Stiffness-anisotropy of porous implant geometries

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INTRODUCTION: Cellular lattice structures can be used to adjust mechanical properties of bone implant materials, preventing *stress shielding*. Additionally, open-porous structures allow bone cells to migrate into the openings and form a strong connection between the surrounding bone material and the load bearing implants. Under anatomical conditions, such implants are usually exposed to biomechanical forces acting in various directions. This study evaluates the stiffness anisotropy of different lattice geometries, calculated by Finite Element Analysis (FEA).

METHODS: The angular stiffness anisotropy is simulated by COMSOL Multiphysics (Stockholm Sweden, version 5.0). The validity of the FE-Model was proved in a preliminary FEA-study [1]; furthermore, the stiffness anisotropy was investigated by simulating the rhombic-dodecahedral (RDH) lattice geometry rotated around one single axis [2].

In this study, we compare the stiffness anisotropies of four different lattice structures: Type A consists of orthogonal struts with thickness 0.2 mm. Unit cell type B is built by subtracting cylinders (Ø = 0.6 mm) along the room-diagonals of a cube. Type C is based on a cube resected by a sphere (Ø = 1.36 mm), and the unit cell type D represents an extended RDH beam model with strut size 0.4 mm. The porosities of the corresponding lattice structures are given in Tab. 1. The stiffness anisotropy is investigated by rotating the geometries around two axes γ and δ.

RESULTS: For all four types of lattice geometries, the elastic gradient (EG) is calculated for all rotation angles γ and δ in the range of 0°-45° (Fig. 1). The ratios between minimum and maximum EG, as a measure of mechanical anisotropy, differ significantly among the varying lattice types A - D (Tab. 1).

Table 1. Porosity and anisotropy of elastic gradients (EG) referring to structures A - D.

Lattice Type	A	B	C	D
Porosity	0.83	0.76	0.71	0.73
EG Ratio	700 %	450 %	200 %	120 %

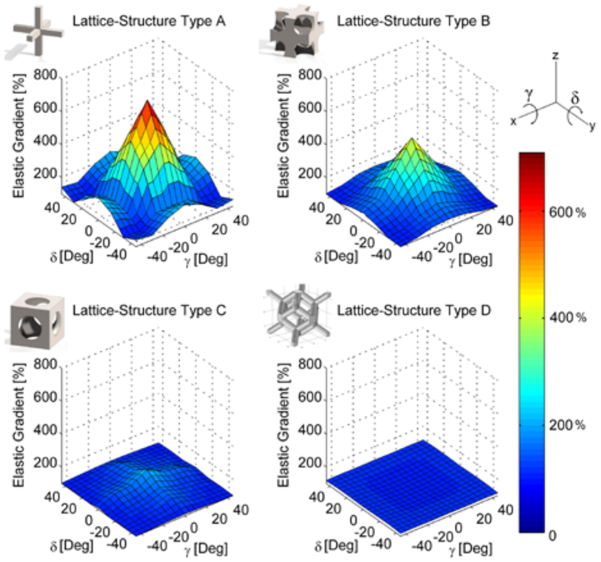

Fig. 1: Elasticity map of all four lattice types in relation to the rotation around the angles γ and δ.

DISCUSSION & CONCLUSIONS: The numerical results show distinctive elasticity maps among the four individual lattice types. Depending on the direction, the stiffness varies between 120 % and 700 %. The high stiffness anisotropy of lattice types A and B can be explained by the pronounced orthogonal struts included in the geometries of these unit cells. The RDH lattice structure type D shows the highest mechanical isotropy and represents a promising candidate for the design of isotropic implants. This leads to an isotropic displacement of the lattice structure under varying compressional directions which might be important for continuing stimulation of the surrounding bone.

REFERENCES: [1] S. Zimmermann (2014) *Structure -Mechanical FEM Analysis and Physical Validation of Porous Titanium Bone Scaffolds*, Master Thesis, FHNW, p 78. [2] S. Zimmermann, M. de Wild (2014) *Density- and Angle-Dependent Stiffness of Titanium 3D Lattice Structures*, *BioNanoMat* **15 S1**:35.

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