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Self-Supervised GAN Based Synthetic CT Generation From Head and Neck CBCT

Lorenzo Colombo1, Ayoub Oumani2, Marius Schmidt-Mengin2, Sofiane Horache2, Sami Romdhani2, Sanmady Kandiban1, Blandine Romain1, Gizem Temiz1, Olivier Teboul2, Nikos Paragios3, Pascal Fenoglietto4
1 TheraPanacea, Clinical Affairs, Paris, France.
2 TheraPanacea, AI Engineering, Paris, France.
3 TheraPanacea, CEO, Paris, France.
4 Institut du Cancer de Montpellier, Department of Radiation Oncology, Montpellier, France.

Purpose/Objective:

Cone-beam CT (CBCT) is an essential component of treatment delivery in radiation therapy. To date, its main usage is primarily devoted to patient positioning due to limited quality, resolution, and field of view. Harnessing and using CBCT beyond patient positioning could contribute to the effective implementation of adaptive treatment at scale. This would require improving substantially the quality of signal and augmenting the field of view such that organ at risk annotation, full scale dose simulation and replanning can be performed. In this study an artificial intelligence- based synthetic-CTs (sCT) is proposed and clinically evaluated to overcome these challenges and potentially unlock the full potential of CBCT for adaptive radiotherapy for head and neck cancer care.

Material/Methods:

The training of a CT from CBCT AI model is notoriously difficult because of the impossibility to acquire CBCTs that are perfectly aligned with CTs. In this work we circumvented this predicament using a patented fake CBCT simulation: instead of trying to align a training CBCT to a CT which is always imprecise, a fake CBCT is generated from a CT by removing projections and adding noise. The AI model learns to predict the original CT from the simulated fake CBCT. In a second training stage, the GAN was presented with real CBCTs and trained such that the synthetic CTs generated from them were indistinguishable from real CTs. The training cohort included 1063 planning CTs and 228 CBCTs.
As the field of view of a CBCT is smaller than a planning CT, the synthetic CT (sCT) is enlarged using the planning CT to perform the OAR segmentation and dose computation. This is done in the X, Y and Z directions.
An independent, retrospective cohort of 10 head and neck cancer patients treated at two European cancer care excellence centers were selected for this evaluation. Planning CTs were deformably registered to the CBCTs for each patient to account for changes in the patient body and positioning. Treatment plans were optimized on the warped CT (wCT) and recalculated on the sCTs for image and dosimetric evaluation. For the analysis, wCTs and synthetic CTs were compared based on a) DVH-parameters (D2%, D50%, D95%,D98% and Dmean) for the PTV, and b) dose distributions compared with global gamma criteria (2%/2mm and 3%/3mm).

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Results:

Table 1 presents a comparative analysis of the disparities in DVH between the dosage computed on the extended FoV sCTs derived from CBCTs and the dosage calculated on the deformed CTs. The discrepancies in DVH are denoted by the median and mean relative difference, encompassing the minimum and maximum values for seven DVH indicators, namely, Dmean, Dmax, D98%, D95%, D50%, D5%, and D2% for PTV. Notably, the most significant disparities were recorded for the Dmax (0.58%) parameter, while the smallest disparities were noted for the Dmean (0.14%) parameter. Furthermore, the variations in the gamma pass rate, depicted via the median values, were 99.93%, 99.80%, 99.68%, and 99.99%, 99.98%, and 99.97% for 0%, 10%, and 20% cut-off dose for 2%/2mm and 3%/3mm, respectively.

Structure	DVH parameter	Median relative dose difference with wCT (%)	Mean relative dose difference with wCT (%)	Minimum relative dose difference with wCT (%)	Maximum relative dose difference with wCT (%)
PTV	Dmean% [Gy]	0.14	0.26	0.01	1.20
	Dmax% [Gy]	0.58	0.62	0.01	1.81
	D98% [Gy]	0.53	0.87	0.06	2.97
	D95% [Gy]	0.38	0.58	0.04	2.57
	D50% [Gy]	0.16	0.31	0.01	1.23
	D5% [Gy]	0.25	0.35	0.00	1.48
	D2% [Gy]	0.29	0.39	0.00	1.58

Table 1: Overall dosimetric results comparing synthetic CTs and warped CTs

Conclusion:

In this study, we have demonstrated the potential of leveraging artificial intelligence to enhance CBCT images into high-resolution CT scans. Our current assessment has confirmed that using CBCT-derived synthetic CT for treatment planning in head and neck cancer is comparable in quality, as evidenced by dosimetric measures. Future endeavors will involve seamlessly integrating this advancement into a comprehensive adaptive workflow, encompassing organ at risk (OARs) annotation, full-scale dose simulation, and replanning for more effective implementation.

Keywords: Adaptive RT, Synthetic-CT, Dose calculation