tracking) may mitigate the detrimental effects of motion, but requires reliable target motion monitoring. On a conventional linac, monitoring can be obtained by intrafraction kilovoltage monitoring (KIM) using continuous imaging of implanted fiducials with a standard gantry-mounted x-ray imager. However, KIM adds imaging dose, is incompatible with large couch rotation, and KIM images suffer from MV scatter onto the kV imager. This study investigates the use of external monitoring combined with sparse kV imaging during beam pauses to overcome KIM limitations.

Material and Methods: Six patients with 2-3 implanted gold markers received three fraction liver SBRT on a conventional linac. A setup CBCT was acquired with simultaneous recording of the motion of an external marker block on the abdomen (Fig. A). The 3D marker motion during the CBCT was estimated at 15Hz from the 2D motion in the CBCT projections and used to establish an external correlation model (ECM) of the internal marker motion INT(t) in each direction (RL, SI, AP) as a function of the external marker block motion EXT(t): INT(t) = A·EXT(t) + B·EXT(t-τ) + C, where A, B, C are coefficients and τ is a time constant. During treatment delivery, INT(t) was estimated from the external motion at 20Hz, while MV-scatter-free kV images were acquired every 3s during beam pauses. INT(t) was estimated from the ECM of the CBCT without any model update and with updates of the coefficient C by use of the first image of each treatment field. Post-treatment, the 3D marker positions were estimated for each intra-treatment kV image and used as ground truth to quantify the root mean square error (rmse) of the INT(t) estimations.

Results: Figs. B-C compare the estimated INT(t) with and without model updates with the ground truth positions in intra-treatment kV images at one fraction. Table 1 shows the mean rmse for all fractions. ECM updates more than halved the SI rmse. Substantial internal cranial baseline drift up to 7 mm (mean 1.4 mm) occurred between the setup CBCT and the last field without a similar drift for the external marker. One patient was omitted for further data evaluation. Table 1 summarizes the tracking angles and the dose distribution, which would be clinically not acceptable. Therefore this patient was omitted for further data evaluation. The table shows the performance of the ECM to motion during the CBCT. Note that model-update (second column) was only performed in the SI direction.

<table>
<thead>
<tr>
<th>Pre-treat</th>
<th>Intra-treatment kV images</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE [mm]</td>
<td>With update</td>
</tr>
<tr>
<td>RL</td>
<td>0.19</td>
</tr>
<tr>
<td>SI</td>
<td>0.61</td>
</tr>
<tr>
<td>AP</td>
<td>0.31</td>
</tr>
<tr>
<td>3D</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Table 1: Mean rmse of the ECM for all fractions. The first column describes the fit-performance of the ECM to motion during the CBCT. Note that model-update (second column) was only performed in the SI direction.

Conclusion: A correlation model between external surrogate motion and internal liver motion was established on a conventional linac from pre-treatment CBCT projections and used to estimate the intra-treatment target motion INT(t) with and without model update. A simple update based on only one kV image per field substantially improved the localization accuracy. Real-time update of the model in all 3 motion directions is currently being developed and is expected to further improve the localization accuracy. The proposed method increases the versatility and reduces the imaging dose compared to current clinical KIM implementations.

OC-0210

Motion management for partial arc VMAT treatments using intra-fractional 2D/3D registration

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Purpose or Objective: Rotational radiotherapy IMRT (VMAT) has shown superior delivery efficiency with similar overall treatment plan quality compared to conventional IMRT. For lung treatments intra-fractional tumor motion is a major source of uncertainty in dose application leading to the enlargement of the PTV margins and possibly to increased dose delivery to OARs. Motion management by tracking the tumor using intra-fractional kV planar images has the potential to reduce position uncertainty and reduce the PTV margins. The challenge for rotational treatments is the poor tumor visibility at certain gantry angles. In this work we investigate the feasibility of delivering VMAT treatments using only partial arcs where the tumor is well visible and therefore tracking is feasible.

Material and Methods: For our study we used the x-ray images acquired for CBCT reconstruction from five patients with NSCLC undergoing hypo-fractionated SBRT treatment (3 fractions of 13.5Gy prescribed to the 65% isodose). These x-rays are comparable to kV fluoroscopy images acquired during a VMAT treatment. For each patient the evaluation consisted of two steps: first real-time 2D/3D registration was used to track the tumor location on each of the x-rays from the CBCT acquisition. We determined the gantry angle intervals for which it was possible to track the tumor by comparing registration results with manually annotated diaphragm motion. Second, VMAT plans were created for partial arcs chosen depending on the anatomy and tumor location (U=unlimited) for a PTV based on an ITV approach (ITV plus 4mm margin) and for the limited partial arcs where the tumor tracking worked (L-limited) for a PTV based on the midventilation CTV (5mm margin). The L partial arc plans were evaluated using the U plans as benchmark.

Results: For all cases it was possible to track the tumor in two arcs of about 90 degrees, typically with imaging around anterior-posterior (AP) or posterior-anterior (PA) projections. For patient 5 it was possible to track the tumor in all projections. In terms of plan quality, a target coverage of at least 99% to the 65% isodose was aimed for and could be achieved for all the 3 plans and for all the L plans except for one, where the available angle range led to an unfavorable dose distribution, which would be clinically not acceptable. Therefore this patient was omitted for further data evaluation. Table 1 summarizes the tracking angles and the DVH parameters. Figure 1 shows example tracking results and obtained plans for one patient.
Conclusion: The results indicate the feasibility of VMAT treatments under tumor tracking for selected patients. The arcs available for planning influence the quality of treatment. The L partial arc plans had clinically acceptable quality in four patients. Treatments with reduced margins could be safely delivered by gating the treatment beam if the tumor motion exceeds the margins. Also, a great advantage is that the dose delivered to the tumor could be exactly monitored.

OC-0211
Real-time MRI-guided Radiotherapy for pancreatic cancer
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Purpose or Objective: Pancreatic cancer with vascular involvement has a poor prognosis regardless of treatment. The toxicity of chemoradiation to adjacent normal organs can contribute to treatment discontinuation and adverse outcomes in some patients. We hypothesized that real-time MRI-guided radiotherapy for borderline or locally advanced pancreatic carcinoma would enable safer treatment delivery with tight margins and diminished normal tissue toxicity than conventional treatment approaches.

Material and Methods: Patients with borderline or locally advanced pancreatic cancer were eligible for evaluation for MRI-guided radiotherapy. Patients underwent complete staging, including baseline CA19-9 and triple phase CT imaging. Patients underwent simulation with an inhalal breal hold 3D and cine scans on a MRI Guided Treatment Planning system. Locoregional lymph node coverage was incorporated at the discretion of the Radiation Oncologist. The mean CTV to PTV expansion was 3 mm (range 2-5 mm). The primary CTV was tracked in real-time throughout treatment and the PTV or similar structure was used as a boundary for triggering treatment. A patient initiated repeated breath hold strategy was used to increase the reproducibility and duty cycle of radiotherapy.

Results: We have completed treatment for our first 5 patients with borderore or locally advanced pancreatic adenocarcinoma. The population was 4:1 Male:Female with a mean age of 61.8 years (range 52-67). All patients had an elevated CA19-9 at presentation, with a mean of 714 U/mL (range 62 - 2350 U/mL). Locoregional lymph nodes were already available, thus providing a potential means of non-invasive, online motion monitoring with high soft-tissue contrast. This work investigates the feasibility of liver motion tracking using optical flow registration of Cine-MR images series.

OC-0212
Liver motion tracking using optical flow cine-MRI registration
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Purpose or Objective: The development of radiotherapy treatment units with integrated MRI scanners is stimulating interest in fully MRI-guided treatment protocols. Cine-MR sequences capable of acquiring 5-6 2D images per second are already available, thus providing a potential means of non-invasive, online motion monitoring with high soft-tissue contrast. This work investigates the feasibility of liver motion tracking using optical flow registration of Cine-MR images series.

Material and Methods: Livercine-MRI series (balanced steady-state free precession, 256x256 pixel, 1.28x1.28mm spacing, f = 3.3Hz) providing 220 images over a 70s scan were acquired in 25 patients and 5 healthy volunteers after informed consent. Ground-truth liver motion consisted in the trajectories of numerous sparse features (PFT) extracted using an previously tested algorithm based on the Scale Invariant Feature Transform(SIFT) [1]. For each subject, optical flow (OF) registration, as proposed in [2], was applied between the first image of the series and each subsequent frame, thus obtaining time-resolved dense motion fields [Fig. 1]. Trajectories based on OF were then derived by applying these motion fields to the positions of the SIFT features detected in the first image. To assess the accuracy of the motion fields, the 2D frame-by-frame distances (D_{SIFT-OF}) between PFT and POF were calculated for every trajectory and, for each subject, their distributions were described with median, inter-quartile range, 5th and 95th percentiles. Linear correlation coefficients (r_{SIFT-OF}) between