Real-time MRI-guided Radiotherapy for pancreatic cancer


Material and Methods: with tight margins and diminished normal tissue toxicity than pancreatic carcinoma would enable safer treatment delivery MRI guided radiotherapy for borderline or locally advanced purposes or objectives: University of Wisconsin, Department of Human Oncology, Madison, USA Material and Methods: 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 S.A. Rosenberg1, A. Wojcieszynski1, C. Hullett1, M. Geurts1, S.J. Lubner2, N.K. LoConte2, D.A. Deming2, D.L. Mulkerin2, C.S. Cho3, S.M. Weber3, E. Winslow1, K.A. Bradley1, J. Bayouth1, P.M. Harari1, M.F. Bassetti3

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 inhale breath 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 borderline 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). Local recurrences were treated in 4/5 patients. The mean PTV was 222.7 cc (range 40.3-346.4 cc). The PTV was treated to 50.4 Gy at 1.8 Gy per a fraction with concurrent chemotherapy for all patients. With a median follow-up of 166 days (range 50 - 278 days), an average 66% reduction in CA19-9 1-2 months following chemoradiation was observed. The OS is 60% at time of follow up. One grade 4 toxicity was observed with duodenal ulceration during radiotherapy requiring hospitalization. The number of patients, overall survival, local control, progression free survival, and changes in CA19-9 levels will be updated at the time of presentation.

Conclusion: Real-time MRI-guided radiotherapy enables the design and delivery of highly conformal treatment for patients with borderline or locally advanced pancreatic carcinoma. A significant reduction in CA19-9 levels after treatment was observed. Real time MR imaging throughout treatment enables high precision tracking to minimize treatment margins and normal tissue dose exposure. MRI-guided radiotherapy may provide opportunities for normal organ toxicity reduction and future dose escalation strategies.

OC-0212 Liver motion tracking using optical flow cine-MRI registration M. Serenzi1, C. Paganelli2, P. Summers2, M. Bellomi3, G. Baroni1, M. Riboldi1

Purpose or Objective: The development of radiotherapy treatment units with integrated MRI scanners is stimulating interest in fully MRI-guided treatment protocols. Cine-MRI 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 (P0) extracted using apreviously 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 (P0) 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 (DUF) between P0 and P0 were calculated for every trajectory and, for each subject, their distributions were described with interquartile range, 5th and 95th percentiles. Linear correlation coefficients (rSIFT-OF) between
PSIFT and POF were also calculated. Finally, the computation time required for OF registration was measured.

Results: A total of 1345 trajectories were extracted (from 5 up to 99 per subject). Table I reports the motion fields accuracy results. The median value of $D_{\text{SIFT-OF}}$ was within the pixel size (1.28 mm) in 27 out of 30 subjects. The median $r_{\text{SIFT-OF}}$ was $0.92 \pm 0.08$ (mean ± SD among all subjects) with just 18/1345 trajectories reporting not statistically significant correlations ($t$-test $p$-value $\geq 1\%$) to SIFT. The computation time for a single registration was $49.2 \pm 2.4$ ms (mean ± SD, 3.20GHz processor, 64GB RAM).

Conclusion: Liver motion trajectories obtained through OF registration were comparable to those measured using robust feature matching. Moreover, the OF method calculates a dense motion field that can be used to simultaneously track multiple internal structures (e.g. tumour and OAR contours) during irradiation. Finally, OF registration appears well suited to online motion monitoring, as it is fully automated and its low computational cost allows tracking within current cine-MRI acquisition periods.

Material and Methods: kV images, continuously acquired at 7 or 11 frames/s during FFF VMAT spine SBRT of 18 patients, comprising 89 fluoroscopy datasets (1 dataset/arc), were analyzed off-line. Four patients were immobilized in a head/neck mask, 14 had no rigid immobilization. 2D reference templates of the planning CT (1 template/* arc*) were created in the form of filtered DRRs. The 360 templates consisted of the contoured vertebra + 2 mm. kV projection images were pre-filtered with a band-pass filter. Normalized cross correlation was used to find the 2D template position resulting in the best match between template and kV image. Multiple registrations were triangulated to determine 3D position. Average position and SD were calculated for each resulting motion trajectory. These SDs include spine stability and precision of the template matching + triangulation. To verify the accuracy and precision, mean and SD of 2 stationary phantom datasets with different baseline shifts were measured.

Results: Template matching + triangulation was performed within 0.1s/image. For the phantom, SDs were 0.21–0.23 mm for left-right (LR), 0.20–0.18 mm for superior-inferior (SI) and 0.24–0.23 mm for the anterior-posterior (AP) direction. The maximum difference in average detected and applied shift was 0.15 (LR), 0.37 (SI) and 0.03 (AP) mm. The table summarizes the SDs and percentages of tracked images for the clinical datasets. The template matching software performed less well for datasets in which the kV projection images contained overlying structures (e.g. clavicle, ribs, heart, diaphragm). Maximum spine position offsets were: -1.43-2.20 (LR), -3.48-0.68 (SI) and -1.14-1.52 (AP) mm. Average positional deviation was 1 mm in all directions in 90% of the arcs. 91% of all tracked points (total combined x, y and z points=81327) deviated by <1 mm from the planned position, 97.4% by <1.5 mm, and 98.8% by <2 mm.

Table I. Minimum, Mean ± Standard Deviation and Maximum values among 30 subjects of the $D_{\text{SIFT-OF}}$ distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Mean ± SD</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th Percentile</td>
<td>0.21</td>
<td>0.23 ± 0.03</td>
<td>0.33</td>
</tr>
<tr>
<td>Median</td>
<td>0.85</td>
<td>1.04 ± 0.16</td>
<td>1.45</td>
</tr>
<tr>
<td>IQR</td>
<td>0.72</td>
<td>1.08 ± 0.29</td>
<td>1.89</td>
</tr>
<tr>
<td>95th Percentile</td>
<td>2.20</td>
<td>4.39 ± 1.17</td>
<td>8.34</td>
</tr>
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Conclusion: Spine SBRT requires high positioning accuracy to avoid target miss and excessive OAR dose. However, conventional linacs do not allow high resolution spine position monitoring during irradiation. We analyzed kilo-voltage (kV) images routinely acquired by the gantry-mounted imager during spine SBRT using markerless template matching + triangulation. The aims were to determine whether this method would be suitable for sub-mm, sub-second on-line verification of spine position, and to determine spine stability.

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