Lung cancer patients with atelectasis, pleural effusion, and pneumonia: When do we need to adapt the treatment plan?

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Purpose/Objective: Lung cancer patients experience changes of the lung tissue density due to atelectasis, pleural effusion or pneumonia/pneumonitis. Changes may be an indication for adaptation of the treatment plan in order to preserve sufficient target coverage. This study investigates when and for how many patients adaptation is needed due to these kinds of changes.

Materials and Methods: We have analysed 165 lung cancer patients (Small Cell and Non-Small Cell) with daily cone-beam CT (CBCT). The CBCT scans were reviewed to find all patients with atelectasis, pleural effusion, pneumonia/ pneumonitis. For all patients we looked for the fraction number, when the change appeared and disappeared, the measurable size of the change and the consequences for the dose distribution. In addition it was estimated if the lung change gave rise to a shift of the tumour leading to a geometric miss.

Results: 43 patients (26%) of the 165 lung cancer patients investigated had changes in their lung. 24 (15%) experienced atelectasis, 19 (12%) pleura effusion and 8 (5%) had pneumonia/pneumonitis visible on CBCT. Only major density changes had consequences for the dose distribution, and we found that 7% need an adaptive treatment plan, when we accept 1% change in the mean dose to PTV (Planning target volume) and under dosage of 3% of the PTV.

In 42% of the atelectasis cases (6% of all patients) an appearing or disappearing atelectasis introduced a shift of the tumour larger than 5 mm and hence a risk of geometric miss with consequences for the dose distribution.

With respect to the appearance and disappearance there is no system for pneumonia/pneumonitis and pleural effusion. For the atelectasis the time of appearance and disappearance is shown in fig. 1. Half of the atelectasis cases are present at CT, while the other half appears during treatment. Only three patients have an atelectasis at CT that does not disappear at some point during the treatment.

Conclusions: For the 165 patients reviewed on CBCT an adaptive plan is necessary to assure a correct target coverage either due to changes in lung density in 12 patients (7%) or due to shift of the tumour because of the anatomical changes in 10 patients (6%). In total this corresponds to 12% of the patients being candidates for an adaptive treatment plan as a few patients are present in both groups. We do not find a clear system in the time of appearance nor disappearance of the changes, and we therefore recommend that an adaptive strategy is based on population based criteria, but evaluated on the individual patient by the RTT on a daily basis.

Fig. 1: Appearance and disappearance of atelectasis in 24 patients. For each patient the grey bar shows the time interval with atelectasis present. Fraction 0 represents the planning CT-scan.

Table 1: The tumor and lymph node baseline shift (in cm) in the original (pCT) and generated average patient model (µCT).

<table>
<thead>
<tr>
<th>Patient ID</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node (cm)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Tumor (cm)</td>
<td>0.3</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Conclusions: The average patient model based on deformable registration of the planning CT to CBCTs acquired prior to treatment is capable of reducing the systematic baseline shift of the tumor with respect to the carina large enough that a new planning could be beneficial, and at which fraction the replanning process should be started. Five patients were thus selected.

For these patients the planning CT scan was deformably registered (multi resolution b-spline model combined with a smoothness penalty term) to the CBCTs made during the previous 6 fractions. The inverse deformation field was applied to the original planning CT to obtain the average patient model.

To validate this model, the generated CT scan was rigidly registered to the underlying CBCTs. If the generated CT is a good model of the patient anatomy, these rigid registrations should reduce the systematic baseline shift of the tumor and lymph nodes with respect to the carina.

Results: The figure shows the planning CT scan (a) of one patient with delineated tumor, the CBCT (b) where the baseline shift of the tumor is apparent, and the generated CT (c) which accommodates the baseline shift. Table 1 shows in the first column of each patient the average baseline shift (in all three directions combined) over 6 fractions as seen in the CBCTs relative to the planning CT for both tumor and lymph node marker. The second column of each patient shows the average baseline shift with respect to generated average CT. This table shows a reduction in systematic baseline shift for the tumor for all patients. The lymph node positions are less well modeled, as they are hidden inside the mediastinum.
registration algorithm underlying the average patient model might further reduce these baseline shifts, and enhance performance within the mediastinum.

OC-0242
A general framework for selecting CTV-PTV margins in SBRT and its application for liver cancer
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Purpose/Objective: To provide a framework for selecting CTV-PTV margins in SBRT for achieving institution-specific requirements on target coverage.

Materials and Methods: The Van Herk et al. (VH) formalism, providing margin components for systematic and random errors, was extended to allow selection of margins for SBRT. VH accounts for systematic errors, requesting that 90% of treated patients should have 100% of the CTV covered by at least 95% of the prescribed dose, providing the well-known margin component 2.5 \(\Sigma\). We generalized this model to allow selection of margins for nearly (95-100%) full CTV coverage for a high percentage (90-98%) of treated patients. For random errors, a model based on VH was fitted using clinical dose distributions to account for typical SBRT prescription levels (67% and 80%), and the variety in dose gradients resulting from multiple beams. As a result, we propose margins to be selected according to:

\[ M = \alpha \Sigma_{\text{eff}} + \begin{cases} 0.075 \sigma^2_{\text{eff}} & \text{for } D_{\text{pres}} = 67\% \\ 0.075 \sigma^2_{\text{eff}} & \text{for } D_{\text{pres}} = 80\% \end{cases} \]

where \( \Sigma_{\text{eff}} \) and \( \sigma_{\text{eff}} \) represent effective standard deviations of the systematic and total random errors (consisting of intra and inter-fraction random errors), respectively. A look-up graph is provided for \( \alpha \), requiring the radius (\( R_{\text{ref}} \)) of a sphere with a volume equal to the clinical CTV.

Monte Carlo simulations were used to test the overall performance of the framework using 25 liver SBRT treatment plans at 67% and 80% prescription dose levels, simulating clinically representative target configurations of the bladder as seen in CBCTs acquired during the first days of treatment. The resulting plans are highly dependent on the bladder shapes in this limited sample of bladder geometries. The aim of this study was to investigate whether use of deformation vector fields derived from registration of these initial CBCTs to the planning CT results in more conformal plan libraries, evaluated on the basis of the treated volume across the treatment course.

Materials and Methods: A series of bladder cancer patients originally treated using non-adaptive RT (with anisotropic margins of up to 2 cm) were re-planned with two alternative ART strategies. The first strategy considered has recently been introduced clinically in our institution, and is a contour-based adaptive scheme based on the union of the bladder volumes from CBCT-scans of first week of treatment (Clinical ART). The 2nd strategy was based on deformation vector field libraries (DVFs) from deformable image registrations between the planning CT and each of the CBCTs from the first week of treatment (DVF-based ART). In the DVF-based approach the library plans were created using combinations of the overall mean DVF (mDVF) and its standard deviation (sdDVF). In all plans for both strategies, a 5 mm isotropic margin for intra-fractional bladder motion was used. The treatment course averaged volume of the selected target volumes was calculated for each patient using each of the ART strategies. The volume ratios relative to the non-adaptive treatment for the two strategies were compared using a Wilcoxon signed rank test. Normality of the distribution of DVFs was validated on voxel level by using the Shapiro-Wilk test. The study was based on five patients with a total of 146 daily CBCT scans.

Results: The median and range of the volume ratio, compared to non-adaptive RT (PTV_{\text{ART}} / PTV_{\text{non-ART}} = 0.60 [0.48-0.65]) for DVF-based ART, compared to 0.71 [0.63-0.79] for our current clinical ART strategy (p=0.04). The number of fractions where the bladder was not completely covered with the large size plan was 5% and 10% for the clinical ART and DVF-based strategy, respectively. The Shapiro-Wilk test showed normally distributed deformation vectors over on average 76% of the entire DVFs.

Conclusions: The use of DVFs from deformable registrations for creation of ART plan libraries is feasible and leads to an additional, statistically significant improvement in normal tissue sparing compared to an already highly conformal, clinically applied ART strategy.

OC-0243
Optimization of plan selection strategies in online ART of bladder cancer based on deformation vector fields
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Purpose/Objective: Adaptive radiotherapy (ART) of bladder cancer often involves daily selection from a library of treatment plans. The plans may be derived from Boolean operations on the geometrical configurations of the bladder as seen in CBCTs acquired during the first days of treatment. The resulting plans are highly dependent on the bladder shapes in this limited sample of bladder geometries. The aim of this study was to investigate whether use of deformation vector fields derived from registration of these initial CBCTs to the planning CT results in more conformal plan libraries, evaluated on the basis of the treated volume across the treatment course.

Materials and Methods: A series of bladder cancer patients originally treated using non-adaptive RT (with anisotropic margins of up to 2 cm) were re-planned with two alternative ART strategies. The first strategy considered has recently been introduced clinically in our institution, and is a contour-based adaptive scheme based on the union of the bladder volumes from CBCT-scans of first week of treatment (Clinical ART). The 2nd strategy was based on deformation vector field libraries (DVFs) from deformable image registrations between the planning CT and each of the CBCTs from the first week of treatment (DVF-based ART). In the DVF-based approach the library plans were created using combinations of the overall mean DVF (mDVF) and its standard deviation (sdDVF). In all plans for both strategies, a 5 mm isotropic margin for intra-fractional bladder motion was used. The treatment course averaged volume of the selected target volumes was calculated for each patient using each of the ART strategies. The volume ratios relative to the non-adaptive treatment for the two strategies were compared using a Wilcoxon signed rank test. Normality of the distribution of DVFs was validated on voxel level by using the Shapiro-Wilk test. The study was based on five patients with a total of 146 daily CBCT scans.

Results: The median and range of the volume ratio, compared to non-adaptive RT (PTV_{\text{ART}} / PTV_{\text{non-ART}} = 0.60 [0.48-0.65]) for DVF-based ART, compared to 0.71 [0.63-0.79] for our current clinical ART strategy (p=0.04). The number of fractions where the bladder was not completely covered with the large size plan was 5% and 10% for the clinical ART and DVF-based strategy, respectively. The Shapiro-Wilk test showed normally distributed deformation vectors over on average 76% of the entire DVFs.

Figure 1: The volume ratio PTV_{\text{ART}} / PTV_{\text{non-ART}} over the entire treatment course of each patient is shown for the clinical treatment strategy as well as the DVF-based strategy.

Conclusions: The use of DVFs from deformable registrations for creation of ART plan libraries is feasible and leads to an additional, statistically significant improvement in normal tissue sparing compared to an already highly conformal, clinically applied ART strategy.