Dosimetric evaluation of synthetic 3DCTs reconstructed from a single x-rays radiograph using convolutional neural network

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Purpose

All proton therapy treatment rooms are equipped with x-rays imaging devices to position the patient accurately. However, radiographs are not suited for proton dose calculation. This can be overcome by reconstructing a 3D computed tomography (CT) using a convolutional neural network (CNN). In this study, the suitability of these 3DCT images for proton therapy treatment of lung cancer patients was evaluated in terms of dosimetric accuracy.

Methodology

Five patients treated for a lung cancer in *Cliniques Universitaires Saint-Luc* were studied. For each patient, a data augmentation tool was used to create 1500 synthetic 3DCTs (sCTs) from the planning 4DCT [1]. 1500 digitally reconstructed radiographs (DRRs) were generated from each sCT and given as input to a CNN that learns to reconstruct the associated 3DCT. A test set composed of 50 ground-truth (GT) 3DCT and their corresponding DRRs is used to evaluate the accuracy of the predicted (P) 3DCT.

In proton therapy treatment planning, the stopping power ratio (SPR) is used for computed the water equivalent path length (WEPL), which is successively used for the computation of the required proton energy in the beam axis. In this study, SPR values are obtained using the CT calibration implemented in MCSquare [2]. WEPLs are computed along 3 beams whose angles are specific to the position of the tumor. SPR and WEPL difference maps are computed using the equations:

$$\Delta\mathrm{SPR} = \frac{\overline{\mathrm{SPR}_{\mathrm{GT}}} - \overline{\mathrm{SPR}_{\mathrm{P}}}}{\overline{\mathrm{SPR}_{\mathrm{GT}}}} \cdot 100 \;\; ; \;\; \Delta\mathrm{WEPL} = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} (\mathrm{WEPL}_{\mathrm{GT}} - \mathrm{WEPL}_{\mathrm{P}})^2$$

where $\bar{x}$ is the mean of x.

SPR and WEPL differences are reported as the median over the 50 images in the test set. Besides, the SPR is directly computed on regions of interest and the WEPL is focused on a rectangular box around the organ of interest.

Results

Figure 1 shows an overview of CT, SPR map and WEPL map for Patient 4 with difference maps between GT-based and P-based images.

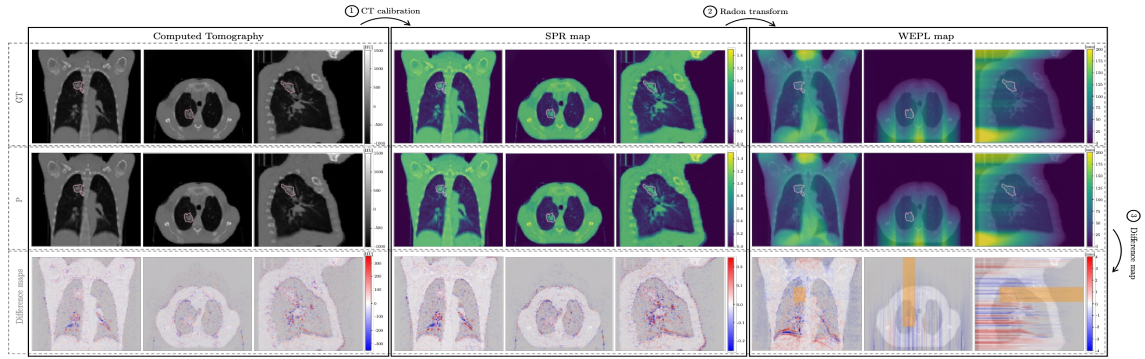

Figure 1. Overview of CT, SPR and WEPL along beam 0° maps for GT and P 3DCTs together with difference maps between the GT and the P images for Patient 4. The rectangular box associated to the GTV and on which the WEPL difference along beam 0° is computed is shown in orange.

The results of the SPR and WEPL differences are reported in Table 1. In general, the SPR estimates based on the P-3DCT are lower than for GT-3DCT and the largest SPR differences between both are found in the lungs. In the rectangular boxes around the regions of interest, the difference between GT- and P-based WEPL is always between 0 and 1 mm, whatever the patient and the angle of the beam. This difference is lower on the rectangular box around the GTV, and of the same order of magnitude for the heart and both lungs. In other areas of the image, the difference can be greater, up to 4 mm for Patient 4 and beam 0°, as seen on Figure 1.

Patient #	SPR difference (%)			WEPL difference (mm)								
	GTV	Heart	Lungs	GTV			Heart			Lungs		
Patient 1	0,107	0,224	-0,808	Beam 310°	Beam 10°	Beam 250°	Beam 310°	Beam 10°	Beam 250°	Beam 310°	Beam 10°	Beam 250°
				0,023	0,016	0,024	0,231	0,135	0,215	0,114	0,074	0,107
Patient 2	0,395	0,566	-0,274	Beam 320°	Beam 100°	Beam 30°	Beam 320°	Beam 100°	Beam 30°	Beam 320°	Beam 100°	Beam 30°
				0,028	0,102	0,019	0,153	0,222	0,137	0,144	0,193	0,146
Patient 3	0,203	0,381	0,402	Beam 210°	Beam 260°	Beam 320°	Beam 210°	Beam 260°	Beam 320°	Beam 210°	Beam 260°	Beam 320°
				0,044	0,098	0,052	0,084	0,279	0,085	0,078	0,158	0,085
Patient 4	0.139	0,203	0,345	Beam 0°	Beam 270°	Beam 315°	Beam 0°	Beam 270°	Beam 315°	Beam 0°	Beam 270°	Beam 315°
				0,005	0,059	0,018	0,029	0,085	0,041	0,083	0,119	0,066
Patient 5	0,357	0,287	-2,503	Beam 30°	Beam 75°	Beam 120°	Beam 30°	Beam 75°	Beam 120°	Beam 30°	Beam 75°	Beam 120°
				0,109	0,379	0,351	0,174	0,632	0,532	0,169	0,398	0,354

Table 1. Results of the SPR and WEPL differences for the three regions of interest and each patient.

Conclusion

The results of this study show that the predicted 3DCTs are of sufficient quality for dose calculation. The proposed method may be considered for on-line and off-line proton therapy treatment adaptation.

References

1. Loÿen E, Dasnoy-Sumell D, Macq, B, Patient-specific three-dimensional image reconstruction from a single X-ray projection using a convolutional neural network for on-line radiotherapy applications, Physics and Imaging in Radiation Oncology, 2023, https://doi.org/10/1016/j.phro.2023.100444.
2. Wuyckens S, Dasnoy-Sumell D, Janssens G, Hamaide V, Huet M, Loÿen E, et al., OpenTPS -- Open-source treatment planning system for research in proton therapy, arXiv, 2023, https://doi.org/10.48550/arXiv.2023/00365.