Figure 1. Schematic view of the experimental set-up and dose profiles at 129mm depth averaged over 4mm for experimental data (red circles), Astroid (left filled green squares), Gate G4.9.5 (green circles), 4P (orange squares), MCSQUARE (left filled red circles), Raystation PBA (purple triangles) and Raystation MC (filled triangles).

Table 1. γ-index passing rates [%]	5%/3mm	5%/1mm	3%/3mm	3%/1mm	2%/2mm
Astroid (PBA)	50.46	50.46	40.37	40.37	37.46
Gate	69.69	65.31	68.13	60.94	62.81
4P	84.29	79.85	82.98	76.97	68.83
MCSQUARE	82.73	81.17	71.22	65.46	64.14
Raystation PBA	37.19	34.69	30.31	25	17.81
Raystation MC	77.81	70.94	73.75	67.19	65.31

Conclusions: An experimental set-up for dose determination in heterogeneous media in proton beam therapy was developed. Various dose engines using different techniques and computer technologies were compared to data. Overall, MC simulations show better agreement with experimental data than pencil beam algorithms, including the superfast MCSQUARE and Raysearch-MC, which is promising for future clinical use. The data obtained in the phantom experiment will be used as a basis to interpret disagreements between dose distributions calculated by MC and analytical algorithms in clinical cases.

PO-0889
A multi-institutional study for the evaluation of DIR algorithms for structure delineation in virtual phantoms
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Purpose/Objective: This study investigates the accuracy of various algorithms for deformable image registration (DIR), to propagate regions of interest (ROIs) in virtual phantoms using different commercial systems. This work is a preliminary step to provide a consistent quality assurance check among different institutions on the use of DIR before its clinical implementation for ROIs and dose propagation in adaptive radiotherapy.

Materials and Methods: Ten Italian institutions with 4 available commercial solutions provided data to assess the agreement of DIR-propagated ROIs with automatically drown ROIs considered as ground-truth for the comparison. The DIR algorithms were tested on a specific virtual phantom made of three cylinders of different gray density inside a uniform cube phantom (CT1, Fig 1a) with two data sets obtained by specific Deformation Vector Field (DVF) applied to the reference data set (CT2 and CT3). The different software used in this study are based on various algorithms: a multi-resolution modified basis Spline (B-Spline), a radial basis function, an intensity-based free-form, an Hybrid intensity and structure based and a Biomechanical model based. The DIR-mapped ROIs were then compared with the reference ROIs using the Dice Similarity Coefficent (DSC) and the Mean of the Hausdorff Distance (MHD).

Results: Figure 1a shows examples of the DIR-propagated ROIs while figure 1b shows the DSC for the three considered ROIs. Mean values for DSC were 0.93±0.08, 0.94±0.04 and 0.92±0.12 respectively for the three considered ROIs (Cylinder 1, Cylinder 2 and Cylinder 3) on CT2; 0.93±0.08, 0.94±0.04 and 0.94±0.11 were the average values on CT3. Regarding MHD values we obtain 0.14±0.23, 0.19±0.31 and 0.22±0.47 for CT2 while 0.09±0.15, 0.08±0.06 and 0.17±0.39 are the values obtained for CT3. Minimum and maximum values for DSC and MHD resulted respectively 0.65 and 1.23mm
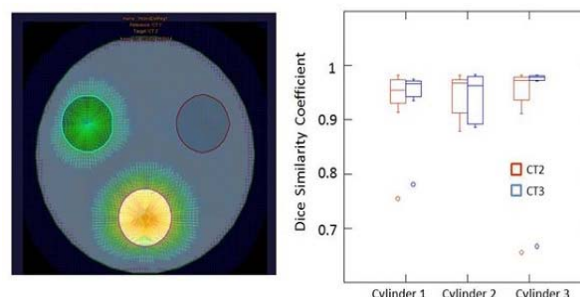

Figure 1. a) b)

Conclusions: Although the different algorithms used in this study are significantly dissimilar in their approach to

calculate deformation fields, little difference in Dice and MSHD was observed showing acceptable accuracy with all the different commercial platforms analyzed in this study. However, in some specific cases the single user has to improve the accuracy of DIR also for such easy DVFs showing the importance of multi institutional approach. Additional research is currently underway using virtual anthropomorphic phantoms to develop further tools that will aid physicians in understanding the impact of DIR uncertainties on dose mapping .

PO-0890
### Mixed beam inverse planning strategies
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Purpose/Objective: Modulated electron radiation therapy (MERT) involves the delivery of electron beams with a dynamic collimation device such as the few leaf electron collimator (FLEC) or an electron multi-leaf collimator (EMLC). When planning a MERT case, hundreds to thousands of electron dose distributions must be generated before optimisation can proceed, and charged particle dose calculation with general-purpose Monte Carlo (MC) simulation codes is too lengthy to create plans in a clinically feasible time frame. In addition, with the trajectory editing capabilities of modern linear accelerators, dynamic delivery incorporating gantry and couch movement is made possible for MERT, which allows for an increase in plan quality at the cost of expanding the number of degrees of freedom to optimise in order to create plans.

Materials and Methods: We implemented a pre-calculated Monte Carlo (PMC) method on graphical processing units (GPU) to greatly reduce dose calculation times while preserving the accuracy of general purpose MC codes. The PMC method involves pre-calculating charged particle tracks in various media such as water, bone, lung and air, and storing the data in a database. These tracks are then recycled to quickly produce dose distributions with minimal losses in accuracy over conventional MC codes in clinical situations.

With the ability to create dose distributions rapidly, we then created an optimisation algorithm to produce the highest quality plans with the lowest number of fields by using a column generation approach. Current work is being done on angle selection and trajectory optimisation. As a preliminary step, a basic algorithm was created to resolve the optimal angles of electron beam delivery by first eliminating all angles where the beam would travel further than its R_{50} value. Each beamlet within the angle was then scored based a simple integration of the percent depth dose curve within the target, with any contribution inside organs at risk being penalised. The highest scoring beamlets were selected for optimisation.

Results: The PMC method resulted in efficiency increases of 300-800 times over DOSXYZnrc depending on the simulation geometry. The RMS error between PMC and DOSXYZnrc simulations was below 1% for both homogeneous and heterogeneous benchmark cases. The efficiency increase allows dose distributions to be calculated rapidly enough for treatment planning purposes.
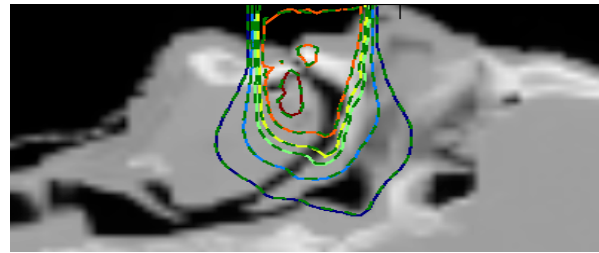
The preliminary method for angle selection adequately reduced the number of optimisable beamlets to a computational manageable amount. Further work will include fully optimising MERT plans and the addition of photon fields.

Conclusions: With the ability to create electron plans using all the degrees of freedom of a linac, a mixed beam approach incorporating both electrons and photons in the optimisation process could allow the creation of superior plans with higher target conformity and lower dose to organs at risk.

PO-0891
Experimental verification of 4DCT-based dose accumulation for IMRT and VMAT beam techniques in lung and liver SBRT
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Purpose/Objective: SBRT aims to deliver high dose in few fractions, thus requiring high confidence in accuracy of the treatment planning and delivery process. Respiratory motion is usually considered by 4DCT imaging to delineate the internal target volume (ITV) as a basis of the PTV definition. However, dose calculation is widely performed on average CT (AvCT) data excluding motion patterns. Dose accumulation methods are currently under development to account for motion induced under- and over-dosages in the PTV. This study aims to examine dose accumulation methods for SBRT plans of liver and lung lesions.

Materials and Methods: SBRT liver and lung treatment plans were created for a 4D motion phantom using IMRT and VMAT beam techniques with normal/high dose modulation (VARIAN Eclipse 10, AAA dose algorithm). The phantom has an abdominal shape and consists of solid-water with bone, lung and tumor inserts. The PTV includes the CTV plus 2cm safety margin. Dose distribution deviations through tumor motion and interplay effects were determined by comparing 2D dose measurements (PTW Octavius 1000 SRS) with and without phantom motion during dose delivery. Simulation of corresponding motion-induced dose changes were accomplished by rigidly moving the target within the AvCT based dose distribution. To account for VMAT interplay effects, the arcs were divided into 5° sub-arcs with approx. 2s beam-on time. Tumor motion trajectories cover sinusoidal patterns in CC, AP, and LAT as well as tumor trajectories extracted from clinical 4DCT data.

Results: Oft-reported dose blurring surrounding the PTV was observed. IMRT beam techniques resulted in greater dose homogeneity covering the target volume compared to VMAT.