Intra-fraction motion in Plan-of-the-Day IMRT for cervical cancer assessed by pre- and post-fraction CBCT scans

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Purpose/Objective: In our institute, cervical cancer patients are treated with a library-based Plan-of-the-Day (PotD) protocol. In this protocol an in-room Cone Beam CT (CBCT) scan acquired just before dose delivery is used to select the treatment plan that is best fitting the observed anatomy. However, treatment accuracy may be compromised by shape and position changes of the cervix-uterus resulting from intra-fractional filling of the bladder and rectum, and by intra-fraction variations in patient setup. The purpose of this study is to quantify these uncertainties using pre- and post-fraction acquired CBCT scans.

Materials and Methods: Intra-fraction uncertainties were evaluated for 16 cervical cancer patients with a tip-of-uterus displacement larger than 2.5 cm as measured in an empty and full bladder planning CT scan. The treatment protocol includes a post-fraction CBCT to verify target coverage after dose delivery. In 316 pre- and post-fraction CBCT scans, the bladder, cervix-uterus, and rectum were delineated and volume changes in bladder and rectum filling were calculated. The pre- and post-fraction CBCT scans were aligned to the bony anatomy to quantify intra-fraction patient setup motion. To quantify intra-fraction displacements of the cervix-uterus, an in-house developed point-based non-rigid registration method was used to non-rigidly align the pre-fraction target shape to the post-fraction one (Fig. 1a). The intra-fraction distances were projected on the average cervix-uterus shape obtained by the non-rigid registration. Finally, intra-fraction cervix-uterus motion was correlated to volume differences in bladder.

Results: The mean time between the pre- and post-fraction CBCT scans was 20.8±13.2 minutes (1SD). Bladder volume increased on average by 62±55 ml over all treatment fractions and rectum volume increased on average 4.6±32.8 ml. Table 1 summarizes the overall mean, systematic and random error for the intra-fraction patient setup motion, and the mean, SD, and 95th percentile for the intra-fraction cervix-uterus motion. Figure 1b shows for one patient a color representation of the treatment-averaged intra-fraction distances projected on the patient’s average cervix-uterus shape. The population-mean intra-fraction cervix-uterus displacements were 3.0±1.4, 4.7±2.8, and 3.4±2.1 mm projected on the LR, CC, and AP axis, respectively. There was a significant correlation between bladder inflow rate and cervix-uterus motion (R=0.6 and p<0.01).

Conclusions: Intra-fraction patient setup motion was small. Intra-fraction motion of the cervix-uterus was considerably larger and should not be ignored in the design of PotD strategies. For example, the results of this study can be used...
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.

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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.

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A comprehensive evaluation of the potential of motion mitigation using re-scanning for the Varian ProBeam proton therapy system in the context of liver tumour treatments

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**Purpose/Objective:** To systematically evaluate the effectiveness of re-scanning for the Varian ProBeam PBS 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-