Results: For the inline configuration, B_z did not affect the beam trajectory, and the radial magnetic fields B_r in the Linac were about 0.02 T. A cylinder steel shield, 1-mm thick, was used to compensate for the B_r influence, which altered the uniformity of DSV from 5 parts per million (ppm) to 400 ppm. For the perpendicular configuration, B_z in the Linac was more than 0.3 T, which altered the beam trajectory significantly. The beam was deflected from the electron gun axis and this effect increased with the magnetic field value. A 5 mm-thick cylinder steel shield was used to surround the Linac to compensate the Linac losses, which influenced the uniformity of DSV to several thousand ppm.

Conclusions: This study reveals a novel and optimal design for integrating an MRI scanner with a Linac. For the inline configuration, the radiation beam was influenced slightly and a thin steel shield was required. For the perpendicular configuration, a thick shield was used as the beam was affected greatly. For both configurations, the effect of magnetic fields on uniformity of DSV could be modulated by the shimming technique of MRI magnet. This novel approach, with exquisite spatial resolution in soft tissues and accurate online position verification and monitoring arising from MRI, would ensure that the radiation beam remains on target and offer treatment insight impossible with the current design. It may be useful in tailoring tumor treatment regimens which simultaneously combine radiation and MRI in the future.

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Distortion Inherent to Magnetic Resonance Imaging (MRI) Can Lead to Geometric Miss in Radiosurgery Planning

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Purpose/Objective(s): MRI-based planning is standard for intracranial stereotactic radiosurgery (SRS). However, anatomic distortion is present in all MR images due to the nonlinearity of gradient fields and can measure up to several millimeters, causing a potential for clinically meaningful "shift" of the target. Computational solutions exist for correcting this MR distortion, but have not been widely adopted for radiation planning. Here, we demonstrate the benefits of applying intracranial MRI distortion correction on accuracy of SRS targeting for brain metastases and show the potential for uncorrected MRI to lead to geometric miss.

Materials/Methods: Eighteen SRS cases with a single brain metastasis were studied retrospectively. MRIs were acquired using a standard protocol (3-Tesla, pre- and post-gadolinium 3D volumetric, T1-weighted, inversion recovery spoiled gradient-echo sequence). MR images were corrected for gradient nonlinearity distortion using a previously validated method based on specifications provided by the scanner manufacturer in the form of spherical harmonics. A single radiation oncologist contoured the gross tumor volume (GTV) on the corrected T1 post-contrast MRI only. The manufacturer-specified distortion field was then re-applied to GTV masks to permit direct comparison of corrected and uncorrected GTVs Displacement of the center of mass of the uncorrected GTV from that of the corrected GTV was measured for each subject. To assess the clinical significance of anatomic distortion, the corrected MRI volume was co-registered (fused) to the patient's simulation CT, and an SRS plan was generated using the uncorrected GTV. Prescription doses were determined by size of GTV. To assess whether distortion was sufficient to cause a potential geometric miss, the percent of the true GTV receiving less than 90% of the prescription dose was calculated. Results were summarized with median value (1st and 3rd quartiles in parentheses, where applicable).

Results: The median volume of the contoured GTVs was 1.25 cm^3 (0.2-6.0 cm^3). Prescription doses ranged from 20-24 Gy in a single fraction. Median displacement of the GTV due to gradient distortion was 0.9 mm (0.8-1.0 mm), with a minimum of 0 mm and a maximum of 3.9 mm. The percent of the true GTV underdosed (< 90% of prescription dose) was 15.5% (10.8-24.5%), with a minimum of 3.8% and a maximum of 87.3%. Six of the 18 lesions studied (33%) had greater than 20% of the true, corrected, GTV outside the 90% isodose line.

Conclusions: While MRI distortion is often subtle on visual inspection, there is a significant clinical impact of this distortion on SRS planning. Distortion-corrected MRI should uniformly be used for intracranial radiosurgery planning because uncorrected MRI can yield shifted GTVs and potential geometric misses.

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Benchmark and Performance Evaluation of a Clinical ^{60}Co IMRT Treatment Planning System for Magnetic Resonance Image Guided Radiation Therapy (MR-IGRT)

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Purpose/Objective(s): To investigate the capabilities of a commercial Monte Carlo-based treatment planning system for a ^{60}Co MR-IGRT for a variety of sites.

Materials/Methods: A commercial MR-IGRT system has been commissioned. An integral component of the system is a Monte Carlo-based treatment planning system that models the delivery unit's three ^{60}Co heads each with a doubly divergent multileaf collimator consisting of leaves that project to 1.05 cm at isocenter. The system is designed for online adaptive IMRT treatment planning using volumetric MR images acquired immediately prior to treatment. To investigate the treatment planning capabilities of ^{60}Co IMRT, the planning system was used to create plans for 10 selected patients: head and neck (n = 2), thorax (n = 2), breast (n = 2), abdomen (n = 1), and bladder (n = 1), and prostate (n = 2) who previously received treatment in our department with linear accelerators. The same input data were used to create the ^{60}Co plans (CT datasets and contours). Isodose and dose volume histogram (DVH) comparisons were conducted by physicians and physicists. DVH points for coverage and organ at risk (OAR) sparing typical for our clinic, which largely follow RTOG and other standards, were evaluated and compared. For all cases, the mean doses to relevant OARs, target coverage, and target homogeneity were determined.

Results: For the plans presented, all hard planning constraints that were achievable with Linac-based plans were also found to be achievable with the ^{60}Co plans. An increase to the target $D_{5\%}$ by a mean of 1.8% [-1.8%, + 5.5%] relative to Linac-based plans was observed. For H&N, breast, thorax, and bladder patients, only minor differences in mean dose were observed between ^{60}Co and Linac plans for parotids, larynx, lungs, heart, and rectum with a range [-1 Gy, 4 Gy] with no clear trend in either direction. In one thorax patient the esophagus mean dose increased by 9 Gy but remained less than 30 Gy. For the prostate cases, differences in V_{65Gy} to bladder and rectum ranged between -2% to 4%, and penile bulb doses increased but remained less than 50 Gy.

Conclusions: A commercial treatment planning system designed for ^{60}Co IMRT is capable of producing clinically-acceptable treatment plans for