computation time. Thus, in order to gain efficiency, a new macro MC (MMC) method for proton dose calculations has been developed. **Materials and Methods:** The MMC transport is based on a local to global MC approach for the local simulations and the GEANT4 is used for the global simulation. These simulations consist of mono-energetic proton pencil beams impinging perpendicularly on slabs of different materials (water, air, lung, adipose, muscle, spongiosa, cortical bone) as well as of different thicknesses. During the local simulation the physical characteristics such as lateral displacement, direction distribution and energy loss have been scored for primary and secondary particles. Thereby multiple scattering, ionization as well as elastic and inelastic interactions have been taken into account. The scored data from appropriate slabs is then used for the MMC particle transport in the global simulation. During this simulation, the energy loss along the path between entrance and exit positions of the selected slab is calculated. Additionally, the radiation transport of neutrons, also based on local simulations, as well as the secondary ions are included into the MMC transport for the dose calculations. In order to validate the MMC transport, calculated dose distributions using GEANT4 and the MMC transport have been compared. For this purpose, dose distributions for different mono-energetic proton beams impinging on different phantoms including homogeneous and inhomogeneous situations as well as on a patient CT data set have been calculated. **Results:** For the calculated integral depth dose curves the agreement is better than 1% or 1 mm for all pencil beams and phantoms considered. For the dose profiles the agreement is within 1% or 1 mm in all phantoms for all energies and depths. The same level of agreement is found for the depth dose curves and profiles using a broad incident proton beam on the phantoms. The comparison of the dose distribution calculated using either GEANT4 or MMC in the lung, adipose, muscle, spongiosa, cortical bone) as well as of different pencil beams and phantoms is better than 1% or 1 mm for all pencil beams and phantoms considered. For the dose profiles the agreement is within 1% or 1 mm in all phantoms for all energies and depths. The same level of agreement is found for the depth dose curves and profiles using a broad incident proton beam on the phantoms. The comparison of the dose distribution calculated using either GEANT4 or MMC in the patient also shows an agreement of within 1% or 1 mm. The efficiency of MMC is up to 200 times higher than for GEANT4. **Conclusions:** The agreement found in the comparisons of the calculated dose distributions demonstrates that the newly developed MMC transport for proton beams is suitable for very accurate and efficient dose calculations. In future, the MMC transport will be coupled with a beam model in order to allow treatment planning for radiotherapy with proton beams. This work was supported by Varian Medical Systems.

**OC-0440**

**Modeling of continuous patient deformation using Monte Carlo simulation**

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**Purpose/Objective:** A key challenge of dynamic radiotherapy treatment techniques is the difficulty of incorporating intra-fraction organ deformation in the dose calculation algorithms to generate more accurate and realistic dose distributions. The aim of this study is to use Monte Carlo simulation methods to calculate realistic dose distributions that include both the continuous deformation of organs and the continuous motion of treatment machine components for volumetric modulated arc therapy and helical tomotherapy treatments. **Materials and Methods:** We have developed a 4D Monte Carlo-based calculation method capable of simulating a wide variety of treatment techniques without the need to resort to discretisation approximations. The method includes: e.g. central simulation of geometry parameters using a random time variable associated to each simulated particle. We have previously presented a method to model the continuous motion of treatment machine components. In this study, the DOXY2znrc user code was further modified to account for the continuous intra-fraction deformation of patient geometry. More specifically, we have implemented two methods to update the transport grid densities as a function of time and two methods to map the energy deposited in the time dependent transport grid back to a reference grid. **Results:** The density mapping method to update the transport grid densities as a function of time was found to be superior to the density interpolation method when the patient motion is much greater than the voxel size. The voxel average method to map the energy deposited in the time dependent transport grid back to a reference grid was found to be superior to the voxel center method but requires the appropriate use of energy/mass corrections factors. Verification with a mathematical phantom and measurements with a moving phantom show that the methods were appropriately implemented in the EGSnrc user codes.

**Conclusions:** We have developed a 4D Monte Carlo-based calculation method that successfully models continuous deformation of organs and continuous motion of machine components.

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**OC-0441**

Introduction of a fast 4D PET/CT protocol for radiotherapy planning in a multidisciplinary approach

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**Purpose/Objective:** Breathing motion induces artifacts in 3D PET that lower the geometric and quantitative accuracy required for treatment planning. On the other hand, acquisition of 4D PET typically takes much more time. Our purpose was to implement a fast protocol for 4D PET/CT acquisition for radiotherapy treatment planning of lung tumors. **Materials and Methods:** Radiotherapy technologists (RTT) and nuclear medicine technologists (NMT) closely collaborated to develop the clinical protocol described below. The RTT is responsible for patient positioning and 4D reconstruction of the data, whereas the NMT is responsible for the PET/CT acquisition and 3D reconstruction. Patients were scanned in treatment position on a flat table top with arm and knee support on a Phillips PET/CT scanner. An air bellows belt (Mayo Clinic) was placed around the upper abdomen to register the respiratory signal. The acquisition protocol consisted of 1) a whole body 3D CT, 2) a fast whole body 4D PET with a 2 min scan time per bed position, identical to our standard 3D PET protocol and 3) a 4D CT of the thorax. The PET scan is reconstructed in 4D using the 4D CT for attenuation correction for the thorax region; and a regular 3D PET is reconstructed from the same data for the whole body scan. The 4D PET is subsequently motion compensated (MC). To that end, first the patient specific motion pattern is derived from the 4D CT using deformable image registration. Subsequently, the deformation is compensated in all phases of the 4D PET scan. Finally, summing all phase bins results in a 3D MC PET. We determined the SUVmax value in the tumor and the size of the dominant tumor region, i.e. the region enclosed by the 50% SUVmax region. To clinically validate this novel protocol, 20 lung cancer patients were included in a feasibility study. Both the logistics and image quality were evaluated. **Results:** During protocol development, RTTs became aware of the proper handling of a radioactive patient, the importance of instructing patients before FDG administration and in keeping a distance whenever possible. NMT became aware of the importance of proper patient positioning and respiratory monitoring systems. The novel 4D-PET/CT procedure took 6 (± 3) min more than a regular 3D PET/CT acquisition. This is 15-30 min less than a standard 4D PET/CT procedure. Compared to 3D PET images (figure 1b) and the single phase images (1a), the MC PET images (1c) provided better contrast and sharper images. Higher maximum SUV values (up to 25%) were detected in the tumor (mean increase 5.4% (SD=7.16)) and the apparent size of the tumor was up to 46% smaller (mean 5.47% (SD=9.67)). **Conclusions:** A multidisciplinary approach in protocol development and image acquisition is essential to derive safe and efficient workflows. Our novel 4D PET/CT acquisition protocol saves 15-30 minutes acquisition time and improved PET image quality. This approach can also be implemented for other organs affected by respiratory movements such as the liver.
A comparison of the variation of rectal size for different bowel preparation regimes for prostate irradiation.

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Purpose/Objective: Variation in rectal volume can impact greatly on the position of the prostate and seminal vesicles. Variation in rectal volume whilst delivering a course of radiotherapy may lead to partial treatment of the expected volume or increased radiation side effects and late complications due to irradiation of the anterior rectum wall. It is therefore desirable for the rectal volume to be consistent, allowing accurate and reproducible delivery of prostate irradiation. In response to the introduction of IMRT within our institution and the number of patient rescans due to rectal size, the administration of micro enemas was introduced. An audit was conducted to assess the impact of micro enemas on rectal volume and variation, in comparison with other bowel preparation used.

Materials and Methods: An audit was conducted on a sample of 35 prostate patients receiving conformal radiotherapy or IMRT. Within this sample patients were administering micro enemas, taking bulk forming laxatives (fybogel) or having no bowel preparation prior to treatment. Patients were imaged using CBCT following a NAL protocol with weekly imaging thereafter. For each image, average and superior rectum size measurement were taken using the XVI software. The average and standard deviation of the average and superior rectum sizes were calculated and the ratio of standard deviation to mean was used as a measure of change. The data collected was analysed to compare the number of images taken for each set of patients and to compare the variation in rectum size for each of sets of patients.

Results: In our audit the average number of images taken per patient was not significantly different for patients administering micro enemas (12.58) than those not administering micro enemas (12.86). The maximum number of images taken for a non micro enema patient (27) however was significantly more than for a micro enema patient (17). When analysing the change in rectal volume for the different groups of patients the change in average rectal sizes for patients administering micro enema was 10.4±4.8% whilst the patients taking bulk forming laxatives (fybogel) or having no bowel preparation prior to treatment was 13.0±3.9% and the superior rectal sizes were 12.1±5.7% and 13.4±4.4%. Using a one sided students T-test the difference to treatment was 13.0%±3.9% and the superior rectal sizes were 10.4%±4.8% whilst the patients taking bulk forming laxatives (fybogel) or having no bowel preparation prior to treatment was 12.5±8% than those not administering micro enemas (12.86).

Conclusions: In conclusion the audit shows the administration of micro enemas is more favourable bowel preparation giving less variation in rectal volume. However due to the sample size the result was not statistically significant. A collection of further data to increase the sample size is planned, in order to obtain a more definitive result to inform our institution of the more favourable bowel preparation regime.

OC-0443
Plane selection for cervix patients inter-observer study: Is CBCT image quality good enough to make a decision?

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Purpose/Objective: In cervix patients, day-to-day variation in bladder filling often causes large deformation of the uterus, which cannot be corrected with a table adjustment. Multiple plans tailored to a range of plausible uterine shapes that are made prior to treatment can mitigate these variations, by selecting the best-fitting plan based on daily Cone Beam CT (CBCT) scans. This strategy, however, requires adequate visibility of the regions of interest on CBCT. The purpose of this study was to evaluate the consistency between observers in the optimal plan for cervix patients.

Materials and Methods: The clinical target volumes (CTV) for this study were generated by acquiring full and empty bladder pre-treatment CT scans for random selection of 4 consecutive patients. Cervix and uterus were delineated on both scans. Using deformable registration of these delineations, two intermediate and two extrapolated delineations were generated forming a library of 6 plans: extra-empty, empty, intermediate 1, intermediate 2, full and extra-full. The average distance between tip-of-uterus and CTV in a library was 12 mm, with a standard deviation of 6 mm. These patients underwent regular treatment, for which daily CBCT scans were acquired prior to treatment. Retrospectively these CBCT scans (91 in total) were used to simulate plan selection with the library of CTV's.

For this study we performed a baseline measurement with 9 observers (all RTTs). After this measurement, these observers determined the golden standard together with an experienced radiation oncologist, during a workshop. One month later, the second measurement was conducted. Both structure selections were compared with the golden standard.

Results: For the first round of observations, 77.2% of plan selections were in accordance with the gold standard. 22.5% of all selections were 1 plan off. 0.3% were 2 plans off. After the workshop, 83.9% of all decisions were in accordance with the gold standard. 16.0 % of all selections were 1 plan off. One observation (0.1%) was more than 1 plan from the gold standard. The workshop showed that the inconsistency in plan selection often was not caused by the image quality. It was rather because of shape changes that were not captured on the pre treatment scans like differences in rectal filling or regression of tumours.

Conclusions: Observers showed large consistency in selecting the structure that would fit best on the anatomy of that day, even with the less-than-perfect image quality of the CBCT. Plan selection based on daily CBCT by RTT for cervix patients is therefore feasible. Occasionally selecting a plan adjacent to the gold standard is deemed acceptable in fractionated RT. This chance will be further reduced by sharing the responsibility of selecting a plan in a clinical workflow between two RTTs. Having a workshop had a positive outcome on the inter-observer variation.

OC-0444
From bone match to soft tissue match using daily CBCT for lung cancer patients. How do we implement this change?

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Purpose/Objective: In our department daily CBCT matching using bony structures is used when treating most diagnose groups. We deliver approximately 2600 curative lung cancer treatments yearly. Studies and local calculations have shown that matching on the tumour volume instead of bones improves the precision of patient setup with the possibility of shrinking safety margins and sparing dose to organs at risk. Hereby, it is possible to escalate the dose, which may improve local tumour control. Based on the daily CBCTs, this study compares match on bones to match on the tumour volume looking at deviations measured for both target and normal tissue. How will it be possible for the Radiotherapists (RTTs) to evaluate the soft tissue match? What is the challenge in regard to the normal tissue? The purpose of this study is to find a method for implementing match on the soft tissue.

Materials and Methods: CBCTs from the daily IGRT used for setup of our curative lung cancer patients were retrospectively analysed in Offline Review (Varian Medical Systems). We reviewed 30 consecutive lung cancer patients with local advanced disease treated in the period from the 15th of November 2011 to the 31st of May 2012. A standard three board (Q-fix) was used for fixation of all patients at CT, PET-CT, CBCT and treatment. Bone match and soft tissue match were performed using the CBCTs of session 1, 6, 11, 16, 21, 26, 30 for all patients. The ITV, which was contoured as the CTV + 5 mm, was used for the soft tissue match. All deviations above 5 mm observed for both target and selected normal tissue structures were recorded.