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High-speed kV-CBCT lung cancer imaging within single breath-hold: dose exposure and image quality phantom study

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Lung tumors treated with hypo-fractionated deep-inspiration breath-hold benefit strongly from fast imaging and treatment. While treatment can be accelerated with flattening-filter-free techniques, conventional kV-CBCT for patient positioning takes about 2-4min in repeated breath-hold. Acceleration of linac gantry rotation from 3°/s to 18°/s would allow image acquisition within single breath-hold.
A comparison study between faster CBCT (18°/s) and conventional, clinical CBCT (3°/s) was performed to evaluate dose exposure and image quality. An inhomogeneous thorax phantom with four different tumor-mimicking inlays was used to simulate a lung cancer patient. The imaging preset setup was 200° rotation, 100kV and 0.1mAs/frame in conventional and faster CBCT. Dose exposure was determined at representative positions. Image quality was analysed regarding signal-to-noise ratio (SNR) in tumor and lung tissue, contrast-to-noise ratio (CNR), and geometry of tumor-mimicking shapes.
The dose exposure in different positions (tumor, both lungs, central and peripheral positions) was reduced by a factor of 3.8-4.8 (73.3-79.2%) to sub-mGy range; the lowest dose-reductions occured at the start- and stop-position of the gantry rotation due to gantry braking characteristics. In the high-density tumor-mimicking inlay and the low-density lung, the SNR was reduced by 10% respective 40% with faster gantry rotation. The CNR between tumor- and lung-material was reduced up to 70% due to undersampling. However, the image quality for tumor localization was still sufficient. The geometric shapes of the tumor-mimicking inlays were measured and comparison with the sizes provided by the manufacturer showed a mean difference of (-0.5±0.7)mm for conventional, and (-0.8±0.8)mm for faster CBCT, with maximum difference 2mm.
In conclusion, this study showed promising results for high-speed kV-CBCT lung tumor imaging with faster gantry rotation. Imaging times of ~10s in combination with fast treatment delivery could lead to future combined imaging and treatment within only several breath-holds and thus potentially increase treatment accuracy and patient comfort.

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Is the assumption correct that the human body is rigid during couch tracking?

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Introduction: Couch tracking is one approach to mitigate intrafractional tumor motion in radiotherapy. The couch countersteers the tumor motion, however this might affect the patient's motion relative to the couch. This relative motion introduces uncertainty about the actual tumor position, and may degrade the couch tracking performance. So far, the magnitude of the relative motion is unknown.
Method and Materials: 85 volunteers were placed on a robotic couch that could move based on the volunteers' respiration. The couch switched three times between static and tracking conditions. An optical sensor recorded (10 Hz) a three-dimensional point cloud representing the surfaces of the volunteer and the couch. Markers placed on the volunteers (body markers) and the couch (couch markers) were tracked in these point clouds. The couch marker trajectories were combined to a rigid body trajectory, relative to which the body markers should ideally not move. The body marker motion consisted of relative motion and respiratory motion components. The respiratory component was subtracted from the body marker motion by correlating it to the measured respiration. Body markers with correlation coefficients below 0.9 were removed from further analysis. Finally, the difference of the body markers' relative motion between static and tracking was analyzed.
Results: Under tracking conditions, the markers showed significantly larger relative motion for all three dimensions ($p<0.0001$). The 95% confidence intervals were [0.29,0.39] mm, [0.31,0.44] mm and [0.32,0.4] mm for left-right, superior-inferior, and anterior-posterior relative motion, respectively. The largest differences were 2.1 mm (left-right), 2.3 mm (superior-inferior), and 2.3 mm (anterior-posterior) over all markers of all volunteers.
Conclusion: During couch tracking, the relative motion of the patient to the treatment couch was small for the majority of volunteers. However, a few volunteers exhibited substantial relative motion, therefore, patients should be checked on their relative motion before couch tracking treatment.

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Dynamic treatment-couch tracking for motion mitigation during prostate SBRT – a geometric and dosimetric validation study

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Purpose: Prostate SBRT treatments demand high accuracy in dose application. Intra-fractional prostate motion might lead to target miss or increased dose to surrounding organs. The potential of dynamic treatment-couch tracking to mitigate the effect of the prostatic motion during prostate SBRT was evaluated geometrically and dosimetrically.
Methods: For ten prostate cancer patients, SBRT treatment plans with integrated boosts (prostate+5 mm: 5x7 Gy, index lesion+3 mm: 5x8 Gy) were prepared. For the geometrical evaluation, the plans were applied to a small lead ball placed at the beam isocenter. The ball was moved according to five prostate motion curves without motion compensation or with real-time compensation using the treatment couch while MV images were taken. These show the field edges in respect to the lead ball. The over- and underexposed areas were evaluated by comparison with static reference images. For the dosimetric evaluation, the plans were applied to a Delta4 phantom. The phantom was moved with and without couch tracking. The measurements were compared to a static reference measurement. The dose to 95% (D_{95}) of the prostate and index lesion and the gamma agreement ($\gamma_{1\%/1mm}$) of rectum and urethra were evaluated.
Results: The median (quartiles) over- and underexposed area was reduced significantly from 2.02 cm^2 (1.55 cm^2, 2.51 cm^2) without motion compensation to 0.45 cm^2 (0.40 cm^2, 0.54 cm^2) with couch tracking. The prostate D_{95} and index lesion D_{95} were significantly improved with tracking showing values closer to the static references. The rectum $\gamma_{1\%/1mm}$ was improved significantly from 64.2% (47.3%, 88.9%) without compensation to 100.0% (100.0%, 100.0%) with tracking and for the urethra $\gamma_{1\%/1mm}$ from 77.5% (59.6%, 92.9%) to 100.0% (100.0%, 100.0%).
Conclusion: Couch tracking significantly improved the accuracy of prostate SBRT in the presence of motion and was proven to be a feasible motion mitigation method applicable at conventional linear accelerators.

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Motion extraction from 4D-MRI for MR-guided particle therapy of pancreatic cancer

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For the treatment of abdominal tumors, information about anatomical motion is essential. In particular, this is the case for particle therapy, where, due to the well-defined particle range and the inverse dose profile, motion-based uncertainties might lead to misdosages to the target and deliver unwanted dose to normal tissue. Time-resolved volumetric magnetic resonance imaging (4D-MRI) shows high potential to provide the necessary motion information without applying any additional dose to patients. The purpose of this study was to extract the motion of the pancreas from 4D-MRI data as a step towards MR-guided particle therapy of pancreatic cancer. For this purpose, 4D-MR images (spoiled 3D-encoded gradient echo, radial VIBE) were taken of several volunteers and sequence parameters were optimized to obtain high contrast between pancreas and its surrounding tissue. 4D-MRI data were reconstructed with an in-house developed self-gated motion-compensated algorithm. This algorithm provides 3D images of 20 breathing phases by including artifact-robust motion estimation into image reconstruction. For each volunteer, the pancreas was manually segmented on one of the available 20 breathing phases of the respective 4D-MR data set. The vector fields between the different breathing phases were calculated using first rigid and then B-Spline image registration algorithms. The pancreas segmentation was then transformed based on the calculated vector fields into each breathing phase. The trajectory of the center-of-mass of the pancreas was extracted from these data as well as Dice coefficients which describe the overlap of segmentations in different breathing phases. We identify the main motion of the pancreas in cranio-caudal direction and observe absolute motion amplitudes of 12-16 mm. The small Dice coefficients (mean 0.57, range 0.28-0.89) and the patient-specific motion patterns show that motion needs to be assessed carefully. 4D-MRI can be utilized to provide this crucial information.

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Monte Carlo framework for the evaluation of interplay effects between dose application and respiratory motion

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We developed a 4D dose recalculation workflow to simulate the dose delivered to a moving target volume. The aim is to evaluate interplay effects between actual dose delivery and the motion of the tumor. The workflow combines Monte Carlo dose calculation with the linac log files and a dose accumulation based on 4D-CT images. Log data from the linac are retrieved with the Delivery Parameter Log File converter for Integrity (Elekta) and converted into small treatment plan fragments, each covering for example 0.1s. Every plan fragment is forward calculated on every 4D-CT phase using MCverify/Hyperion V2.4 (research version of Monaco 3.2, Elekta). This allows the simulation of arbitrary respiratory curves with a resolution of 0.1s by assigning every fragment to a distinct 4D-CT phase (e.g. changes in breathing frequency, different respiration patterns as well as simulation of gated treatments). As a final step AVID (a software framework for medical data processing developed at Deutsches Krebsforschungszentrum (DKFZ)) is used to accumulate dose fragments for each 4D-CT phase and to combine them to a total dose based on deformable image registration (plastimatch).
The developed workflow was validated with the Dynamic Thorax Phantom (CIRS) and applied to a lung tumor patient case (tumor volume 9cm^3, crano-caudal movement of 1.6cm in the 4D-CT).
Due to the large fields used in 3D-Conformal- and Dynamic Conformal Arc-plans, the dose distribution in the GTV was robust against changes in the simulated breathing. Advanced techniques showed relative changes in $D_{98\%}$ of 3.8% for IMRT and 2.4% for VMAT respectively (periodic breathing, treatment start in exhale compared to treatment start in inhale). Differences for $D_{2\%}$ were less prominent in the evaluated example case.
The developed workflow is able to show potential interplay effects between dose application and tumor motion for different treatment techniques and breathing scenarios.