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Local stress investigation of periprosthetic fractures by total hip replacement - a finite element analysis

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Introduction: Every year, 350000 knee and hip prostheses are implanted solely in Germany. Thus, hip replacement is one of the ten most common surgeries. Because of rising life expectancy and increased mobility of patients, an increase of femoral fractures near the implanted hip joint can be observed. A reason for these periprosthetic fractures is the alteration of the femur's physiological properties. Periprosthetic fractures require surgery with plate and screw systems. In most cases, a screw is mounted in the pre-damaged bone material. This can lead to further losses of bone substance. The new medical approach is to fix the periprosthetic fracture through an LISS-plate, which is screwed into the artificial hip joint.

Methods: By means of the FE-method, a model of a thighbone with a hip prosthesis was created. In this model, local stress on the head of the hip prosthesis was studied extensively by application of a static stress. In the next step, the prosthesis was drilled in two positions and was subsequently fixed through an LISS-plate (TiAl6Nb7). The results are compared to non-drilled prostheses. Additionally, the prosthesis material was varied. On the one hand a cemented variant of a cobalt-iron alloy (CoCrMo) was used. For comparison, a cementless system with the forged alloy TiAl6V4 was studied.

Results: It is shown that all deformations of the prosthesis are in the elastic range. When comparing the drilled and the non-drilled prosthesis, higher load peaks can be detected in the drilled specimen. The highest stresses occurred at the hip in the prosthesis's joint head and around the drill holes.

FE analysis only represents a simplified model. The bone was defined as complete cortical material, bone-remodeling processes were not considered. The prosthesis model has been simplified to consist of solid material with given properties. Coatings have been neglected. Next steps will be in-vitro tests.

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Development and validation of a equipment-specific Geant4 model for Elekta Agility collimator

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The goal of this study is to develop and validate an equipment-specific Geant4 model of an Elekta Agility collimator to be used in Monte-Carlo simulations of dose distribution.
The Diaphragms and Multi-Leaf Collimators (MLC) were initially modelled based on Agility data available in literature. As geometry might change for different machines, specific MLC features, as tongue and groove (T&G), gap between leaves and positioning, have been defined as mathematical functions. The user can tune such features in order to match experimental measurements performed in a specific machine.
The Elekta Precise IAEA phase space files for 6 MV photon beam were used as primary generators. For validation of the model, simulation of dosimetric characteristics were carried out in Geant4 v.10.01.p02. Different rectangular fields were delivered to a virtual water phantom. Percentage depth dose (PDD) curves and lateral profiles were then compared to corresponding measurements conducted in an Elekta Synergy linac coupled with Elekta Agility collimation system. Furthermore, intraleaf and interleaf leakage and T&G effect were also investigated.
Good agreement was obtained between measured and simulated data for PDD and lateral profiles. However, small discrepencies were observed in small fields which could be attributed to the use of an Elekta Precise phase space. Moreover, a maximum leakage value of 0.55 % was observed for both measured and simulated data. An underdosage of approximately 20 % was observed due to the T&G effect in measurements and simulations. The obtained results are compatible with literature data.
The developed model was proven able to reproduce the Elekta Agility collimator. Small discrepancies might be corrected for by developing a more adequate phase space. Validation for 15 MV photon beam and IMRT plans is also foreseen.

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Towards PET monitoring at the Austrian ion beam therapy center MedAustron

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At the MedAustron proton and carbon ion facility in Wiener Neustadt/Austria, patient treatment started in December 2016. Ion beam therapy allows tumor conformal dose distributions, however, it is sensitive to deviations from the treatment plan, e.g. due to anatomical changes. Therefore, special care in quality assurance is required. Up to now, PET is the only clinically proven method for performing a 3D in-vivo dose monitoring for proton and ion therapy. At MedAustron, a Philips Gemini TF BigBore PET/CT is available in the vicinity of the treatment rooms, exclusively dedicated to offline PET monitoring after the irradiation. First workflow tests with PMMA targets, which were irradiated with protons, transported to the PET/CT using a patient trolley, and scanned in the PET/CT, have been successful and results will be presented. The targets were irradiated with protons of 198 MeV and 169 MeV. The PET acquisition can be started within 5 minutes after the end of the irradiation. The experimental effort is being accompanied by the establishment of software required for the clinical implementation of the PET monitoring. For the prediction of the activity distribution, the simulation tool GATE is used. The simulations are performed on a small in-house cluster. GATE provides several useful features for this purpose, e.g. an already implemented washout model and the possibility to model the PET scanner. Simulation results are compared with the data obtained during the workflow tests. Further tests are being planned, and for the second half of 2017 a patient study is under preparation.

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Simulation of electrical fields in cardiac resynchronization therapy and temperature spread in HF ablation

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The electrical field (E-field) of the biventricular (BV) stimulation is important for the success of cardiac resynchronization therapy (CRT) in patients with cardiac insufficiency and widened QRS complex.

The aim of the study was to model different pacing and ablation electrodes and to integrate them into a heart model for the static and dynamic simulation of BV stimulation and HF ablation in atrial fibrillation (AF).

The modeling and simulation was carried out using the electromagnetic simulation software CST. Five multipolar left ventricular (LV) electrodes, four bipolar right atrial (RA) electrodes, two right ventricular (RV) electrodes and one HF ablation catheter were modelled. A selection were integrated into the heart rhythm model (Schalk, Offenburg) for the electrical field simulation. The simulation of an AV node ablation at CRT was performed with RA, RV and LV electrodes and integrated ablation catheter with an 8 mm gold tip.

The BV stimulation were performed simultaneously at amplitude of 3 V at the LV electrode and 1 V at the RV electrode with a pulse width of 0.5 ms each. The far-field potential at the RA electrode tip was 32.86 mV and 185.97 mV at a distance of 1 mm from the RA electrode tip. AV node ablation was simulated with an applied power of 5 W at 420 kHz at the distal ablation electrode. The temperature at the catheter tip was 103.87 °C after 5 s ablation time and 37.61 °C at a distance of 2 mm inside the myocardium. After 15 s, the temperature was 118.42 °C and 42.13 °C.

Virtual heart and electrode models as well as the simulations of electrical fields and temperature profiles allow the static and dynamic simulation of atrial synchronous BV stimulation and HF ablation at AF and could be used to optimize the CRT and AF ablation.

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Monte-Carlo based CT simulation of virtual patients for image guided radiotherapy

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In image guided radiotherapy, a new CT is necessary whenever the dose distribution in a changing anatomy needs to be re-planned or re-checked. However, acquiring new CT images along with each treatment is not always feasible. In order to prevent additional exposure to radiation or because there is no CT scanner available it might be omitted. For instance, ion therapy particle facilities are currently not equipped with in-room 3D imaging, but use 2D fluoroscopic projections. Here, positioning and dose calculation exclusively rely on image registration with the planning CT. Due to the resulting vector field, (motion) artefacts and the statistical noise distribution from the planning CT are deformed unphysically. In order to tackle these shortcomings, we propose a new approach based on virtual imaging of patients. First, a reduced representation of the patient body is obtained from feasible images, i.e. a diagnostic CT. This representation is used to construct a virtual patient geometry resembling the real patient. On a computer level this is a hierarchy of nested tessellated volumes, each consisting of one distinct material. Secondly, a dedicated Monte-Carlo (MC) simulation of a Cone Beam CT (CBCT) is performed. It features a gantry hosting a 140 keV photon point source and a flat solid-state detector. A facility to load the virtual patient geometry from a XML-like file format is provided. Combining patient model and MC simulation we are able to produce a fully virtual CBCT image of a patient. As an advantage, we can control the noise level, resolve motion artefacts and dismiss common artefacts occuring in planning CTs. The validation of our workflow for generation of virtual images of simple phantoms and patient-like geometries will be presented. Possible future applications combining virtual imaging and a biomechinal model of patient movement will be discussed.