A MULTI-METRIC APPROACH FOR EVALUATING MR DISTORTION CORRECTION IN CRANIAL SRS

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Introduction

In high-dose Stereotactic Radiosurgery (SRS), sub-millimeter accuracy is a critical factor. While MRI is the most adequate imaging method for defining targets, its inherent geometric distortions can compromise treatment accuracy and, by extension, procedure results.

This is particularly sensitive in functional radiosurgery, where the radioablation of the target does not allow for additional dose margin. Checking the distortion correction algorithms during treatment planning is required, although it can be challenging to assess their effectiveness due to the complexity and non-linear nature of magnetic field irregularities. This study introduces a flexible, software-based quality assurance (QA) method that relies on virtual phantoms to carefully check correction accuracy, with the possibility to include dedicated phantom and/or clinical data.

References

[1] Belloeil-Marrane T., et al. (2025) Virtual phantom methodology for assessment of MRI distortion correction in high-precision stereotactic radiosurgery treatment planning.

[2] Raggio C.B., et al. (2025) FedSynthCT-Brain: A federated learning framework for multi-institutional brain MRI-to-CT synthesis

[3] Chris A. Cocosco et al (1997) BrainWeb: Online Interface to a 3D MRI Simulated Brain Database

Methodology

Based on our initial study[1], a dedicated evaluation software was developed in Python, aiming to assess the accuracy of post-acquisition distortion correction software for cranial SRS. During the first steps, the program imports the DICOM T1- and T2-weighted (T1WI/T2WI) MR data and allows for burn-in artificial contrast-enhanced lesions in images. Optionally, with T1WI, a synthetic Computed Tomography (sCT) can be processed using the validated deep-learning model FedSynthCT-Brain[2], providing the intermodal image-to-image translation. Next, simulated MR distortions are propagated to the initial MRI data to generate distorted datasets with different levels of intensity non-uniformity (RF) and noise, based on the BrainWeb model[3].

Following that, the MR datasets and sCT are exported to a commercial treatment planning system and processed using a multi-rigid registration algorithm (Brainlab Elements RT 4.5) to correct the MR distortion. The effectiveness of the correction can then be measured automatically by reimporting the corrected and non-corrected datasets in the evaluation software, using several metrics: **for full-image comparisons**: Root Mean Squared Error (RMSE), Structural Similarity Index (SSIM), and Peak Signal-to-Noise Ratio (PSNR); **for local volumetric comparisons**: Dice Similarity Coefficient (DSC) and Hausdorff's distances.

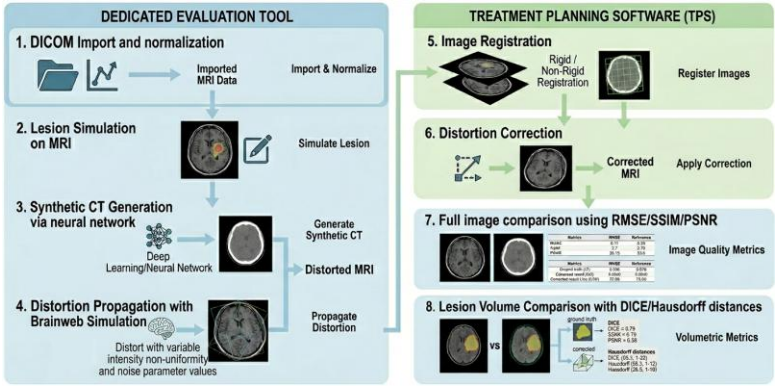

Figure 1: Distortion Correction Evaluation Workflow

Figure 2: Dedicated Evaluation Software Interface

Results

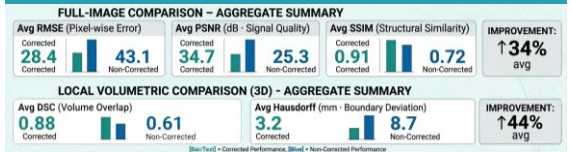

Figure 3: Aggregate Summary Of Experimental Results

The results show that distortion correction improved image correlation across all the T1WI datasets. Corrected images had better spatial agreement with the reference synthetic CT than uncorrected scans. Both global and local metrics consistently demonstrated improved spatial data, clearly showing how well the algorithm performed, even with higher RF inhomogeneity and noise.

Conclusion

This method provides a proven, adaptable, and accessible way to set up and routinely check MRI distortion correction tools. By removing the need for special equipment or extra imaging time, this approach allows for more frequent and detailed validity checks. This helps ensure that SRS planning uses precise/accurate data for treatment delivery, leading to decreased geometric uncertainty in defining targets for critical cranial functional treatments.