The evaluation of treatment plans for compliance with prescribed treatment objectives is often a manual process that is susceptible to errors or omissions arising from non-standardized procedures, time constraints or human factors. In an effort to improve the consistency and accuracy of this process we have developed software that automates the comparison between patient dose-volume histograms (DVH) and pre-defined dosimetric constraints. Treatment objectives and constraints (i.e. care plans) are stored in a database, categorized by disease site. Constraints have optional soft and hard limits which can be either modified or overridden on a per-patient basis at the discretion of the clinician. Configurable plugins automate the import of patient DVH data from the treatment planning system (currently supporting Monaco, XiO, and TomoTherapy). An optional report summarizing the results of a comparison can be generated for inclusion in the patient treatment record. Results from each comparison are stored in a database enabling the analysis of program wide care plan compliance, average or mean doses to critical organs, or other values of interest. The software is run on a centralized server and accessed by users through any modern web browser. It will be released as free, open source software in the near future.
Treatment planning workflow for very high-energy electron beam radiotherapy

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\textbf{Purpose}: To develop treatment planning workflow for rapid radiotherapy delivered with very-high energy electron (VHEE) scanning beam.

\textbf{Methods}: VHEE radiotherapy treatment planning was performed by linking Monte Carlo (MC) dose calculations with inverse optimization in a research version of RayStation. In order to study a number of treatment parameters, a Matlab graphical user interface (GUI) for calculation of VHEE beamlet dose was developed. Through the GUI, EGSnrc MC simulations were run for a number of beam energies, number of beams, beamlet spot and grid sizes, and machine bore sizes. VHEE plans for a pediatric patient with a 4.3 cm\textsuperscript{3} brain target optimized with spot-scanning algorithm in RayStation were compared to the clinically delivered 6 MV VMAT plan.

\textbf{Results and Discussion}: VHEE beam energy had the largest effect on the quality of dose distributions. For the same target dose, the mean doses to critical organs decreased by 10-15\% when planned with 100 MeV compared to 60 MeV. VHEE plans calculated with 36 beams outperformed plans calculated with 13 and 17 beams. While beamlet spacing and bore size had a small effect on VHEE dose distributions, 0.1-3mm beamlet sizes resulted in identical dose distributions. Critical organ doses were by up to 70\% lower in the best VHEE plan compared to the clinical 6 MV VMAT plan.

\textbf{Conclusions}: We have developed a GUI for MC beamlet generation for treatment planning of VHEE radiotherapy. We have demonstrated that pediatric VHEE plans resulted in significant critical organ dose sparing compared to the clinical VMAT plan.

\textbf{Conflict of interest}: The research has been in part supported by RaySearch Laboratories.
Automated delivery and quality assurance of a modulated electron radiation therapy plan

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Modulated electron radiation therapy (MERT) offers the potential to improve healthy tissue sparing through increased dose conformity. Challenges remain, however, in accurate beamlet dose calculation, plan optimization, collimation method and delivery accuracy. In this work, we investigate the accuracy and efficiency of an end-to-end MERT plan and automated-delivery workflow for the electron boost portion of a previously treated whole breast irradiation case. Dose calculations were performed using Monte Carlo methods and beam weights were determined using a research-based treatment planning system capable of inverse optimization. The plan was delivered to radiochromic film placed in a water equivalent phantom for verification, using an automated motorized tertiary collimator. The automated delivery, which covered 4 electron energies, 196 subfields and 6183 total MU was completed in 25.8 minutes, including 6.2 minutes of beam-on time with the remainder of the delivery time spent on collimator leaf motion and the automated interfacing with the accelerator in service mode. The delivery time could be reduced by 5.3 minutes with minor electron collimator modifications and the beam-on time could be reduced by and estimated factor of 2-3 through redesign of the scattering foils. Comparison of the planned and delivered film dose gave 3%/3 mm gamma pass rates of 62.1, 99.8, 97.8, 98.3, and 98.7 percent for the 9, 12, 16, 20 MeV, and combined energy deliveries respectively. Good results were also seen in the delivery verification performed with a MapCHECK 2 device. The results showed that accurate and efficient MERT delivery is possible with current technologies.
Respiratory margin derivation and verification in partial breast irradiation

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Partial breast irradiation (PBI) following breast-conserving surgery is emerging as an effective means to achieve local control and reduce irradiated breast volume. Patients are planned on a static CT image; however, treatment is delivered while the patient is free-breathing. Respiratory motion can degrade plan quality by reducing target coverage and/or dose homogeneity. A variety of methods can be used to determine the required margin for respiratory motion in PBI. We derive geometric and dosimetric respiratory 1D margin. We also verify the adequacy of the typical 5 mm respiratory margin in 3D by evaluating plan quality for increasing respiratory amplitudes (2-20 mm). Ten PBI plans were used for dosimetric evaluation. A database of volunteer respiratory data, with similar characteristics to breast cancer patients, was used for this study. We derived a geometric 95%-margin of 3 mm from the population respiratory data. We derived a dosimetric 95%-margin of 2 mm by convolving 1D dose profiles with respiratory probability density functions. The 5 mm respiratory margin is possibly too large when 1D coverage is assessed and could lead to unnecessary normal tissue irradiation. Assessing margins only for coverage may be insufficient; 3D dosimetric assessment revealed degradation in dose homogeneity is the limiting factor, not target coverage. Hotspots increased even for the smallest respiratory amplitudes, while target coverage only degraded at amplitudes greater than 10 mm. The 5 mm respiratory margin is adequate for coverage, but due to plan quality degradation, respiratory management is recommended for patients with respiratory amplitudes greater than 10 mm.
Evaluation of dose difference between VMAT plans with and without jaw tracking

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The goal of this study is to quantify the dose difference between VMAT plans calculated with and without jaw tracking. In this study the sites were chosen so that there would be jaw tracking in the direction perpendicular to the leaf motion (Y jaws). For VMAT plans without jaw tracking in the Y direction there is additional dose (over the leaf transmission) leaking through abutting leaves that can’t be moved out of the field and therefore move across the treatment field during delivery. VMAT plans for four head and neck patients with concurrent boost and three pelvis patients with concurrent prostate boost were generated using jaw tracking. A code was written in Matlab to convert each VMAT plan with jaw tracking (JT plan) to a VMAT plan with static jaws (SJ plan). The ST plan dose distribution was then recalculated and compared to the JT plan dose. VMAT plans with static jaws leave an additional dose trail compared to VMAT plans with jaw tracking. Between 6.7 and 230 cc of the SJ plans received an additional 2\% of the prescription dose when compared to the JT plans and 0.5 to 30.1 cc received an additional 4\% of the prescription dose. The additional dose trail left by the 2 arcs VMAT plans was less than the 1 arc VMAT for most plans presented in this study. This additional dose is given to normal tissues and/or critical structures surrounding the PTV.
Purpose: To describe and evaluate a novel system for generalized Real-Time Interactive Planning (RTIP) applied to head & neck (H&N) VMAT.

Methods: The clinician interactively manipulates dose distributions using DVHs, isodoses, or rate of dose fall-off, which may be subjected to user-defined constraints. Dose is calculated using a fast Achievable Dose Estimate (ADE) algorithm, which simulates the limits of what can be achieved during treatment. After each manipulation contributing fluence elements are modified and the dose distribution updates in effectively real-time. For H&N VMAT planning, structure sets for 11 patients were imported into RTIP. Each dose distribution was interactively modified to minimize OAR dose while constraining target DVHs. The resulting RTIP DVHs were transferred to the Eclipse™ VMAT optimizer, and conventional VMAT optimization was performed.

Results: Dose calculation and update times for the ADE algorithm ranged from 2.4 to 22.6 milliseconds, thus facilitating effectively real-time manipulation of dose distributions. For each of the 11 H&N VMAT cases, the RTIP process took ~2-10 minutes. All RTIP plans exhibited acceptable PTV coverage, mean dose, and max dose. 10 of 11 RTIP plans achieved substantially improved sparing of one or more OARs without compromising dose to targets or other OARs. Importantly, 10 of the 11 RTIP plans required only one or two post-RTIP optimizations.

Conclusions: RTIP is a novel system for manipulating and updating achievable dose distributions in real-time. H&N VMAT plans generated using RTIP demonstrate improved OAR sparing and planning efficiency.

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