

Electro-Stimulating Implants for Bone Regeneration:

Parameter Analysis on Design and Implant Position

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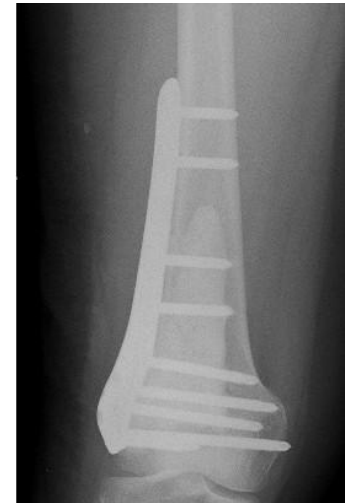


Outline

- Background
- Method and Materials
- Results of Numerical Simulation
- Discussion and Outlook

Bone defects

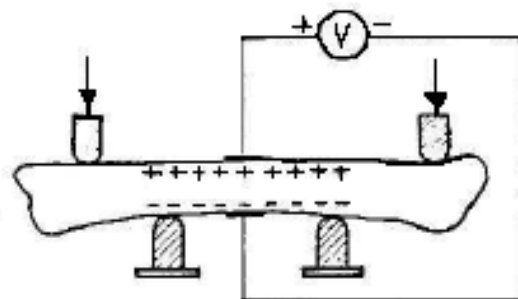
- Tumor
- Infection
- Fracture
- Implant loosening



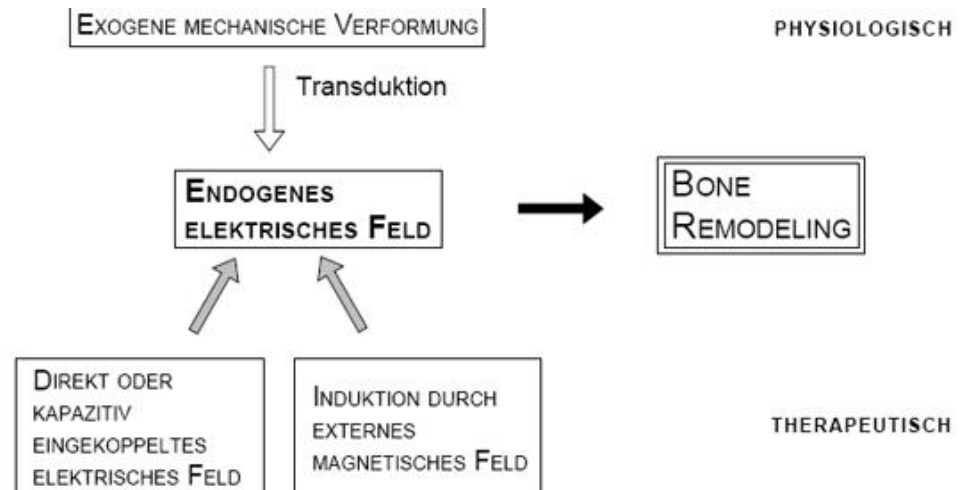
Why electro-stimulation of bone tissue?

- Bone growth
- Bone regeneration
- Fracture healing

Theory: Reciprocal piezoelectric effect



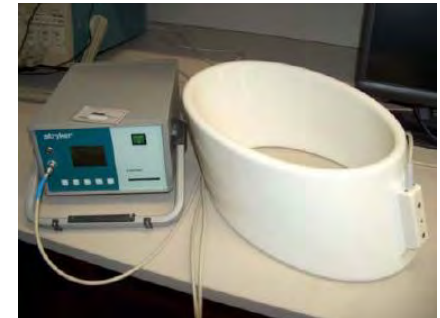
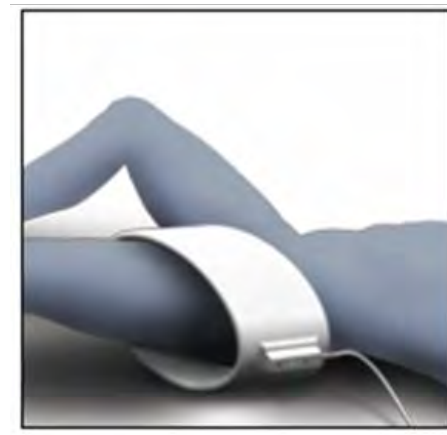
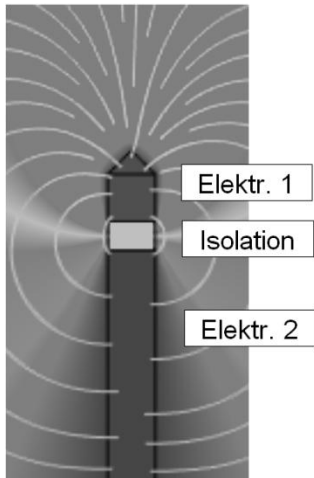
Piezoelectric effect
Yasuda et al. 1957



Habel 2004

Clinical Application of Electro-stimulation

Treatment of avascular femoral head necrosis by ASNIS-S screw



stimulation parameter:
sinusoidal, 20 Hz, 700mV

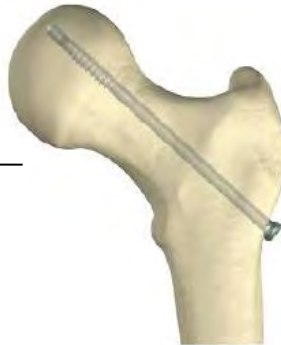
Stryker Trauma GmbH, ASNIS III S-Series operative technique manual

Methods

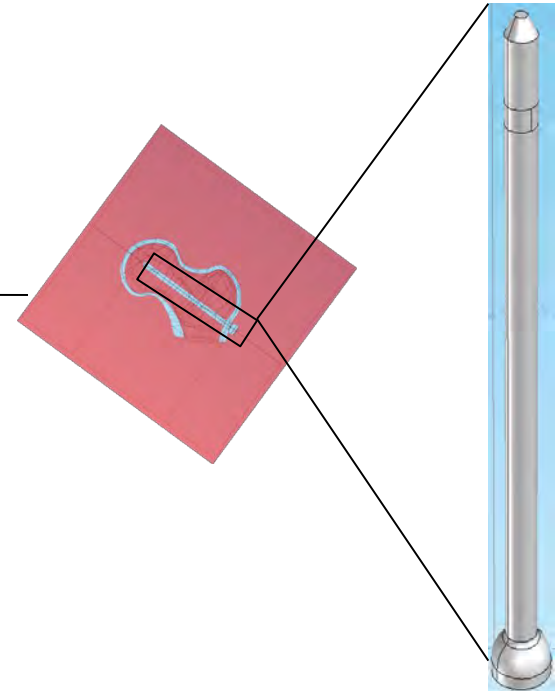
Real



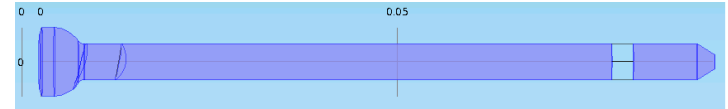
Artificial femur (Sawbone)



Comsol Multiphysics



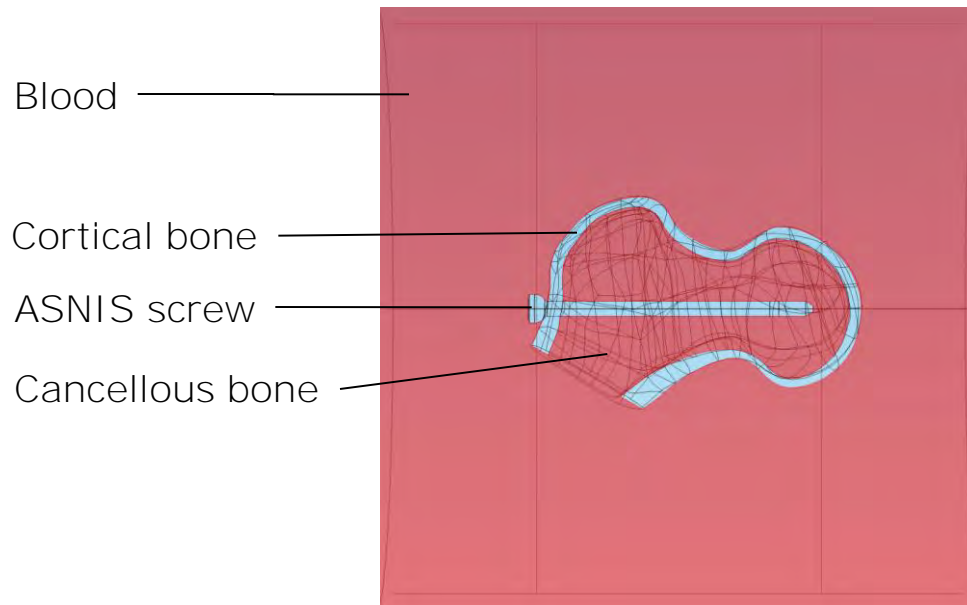
COMSOL Settings



- Geometry shape order: Linear
- Module: AC/DC module-Electric currents-Frequency domain
- Bondary conditions
ASNIS screw: Electric potential (700mV) and electric isolation
- Mesh
Screw boundary: free triangular, max element size: 35 μm
Bone: free tetrahedral, max element size: 1.5 mm
Surrounding material: free tetrahedral, max element size: 2 cm

Total approx. 1,28 million elements, approx. 1,7 million DOF
- Solver: Iterative solver- Conjugate gradients

Material Parameters



Material	Conductivity σ [S/m]	Relative Permittivity ϵ_r
Human Blood	0.7	5 260
Cortical bone	0.020045	25 119
Cancellous bone	0.078902	4 020 200

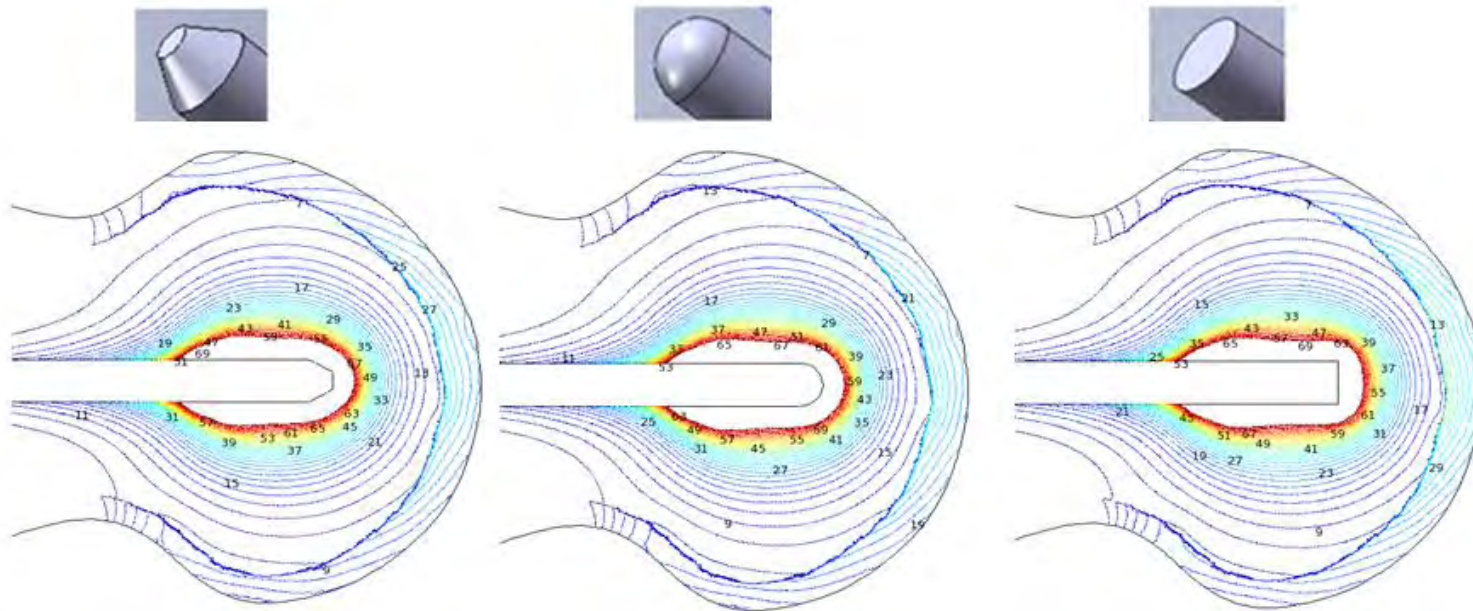
- Sinusoidal external magnetic field 20Hz
- Voltage in the implant 700mV

[1] Gabriel C, Gabriel S, Corthout E. The dielectric properties of biological tissues: I. Literature survey. Phys Med Biol 1996; 41: 2231-49.

[2] Gabriel S, Lau RW, Gabriel C. The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz. Phys Med Biol 1996; 41(11): 2251-69.

[3] Gabriel S, Lau RW, Gabriel C. The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues. Phys Med Biol 1996; 41: 2271-93

Parameter variation - Tip shape

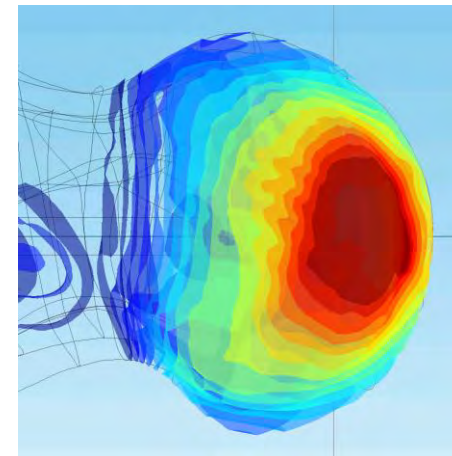
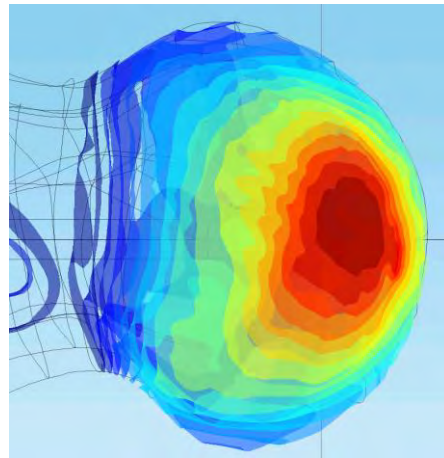
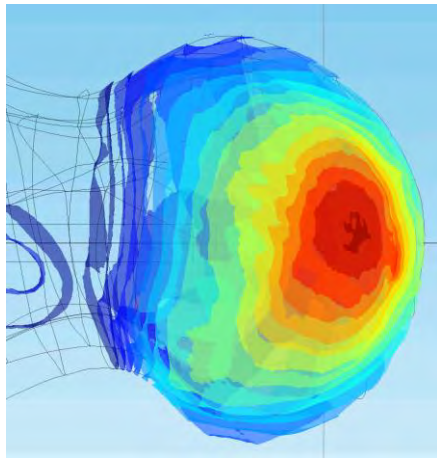
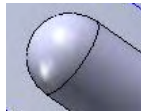


Contour: Electric field norm (V/m)

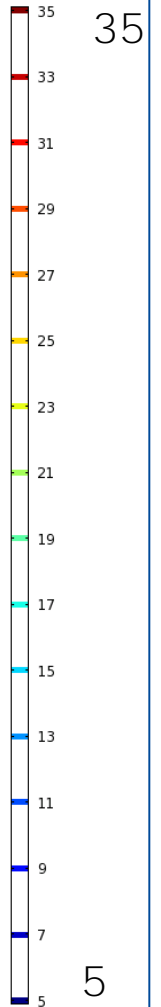
- Optimized electric field for avascular femoral head necrosis: 5-70V/m

W. Kraus Magnetfeldtherapie und magnetisch induzierte Elektrostimulation in der Orthopädie. Orthopäde, V 13, PP 78-92, 1984

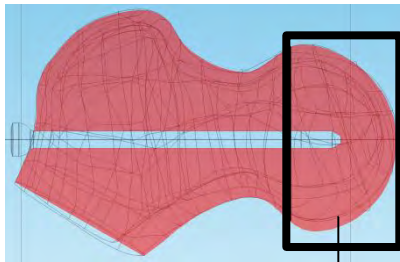
Parameter variation - Tip shape



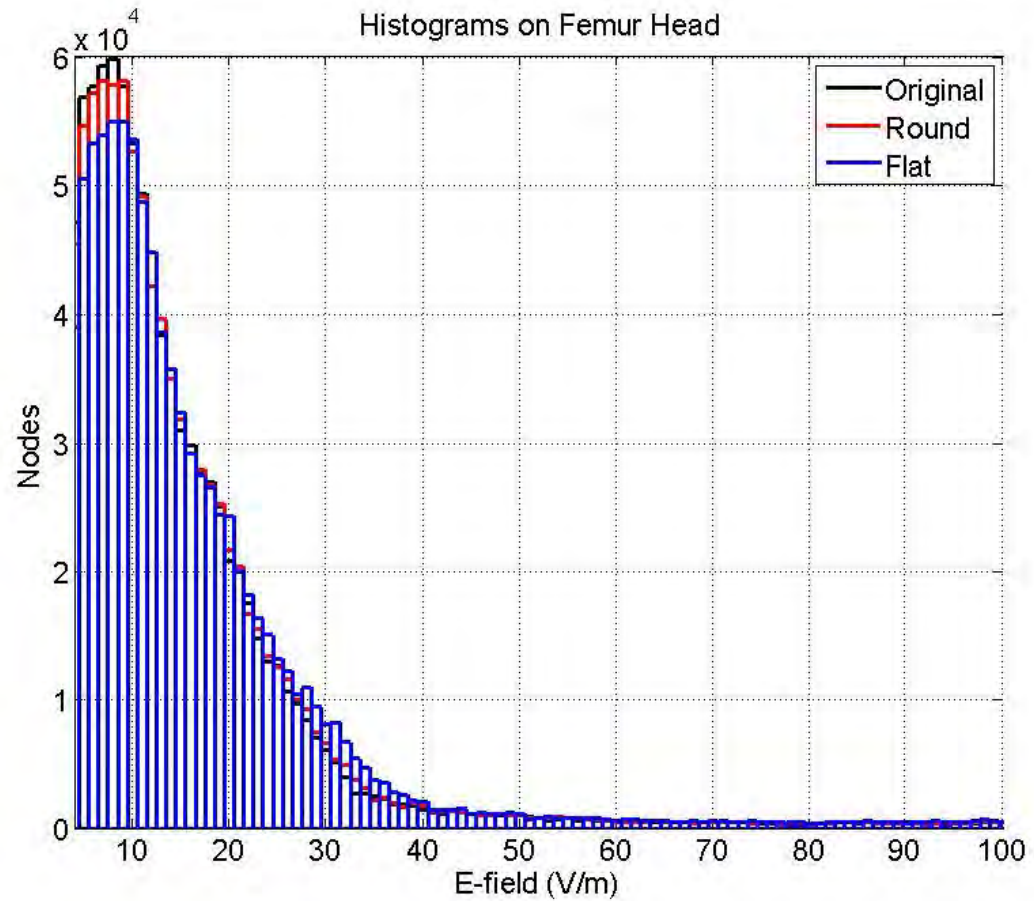
Isosurface: Electric field norm (V/m)



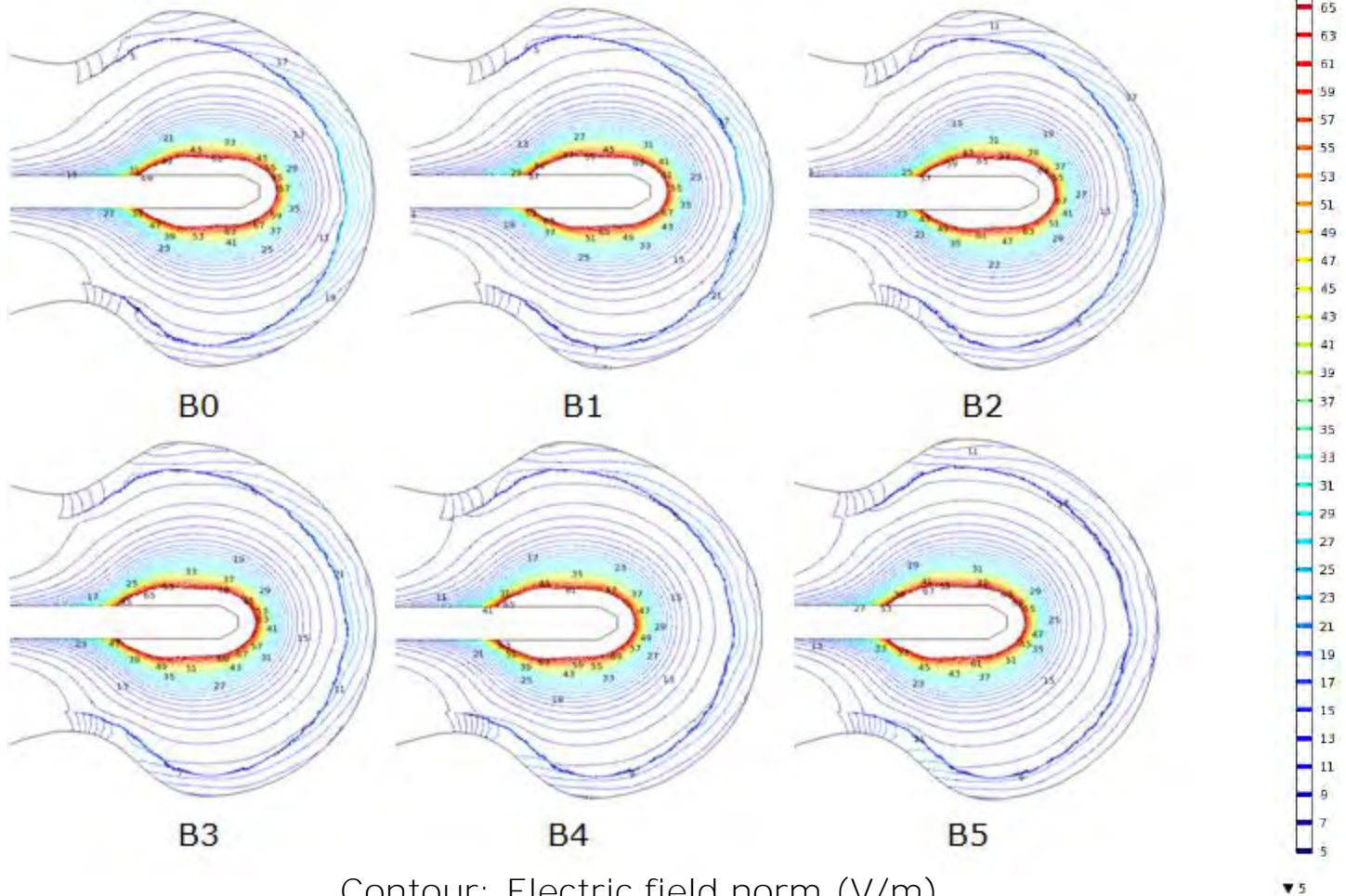
Parameter variation - Tip shape



Femoral head

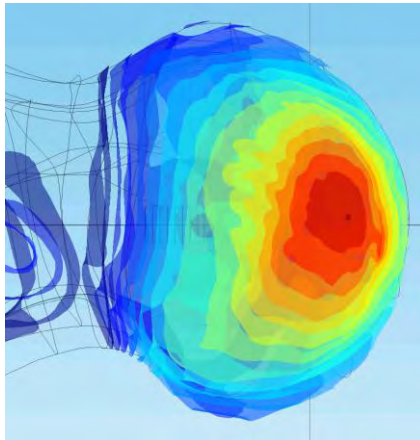


Parameter variation – Screw positioning backward

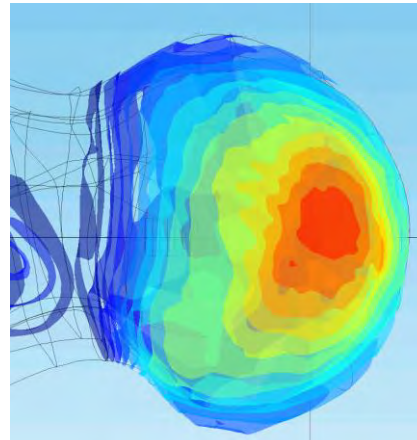


Contour: Electric field norm (V/m)

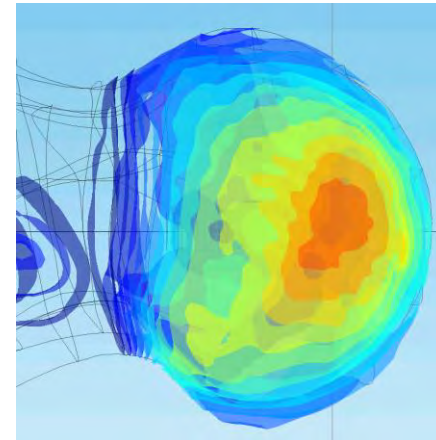
Parameter variation – Screw positioning backward



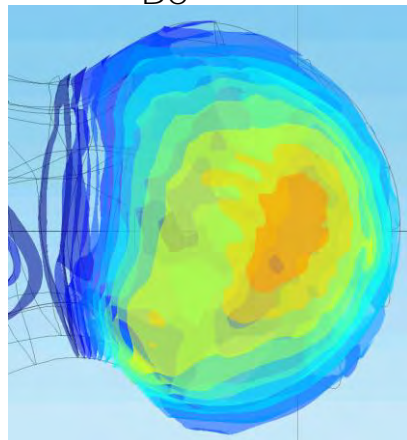
B0



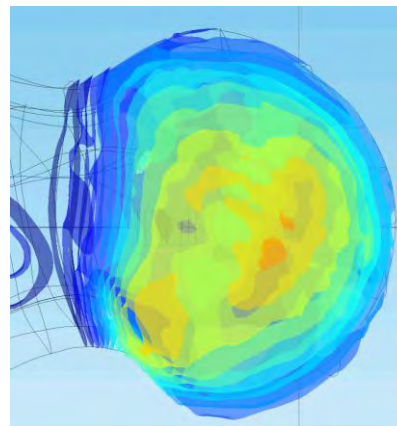
B1



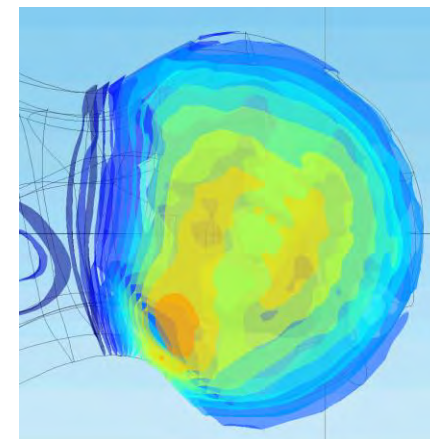
B2



B3

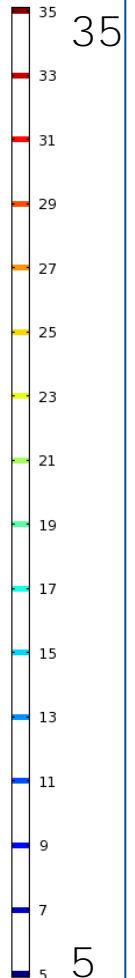


B4

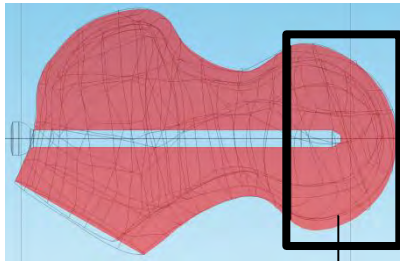


B5

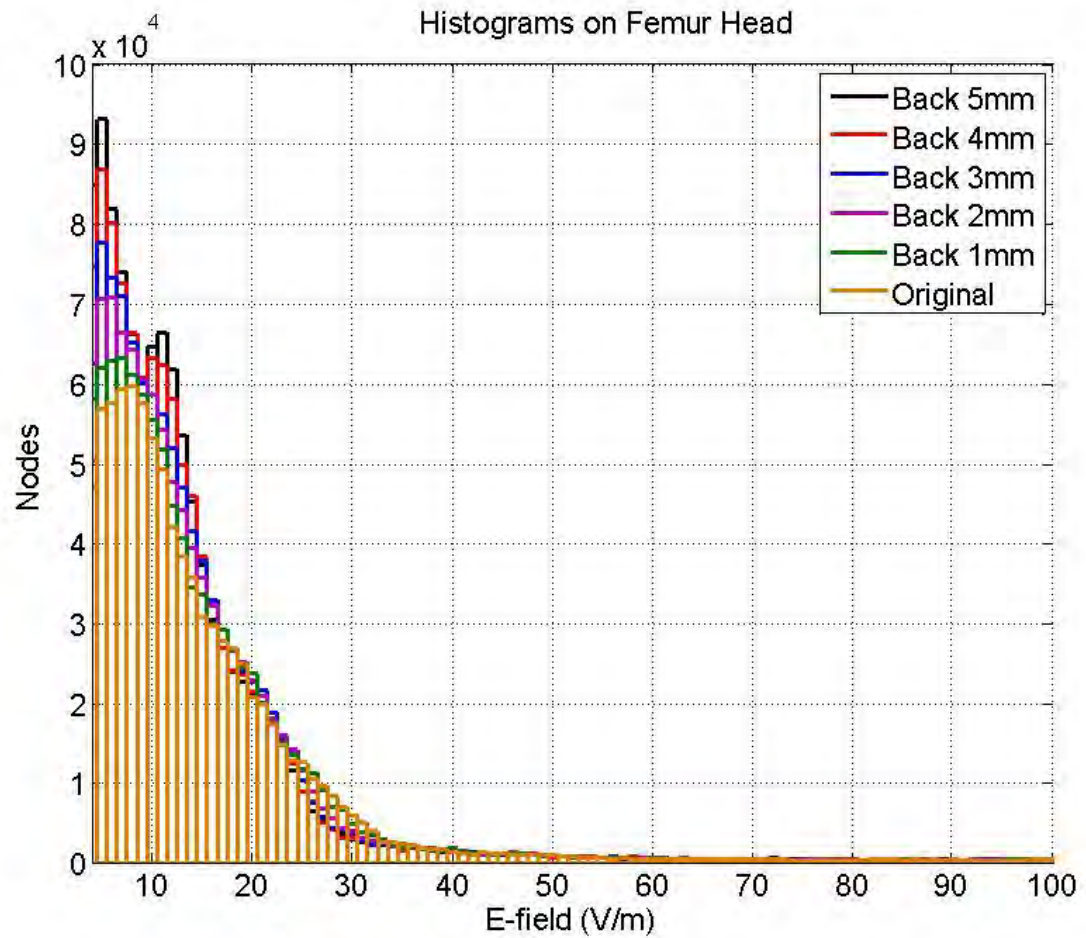
Isosurface: Electric field norm (V/m)



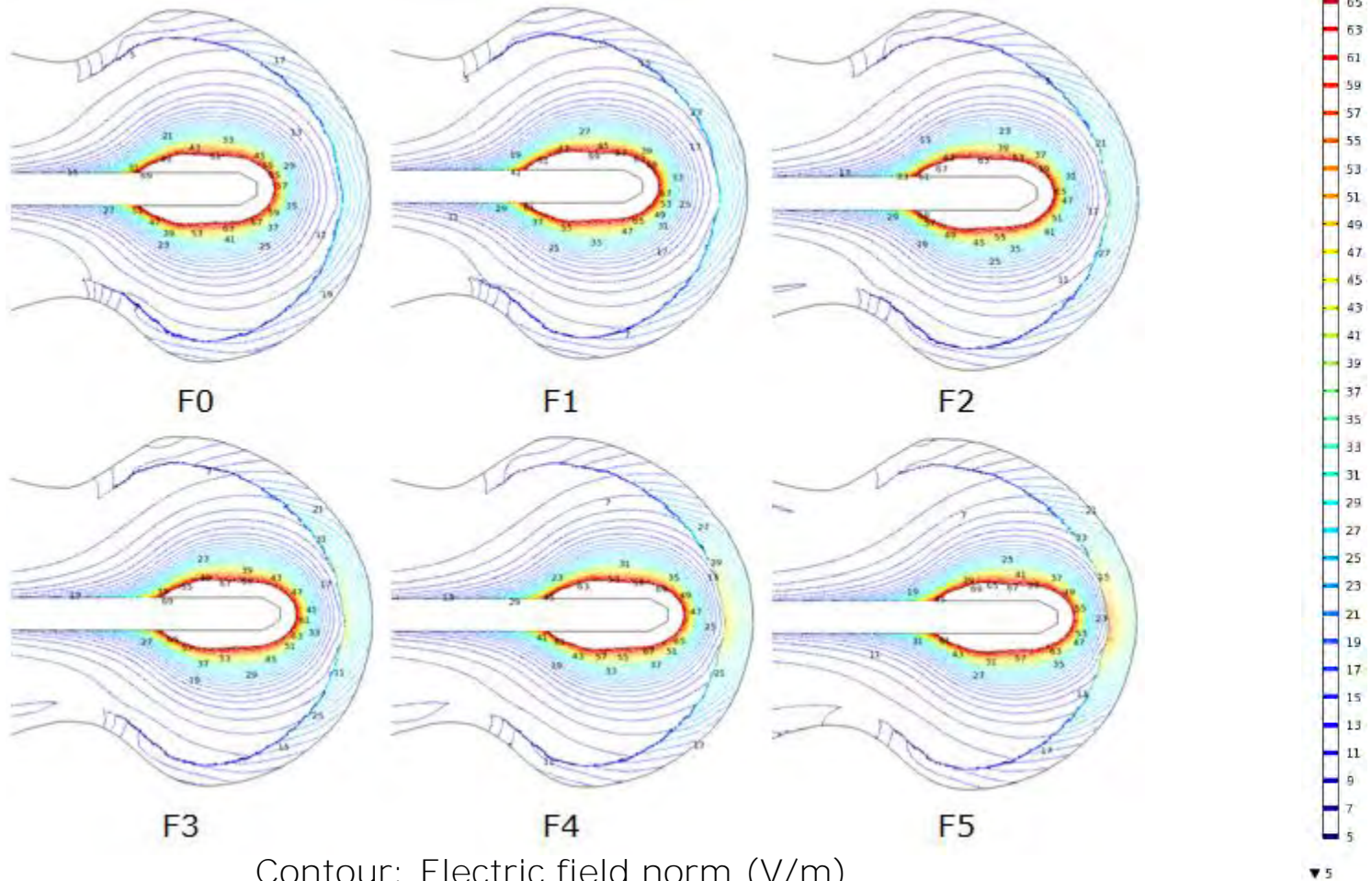
Parameter variation – Screw positioning backward



Femoral head

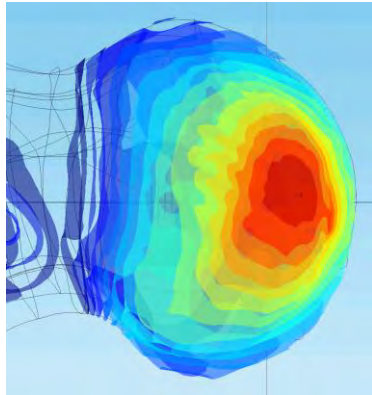


Parameter variation – Screw positioning forward

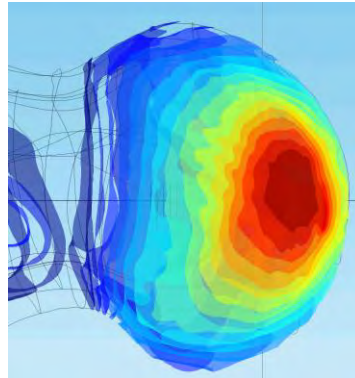


Contour: Electric field norm (V/m)

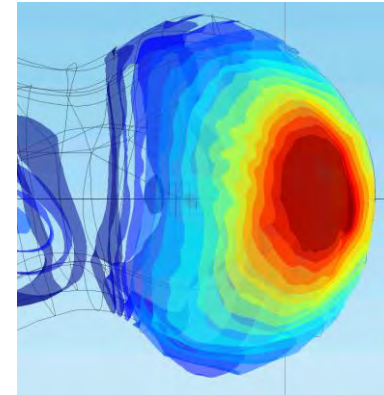
Parameter variation – Screw positioning forward



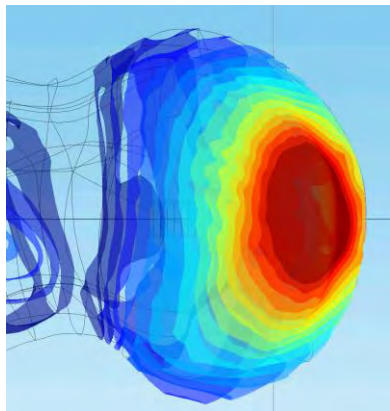
F0



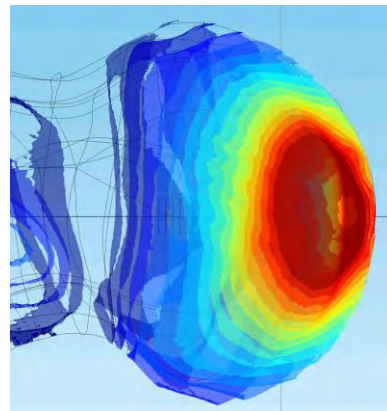
F1



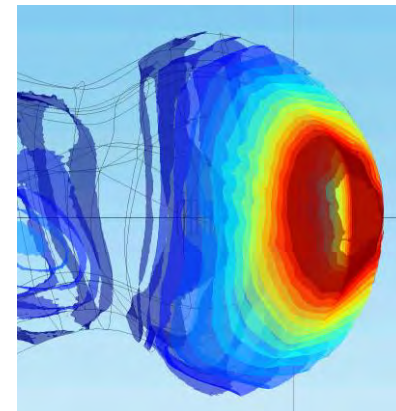
F2



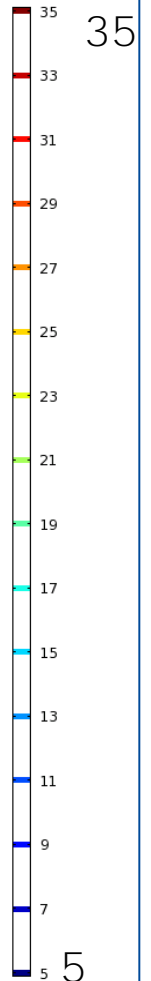
F3



F4

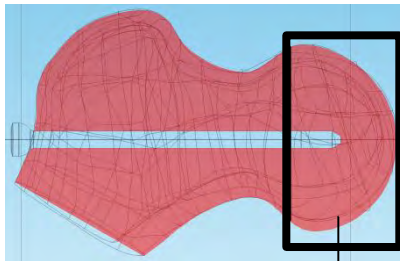


F5

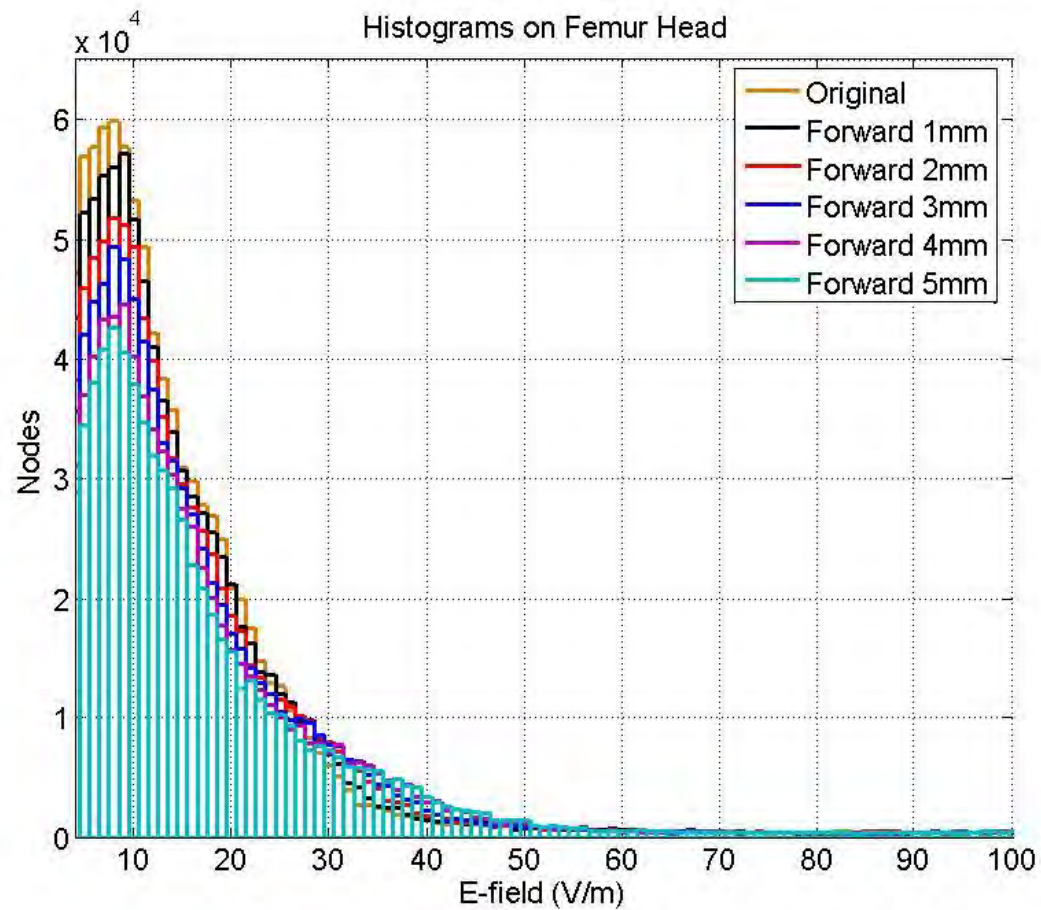


Isosurface: Electric field norm (V/m)

Parameter variation – Screw positioning forward



Femoral head



Discussion

- Numerical simulation is not yet validated
- Artificial bone compares to real human femoral head geometry
- Bone defects are not considered

Outlook

- Simulation with bone material parameter data of our working group
- Simulation and validation with a real human femoral head
- Classification of patients bone defects according to own MRI data
- Simulation with different bone defects



Kind thanks
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