MRI Planning Workflow for CT Simulation Free Stereotactic Radiosurgery

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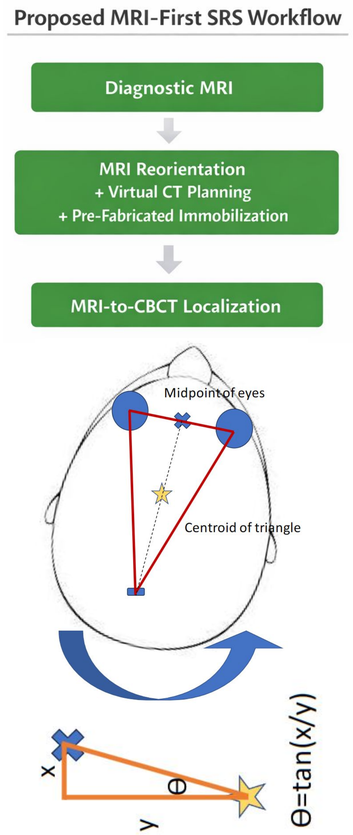
Introduction

Magnetic resonance imaging (MRI), particularly T1-weighted imaging with contrast, is the preferred modality for diagnosing intracranial lesions and provides excellent soft tissue contrast for target delineation in stereotactic radiosurgery (SRS). Although this diagnostic MRI could be directly used for treatment planning, conventional workflows require a separate CT simulation for dose calculation and treatment setup. This necessitates either additional imaging or delays between diagnostic MRI and treatment delivery, potentially impacting treatment timeliness and accuracy. These delays are clinically significant, as studies have demonstrated measurable progression of brain metastases within 1–2 weeks, reducing local control. To address this limitation, we investigate a treatment planning workflow which would enable CT simulation–free multi-target SRS with pre-planning, immobilization, and image guidance performed directly from the diagnostic MRI, thereby minimizing time to treatment while maintaining clinical accuracy.

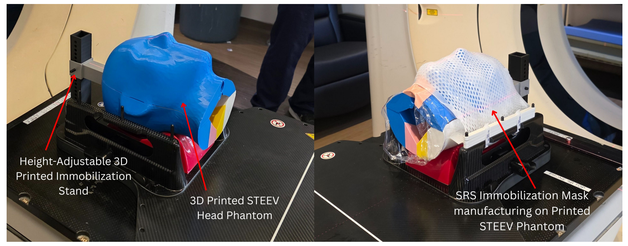
Methods

This study addressed three key challenges for MRI-only SRS: (1) immobilization and skull orientation, (2) dosimetric accuracy without CT-based electron density, and (3) localization accuracy using MRI-based image guidance. For immobilization, patient-specific masks were fabricated on 3D-printed head phantoms generated from MRI-derived surface anatomy and oriented using a custom mounting system; the same transformation was applied to the MRI for treatment planning. Additional phantom studies were performed to quantify mask fit, rotational stability, and reproducibility of head positioning under applied torque. For dosimetric evaluation, pseudo virtual CT datasets were generated from MRI and compared against conventional CT-based plans in a cohort of patients (n=10), with target dose metrics evaluated using manual density assignment approaches validated in prior work. For localization, three physicists independently performed image registrations across ten patients to compare standard workflows (MRI-to-CT-to-CBCT) with a direct MRI-to-kV-CBCT approach.

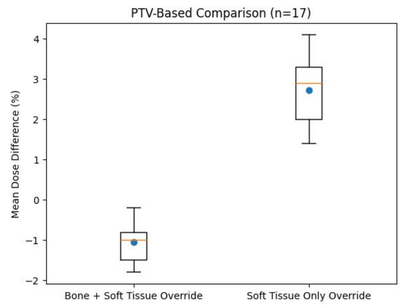


Results

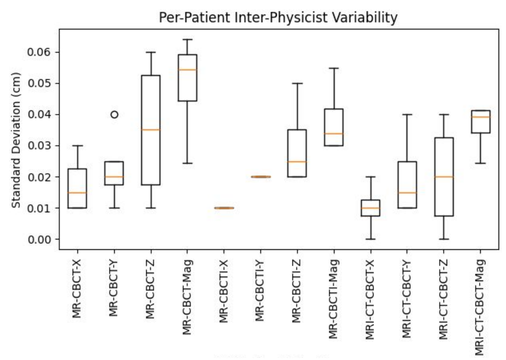
MRI-derived immobilization achieved highly reproducible head orientation under phantom torque testing. The printed mask demonstrated rotational standard deviations of 0.15°, 0.26°, and 0.05° about the x-, y-, and z-axes, respectively, compared with 0.21°, 0.62°, and 0.13° for the conventional mask.



Virtual CT–based planning reproduced multi-target SRS dosimetry with minimal differences relative to CT-based plans, with average deviations of 1.3% ± 0.4% for mean dose, D95, and D5. Prior density override analysis confirmed that inclusion of both bone and soft tissue is necessary to maintain this level of agreement, with errors remaining within approximately 1–2% when both are modeled.



Mean inter-physicist variability was sub-millimeter across all methods. MR–CBCT showed the highest variability (0.015, 0.022, 0.036 cm in X/Y/Z), which decreased with iterative reconstruction (MR–CBCTI: 0.010, 0.020, 0.027 cm). The MRI→CT←CBCT workflow demonstrated comparable or lower variability (0.007, 0.018, 0.020 cm). Variability was greatest in the Z direction for all methods. Overall, all approaches achieved <0.4 mm agreement, with iterative CBCT providing the most consistent results.



Conclusions

This work demonstrates the feasibility of a CT simulation–free SRS workflow. The approach maintains dosimetric accuracy within ~1–2%, achieves sub-millimeter localization precision, and improves immobilization reproducibility. These results provide strong proof of principle for an MRI-only workflow. However, further work is needed to streamline key components, including optimization of the mask fabrication process, improvement of MRI-based bone auto-contouring, and resolution of remaining workflow and integration challenges.

Main Takeaway

By eliminating the need for CT simulation, this approach has the potential to significantly reduce time from imaging to treatment, improve clinical efficiency, and better align treatment planning with the anatomy visualized on MRI. Overall, these findings support continued development and clinical translation toward a fully MRI-only radiosurgery paradigm.

Next Steps

The immediate next step is the clinical rollout and evaluation of the Phase 1 trial, focusing on patients with prior SRS treatment and reuse of existing immobilization. This phase will validate the feasibility of a ~1-day simulation-to-treatment timeline while maintaining planning accuracy, workflow efficiency, and patient safety. Key endpoints include treatment turnaround time, dosimetric consistency relative to standard workflows, and clinical/operational reliability across the initial patient cohort (~5 patients). Data from Phase 1 will guide iterative refinements and progression to Phases 2–3. Ongoing work will also quantify tissue compression for mask fitment, assess hair-related fit variability, and develop MR-based bone auto-contouring and synthetic CT generation for accurate electron density assignment. The long-term goal is a fully MRI-driven, simulation-free SRS workflow that reduces time-to-treatment while preserving sub-millimeter precision and clinical quality.

Acknowledgements

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References

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