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HIGH RESOLUTION 3D-PRINTING OF TRABECULAR BONE BASED ON MICRO-CT DATA

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Objective: Modern high-end 3D-printers enable resolutions up to 16μm. Purpose of the presented study was firstly, to investigate the quality and difference of microCT-based trabecular bone structures, and secondly, the biomechanical properties of such 3D-printed trabecular bone samples.
Methods: Micro-CT scans of human trabecular samples with different bone quality were performed with a vivaCT40 (Scanco/CH) and analyzed according to the standard settings. Based on these data, typical STL-files were created for 3D-printing purpose for the use with a high-end 3D-printer. The washing-out procedure of the necessary supporting material was optimized with appropriate chemical solutions. In the next step, original bone structures were compared with the 3D-printed copies from micro-CT data by image registration.
Results: The selected procedure enables high conformity between original and high resolution 3D-printed trabecular bone structures. The conformity is affected by image and printing resolution, thresholding and filtering parameters.
Conclusion: After further optimization of the selected 3D-printinting materials, it is possible to achieve appropriate E-module values of different trabecular bone qualities. Such artificial created bone samples may be helpful for future standardized biomechanical testing of newly developed osteosynthesis screws and implants for osteoporotic fractures.

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TOWARDS CORTICAL BONE BIOMARKERS USING MEASUREMENT OF GUIDED WAVES AT THE FOREARM

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Objective: New areas of research are directed towards developing novel quantitative ultrasound approaches for in vivo cortical bone characterization. A step forward has been made recently with reports showing that cortical bone behaves as a waveguide (WG) for ultrasound. Measurements of the guided modes dispersion relationships, together with appropriate waveguide modeling have the potential for providing estimates of strength-related bone properties such as cortical thickness (Ct.Th) and stiffness. Stiffness is largely determined by mineralization and cortical porosity (Ct.Po). This work presents the first in vivo ultrasound-based estimates Ct.ThUS and Ct.PoUS in a cohort of fifteen subjects (24 - 84 years old).
Methods: Cortical bone is readily accessible for axial transmission measurements at the radius using a 1-MHz bi-directional multi-element probe. The full time response of the WG for all possible pairs of transmitter-receiver was recorded and then processed using a 2-D time-space Fourier transform associated with a singular value decomposition-based denoising step. The dispersion relationships were used to estimate Ct.ThUS and Ct.PoUS based on a comparison of measured and model-predicted dispersion curves. The post-processing relies on finding the optimal pairing of measured and predicted dispersion curves by adjusting the thickness and porosity of a 2-D free transverse isotropic plate waveguide model. In this approach, we assumed a homogeneous and uniform tissue mineralization among individuals.
Site-matched measurements of bone mineral density (BMD) and thickness (Ct.Thref) were obtained in nine subjects (24 - 58 years old) using high resolution X-ray peripheral computed tomography.
Results: Results on the nine subjects showed a good agreement between Ct.ThUS (3.6 ± 0.3mm) and Ct.Thref (3.6 ± 0.3, RMSE $= 0.15$ mm). A particular guided mode, the fundamental flexural mode A0, was identified in twelve subjects. The asymptotic velocity of the A0 mode (1730 ± 55 m.s-1), independent of Ct.Th but largely determined by the stiffness was found to vary between 1600 - 1780 m.s-1. According to our model, these values correspond to porosity values falling in the range 5 - 20%.
Conclusion: This paper describes our recent progress towards the proof-of-concept of the guided wave approach for providing quantitative assessment of cortical bone biomarkers. Still at an early stage of development, the approach needs to be fully validated and several challenges need to be overcome, including signal post-processing and refinement of the models to better account for structural and material heterogeneity of the cortical bone.

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A NOVEL OPTICAL APPROACH FOR ASSESSING IN VIVO BONE SEGMENT DEFORMATION AND ITS APPLICATION IN MUSCLE-BONE RELATIONSHIP STUDIES IN HUMANS

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Objective: The experienced mechanical loading is a key determinant for bone adaptions to build appropriate architecture. With a novel optical approach, we have recently reported that the human tibia shaft mainly experiences antero-posterior bending and torsional segment deformation during walking. Ample evidence demonstrates that muscle contractions are closely related to bone adaptation. However, it remains unclear which loading regimes on bone are primarily produced by regional muscle contractions. The contribution of muscular contractions on the bone loading is still under debate. Taking the human tibia as a subject, the tibia deformation regimes and its relationship with muscular activities during different locomotor activities were investigated in the present study.
Methods: Tibia deformation was recorded in five subjects utilizing a novel optical approach established in our lab. Briefly, two marker clusters with three non-collinear retro-reflective markers on each cluster were affixed into the proximal and distal anterior-medial aspect of tibia cortex by bone screws. The markers trajectories were captured at 300 Hz with an optical system during different activities. Tibia deformations regimes, namely bending and torsion angles, were computed from the relative movement of the proximal cluster with respect to the distal cluster. Muscle activities were assessed with electromyography.
Results: The proximal tibia primarily bends to the posterior aspect (bending angle: 0.15° - 1.30°), medial aspect (bending angle: 0.38° - 0.90°) and twisted to the external aspect (torsion angle: 0.67° - 1.66°) during walking. Peak posterior bending and peak torsion occurred during the first (22%) and second half (76%) stance phase, respectively. Peak to peak (p2p) antero-posterior (AP) bending angles increased linearly with speed during walking and running, but p2p torsion angles remained constant.
The largest p2p bending angle was observed during maximum single leg hopping, with p2p AP bending angle of $5.05 \pm 0.33^\circ$. The p2p torsion angle was larger with forefoot than rearfoot stair ascent and running. The tibia deformation regimes were characterized by torsion ($1.35^\circ \pm 0.07^\circ$) rather than bending ($0.52^\circ \pm 0.07^\circ$) during maximum isometric plantar flexion.
Conclusion: Bending and torsion predominated the tibia deformation regimes during the investigated activities. Unexpected large torsion deformation, at least partially contributed by muscle contractions, might be another candidate to drive the long bone adaption. These new findings therefore confirm the notion of muscle contraction as an important determinant of bone mechano-adaptation, and they also shift the focus from loading magnitude to loading patterns in muscle bone interactions.

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SHAPE AND APPEARANCE MODELS DO NOT DISCRIMINATE HIP FRACTURE BETTER THAN TOTAL FEMUR INTEGRAL BMD ALONE

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Objective: To investigate whether statistical parameters describing the 3D shape of the proximal femur and its local BMD distribution can discriminate subjects with and without acute osteoporotic hip fractures.
Methods: QCT datasets of the femur from 98 postmenopausal women (46 with acute hip fractures) from the EFFECT study were used. Statistical shape models were built by non-rigid registration of randomly selected segmented femurs to one femur arbitrarily selected as reference using diffeomorphic demons. Models included both unfractured subjects (ctrl) and fractured