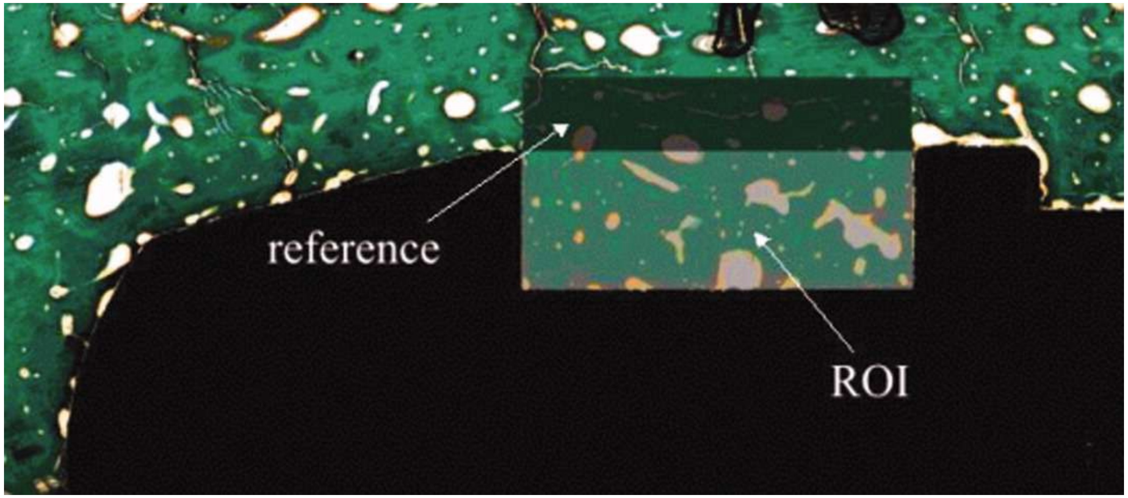
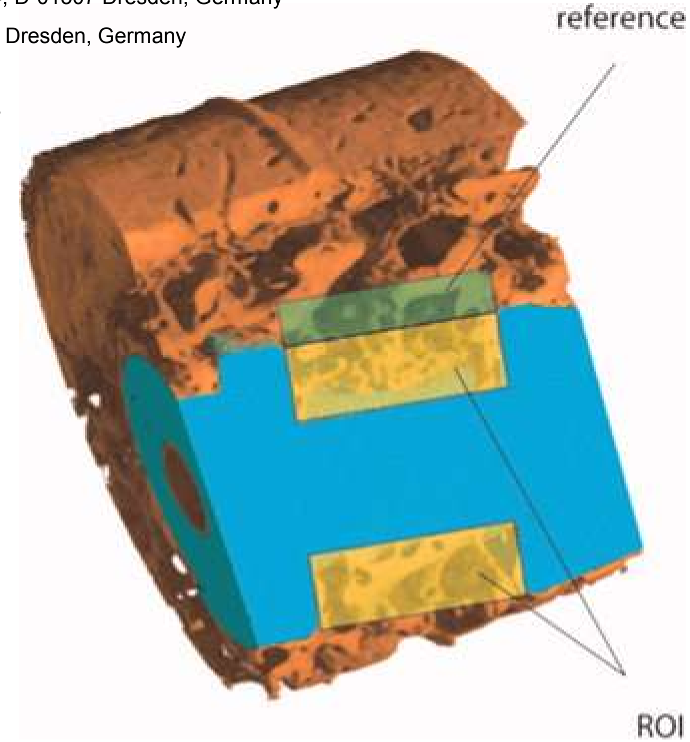
email: Bernd Stadlinger (stadlinger@gmx.de)

Journal of Biomedical Materials Research Part B: Applied Biomaterials; Epub 22.Feb.2007





SRµCT Interface Analysis

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Biomaterials
Biomaterials 26 (2005) 3009–3019
www.elsevier.com/locate/biomaterials

Osteoconductive modifications of Ti-implants in a goat defect model: characterization of bone growth with SR µCT and histology

Ricardo Bernhardt[a,*], Juliette van den Dolder[b], Sussane Bierbaum[a], Rene Beutner[a], Dieter Scharnweber[a], John Jansen[b], Felix Beckmann[c], Hartmut Worch[a]

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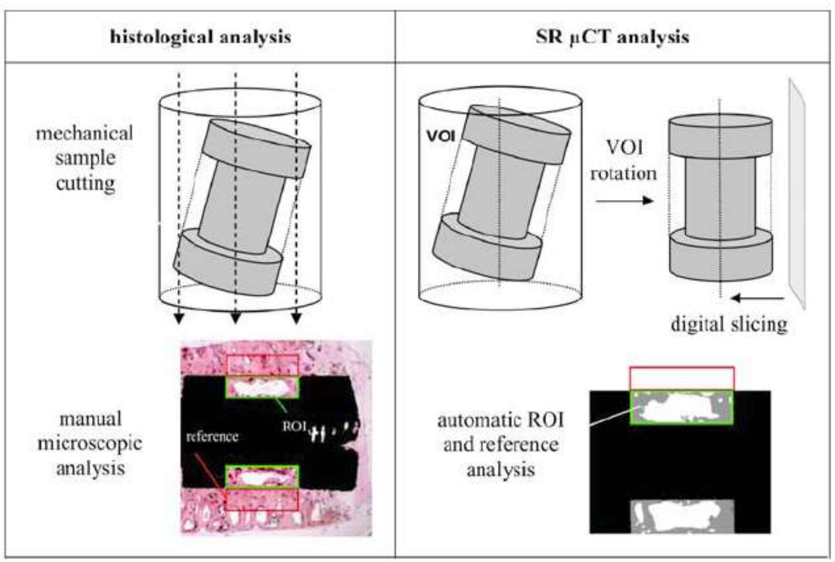
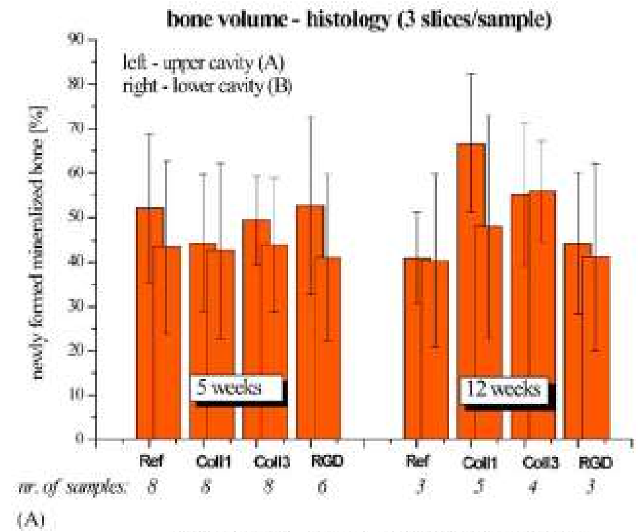
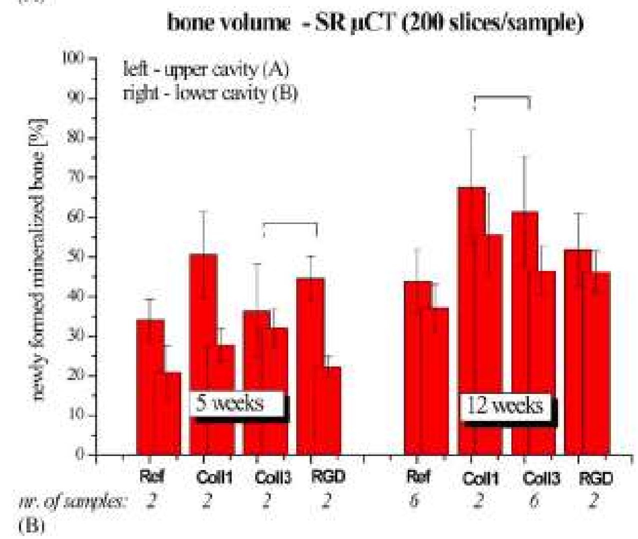
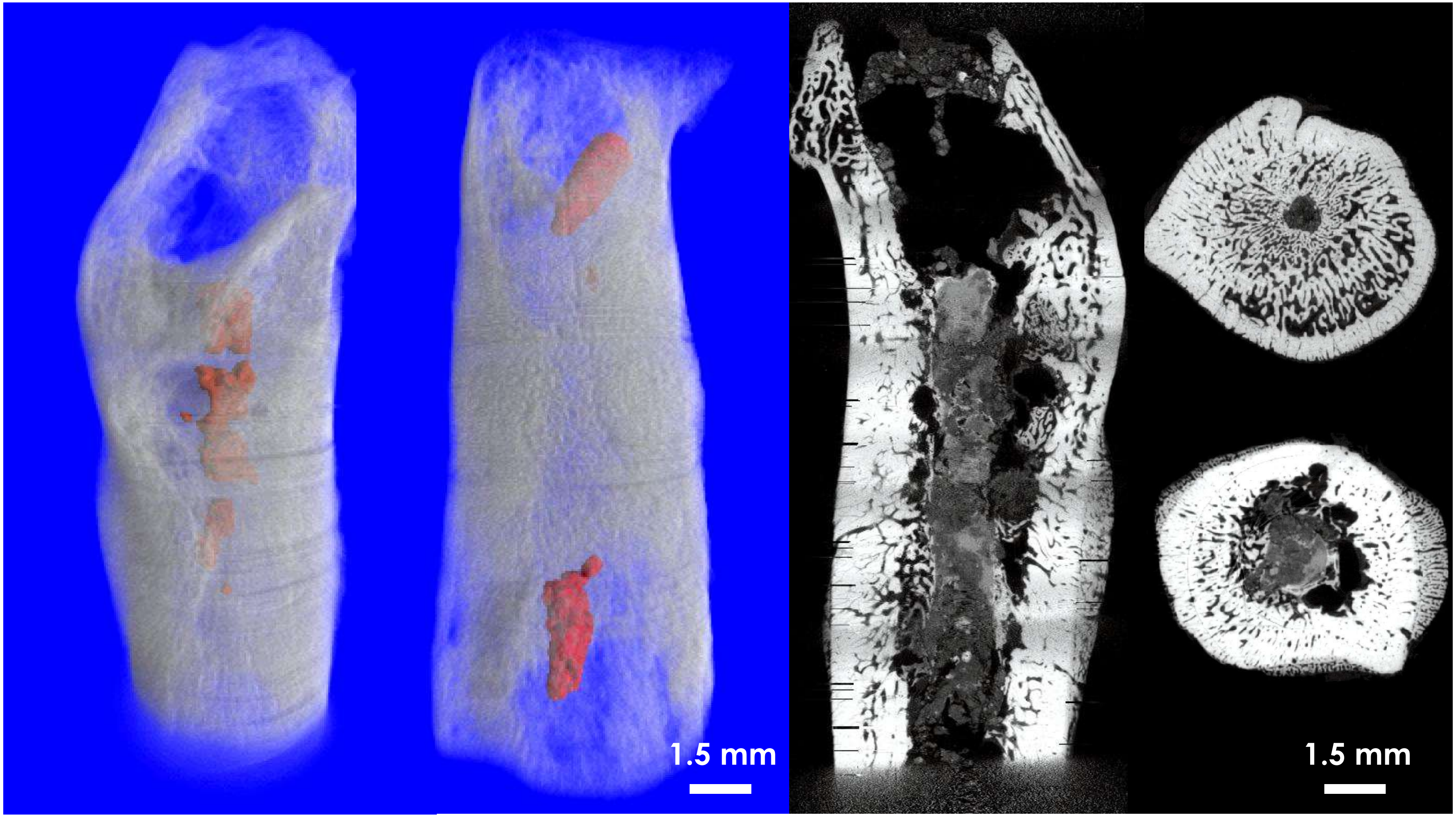
Received 12 May 2004; accepted 26 August 2004
Available online 5 October 2004







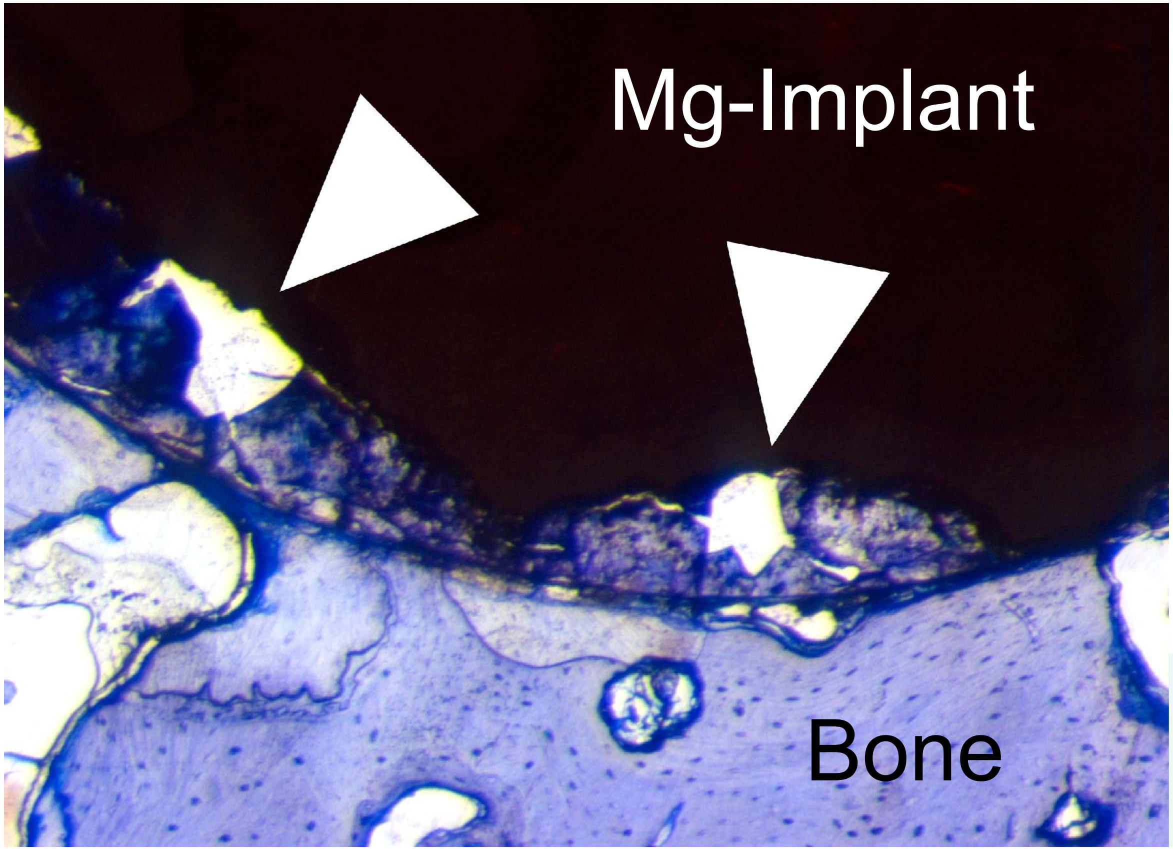
Biodegradable magnesium alloys



Witte et al.,HASYLAB Ann. Reports, 2004

Laboratory for Biomechanic and Biomaterials,
Department of Orthopaedic Surgery, Hannover Medical School

Limitation of cutting-grinding technique



"Drop-outs" from cutting-grinding technique

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

$$Mg(OH)_2 + 2Cl^- \rightarrow MgCl_2 + 2OH^-$$

For analysis of in-vivo corrosion of magnesium, microtomography is mandatory.

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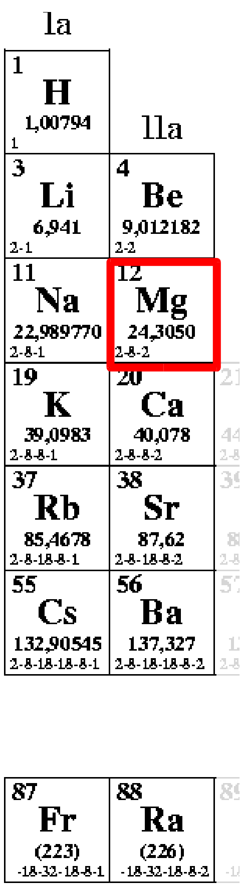
Current biomaterials

material	density [g/cm^3]	Young's modulus [GPa]	tensile strength [Mpa]	breaking elongation [%]
surgical steel (X2CrNiMo18164)	8,0	193	585	55
surgical titanium (TiAl6V4)	4,43	100 – 110	930 – 1140	8 – 15
cortical bone	1,7 – 2,0	3 – 30	80 – 150	3 – 4
DL-PLA (DL-polylactide)	1,24	1,9	29	5,0
magnesium AZ91	1,81	45	240	3
magnesium MgCa (0,8 wt% Ca)	1,75	n/a	290 – 300	2 – 6

Staiger et al., Biomaterials 27 2006

Pathophysiology



Body content of Mg = 21-35 g

Bone	⬄	Serum	⬄	Muscel
60%		const. 1%		39%

excess Mg

↓

Kidney/Intestine

Laboratory for Biomechanic and Biomaterials,
Department of Orthopaedic Surgery, Hannover Medical School

Implantation of Magnesium-Rods

In vivo corrosion of four magnesium alloys and the associated bone response

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Biomaterials 26 (2005) 3557–3563

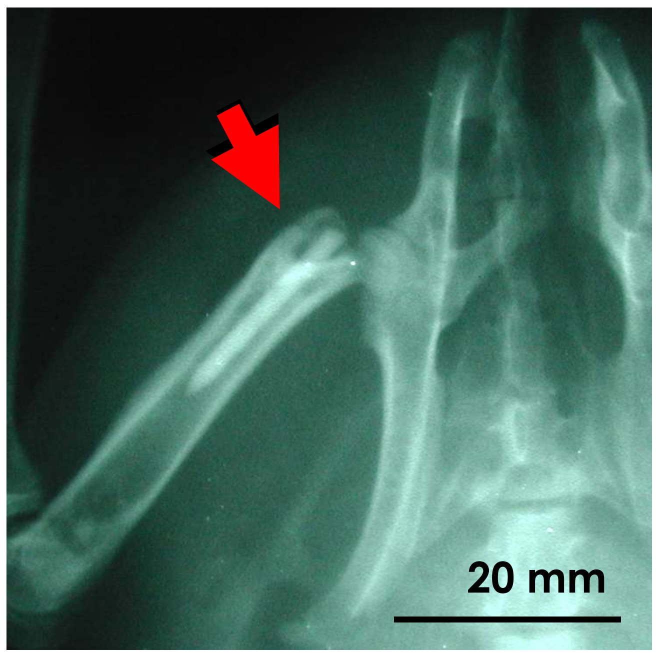
Received 13 June 2004; accepted 22 September 2004
Available online 2 November 2004

Magnesium alloy:

AZ31
AZ91D

WE43
LAE442

Control:
SR-PLA

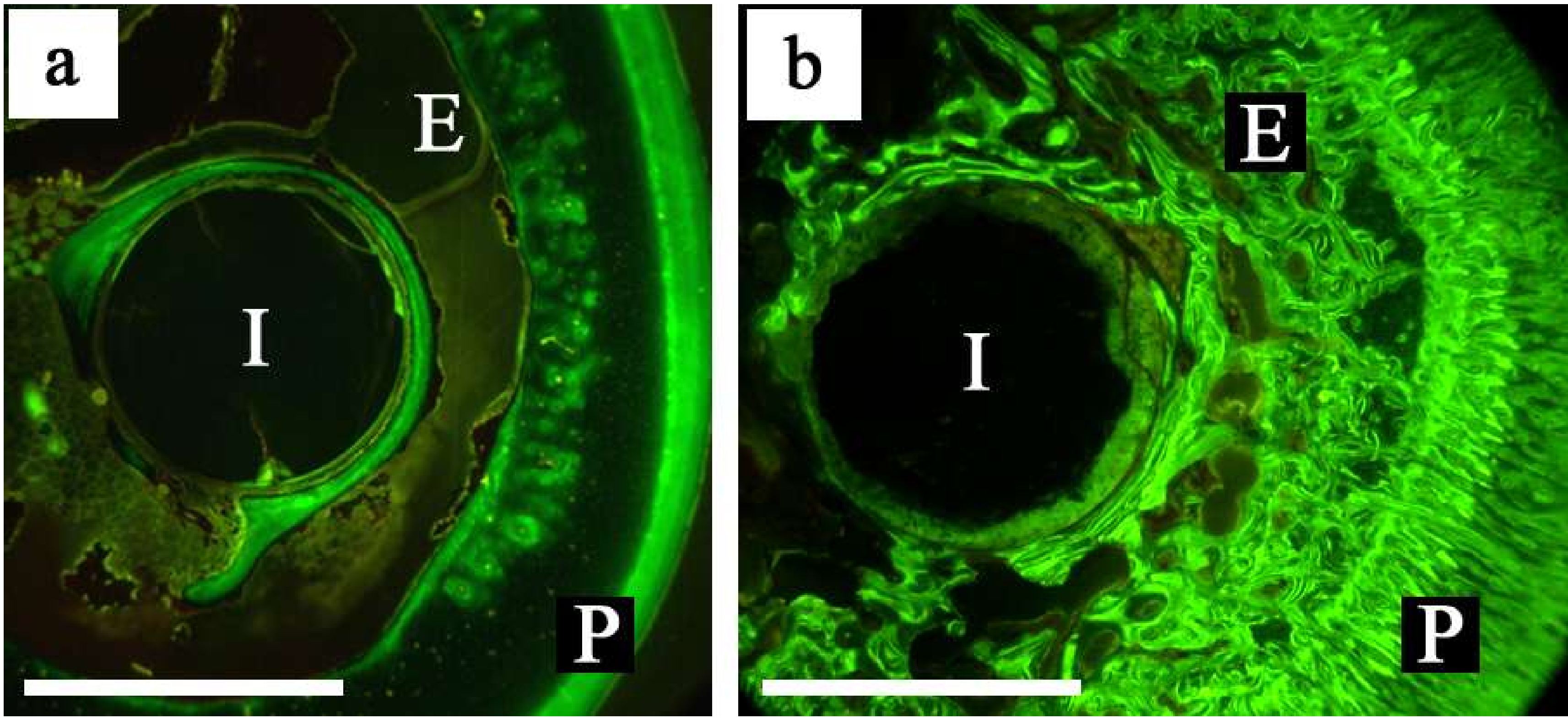


Follow-up post-OP:

6 weeks

18 weeks

New Bone Formation



SR-PLA96 Magnesium

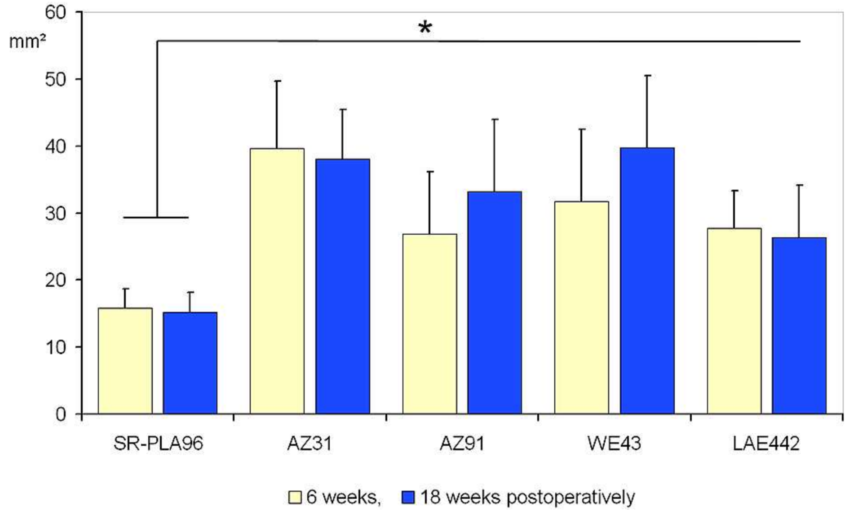
I = Implantat residual; E = endostal new bone formation;
P = periostal new bone formation; Bar = 1.5 mm

Witte et al., Biomaterials 26, 2005

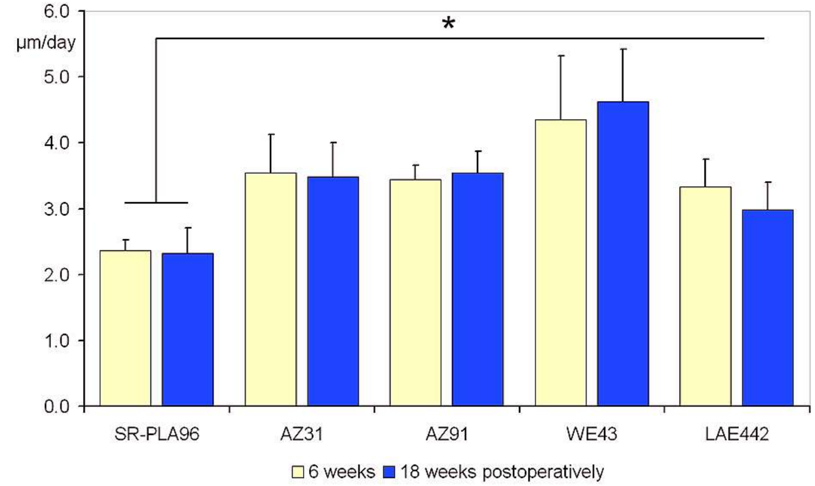
Laboratory for Biomechanic and Biomaterials,
Department of Orthopaedic Surgery, Hannover Medical School

Histomorphometry of Mg-implants

Md.Ar.



MAR



B.Ar./T.Ar

Table 1
Bone area per total area (B.Ar/T.Ar) of implanted magnesium alloys and degradable polymer (SR-PLA96) in guinea pig femura at 6 and 18 weeks postoperatively

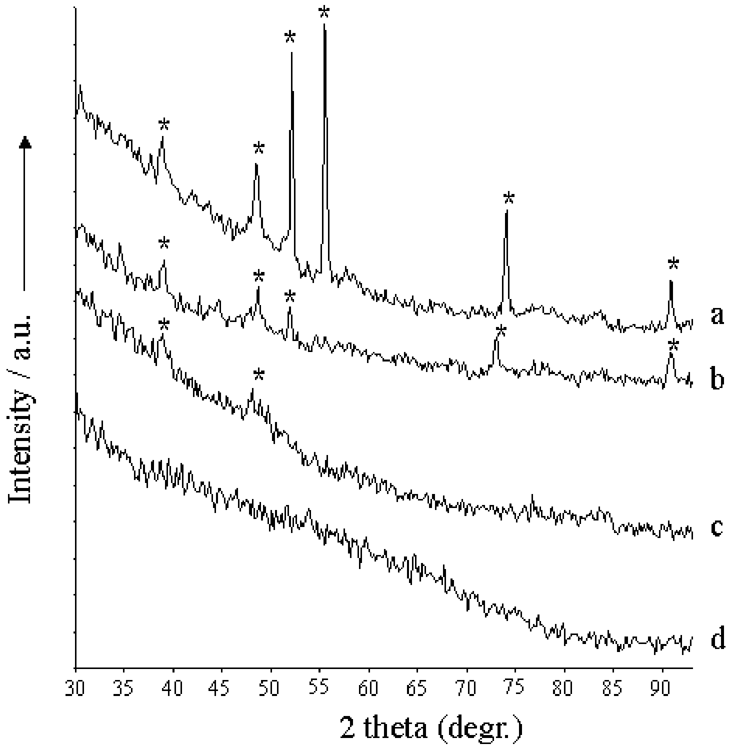
	6 weeks *p*-value	18 weeks *p*-value
AZ31/91	1.000	0.578
WE43/AZ31	0.847	0.806
WE43/AZ91	0.924	0.995
WE43/LAE442	0.646	1.000
LAE442/AZ31	0.996	0.730
LAE442/AZ91	0.980	0.999
SR-PLA96/AZ31	0.909	0.104
SR-PLA96/AZ91	0.963	0.828
SR-PLA96/WE43	1.000	0.605
SR-PLA96/LAE442	0.738	0.690

No siginificant differences were found between groups.

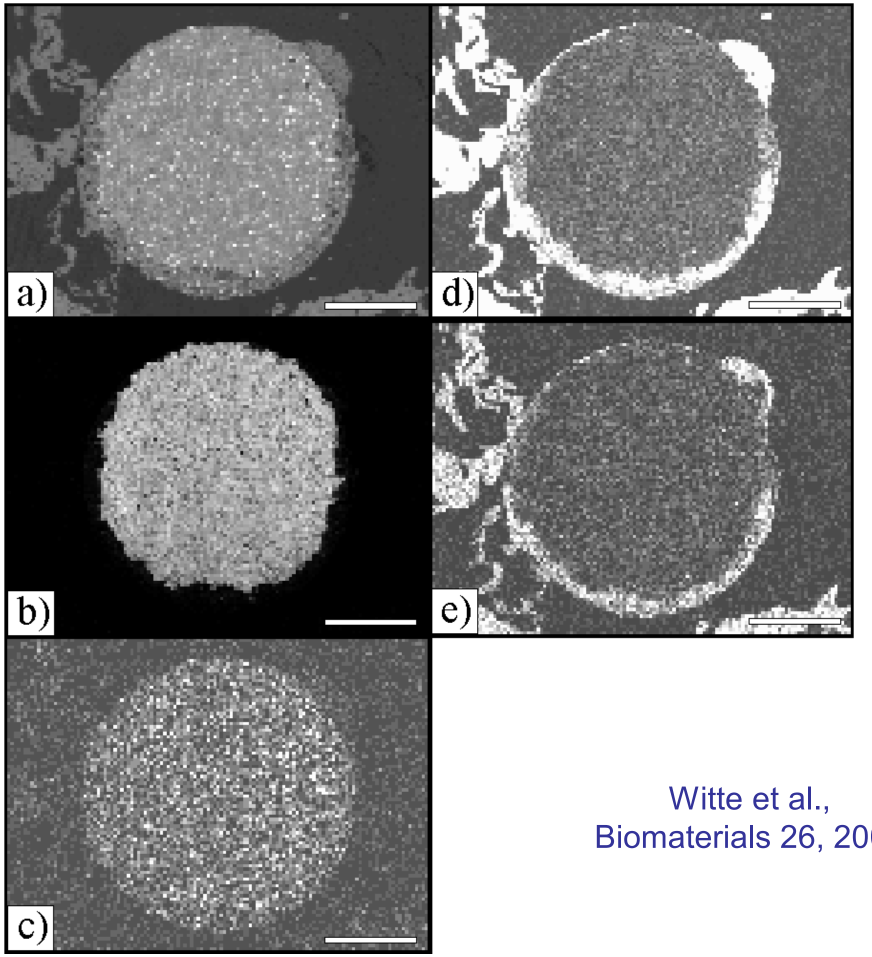
Physiological bone formation is enhanced by magnesium implants.

Witte et al., Biomaterials 26, 2005

Corrosion layer in-vivo



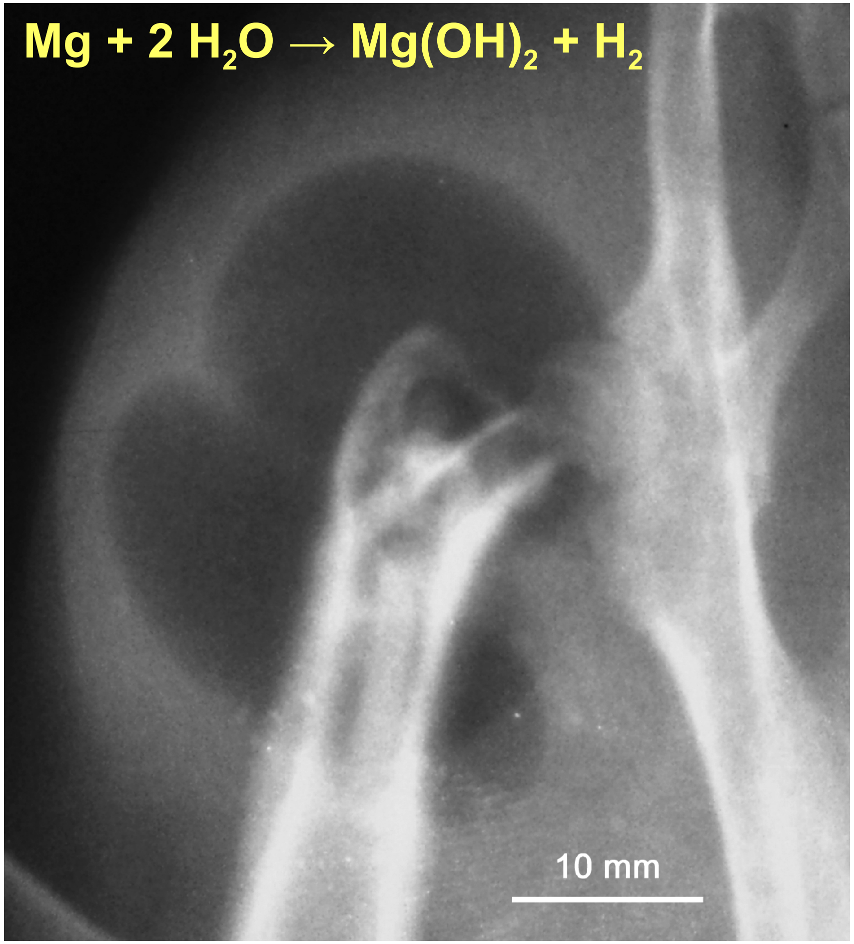
a) magnesium residual
b) corrosion layer
c) bone
d) embedding media



a) BSC; b) magnesium; c) neodymium;
d) calcium; e) phosphorus

Witte et al.,
Biomaterials 26, 2005

Subcutaneous gas cavities



1 g magnesium >> 1.08 l hydrogen gas

Witte et al., Biomaterials 26, 2005

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MMC - Novel biodegradable metals

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Biomaterials 28 (2007) 2163–2174

www.elsevier.com/locate/biomaterials

Biodegradable magnesium–hydroxyapatite metal matrix composites

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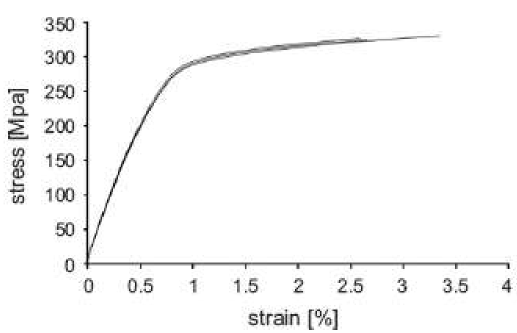
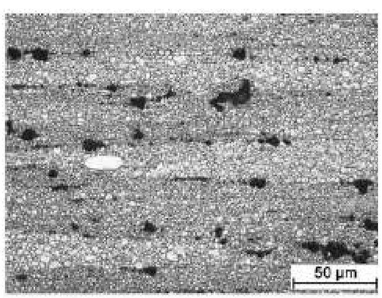
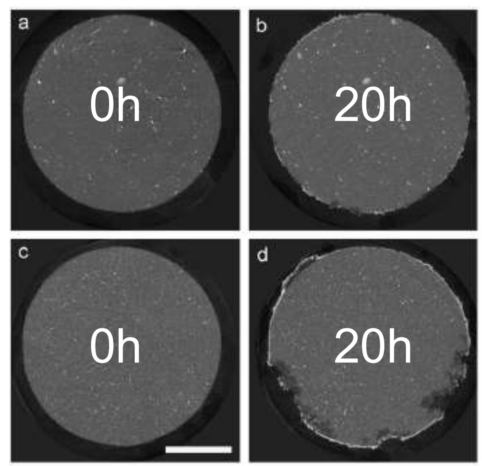
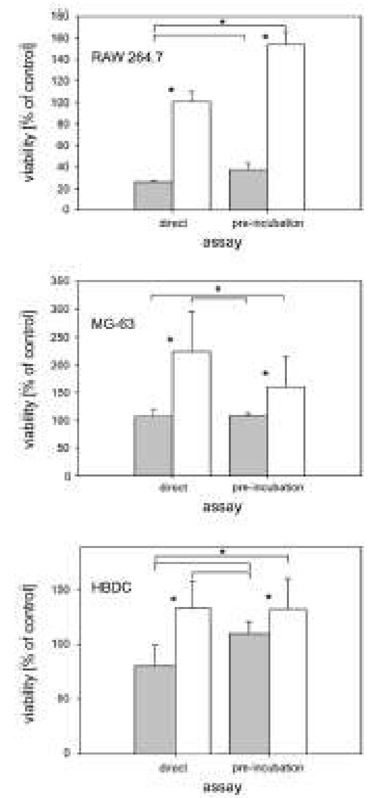
Received 7 August 2006; accepted 31 December 2006
Available online 5 January 2007

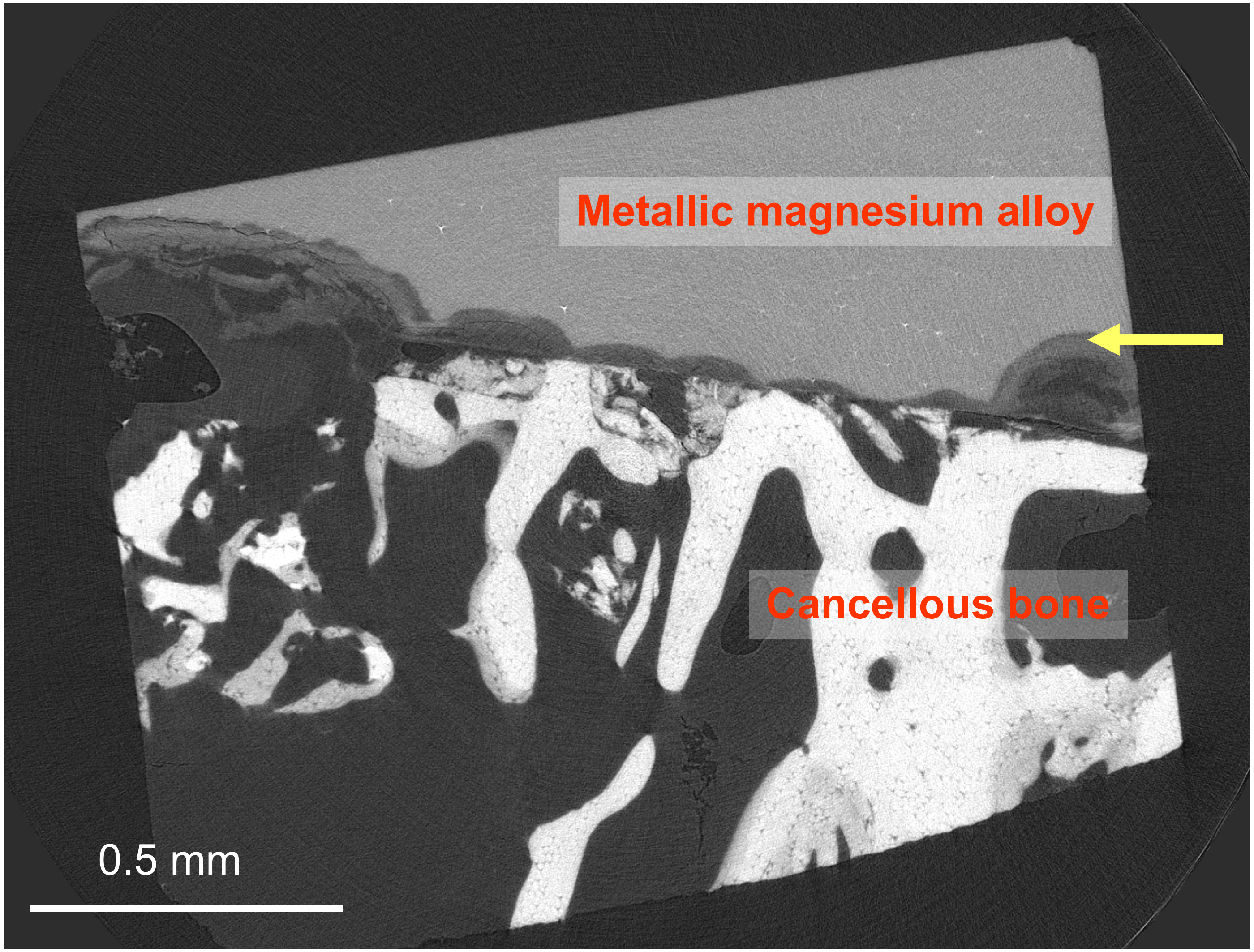








SRµCT in attenuation mode



Corrosion layer

HASYLAB at DESY

beamline HARWI (W2)

photon energy: 31 keV

angular range 0-180°

stepwise 0.25°

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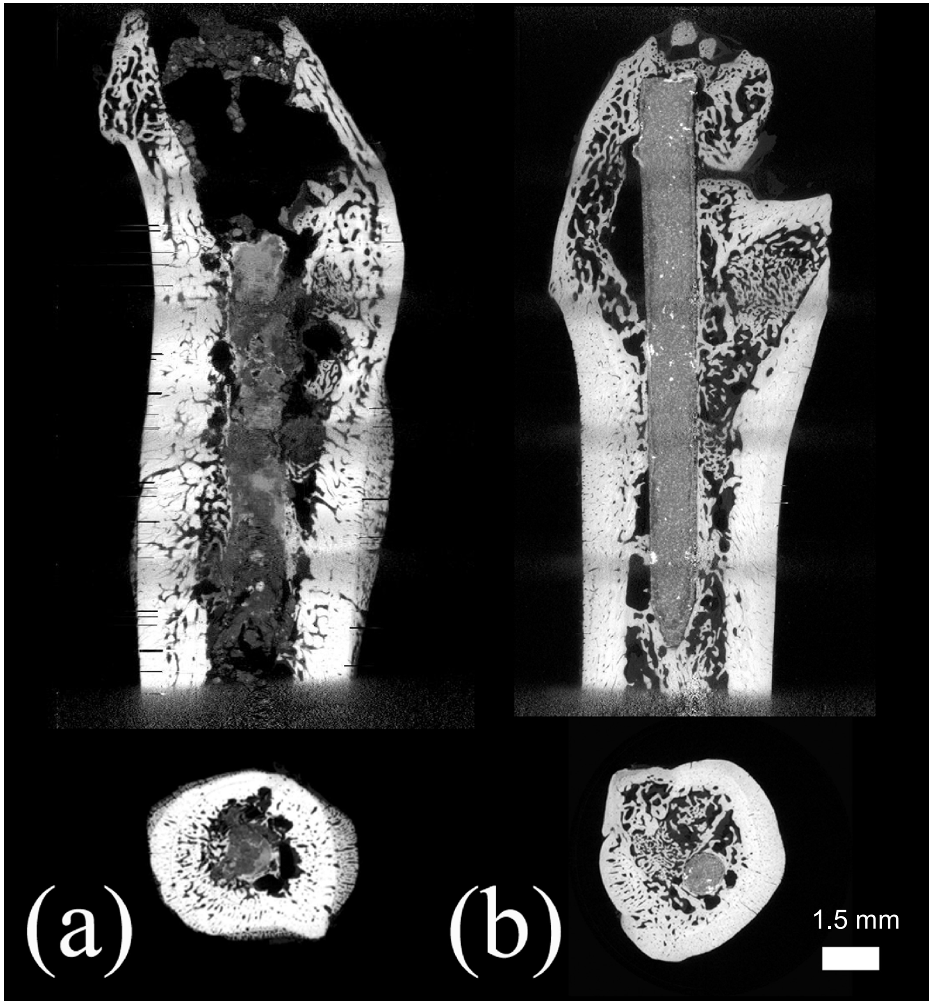
Department of Orthopaedic Surgery, Hannover Medical School

Analysis of the total specimens



AZ91D LAE442

HASYLAB at DESY

beamline HARWI (W2)

photon energy: 31 keV

angular range 0-180°

stepwise 0.25°

voxel edge length: 10 µm

stack of 5 datasets

Witte et al,
Biomaterials 27, 2006

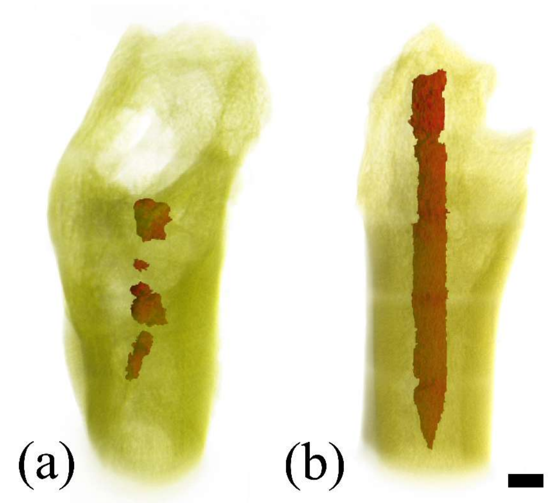
Laboratory for Biomechanic and Biomaterials,
Department of Orthopaedic Surgery, Hannover Medical School

In vivo corrosion rate by SRµCT

$$CR = \frac{W}{A \cdot t \cdot \rho}$$ (Eq. 1)

Reference: ASTM G31-72, 2004

$$CR = \frac{\Delta V}{A \cdot t}$$ (Eq. 2)



CR is the corrosion rate

W is the weight loss

A is the original surface area exposed to the corrosive media

t is the time of immersion

ρ is the standard density

Witte et al., Biomaterials 27, 2006

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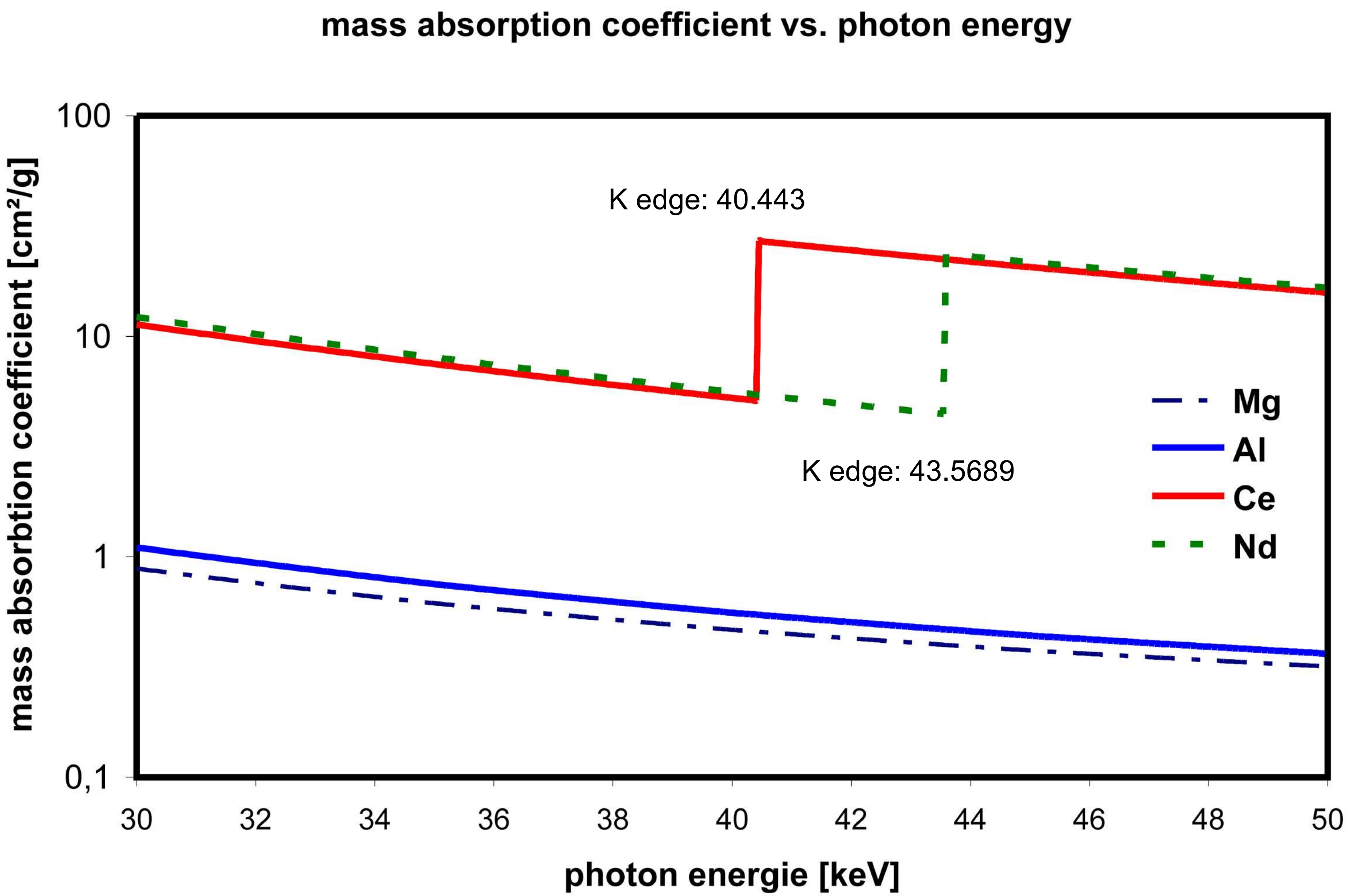
Department of Orthopaedic Surgery, Hannover Medical School

Element-specific SRµCT



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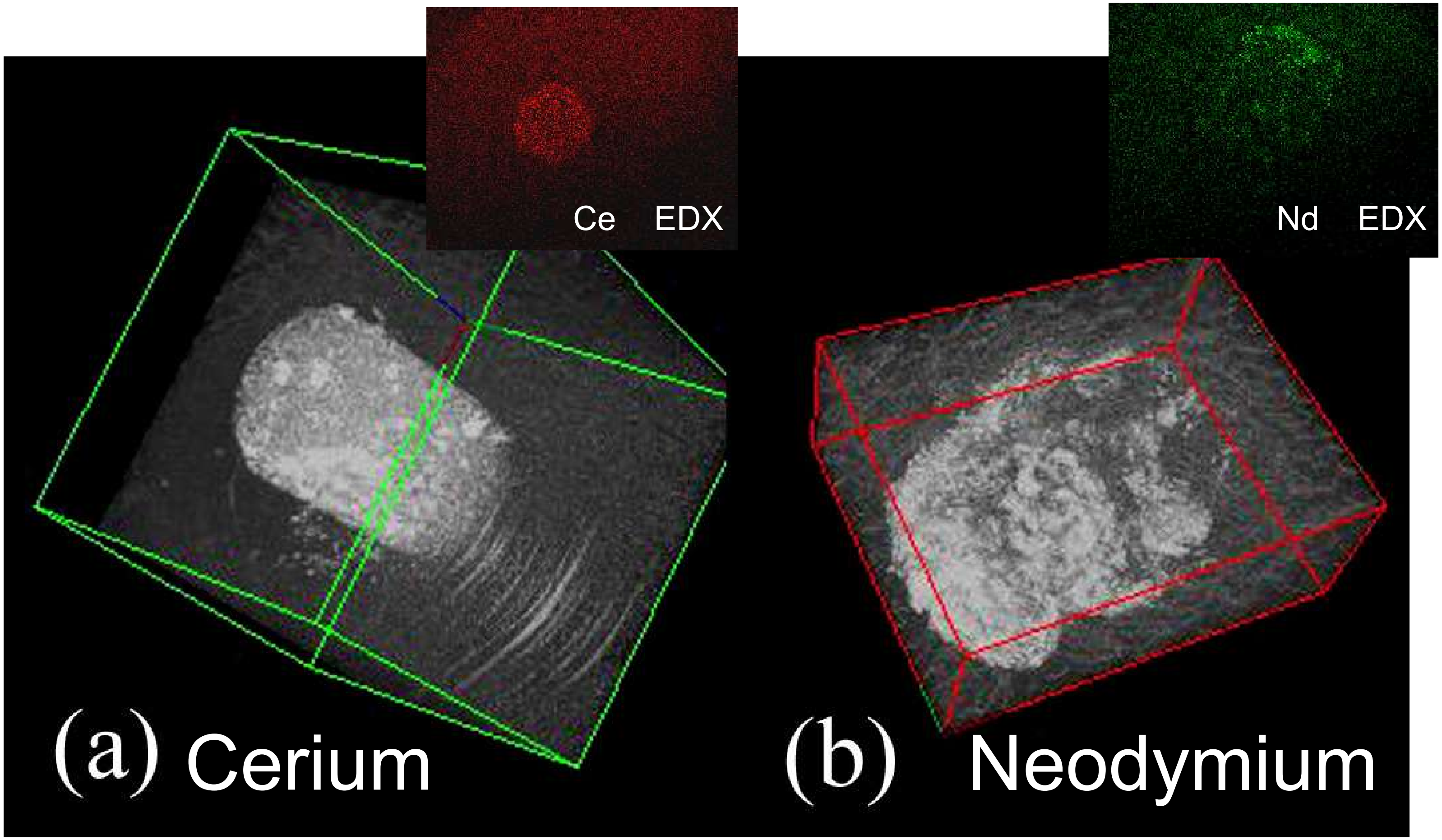

LAE442 WE43

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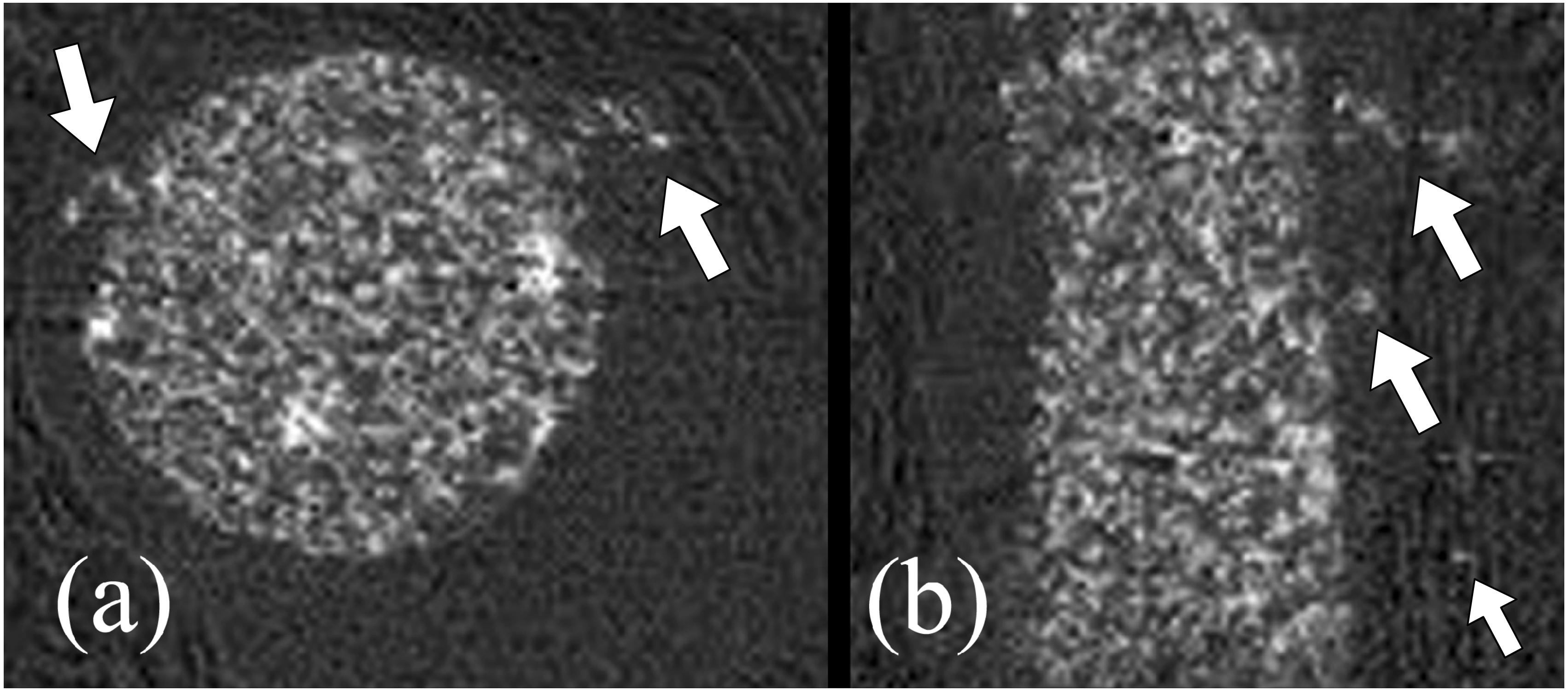
Spatial distribution of cerium (LAE442)



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Summary

SRµCT:

- became a great imaging tool
- has potential for quantitative analysis

- for structural biology and
- for interface analysis of biomaterials.

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Thank you very much !!!

Excellent laboratory staff

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Grants:

German Research Society, Colloabarative Research Project, SFB 599

Bundesministerium für Bildung und Forschung, BMBF

Hannover Medical School

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Laboratory for Biomechanics and Biomaterials

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