Clinical Implementation of 0.55T MRI Simulation for Stereotactic Radiotherapy Using the MAGNETOM Free.Max RT Edition

Joshua Kim, Anthony Doemer, Adina Fratila, Robert Rusnac, Mira Shah, M. Salim Siddiqui, Benjamin Movsas, Kundan Thind

Department of Radiation Oncology, Henry Ford Health, Detroit, MI, USA

Stereotactic radiotherapy (SRT) is a treatment strategy that aims to maximize the biological effectiveness of treatment by delivering a high dose in a few (1–5) fractions. SRT is used in the intracranial treatment of malignant tumors such as brain metastases, of benign tumors such as vestibular schwannomas and acoustic neuromas, and of functional diseases such as trigeminal neuralgia. In order to minimize dose to healthy brain and other nearby radiosensitive organs at risk (OARs), margins of only 0–1 mm around the contoured gross target volume (GTV) are used to define the planning target volume (PTV), and a more heterogeneous dose is allowed within the target in order to achieve rapid dose falloff at the edges. Consequently, very high precision is required for the delineation of the target and OARs, and for patient setup in order to ensure accurate treatment delivery. For contouring, it is essential to have high-quality images that provide high spatial resolution over the full brain and superior soft tissue contrast to be able to distinguish the soft tissue structures within the brain. For this reason, MRI has been the standard for target volume and OAR contouring for SRT. It has been used as an adjunct to CT imaging, with the MR images rigidly registered to the treatment planning CT and used for contouring while the CT image set is used for dose calculation and patient setup at the machine.

While MRI is essential for the contouring of targets and OARs, care must be taken in the selection of imaging sequences used for this task. High-resolution 3D imaging sequences best meet the needs of SRT because they provide high isotropic spatial resolution and are less susceptible to distortions arising from B_0 inhomogeneity [1]. High isotropic resolution is important for avoiding inaccurately contouring the extent of the tumor due to partial volume effect from the larger slice thicknesses and to an added slice gap typically seen in 2D image acquisition sequences [2, 3]. Higher field strengths (1.5–3T) have typically been used for MR simulation. These have allowed for images with a high signal-to-noise ratio (SNR) that is adequate for the needs of SRT while minimizing the scan time for patients. With the recent introduction of the 0.55T MAGNETOM Free.Max RT Edition (Siemens Shenzhen Magnetic Resonance Ltd., Shenzhen, China) for MR simulation, we aimed to establish whether lower field simulation can provide adequate SNR for patients within a reasonable time frame.

Patient scanning and workflow

All volunteers and patients were scanned as part of a study – approved by the Institutional Review Board (IRB) – that focused on workflow and scanning protocol optimization for the MAGNETOM Free.Max RT Edition. For patient scanning, MR simulation was performed immediately following CT simulation, which was facilitated by the MRI scanner's location adjacent to the CT simulation room. To maximize SNR on the 0.55T system, patients were scanned using the standard Head/Neck coil from Siemens Healthineers, with the head immobilized using standard techniques (e.g., thermoplastic mask interface, headphones, padding as needed). A key objective was patient tolerance and minimizing motion artifacts. Therefore, our goal was to keep the scan times of individual clinically necessary sequences to between 6 and 8 minutes, and the total protocol time to under 30 minutes.

Sequence optimization

Clinical MR scans required by physicians for SRT at our institution consist of pre- and post-contrast 3D T1-weighted acquisitions, a T2-weighted acquisition, and a T2 fluid-attenuated inversion recovery (T2 FLAIR) acquisition. Sequence optimization was performed through volunteer and initial patient scanning.

T1-weighted imaging

High-resolution 3D imaging covering the whole brain is needed for contouring lesions and OARs such as the optic nerves [4, 5]. Gradient echo sequences like T1-MPRAGE are commonly used at higher field strengths. On the 0.55T MAGNETOM Free.Max RT Edition, initial testing showed

that the SNR for T1w MPRAGE was insufficient for SRT contouring needs without extending the scan time beyond 10 minutes or increasing voxel size unacceptably. We evaluated alternative 3D sequences: T1 FLASH (gradient echo) and T1 SPACE (turbo spin echo, TSE). Both provided sufficient SNR. However, the T1 SPACE images exhibited excessive smoothing, which was perceived as an undesirable texture and attributed to the high compressed sensing (CS) factor required to achieve acceptable scan times. Reducing the CS factor resulted in prohibitively long scans. The 3D T1 FLASH sequence provided a good balance of improved SNR over MPRAGE at 0.55T, and clinically acceptable scan times (under 7 minutes). While gray-white matter contrast was lower than typical high-field MPRAGE, this was not deemed a concern for radiotherapy contouring purposes.

T2-weighted imaging

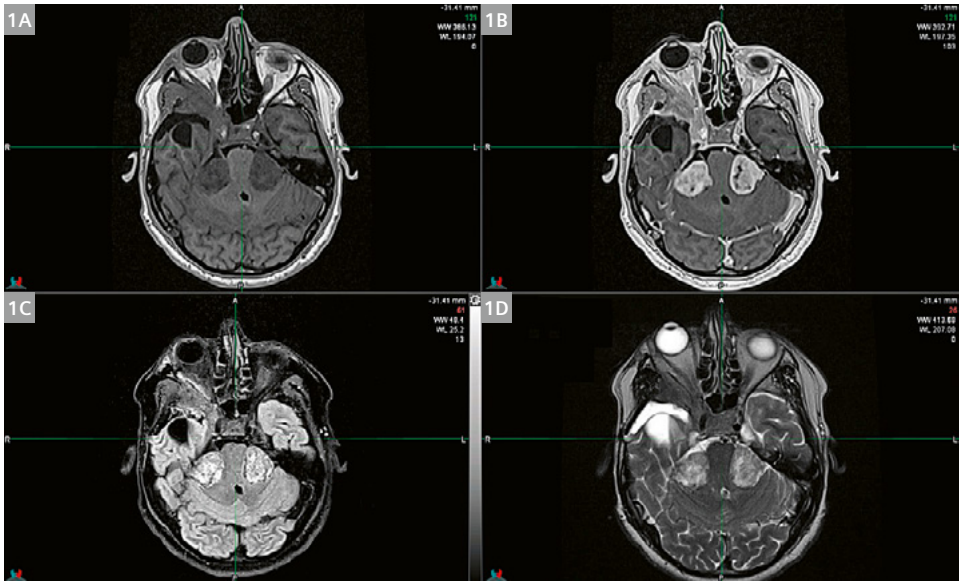
This is used for delineating excision cavities, nonenhancing lesions, and OARs like the cochlea [5, 6]. A 2D TSE sequence provided adequate image quality for physicians' needs. A slice thickness of 4 mm was used, but activating the RT planning add-on allowed for a -50% slice gap, yielding an effective slice spacing of 2 mm for planning.

T2 FLAIR imaging

This is used for contouring vasogenic edema, infiltrating tumor, and defining OAR boundaries like the brainstem [7, 8]. A 3D SPACE sequence was optimized. Sufficient image quality was achieved after adjusting the CS factor to 2.5. The resulting scan time was approximately 9 minutes, which was longer than other sequences but deemed acceptable within the overall protocol time.

Final imaging protocol and contrast administration

For patient scans, the precontrast T1 FLASH and T2 TSE sequences are acquired first. Gadolinium-based contrast agent is then administered. The T2 FLAIR sequence is acquired immediately after injection, allowing time for contrast uptake during this scan. Approximately 10–15 minutes after contrast injection (following contrast-agent manufacturer recommendations), the postcontrast 3D T1 FLASH scan is acquired. Figure 1 displays example images acquired using this protocol for a patient with bilateral vestibular schwannomas and a right-sided meningioma abutting the right optic nerve.



1 **(1A)** Pre-contrast T1 FLASH, **(1B)** post-contrast T1 FLASH, **(1C)** T2 FLAIR, **(1D)** T2 TSE.

	TR (ms)	TE (ms)	α (°)	Acquisition matrix* (mm²)	FOV (mm²)	Slice thickness (mm)	TA (min)
3D T1 FLASH	9.36	3.44	120	180 × 224	198 × 246	1	6:57
Axial T2	11710	115	120	240 × 240	230 × 230	4**	6:38
T2 FLAIR	5000	237	150	256 × 256	256 × 256	2	9:05

Table 1: Imaging protocol
* Interpolation used to provide double the acquisition matrix resolution.
** -50% slice gap in RT mode used for an equivalent slice thickness of 2 mm.

Results

In total, 46 patients requiring SRT planning have been successfully scanned using the optimized brain protocol on the 0.55T MAGNETOM Free.Max RT Edition at our institution. The resulting images consistently provided SNR and spatial resolution deemed sufficient by the treating radiation oncologists for the critical contouring needs of SRT. While individual sequence scan times required adjustments and optimization compared to typical high-field protocols, the total routine clinical protocol scanning time was reliably completed in less than 30 minutes.

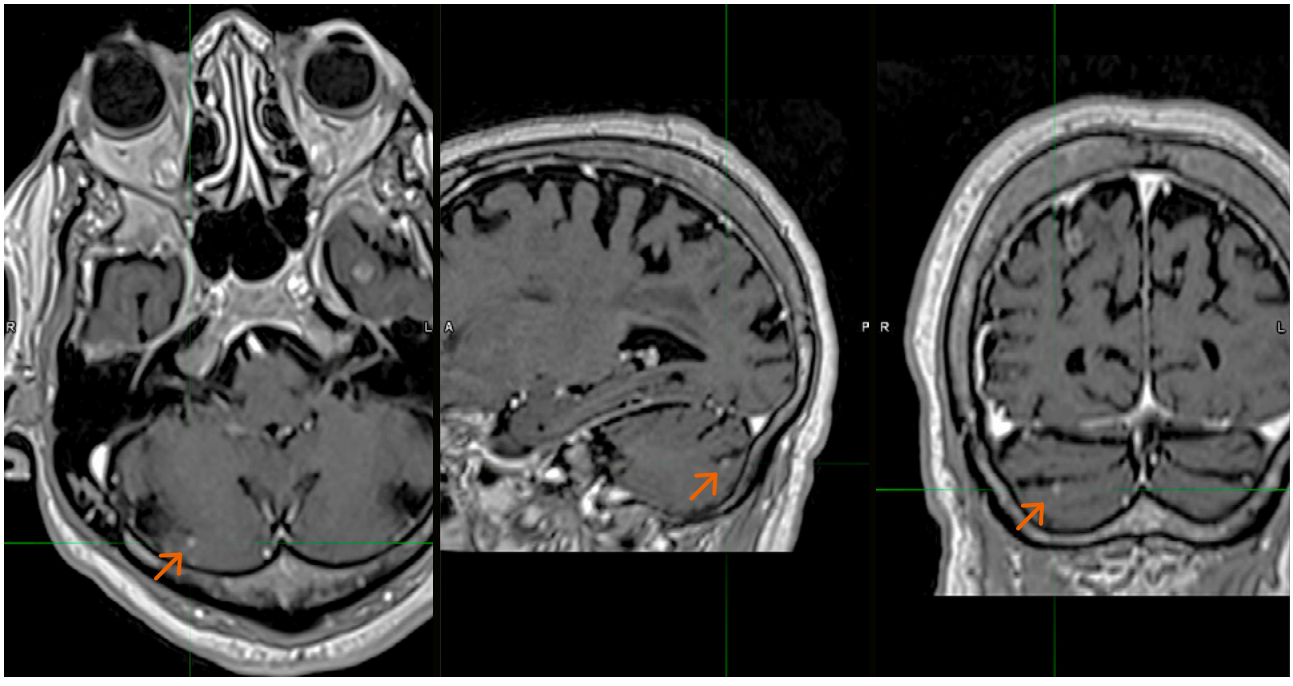
The image quality achieved proved clinically impactful: In one patient scanned for multiple known targets, an additional metastatic lesion measuring less than 0.03 cc, which had not been clearly identified on prior diagnostic scans, was visualized on the postcontrast 3D T1 FLASH sequence (Fig. 2). This finding allowed for the inclusion of this lesion in the SRT treatment plan.

Discussion

This study demonstrates that the 0.55T MAGNETOM Free.Max RT Edition can produce MRI datasets suitable for the demanding requirements of SRT planning. Through careful sequence selection and optimization, particularly using 3D T1 FLASH and optimized 3D T2 FLAIR SPACE sequences, adequate SNR and spatial resolution were achieved for precise target and OAR delineation.

While individual sequence scan times on the 0.55T system are moderately longer than those typically achieved on 1.5T or 3T scanners for similar resolution, the optimization process resulted in a total clinical protocol time of less than 30 minutes, which is well-tolerated by patients and integrates efficiently into the clinical radiotherapy workflow. The successful identification of a very small, previously uncertain metastatic lesion (Fig. 2) underscores that the image quality is not only adequate but clinically robust for identifying small targets that are critical in SRT.

The viability of using a 0.55T system for MR simulation in SRT has significant implications. It potentially broadens access to high-quality MR simulation for radiotherapy centers that may not have access to high-field MR systems due to the cost or siting constraints associated with higher field strengths. Furthermore, the specific design characteristics of the MAGNETOM Free.Max RT Edition (e.g., its 80 cm bore) offer benefits for patient comfort and setup, although this was not formally assessed in this study. This work shows that despite the inherently lower SNR of low-field MRI, optimization strategies can yield clinically excellent results for advanced applications like SRT.



2 Metastatic lesion (arrow) identified in postcontrast 3D T1 image.

Conclusion

The 0.55T MAGNETOM Free.Max RT Edition, when used with an optimized imaging protocol that includes 3D T1 FLASH and 3D T2 FLAIR SPACE sequences, provides image quality sufficient for target and OAR delineation in stereotactic radiotherapy planning. Total protocol times are clinically acceptable, demonstrating that this low-field MR system is a viable and valuable option for MR simulation in radiotherapy.

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Contact

Joshua Kim, Ph.D.
Director of Imaging Physics
Department of Radiation Oncology
Henry Ford Cancer Institute
2799 W. Grand Blvd
Detroit, MI 48202
USA
Tel.: +1 313.916.2180
jkim8@hfhs.org