to define margins to account for these residual uncertainties. By shortening treatment time e.g. by the use of VMAT, we expect the intra-fraction cervix-uterus motion to decrease.

OC-0547
Reproducible tumour position in voluntary visually guided inspiration breath hold lung cancer IGRT
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Purpose/Objective: Treatment-related toxicity for non-small cell lung cancer (NSCLC) patients can potentially be reduced by treating in deep inspiration breath hold (DIBH) due to increased lung volume. We investigated the reproducibility of tumour and lymph node position throughout a course of image guided radiotherapy (IGRT).

Materials and Methods: 17 patients were included prospectively. An optical marker based system with visual guidance was used for respiratory monitoring, enabling comfortable voluntary DIBHs. During a coaching session a gating window of 2-3 mm was adjusted individually to each patient's performance.

Besides imaging for radiotherapy (RT) planning, all patients had three additional imaging sessions at treatment fractions 2, 16 and 31. Each session included three consecutive DIBH CTs and one DIBH CBCT, requiring three additional DIBHs. All patients were treated in free breathing.

The reproducibility of DIBH was evaluated as intra- and inter-fractional variations in DIBH lung volume, intra-fractional uncertainty in tumour position and intra-fractional differential motion between the primary tumour and the mediastinal lymph nodes (using carina as an image registration surrogate). When evaluating intra-fractional uncertainty, the second and third daily DIBH CTs were rigidly registered on the first one, matched either on the tumour or the carina. The intra- and inter-observer uncertainty of the manual registration process was evaluated as well.

Potential impact of DIBH on the CTV-PTV margins was investigated.

Results: Lung volume increased in DIBH by 64% (median; range 35-108%; p < 0.001; paired t-test) compared to free breathing. Variations in lung volume while the patient was in DIBH were small, with intra-fractional median 1.1% (range 0.1-5.6%) and inter-fractional median 2.1% (0.3-4.6%). There was no intra-fractional trend in lung volume changes, but inter-fractionally there was a slight trend towards increased lung volume on day 31 (p<0.004), probably due to tumour shrinkage in some of the patients.

Intra- and inter-observer uncertainties in tumour and carina image registration were < 0.6 mm.

Intra-fractional uncertainty in 3D tumour position was 1.7 ± 1.4 mm (mean ± SD) and below 2 mm for 70% of cases. No trend was observed throughout the RT course. Intra-fractional differential motion between the primary tumour and the mediastinal lymph nodes was 0.0 ± 1.1 mm, indicating good geometrical agreement.

DIBH facilitated a minor margin reduction compared to RT in free breathing, by 1-3 mm, depending on extent of tumour motion in free breathing.

More details are presented in the table.

Conclusions: DIBH is a feasible approach for locally advanced NSCLC. The intra-fractional reproducibility of the tumour position remained high during the whole RT course, provided daily image guidance with tumour match is applied. Additional benefit of DIBH was absence of differential motion between the primary tumour and the mediastinal lymph nodes.

OC-0548
A comprehensive evaluation of the potential of motion mitigation using re-scanning for the Varian ProBeam system
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Purpose/Objective: To systematically evaluate the effectiveness of re-scanning for the Varian ProBeam proton therapy system in the context of liver tumour treatments.

Materials and Methods: 3 deformable motions (mean amplitude of 8/15/20mm, corresponding to Motion A/B/C in figure 1) were extracted from a 4DMRI library (Siebenthal et al 2007, Phys. Med. Biol. 52; Boye et al 2013, Med. Phys. 40) and respectively applied to 3 different liver patient geometries with varying tumour volumes (100/200/400ccm). Reference 3D plans were first calculated to patient specific ITV's (2GyRBE) using spot spacing of 4/8mm for both 1- and 3-field plans. 4D dose calculations were then performed for both regular and irregular motions, each with 4 different starting phases. For each scenario, 1-19 times adaptive-scaled, layered and volumetric rescanning were simulated using the beam profiles, scanning dynamics and beam currents of the Varian ProBeam system. In addition, 4 energy switching times (700/500/200/100ms) were modelled. All 4D dose distributions were assessed by means of the D5-95 metric in the CTV.

Results: In total, more than 100 thousand 4D calculations have been performed, covering 10 different patient, motion and dose delivery variables. Regardless of patient geometry and motion regularity, the 3-field plans can achieve D5-95 values within 6.5% of the static values without any re-
scanning for motions up to 8mm (motion A), which can be further reduced to 2% if 10x rescanning is applied per field (see results of one example patient case in figure 1). For larger motions, given the same rescane#, volumetric re-scanning results in 5% better homogeneity than layered, but requires 6.5 times longer treatment time (for 700ms energy changes). Layered re-scanning can at best achieve homogeneity within about 10% of those of the static case, while volumetric rescanning gets to within 5%, but is extremely case and rescane# specific. By reducing the energy switching time, treatment times can decrease by 68% for volumetric re-scanning (100ms energy changes), but with no further improvements on D5-D95. Motion irregularity has pronounced influence only on the two large motions (B and C) but generally has more effect on volumetric re-scanning than layered re-scanning.

Conclusions: For larger motions, layered re-scanning has been shown to be the most time efficient, whereas volumetric rescanning is more effective for retrieving dose homogeneity. However, for motions below 8mm, both techniques are equally effective, particularly if multiple field plans are used. Taking into account realistic beam and scanning parameters for the Varian ProBeam system, and based on realistic and variable breathing patterns in different liver cases, our results indicate that re-scanning is a viable motion mitigation technique for this system, particularly if layered re-scanning is used.

Improving the clinical applicability of markerless lung tumour tracking with contrast-enhanced kV imaging
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Purpose/Objective: In-room kV imaging is widely applied for intrafraction motion compensation in image-guided radiation therapy (IGRT). The low contrast of lung tumours in kV images and the overlap of high-intensity surrounding structures, such as the mediastinum, may limit the applicability of IGRT techniques in lung cancer treatments. The aim of this study is to apply a CT-based contrast enhancement method to improve markerless lung tumour tracking in kV images, thus enhancing the potential of X-ray-based image guidance in lung cancer patients.

Materials and Methods: The contrast enhancement technique, previously proposed for cone-beam CT [1] and proton radiography [2], consists in subtracting the original image a digital reconstructed radiograph (DRR) obtained by masking out the tumour from the planning CT volume. The target position is identified in the resulting contrast-enhanced (CE) image through template matching, by using as template the projection of the CT tumour volume. The application of the contrast enhancement technique to kV imaging was tested on a clinical dataset of lung cancer patients acquired with the CyberKnife Xsight Lung Tracking System (XLTs). The dataset include two patients (P1-P2) treated in three XLTs fractions and four patients (P3-P6) simulated with the XLTs but not treated, since the tumour was not visible in the stereoscopic kV images. A breath-hold CT scan was collected for each patient and five kV images per view were selected for each treatment fraction and simulation, considering for patients P1-P2 the images with the highest XLTs detection confidence.

Results: As shown in Figure 1, the contrast enhancement method allows tumour localization for all patients except P6, for whom the different diaphragm position in the breath-hold DRR and Live kV images hindered tumour visibility. The Michelson contrast [2] between the tumour and the surrounding structures was increased in the CE images by a factor of at least 2.2 compared to the Live images (Table 1). The median value of the ratio between the tumour contrast in CE images and in Live images was 4.9 and 8.6 for the lung and mediastinum background regions, respectively. For patients P1-P2, the absolute difference in the bidimensional tumour position identified with the XLTs and with the contrast enhancement technique ranged between 0.4 and 1.6 mm, with a median value of 1.2 and 1.0 mm for the horizontal and vertical image directions, respectively.