

Leveraging MRI-Based AI-Driven Synthetic CT Generation for Brain Proton Therapy Planning

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Purpose/Objective:

Assessing the practicality of MRI-based synthetic computed tomography (sCT) in proton therapy planning for brain tumours.

Material/Methods:

Three investigations evaluated the similarity of sCTs, generated using TheraPanacea's MR-Box™ (AI-powered cycleGAN), to their CT counterparts [1]. An intensity-based analysis using boxenplots, a geometric fidelity analysis using the Dice similarity coefficient (DSC) and Hausdorff distance (HD) metrics, and a dose difference analysis involving plan recalculations on sCTs were conducted on ten patients (six adults and four children). MRI scans were acquired using the 3D T1 gradient echo (GE), 3D T1 magnetization prepared rapid gradient echo (MPRAGE) and 3D T1 fast spin echo (FSE) sequences, with and without a Gadolinium-based contrast agent (GBCA) for the first two. AI based contours of organs at risk (OARs), delineated using TheraPanacea's Annotate module, were evaluated against physician-validated segmentations using the DSC and HD metrics. An end-to-end (E2E) validation process was conducted on an Alderson phantom to determine the range error ($\Delta R80$) between simulated and experimental outcomes using Gafchromic™ EBT-XD films and the Proteus®One treatment facility.

Results:

CT showed higher attenuation values than sCT for external, bone, and brain tissues in adults (175 ± 439 HU, 936 ± 420 HU, and 32 ± 5 HU) and minors (140 ± 394 HU, 833 ± 386 HU, and 32 ± 5 HU). MPRAGE + GBCA sCT values closely matched CT values: 153 ± 391 HU (adults) and 126 ± 349 HU (minors) for external, 757 ± 334 HU (adults) and 670 ± 297 HU (minors) for bone, and 24 ± 4 HU for brain in both groups (Figure 1). The external contours displayed superior geometric fidelity (DSC: > 0.97 ; HD: $0.87 - 1.77$ cm) to bone structures (DSC: $0.79 - 0.90$; HD: $1.61 - 4.28$ cm) and air cavities (DSC: $0.74 - 0.87$; HD: $1.78 - 3.29$ cm). Doses received by OARs increased in most cases except for the optic nerves (adults: -1.11 ± 2.10 Gy (GE); minors: -0.43 ± 0.83 Gy (GE + GBCA)). AI-based eye contours had the best results (DSC: $0.85 - 0.92$, HD: $0.23 - 0.41$ cm), but only the brainstem demonstrated cases with sCT superior to CT. The E2E process showed positive $\Delta R80$ results for the CT plan (0.0 ± 0.7 mm), however the sCT plan failed to meet the 1.0 mm threshold (7.4 ± 2.0 mm (MPRAGE)) [2].

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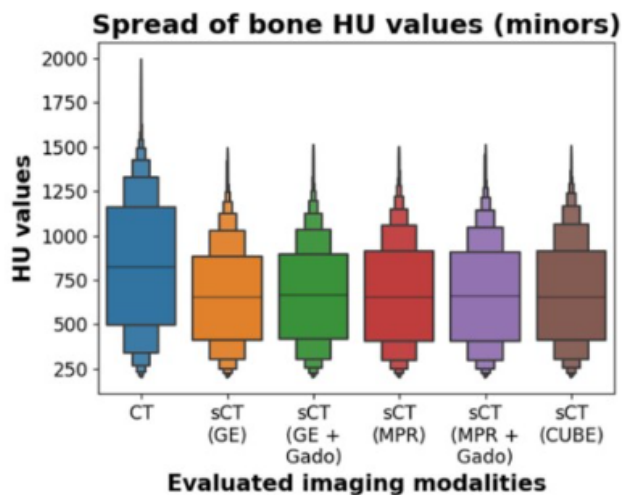


Figure 1: Boxenplots generated from the extraction of voxel intensity values within the external contours from the CT and sCT images of paediatric patients.

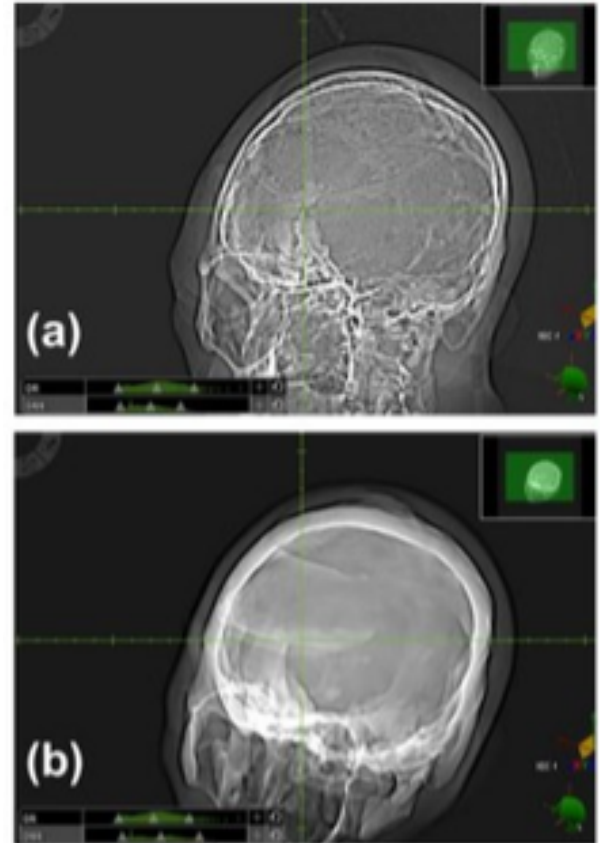


Figure 2: Comparisons of image registration differences between the acquired **(a)** CT and **(b)** sCT scans of the anthropomorphic phantom with the Proteus*One treatment facility's planar positioning scans.

Conclusion:

The 'MPRAGE + GBCA' sCT performed best for adults, with no clear standout for paediatric patients. Future work should address high-density complications and image registration issues from the E2E process (Figure 2).

Keywords: Artificial intelligence, proton therapy, MRI