Use of synthetic cone beam CT in head and neck image guided volumetric modulated radiation therapy

Marina Chalkia1, Michalis Psarras2, Sami Romdhani3, George Patatoukas1, Theodoros Stroubinis2, Despoina Stasinou2, Nikolaos Kollaros1, Maria Protopapa2, Nikos Paragios4, Vassilis Kouloulias5, Kalliopi Platoni1,2
1 Medical Physics Unit, National Kapodestrian University of Athens, 2nd Department of Radiology, General University.
2 Mediterraneo Hospital, Department of Radiation Oncology and Stereotactic Radiosurgery, Athens, Greece.
3 R&D Artificial Intelligence, TheraPanacea, Paris, France.
4 R&D Artificial Intelligence, TheraPanacea, Athens, Greece.
5 Radiation Oncology Unit, National Kapodestrian University of Athens, 2nd Department of Radiology, General University Hospital 'Attikon', Athens, Greece

Purpose/Objective:
Cone-beam computed tomography (CBCT), is being widely used in image-guided radiotherapy (IGRT) to verify the patient position before treatment 1. However, original CBCT (orCBCT) images include a large number of artifacts, such as shading, reduced image contrast, and inaccurate Hounsfield unit (HU) values making it difficult to implement the CT CBCT alignment, and furthermore unsuitable for dose calculation at the frame of adaptive radiotherapy (ART) 2. This study was designed to explore the result of synthetic CBCT (synCBCT) alignment with planning CT. The synCBCT is generated from original CBCT images maintaining the anatomical structure characteristics, but distributing the HU tissue values similarly to that of planning CT. Head and Neck (H&N) cases were considered, as they usually suffer from serious artifacts due to metallic implants at the oral cavity region, or from anatomy changes.

Material/Methods:
In this retrospective study, a total of 21 H&N patients who underwent IGRT VMAT (Varian) treatment accompanied by daily kilovoltage (kVCBCT) were included. Each patient's original CBCT was used to generate a synCBCT (Thepanacea software) for the first (Day 1) and the seventh (Day 17) day of treatment. Day 17 was selected as the mid-therapy day, thus introducing more anatomical changes due to weight loss or PTV changes. Each alignment was performed by two independent expert observers using automated rigid alignment followed by manual correction(s) if needed. We recorded the resulting shifts in 6 directions, 3 translational (x, y, z) and 3 rotational (yaw, pitch, and roll). We performed statistical analysis using a non-parametric paired samples Wilcoxon test with the significance level set to 0.05, for three tests:
o (Test 1): comparison of the set-up errors from alignments of CT-sim on orCBCT vs. CT-sim on synCBCT for Day 1 and Day 17.
o (Test 2): comparison of the set-up errors between Day 1 and Day 17 for each alignment: CT-sim on orCBCT, and CT-sim on synCBCT.
o (Test 3): comparison of the set-up errors between Expert_1 and Expert_2, for Day 1 and Day 17 (for CT-sim on orCBCT, and CT-sim on synCBCT).

Results:
(Test 1): On Day 1, there were no statistically significant differences in set-up errors between alignments of CT-sim on orCBCT and CT-sim on synCBCT for all translational and rotational shifts, except for yaw. The resulted p-values were: 0.063, 0.246, 0.358, 0.008, 0.903, and 0.311 in the vertical, longitudinal, lateral, yaw, roll, and pitch direction, respectively. In the yaw direction, the statistical significance was found with a median difference (orCBCT synCBCT) of -0.05 degrees.
On Day 17, there were no statistically significant differences in set-up errors between alignments using CT-sim on orCBCT and CT-sim on synCBCT for all translational and rotational shifts. The resulted p-values were: 0.920, 0.640, 0.368, 0.225, 1.000, and 0.353 in the vertical, longitudinal, lateral, yaw, roll, and pitch direction, respectively.
(Test 2): There were no statistically significant differences in set-up errors between Day 1 and Day 17 for the alignments of CT-sim on orCBCT for all translational and rotational shifts, except for the pitch. The resulted p-values were: 0.502, 0.366, 0.614, 0.126, 0.365, and 0.003 in the vertical, longitudinal, lateral, yaw, roll, and pitch direction, respectively. In the pitch direction, the statistical significance was found with a median difference (Day 1 Day 17) of -0.6 degrees.
There were no statistically significant differences in set-up errors between Day 1 and Day 17 for the alignments of CT-sim on synCBCT for all translational and rotational shifts. The resulted p-values were: 0.823, 0.411, 0.808, 0.531, 0.968, and 0.100 in the vertical, longitudinal, lateral, yaw, roll, and pitch direction, respectively.
(Test 3): No statistically significant differences were found between Expert_1 and Expert_2 neither for Day 1 nor Day 17 (all p-values> 0.08).

Conclusion:
Overall, our results illustrate that no statistically significant difference was found between orCBCT and synCBCT in any comparison as far as translational shifts are concerned. A difference was found in the yaw direction for Day 1 and in the pitch direction between days 1 and 17. Additionally, both alignments, seem to be user independent. These results indicate that the use of synCBCT can be safely adopted in clinical radiotherapy routine for patient shift verification as it can exhibit equal results with improved image quality especially in cases with strong artifact presence within the field of view. Future perspectives include the ability to perform dosimetric calculations on the synthetic CBCT within the context of online or offline adaptive radiotherapy.

References:
[1] Cho PS et al., "Cone-beam CT for radiotherapy applications", Phys Med Biol, 1995, 40, 1863- 1883.
[2] Gao L et al., "Streaking artifact reduction for CBCT-based synthetic CT generation in adaptive radiotherapy", Med Phys, 2023 Feb, 50(2):879-893, doi: 10.1002/mp.16017, Epub 2022 Oct 18, PMID: 36183234.