Dosimetric evaluation of AI-based synthetic CTs for MRI-only brain radiotherapy

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Purpose

The adoption of MRI in support of radiation treatment (RT) planning has increased dramatically. Due to its excellent soft tissue contrast, MRI is considered standard for target and some OAR definition in brain oncology. The CT images, with their electron density (ED) information, are needed for dose calculations in photon RT. MRI-only radiotherapy eliminates registration errors and reduces patient discomfort, workload and cost. The aim of this study was to evaluate the dosimetric accuracy of an innovative self-supervised generative adversarial neural networks synthetic-CT (sCT) generation from diagnosis MR images for MRI-only workflow for IMRT of brain gliomas.

Material and Methods

T1w-MRI and planning CT images were retrospectively collected for 25 patients for dosimetry evaluation. sCTs were generated using a self-supervised generative adversarial deep learning (DL) approach, trained on a dataset of 1242 T1w diagnosis MRI scans and the corresponding CT scans from multiple devices and manufacturers. The original CT (oCT) images were rigidly registered and resampled on MR images and the patient immobilization mask cleaned on warped CTs (wCTs) applying a mask designed from sCTs based on an erosion/dilatation approach. A comparison between sCTs and wCTs in terms of mean absolute error (MAE) of Hounsfield Units (HU) in 4 different areas (air, bone, water, and head) was carried out. The sCTs and the wCTs were registered on oCTs and the dose matrices were re-calculated using plan transfer using a commercial collapsed cone algorithm. Calculations were also performed on oCT, i.e. without immobilization mask cleaning, to assess the discrimination capabilities of the indices. The absolute differences in DVH-parameters (D2, D50, D95 and D98) for PTV and (Dmax and Dmean) for OARs were calculated. Dose distributions were in addition compared with 2%/2mm global and local gamma index criteria.

Results

The size of tumors varied between 7 cm^3 and 705 cm^3 with an average of 226 cm^3. Qualitative results are shown in Figure 1 and illustrate the crucial role of immobilization mask modeling. Mean MAE of 67HU+/-10HU, 175HU+/-21HU, 188HU+/-40HU and 30HU+/-3HU were obtained for the whole head, bone, air and water areas, respectively, in the independent institutional cohort. The dosimetric results are summarized in Table 1.

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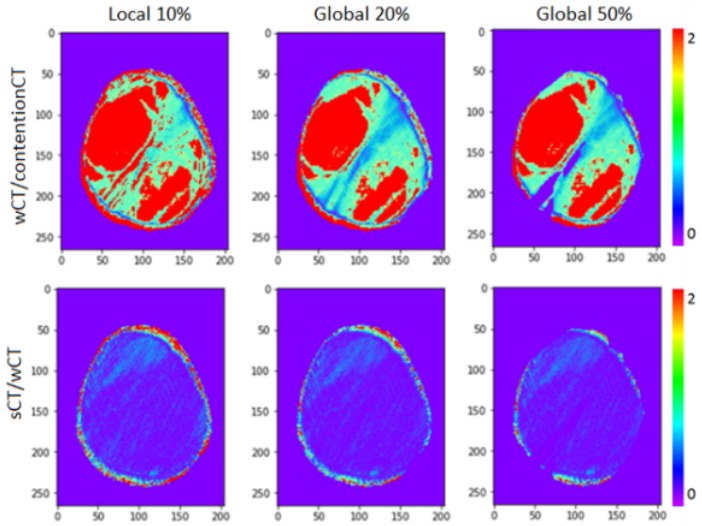

Figure 1: Qualitative illustration of 2%/2 mm gamma index dose maps on a patient from the test cohort (IMRT with 9 fixed beams, volume of the left temporal PTV = 120 cm³, prescription dose = 50 Gy and volume of the right posterior PTV = 188 cm³, prescription dose = 54 Gy, wCT/oCT: local 10% gamma index = 86.5%, global 20% gamma index = 89.0%, global 50% gamma index = 85.1%; sCT/wCT: local 10% gamma index = 95.3%, global 20% gamma index = 99.9%, global 50% gamma index = 99.8%).

Table 1: Summary of the pass rates of the 2%/2 mm local and global gamma indices with thresholds of 10%, 20% and 50% respectively, and results of the absolute differences in DVH. The differences were calculated from the dose maps obtained on the warped CTs (wCT) from which the immobilization masks were removed and the synthetic CTs (sCTs) generated by DL or the original (oCT) with immobilization masks. OARs receiving doses less than 1 Gy were not considered.

		sCT/wCT mean ± sd (min – max)	wCT/oCT mean ± sd (min – max)
2% 2mm Gamma Index Pass Rates (N=25) [%]			
Local 10%		98.7 ± 0.6 (97.4 - 99.5)	86.8 ± 9.4 (61.2 - 97.2)
Global 20%		99.8 ± 0.2 (99.4 -100.0)	91.8 ± 6.8 (75.9 - 98.6)
Global 50%		99.7 ± 0.3 (99.1 - 100.0)	86.8 ± 12.1 (59.2 - 98.9)
DVH Absolute Differences [Gy]			
PTV (N=27)	D2	0.05 ± 0.04 (0.00 - 0.16)	1.17 ± 0.58 (0.35 - 2.23)
	D50	0.05 ± 0.05 (0.00 - 0.19)	0.96 ± 0.45 (0.35 - 2.20)
	D98	0.04 ± 0.04 (0.00 - 0.15)	0.95 ± 0.45 (0.30 - 2.10)
Brainstem (N=24)	Dmax	0.04 ± 0.04 (0.00 - 0.14)	0.63 ± 0.38 (0.01 - 1.23)
	Dmean	0.02 ± 0.02 (0.00 - 0.07)	0.25 ± 0.25 (0.00 - 0.94)
Left Cochlea (N=20)	Dmax	0.07 ± 0.10 (0.00 - 0.44)	0.38 ± 0.35 (0.04 - 1.25)
	Dmean	0.03 ± 0.04 (0.00 - 0.13)	0.28 ± 0.27 (0.02 - 0.82)
Left Hippocampus (N=4)	Dmax	0.08 ± 0.04 (0.04 - 0.13)	0.95 ± 0.76 (0.09 - 1.79)
	Dmean	0.04 ± 0.03 (0.01 - 0.07)	0.87 ± 0.65 (0.06 - 1.44)
Chiasma (N=24)	Dmax	0.07 ± 0.14 (0.00 - 0.67)	0.43 ± 0.38 (0.01 - 1.09)
	Dmean	0.04 ± 0.04 (0.00 - 0.15)	0.30 ± 0.32 (0.00 - 0.88)
Right Optic Nerve (N=21)	Dmax	0.05 ± 0.10 (0.00 - 0.36)	0.26 ± 0.31 (0.00 - 0.82)
	Dmean	0.03 ± 0.04 (0.00 - 0.16)	0.13 ± 0.17 (0.00 - 0.48)
Pituitary Gland (N=21)	Dmax	0.07 ± 0.09 (0.00 - 0.28)	0.34 ± 0.34 (0.00 - 0.96)
	Dmean	0.06 ± 0.07 (0.00 - 0.28)	0.26 ± 0.28 (0.00 - 0.75)

Conclusion

This work successfully evaluated a self-supervised DL based software for sCT generation that allows for superior alignment of training data and makes it possible to train a generative model even with diagnostic MRIs, bypassing the need for patients to be in treatment position on the MRIs. Dosimetric differences were minimal and clinically insignificant for both PTVs and OARs. sCT based MRI-only planning can be feasible to use for RT planning of brain tumours. Future work will investigate feasibility of mask immobilization reconstruction and the accuracy of using sCT for daily CBCT position verification.

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