Radical treatment techniques such as stereotactic body radiation therapy (SBRT) are becoming popular and they involve delivery of large doses in fewer fractions. Due to this feature of SBRT, a high-resolution, pre-treatment dose verification method that makes use of a 3D patient representation would be appropriate. Such a technique will provide additional information about dose delivered to the target volume(s) and organs-at-risk (OARs) in the patient volume compared to 2D verification methods. In this work, we investigate an electronic portal imaging device (EPID) based pre-treatment QA method which provides an accurate reconstruction of the 3D-dose distribution in the patient model. Customized patient plans are delivered ‘in air’ and the portal images are collected using the EPID in cine mode. The images are then analysed to determine an estimate of the incident energy fluence. This is then passed to a collapsed-cone convolution dose algorithm which reconstructs a 3D patient dose estimate on the CT imaging dataset. To date, the method has been applied to 5 SBRT patient plans. Reconstructed doses were compared to those calculated by the TPS. Reconstructed mean doses were mostly within 3% of those in the TPS. DVHs of target volumes and OARs compared well. The Chi pass rates using 3%/3mm in the high dose region are greater than 97% in all cases. These initial results demonstrate clinical feasibility and utility of a robust, efficient, effective and convenient pre-treatment QA method using EPID. Research sponsored in part by Varian Medical Systems.
An emerging treatment option for inoperable primary renal cell carcinoma and oligometastatic adrenal lesions is stereotactic body radiation therapy (SBRT). At our center, kidney SBRT treatments were originally planned with IMRT. The goal was to plan future patients using VMAT to improve treatment delivery efficiency. The purpose of this work was twofold: 1) to develop a VMAT class solution for the treatment of kidney SBRT; and, 2) to assess VMAT plan quality when compared to IMRT plans. Five patients treated with IMRT for kidney SBRT were reviewed and replanned in Pinnacle using a single VMAT arc with a 15° collimator rotation, constrained leaf motion and 4° gantry spacing. In comparison, IMRT plans utilized 7-9 6MV beams, with various collimator rotations and up to 2 non-coplanar beams for maximum organ-at-risk (OAR) sparing. Comparisons were made concerning target volume conformity, homogeneity, dose to OARs, treatment time and monitor units (MUs). There was no difference in MUs; however, VMAT reduced the treatment time from 13.0±2.6min, for IMRT, to 4.0±0.9min. The collection of target and OAR constraints and SmartArc parameters, produced a class solution that generated VMAT plans with increased target homogeneity and improved 95% conformity index calculated at <1.2. In general, the VMAT plans displayed a reduced maximum point dose to nearby OARs with increased intermediate dose to distant OARs. Overall, the introduction of a VMAT class solution for kidney SBRT improves efficiency by reducing treatment planning and delivery time.
Dosmetric evaluation of single versus multi-arc VMAT for lung SBRT

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Five non-small cell lung cancer patients previously treated with stereotactic body radiation therapy using the VMAT (volumetric modulated arc therapy) technique were selected for this retrospective study. Plans were re-optimized using Pinnacle treatment planning system (v9.0, Philips Medical), with the basis for comparison a two-arc plan involving a 360° arc in addition to a 90° arc with a couch kick. Additionally a single 360° arc was optimized for comparison, as well as a partial arc covering ~230°, avoiding the contralateral lung. All plans met target coverage criteria as dictated by RTOG0236. Plans were evaluated based on conformity, sparing of organs at risk and practical considerations of delivery. Conformity was best in the two-arc plan; however the decrease seen in one- and partial arc plans was not statistically significant as tested by the Wilcoxon rank sum test. The partial-arc plan resulted in the lowest esophagus and trachea dose and the highest heart dose, however none of the plans exceeded organ at risk tolerances for lung SBRT. Partial arcs resulted in plans with slightly cooler dose distributions, a decrease in low dose spillage and an overall lower mean lung dose. The decrease in treatment time was on average 36 and 40 seconds for single and partial arcs, respectively, with partial arcs requiring the lowest number of MUs. The slight decrease in conformity seen in one-arc plans is offset by an increase in efficiency (optimization and treatment time, MUs) making the implementation of a single or partial-arc treatment technique clinically desirable.
Evaluation of VMAT interplay effect for lung SABR using TrueBeam 10XFFF beam

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During a VMAT treatment delivery, the interplay effect between the moving target and varying machine parameters result in dose distributions that are different from those initially planned. In this work, we investigate this effect for lung SABR by using 4D dose calculation derived from the Varian TrueBeam trajectory log file. The impact of treatment start phase is also evaluated. A QUASAR™ respiratory motion phantom was scanned with motion amplitudes of 0.4, 1, 2 and 3 cm with a 4 second period. MIP and the average dataset were generated from the 4DCT. A static CT was also acquired with the tumor in its centre position. Plans were optimized with 10X FFF beam until PTV and fictitious critical structures met the dose constraints. Ten temporally interleaved plans were constructed with the temporal machine parameter information from the trajectory log file. Ten plans were calculated with isocentre shifts to simulate respiratory motion and then summed. For each motion amplitude, three separate sum plans were created with various phase shifts (no phase shift, maximum inhalation and maximum exhalation) to assess the impact of treatment start phase. For all the phase shifts investigated, the DVH for PTV demonstrated good dose coverage. However, a careful review of slice by slice plan comparison indicates dose “holes” are observed within PTV. The PTV dose difference between various treatment start phases can be as high as 19%. This assumes all treatment fractions have identical treatment start phase. Our future work includes evaluation of interplay effect for various breathing periods.
The Development of Quality Assurance Methods for Trajectory based Cranial SRS Treatments

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The goal of this work was to develop and validate non-planar linac beam trajectories defined by the dynamic motion of the gantry, couch, jaws, collimator and MLCs. This was conducted on the Varian TrueBeam linac by taking advantage of the linac’s advanced control features in a non-clinical mode (termed developers mode). In this work, we present quality assurance methods that we have developed to test for the positional and temporal accuracy of the linac’s moving components. The first QA method focuses on the coordination of couch and gantry. For this test, we developed a cylindrical phantom which has a film insert. Using this phantom we delivered a plan with dynamic motion of the couch and gantry. We found the mean absolute deviation of the entrance position from its expected value to be 0.5mm, with a standard deviation of 0.5mm. This was within the tolerances set by the machine’s mechanical accuracy and the setup accuracy of the phantom. We also present an altered picket fence test which has added dynamic and simultaneous rotations of the couch and the collimator. While the test was shown to be sensitive enough to discern errors 1° and greater, we were unable to identify any errors in the coordination of the linac collimator and couch. When operating under normal conditions, the Varian TrueBeam linac was able to pass both tests and is within tolerances acceptable for complex trajectory based treatments.
Dosimetric Comparison of 3D Conformal, Flattened and Flattening Filter-Free TrueBeam RapidArc Planning for Lung SBRT

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The major advantages of the VMAT SBRT plans compared to the conventional 3D conformal plan include faster delivery and improved target dose conformity. This study quantifies the dosimetric differences among 3D conformal plan; flattened beam and flattening filter-free (FFF) beam RapidArc Plans for lung SBRT. Five early stage lung cancer patients with various tumor positions and sizes previously treated with 3D non-coplanar SBRT were randomly selected. 4DCT was used for each patient to determine the internal target volume. Abdominal compression was applied to minimize respiratory motion for SBRT patients. For treatment planning, a 5 mm margin was given to the ITV to generate a planning target volume. The prescription dose was 48 Gy in 4 fractions and normalized to 95% of the PTV. Organs at risk (OAR) included spinal cord, esophagus, heart, trachea, bilateral lung, and great vessels. Optimization constraints were set to meet the criteria of the RTOG-0915 protocol. All VMAT plans were optimized with the RapidArc technique using two full arcs in Eclipse treatment planning system. The RapidArc SBRT plans with flattened 6MV beam and 6MV FFF beam were generated and dosimetric results were compared with the previous treated 3D non-coplanar plans. RapidArc plans demonstrated better conformity to target, sharper dose fall-off in normal tissues and lower dose to normal lung and other OARs than the 3D conformal plans. RapidArc SBRT for FFF beam showed comparable target conformity, adequate tumor dose, and clinically acceptable DVHs of OARs to flattened beams and significantly reduced treatment delivery time.
Suitability of a plastic scintillator dosimeter for composite clinical fields delivered using the Cyberknife robotic radiosurgery system

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Plastic scintillation dosimeters (PSDs) have favourable characteristics for small and composite field dosimetry in radiosurgery, however, imperfect corrections for the Čerenkov radiation contamination could limit their accuracy for complex deliveries. In this work, we characterize the dose and dose-rate linearity, directional dependence, and compare output factors with other stereotactic detectors for a new commercially available PSD (Exradin W1). We provide some preliminary comparisons of planned and measured dose for composite fields delivered clinically by a Cyberknife radiosurgery system. The W1 detector shows good linearity with dose (<0.5%) and dose rate (<0.8%) relative to the signal obtained using an ion chamber under the same conditions. A maximum difference of 2% was observed depending on the detector’s angular orientation. Output factors for all detectors agree within a range of ±3.2% and ±1.5% for the 5 and 7.5 mm collimators, respectively, provided Monte-Carlo corrections for detector effects are applied to diode and ion chambers (without corrections the range is ±5.5% and ±3.1% for these two collimators). For clinical beam deliveries using 5 and 7.5 mm collimators, four of the six patients showed better agreement with planned dose for the PSD detector compared to a micro ion chamber. Two of the six patients investigated, however, showed 5% differences between PSD and planned dose, film measurements and the ratio of PSD and micro ion chamber signal suggest that further investigation is warranted for these plans. The W1 detector is a promising tool for stereotactic plan verification under the challenging dosimetric conditions of stereotactic radiosurgery.
Stereotactic Ablative Radiotherapy (SABR) for low, intermediate and high risk prostate cancer using Volumetric Modulated Arc Therapy (VMAT) with a 10x Flattening Filter Free (FFF) beam

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Purpose:

To determine the feasibility of using Volumetric Modulated Arc Therapy (VMAT) with a 10x Flattening Filter Free (FFF) beam for Stereotactic Ablative Radiotherapy (SABR) for low, intermediate and high risk prostate cancer.

Methods and Materials:

Ten anonymized patient CT data sets were used in this planning study. For each patient CT data set, three sets of contours were generated: 1) low risk, 2) intermediate risk, and 3) high risk scenarios. For each scenario, a single-arc and a double-arc VMAT treatment plans were created. Plans were generated with the Varian Eclipse™ treatment planning system for a Varian TrueBeam™ linac equipped with Millenium 120 MLC. Plans were created using a 10x-FFF beam with a maximum dose rate of 2400 MU/min. Dose prescription was 36.25Gy/5 fractions with the planning objective of covering 99% of the Planning Target Volume with the 95% of the prescription dose. Normal tissue constraints were based on provincial prostate SABR planning guidelines, derived from national and international prostate SABR protocols. Plans were evaluated and compared in terms of: 1) dosimetric plan quality, and 2) treatment delivery efficiency.

Results:

Both single-arc and double-arc VMAT plans were able to meet the planning goals for low, intermediate and high risk scenarios. No significant dosimetric differences were observed between the plans. However, the treatment time was significantly lower for a single-arc VMAT plans.

Conclusions:

Prostate SABR treatments are feasible with 10x-FFF VMAT technique. A single-arc VMAT offers equivalent dosimetric plan quality and a superior treatment delivery efficiency, compared to a double-arc VMAT.
The Cyberknife® robotic stereotactic body radiation therapy system is well-suited for treating liver lesions over the respiratory cycle as it includes room-mounted orthogonal x-ray tracking of internal fiducial markers and optical tracking of external markers. The Synchrony™ software generates a model of internal target positions during patient respiration and correlates it to the external optical tracking system for real-time optical-based position corrections of the linear accelerator during beam delivery. Although clinical studies have provided preliminary outcomes for liver lesions treated with the Cyberknife system, to date, there is little data demonstrating the ability of the Synchrony software to track targets in the liver, which deforms throughout the respiratory cycle. In this study, we investigated the respiratory motion model performance for predicting tumour motion. We conducted a retrospective analysis of fifteen liver cancer patients treated on the Cyberknife using the Synchrony optical tracking system. We analyzed Cyberknife tracking information stored in the log files to extract the left-right (LR), anterior-posterior (AP) and superior-inferior (SI) correlation errors between the model-predicted position and the internal fiducial centroid position determined by x-ray imaging. Only translational tracking and corrections were applied during treatment. Overall, the correlation errors were greatest in the SI direction. We calculated radial correlation errors, and determined that the 95th, 98th and 99th percentile errors were 3.4 mm, 4.4 mm and 5.1 mm, respectively. Based on translational correlation tracking errors we expect the clinical target volume will be within 3.4 mm of the planning target volume for 95 % of beam delivery time.