visibility in a lung phantom using 2D and 3D x-ray imaging was previously shown. We report results and experiences from the study examining the performance (structural - and geometrical stability) of the liquid marker during radiotherapy of patients with non-small cell lung cancer (NSCLC) in free breathing (FB) or deep inspiration breath hold (DIBH).

Material and Methods: Fifteen patients had markers implanted into the primary tumour and/or involved lymph nodes. Cone-beam computed tomography (CBCT) images were acquired daily during the course of radiotherapy (66 Gy / 33 fractions). The fiducial markers were contoured automatically on all the daily acquired images, using a 400 Hounsfield Units (HU) level as threshold, in the treatment planning system Eclipse (v. 13.0), the data was retrieved and analysed using Eclipse scripting API and Matlab v2014b, respectively. The stability of the marker inside the tumour and the lymph nodes was evaluated visually. The structural stability of the marker regarding volume and radio-opacity was evaluated as physical measured volume and mean HU, analysed over time. Furthermore the positional stability of all markers was analysed by weekly measurements of the change in global mean HU was larger for all tumours and the lymph nodes.

Results: Two patients did not receive radiotherapy and thus 13 patients with 29 markers were analysed (9 injected into tumours and 20 injected into lymph nodes). Ten patients were treated in DIBH and three in FB. All injected markers stayed in the injected site between planning and end of treatment. The variation in global mean HU was larger for all primary tumour markers (937±227 HU, mean±SD) compared to lymph nodes markers (921±153HU). This might be because primary tumour markers (937±227 HU, mean±SD) compared to lymph nodes markers (921±153 HU, mean±SD) showed > 5 mm inter-fraction variation) were observed on a few patients. Three patients (two DIBH and one FB) showed > 5 mm inter-fraction variation in marker position relative to carina, possibly due to tumour/lymph node shrinkage or anatomical changes. They were all rescanned for treatment adaptation.

Conclusion: The liquid fiducial markers remained stable throughout the treatment course regarding position inside the target, physical volume and radio-opacity on CBCT. The BioXmark® liquid marker offers an interesting alternative to solid markers.

OC-0163 Robustness of proton RT with different beam angles towards inter-fractional motion in the pelvis

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Purpose or Objective: The benefit of proton therapy may be jeopardized by dose deterioration caused by water equivalent path length (WEPL) variations e.g. due to inter-fractional motion. The aim of this study was to explore patient- and population-specific patterns in the robustness towards inter-fractional motion for pelvic lymph node (LN) irradiation of prostate cancer patients using proton beams from different directions.

Material and Methods: Image data sets of 18 patients consisting of a planning computed tomography (pCT) and multiple repeat CT (rCT) scans with target volumes and organs at risk (ORs) outlined in all scans were used. Ray path WEPLs were computed by averaging over beams eye view WEPL maps at all possible beam angle configurations (for both gantry and couch in 5° angle intervals) considering left and right LNs separately. For 0° couch angle the mean and the standard deviation of the WEPL differences between all rCTs and the pCT WEPL map were extracted for the entire population. Finally, single beam spot scanning proton plans were optimized for all gantry angles (couch angle 0°) over the planning target volume (PTV) generated from the clinical target volume (CTV) using isotropic margin configurations (3 and 5 mm). The optimized fluence maps for the pCT for each beam angle were applied onto all rCTs and the dose distributions re-calculated, and dose differences were extracted.

Results: The WEPL analysis for the left and right section of the lymph nodes showed a general pattern of least variation around couch angle = 0°. Furthermore it showed three minima across the mean of the patient WEPL maps at couch angle = 0° for gantry angles of 0°-25°, 125-140° and 170-180° for the left section, as well as gantry angles of 180-220° and 330-355° for the right section, which also appeared to be the angles of lowest variations among patients (Fig.1). The clustering analysis of the WEPL maps at couch angle = 0° against the angles showed for the left section of the lymph nodes that the patients split into three groups from which one group of two patients showed a clearly different pattern of lower variation in the lateral and posterior angles. The other fourteen patients were closer correlated and showed highest variation for the lateral angles (Fig.1). For the right section of the lymph nodes the patients were split into two groups of nine and seven patients, where the seven had a visibly higher variation in the posterior angles as the main difference. The dose calculation results showed similar results as for the WEPL variation, e.g. for the left LNs angles around 25-35°, 100-110° and 160-170° were consistently preferable for the bowel, bladder and rectum as well as LN dose deterioration.

Conclusion: We have found that WEPL maps show population-specific patterns and that there were consistent patterns in which angles are most robust. Similar ‘robust’ angles were also found in the dose/volume analysis.
OC-0164  
Integrate range shifting in immobilisation for proton therapy: 3D printed materials characterisation

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Purpose or Objective: 3D printing technology is investigated for the purpose of patient immobilization during proton therapy. It potentially enables a merge of patient immobilization, bolus range shifting/compensator and other functions into one single patient-specific structure. Beside minimizing the lateral spread of the proton beam due to the removal of the air gap it also ensures the correct range shifting is present for each beam portal. Compared to a movable nozzle snout this reduces the risk of collision and treatment time, hence can increase cost-effectiveness of treatment delivery where the heart dose constraints were exceeded, without exceeding lung dose tolerances. Given the lack of guidelines on LAD contouring and acceptable dose constraints the secondary objective was to evaluate predictive criteria which would define the degree of benefit of DIBH.

Material and Methods: In total 9 materials used in 4 different 3D printed production techniques were subjected to testing. Samples with a nominal dimension of 20x20x80mm were 3D printed. The actual dimensions of each printed test object were measured with a calliper. The samples were compression tested according to a standardized method (ASTM D695). The composition in terms of effective atomic number (Z_eff) and relative electron density (RED) to water were derived from dual-energy CT (DE-CT) data (80kVp,Sn140kVp), allowing estimation of the stopping power ratio (SPR) to water. Range shifting and directional dependence in 3D printed materials were investigated in a 62 MeV proton beam, using radiochromic film in a Plastic Water phantom.

Results: The data of the different experiments are compiled in Table 1. Young’s moduli as low as 1 MPa and as high as 2582 MPa were seen. These experiments will be repeated after extensive radiation exposure to verify radiation hardness of the structural properties. The DE-CT decomposition yielded relative electron densities ranging from 0.62 to 1.20, and Z_eff from 6.06 up to 9.35. The calculated SPR ranged from 0.69 up to 1.21. The differences in range shifts of the obtained Bragg peaks were results of differences in SPR, and of deviations from the nominal 20 mm thickness due to printing technique geometrical tolerances. For 4 out of the 9 materials, a different orientation of the sample with respect to the beam incidence resulted in more than 5% difference in the obtained range shift. Measurements using a Bragg-peak ionization chamber will be included allowing a water equivalent thickness measurement validation of the material decomposition method with DE-CT.

<table>
<thead>
<tr>
<th>Material</th>
<th>3D-printing Production technique</th>
<th>Thickness in orthogonal directions (mm)</th>
<th>Young’s modulus (MPa)</th>
<th>SPR (b)</th>
<th>Z_eff</th>
<th>Residual range (mm)</th>
<th>Directional residual range difference (%)</th>
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<td>ABS</td>
<td>Fixed Deposition Masking (MIM)</td>
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<td>1.14</td>
<td>9.07</td>
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<td>6.6</td>
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<td>Polyurethane Foam</td>
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<td>1.14</td>
<td>7.7</td>
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<td>7.95</td>
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<td>1.00</td>
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<tr>
<td>Plastic Water</td>
<td>Plastic Water</td>
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<td>0.69</td>
<td>8.00</td>
<td>0.69</td>
<td>1.82</td>
<td>1.82</td>
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</table>

Conclusion: 3D printed materials exhibit a wide variation in structural and radiological properties. The quantification of these characteristics can be used for optimal material selection for the design of a 3D printed immobilization structure for proton therapy with integrated range shifting.

OC-0165  
Deep inspiration breath hold - can it be detrimental to the heart?

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Purpose or Objective: Deep inspiration breath hold (DIBH) is widely used internationally as a standard treatment for left sided breast cancer patients. Preliminary results from our institution suggest that there is a cohort of patients who have an increase in cardiac dose with DIBH compared to free breathing (FB). To our knowledge, there are no published studies assessing if DIBH can be a detriment in selected patients. Our primary objective was to identify patient cohorts based on the potential detriment to heart dose constraints. The secondary objective was to evaluate predictive criteria which would define the degree of benefit of DIBH.

Material and Methods: All patients who had left breast or chest wall radiotherapy and had both a FB and DIBH CT simulation scans at a single institution were selected for this study. Planning target volumes (PTV), lung, heart and left anterior descending (LAD) artery were contoured on both the FB and DIBH CT data sets. Both data sets were planned using parallel opposed tangents and dynamic wedges. Plans were prescribed either 50Gy in 25 fractions or 42.4Gy in 16 fractions. DIBH plans were considered acceptable for treatment delivery where the heart dose constraints were reduced, without exceeding lung dose tolerances. Given the lack of guidelines on LAD contouring and acceptable dose constraints, LAD was contoured and doses recorded for...