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Self-supervised GAN based synthetic-CT generation from breast CBCT

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Purpose/Objective:
Cone-beam CT (CBCT) is crucial for delivering radiation therapy, primarily used for patient positioning due to limitations in quality, resolution, and field of view. Extending the utility of CBCT beyond patient positioning could enhance the widespread implementation of adaptive treatment. Achieving this goal involves significantly improving signal quality and expanding the field of view, enabling organs at risk annotation, full scale dose simulation, and replanning. This study proposes and clinically assesses an artificial intelligence-based approach using synthetic-CTs (sCT) to address these challenges, potentially unlocking CBCT's full potential for adaptive radiotherapy in breast cancer care.

Material/Methods:
The training of a CT from CBCT AI model poses a notorious challenge due to inherent difficulty in acquiring CBCTs perfectly aligned with CTs. To address this issue, we employed a patented CBCT simulation that generated synthetic CBCTs by removing projections and adding noise, rather than attempting to align a training CBCT with a CT, which typically yields imprecise results. Generated synthetic CBCT images are used for first-stage AI model training. 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 278 planning CTs and 174 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 augmentation is done in the X, Y and Z directions.
An independent, retrospective cohort of 10 breast 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 shows comparative results of differences in DVH between the dose calculated on the sCTs with extended FoV generated from the CBCTs and the dose calculated on the warped CTs. The differences in DVH are represented by the median and mean relative difference with the minimum and the maximum values for the seven DVH indicators: Dmean, Dmax, D98%, D95%, D50%, D5% and D2% for PTV. The highest and lowest differences were observed for the D95% (0.18%) and D50% (0.09%) parameters, respectively. The differences in gamma pass rate, represented by the median values, were 99.97%, 100.00%, 99.92% and 99.99%, 99.86% and 99.99% 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]	0.08	0.15	0.03	0.44
	Dmax% [Gy]	0.16	0.26	0.00	1.35
	D98% [Gy]	0.14	0.17	0.06	0.37
	D95% [Gy]	0.18	0.17	0.02	0.32
	D50% [Gy]	0.09	0.14	0.02	0.41
	D5% [Gy]	0.10	0.18	0.02	0.71
	D2% [Gy]	0.12	0.20	0.01	0.80

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

Conclusion:

In this work, we have demonstrated the feasibility of using artificial intelligence to transform CBCT images to high resolution CT. Our results demonstrated that the use of CBCT-derived synthetic CT is comparable in terms of dosimetric measures for planning breast cancer treatments, affirming its potential for advancing personalized medicine and expediting clinical routines. Next steps will include the integration of this work in the context of an effective implementation of an adaptive workflow from OARs annotation to full scale dose simulation and replanning.

Keywords: Adaptive RT, Synthetic-CT, Dose calculation