International Journal of Radiation Oncology biology • physics

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Physics Contribution

Three-Dimensional Dosimetric Validation of a Magnetic Resonance Guided Intensity Modulated Radiation Therapy System

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Received Oct 7, 2016, and in revised form Jan 17, 2017. Accepted for publication Jan 23, 2017.

Summary

We validated the dosimetric accuracy of a commercially available magnetic resonance guided intensity modulated radiation therapy (MRgIMRT) system using a hybrid 3-dimensional approach. Measurements performed using PRESAGE radiochromic dosimeters with remote optical computed tomography readout were complemented by independent GPU-

Purpose: To validate the dosimetric accuracy of a commercially available magnetic resonance guided intensity modulated radiation therapy (MRgIMRT) system using a hybrid approach: 3-dimensional (3D) measurements and Monte Carlo calculations.

Methods and Materials: We used PRESAGE radiochromic plastic dosimeters with remote optical computed tomography readout to perform 3D high-resolution measurements, following a novel remote dosimetry protocol. We followed the intensity modulated radiation therapy commissioning recommendations of American Association of Physicists in Medicine Task Group 119, adapted to incorporate 3D data. Preliminary tests ("AP" and "3D-Bands") were delivered to 9.5-cm usable diameter cylindrical PRESAGE dosimeters to validate the treatment planning system (TPS) for nonmodulated deliveries; assess the sensitivity, uniformity, and rotational symmetry of the PRESAGE dosimeters; and test the robustness of the remote dosimetry protocol. Following this, 4 clinical MRgIMRT plans ("MultiTarget," "Prostate," "Head/Neck," and "C-Shape") were measured using 13-cm usable diameter PRESAGE dosimeters. For all plans, 3D-γ (3% or 3 mm global, 10% threshold) passing rates were calculated

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Conflict of interest: M.O., S.M., and D.M. report a collaborative research grant from Washington University during the conduct of the study. In addition, M.O. and S.M. have a provisional patent pending relating to the numerical processing of optical computed tomography data in this work. T.J. reports grants from the National Institutes of Health and grants from Varian Medical Systems, outside the submitted work. S.M. reports grants, travel expenses, and honoraria from ViewRay and grants, travel expenses, and honoraria from Varian Medical Systems, outside the submitted work. S.M. also reports ownership of TreatSafely and Radialogica, outside the submitted work.

Int J Radiation Oncol Biol Phys, Vol. 97, No. 5, pp. 1095–1104, 2017
0360-3016/$ - see front matter
http://dx.doi.org/10.1016/j.ijrobp.2017.01.223

accelerated Monte Carlo calculations. Our results demonstrate that 3-dimensional dosimetry is a feasible and comprehensive approach to commissioning MRgIMRT systems. As MR guided radiation therapy technology advances, our method can validate the dosimetric accuracy of new and complex systems.

and 3D-γ maps were examined. Point doses were measured with an IBA-CC01 ionization chamber for validation of absolute dose. Finally, by use of an in-house-developed, GPU-accelerated Monte Carlo algorithm (gPENELOPE), we independently calculated dose for all 6 Task Group 119 plans and compared against the TPS.

Results: For PRESAGE measurements, 3D-γ analysis yielded passing rates of 98.7%, 99.2%, 98.5%, 98.0%, 99.2%, and 90.7% for AP, 3D-Bands, MultiTarget, Prostate, Head/Neck, and C-Shape, respectively. Ion chamber measurements were within an average of 0.5% (±1.1%) from the TPS dose. Monte Carlo calculations demonstrated good agreement with the TPS, with a mean 3D-γ passing rate of 98.5% ± 1.9% using a stricter 2%/2-mm criterion.

Conclusions: We have validated the dosimetric accuracy of a commercial MRgIMRT system using high-resolution 3D techniques. We have demonstrated for the first time that hybrid 3D remote dosimetry is a comprehensive and feasible approach to commissioning MRgIMRT. This may provide better sensitivity in error detection compared with standard 2-dimensional measurements and could be used when implementing complex new magnetic resonance guided radiation therapy technologies.

Introduction

Magnetic resonance guided intensity modulated radiation therapy (MRgIMRT) can offer several unique advantages to patients receiving radiation therapy. The excellent soft-tissue contrast in magnetic resonance (MR) images can provide improved localization and target definition for many sites (1, 2). These onboard images may also be used for daily adaptive replanning (3, 4), potentially decreasing toxicity to nearby organs at risk and ensuring good target coverage. In addition, MR intratreatment imaging can provide real-time, real-anatomy tracking and/or gated deliveries (5-7), which may decrease the required treatment volume, further reducing toxicity. Finally, all of these benefits are achievable without requiring additional ionizing radiation to acquire patient images. However, the problem remains in verifying the radiation dosimetry under the presence of a magnetic field.

A major consideration for MRgIMRT treatment planning systems (TPSs) is the effect of the magnetic field (B_0) on high-velocity charged particles released via photon interactions. A charged particle moving in the presence of a magnetic field will experience a Lorentz force perpendicular to its velocity, altering its path of travel and subsequent dose deposition. Simulations and measurements have shown that dose kernels from a photon beam will be asymmetrically skewed under the influence of a strong B_0 (8). Furthermore, low-density areas within the patient permit an increased secondary electron range, which may exacerbate this effect (ie, "electron return effect") (8). In addition to these fundamental physics interactions, new magnetic resonance guided radiation therapy (MRgRT) systems incorporating linear accelerators must overcome engineering challenges to maintain primary beam symmetry, stability, and energy due to interference between the accelerating waveguide and the magnetic fields and radiofrequency pulses used for MR imaging. Verifying the radiation dosimetry is absolutely essential in commissioning any new radiation therapy technology and is of particular importance for the complex case of MRgIMRT.

A commercial ^{60}Co MRgIMRT system (ViewRay, Oakwood Village, OH) (9), which uses a 0.35-T magnetic field (B_0) directed along the patient's superior-inferior axis, has recently been commissioned (10) following the American Association of Physicists in Medicine (AAPM) Task Group 119 (TG-119) intensity modulated radiation therapy (IMRT) commissioning recommendations (11). In this prior work, measurements consisted of point doses with an ionization (ion) chamber and 2-dimensional (2D) planar doses with radiographic film and a diode array operated in relative mode. Because of the aforementioned complexity of MRgIMRT, expanding this work into 3-dimensional (3D) measurements was of utmost interest; 3D validation could potentially reveal systematic errors or discrepancies that point and 2D measurements might have missed.

In this work we present our unique solution for 3D dosimetric validation of MRgIMRT systems: a hybrid approach using both measurements and Monte Carlo calculations. We used PRESAGE radiochromic dosimeters (Heuris Inc., Skillman, NJ), which have been well characterized (12-14), to measure the 3D dose distribution in high resolution (isotropic 1 mm). These dosimeters were analyzed using high-resolution optical computed tomography (CT) (15, 16) by way of a novel, recently established remote dosimetry program (17, 18) at Duke 3D Dosimetry Laboratory (Duke University, Durham, NC). Independent Monte Carlo calculations were performed using an in-house-developed, GPU-accelerated platform based on PENELOPE (19). We present results for comprehensive validation of a commercial ^{60}Co MRgIMRT system (9) and propose that this hybrid 3D method is ideal for clinics that are commissioning emerging MRgIMRT technologies.