OC-0478 Neural network based synthetic CTs for adaptive proton therapy of lung cancer

Thummerer, Adrian; Zaffino, Paolo; Seller Oria, Carmen; Meijers, Artūrs; Guterres Marmitt, Gabriel; Seco, Joao; Langendijk, J.A.; Knopf, Antje; Spadea, Maria Francesca; Both, Stefan

Published in:
Radiotherapy and Oncology

DOI:
10.1016/S0167-8140(21)06925-5

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2021

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.
Figure 2. MAEs and pSNR calculated within the body, soft tissue, and bone with respect to the U-net and proposed model.

**Conclusion**

Qualitative and quantitative evaluation indicates that the proposed method can synthesize sCT with accurate CT numbers and best texture information, especially in soft tissue and the body. The achievement can increase treatment precision with sCT and show the potentiality in sCT-based organs contouring and dose calculation for adaptive radiotherapy.

**OC-0478 Neural network based synthetic CTs for adaptive proton therapy of lung cancer**

A. Thummerer,1, P. Zaffino,2, C. Seller Oria,1, A. Meijers,1, G. Guterres Marmitt,1, J. Seco,3, J. Langendijk,1, A. Knopf,1, M.F. Spadea,2, S. Both1

1University Medical Center Groningen, Department of Radiation Oncology, Groningen, The Netherlands; 2Magna Graecia University Catanzaro, Department of Experimental and Clinical Medicine, Catanzaro, Italy; 3Deutsches Krebsforschungszentrum (DKFZ), Department of Biomedical Physics in Radiation Oncology, Heidelberg, Germany; 4Heidelberg University, Department of Physics and Astronomy, Heidelberg, Germany; 5University Hospital of Cologne, Department I of Internal Medicine, Center for Integrated Oncology Cologne, Cologne, Germany

**Purpose or Objective**

Adaptive proton therapy (APT) accounts for anatomical and physiological changes to ensure target coverage and organ-at-risk sparing during the entire treatment course. An imaging modality that may detect these anatomical changes is cone-beam computed tomography (CBCT). However, CBCT images suffer from severe image artifacts (e.g. scatter) that hinder accurate proton dose calculations. Deep convolutional neural networks (DCNN) have shown potential to correct CBCTs and create synthetic CTs (sCTs) that enable proton dose calculations in various anatomical locations (e.g. head/neck, pelvis). In this study such a DCNN together with an accompanying planning CT (pCT) based patient specific correction technique was used to generate sCTs and their suitability for adaptive proton therapy of lung cancer patients was evaluated in terms of image quality and dosimetric accuracy.

**Materials and Methods**

A dataset consisting of CBCT- and same-day repeat CT-images from 33 lung cancer patients, treated with proton therapy, was used to train and evaluate the DCNN. 3-fold cross validation was employed to utilize all 33 patients for image and dosimetric evaluation. After the DCNN-conversion, an automatic patient specific correction method, using a smoothed and truncated difference map between the pCT and sCT, was introduced, mainly to correct CT-numbers of lung tissue, which are difficult to generate consistently and accurately by the DCNN.

For image quality assessment, mean absolute error (MAE) and mean error (ME) were calculated for sCTs with (sCT<sub>cor</sub>) and without (sCT<sub>orig</sub>) the pCT-based correction method. For the dosimetric evaluation, clinical treatment plans were recalculated on both synthetic CTs and gamma pass ratios (3%/3mm) were used to compare dose distributions to those calculated on the reference CT scans.

**Results**

Figure 1 shows an overview of CBCT, CT, sCT<sub>orig</sub> and sCT<sub>cor</sub> for patient 5 together with difference images between sCTs and CT. Average MAEs (ME) of 34.7±7.2 HU (5.2±9.8 HU) and 30.8±4.7 (2.7±4.8 HU) were observed for sCT<sub>orig</sub> and sCT<sub>cor</sub> respectively. The recalculations of clinical treatment plans resulted in average gamma pass ratios of 93.9±4.6 % for sCT<sub>orig</sub> and 96.9±2.2 % for sCT<sub>cor</sub>. Results from the gamma analysis are presented in Figure 2 for each patient individually.
Figure 1: Overview of reference CT, CBCT, original sCT (sCTorig), corrected sCT (sCTcor) together with difference images between sCTs and CT for patient 5 (worst case scenario). A HU window of [1700, 180] was used for all images.

Figure 2: Comparison of 3%/3mm gamma pass ratios of sCT_orig and sCT_cor for each patient individually.
Conclusion
The image quality evaluation and the dosimetric accuracy assessment indicates that neural network based sCTs combined with a patient specific correction method may be utilized for adaptive proton therapy in lung cancer patients.

OC-0479 Towards CBCT-guided online adaptive radiotherapy for prostate cancer patients
L. Zwart1, F. Ong1, L. ten Asbroek1, E. van Dieren1, S. Koch1, A. Bhawanie1, E. de Wit1, J. Dasselaar1
1Medisch Spectrum Twente, Radiotherapy, Enschede, The Netherlands

Purpose or Objective
Current challenges in radiotherapy include daily anatomical changes resulting in underdosage of the target and overdosage of the organs at risk (OARs). Online adaptive radiotherapy (oART) can in theory manage these inter-fractional variations. The aim of this study was to describe the first worldwide clinical implementation of CBCT-guided oART for prostate cancer patients, who were chosen as the first candidates because of inter-fractional variations in the pelvic region and the relative ease of anatomy.

Materials and Methods
Eleven prostate cancer patients were clinically treated with Ethos therapy (Varian Medical Systems, Palo Alto, CA) between February and July 2020, using a fractionation scheme of 20×3 Gy for the prostate and 20×2.7/3.0 Gy for the seminal vesicles for more advanced stages. Prior to the first adaptive fraction, influencers (prostate, seminal vesicles, rectum and bladder) and targets were manually contoured on the acquired planning CT. For each patient, a 9 field IMRT plan was created, applying a CTV-PTV margin of 7 mm in lateral and anterior-posterior direction and 8 mm in superior-inferior direction. During each adaptive session, a CBCT was acquired, on which the influencers were segmented by artificial intelligence and manually adjusted if necessary. After that, targets were propagated from the planning CT to the CBCT using a structure-guided deformation algorithm. The scheduled and adapted plans were recalculated and re-optimized on the CBCT anatomy, respectively. After an independent QA procedure (Mobius3D, Varian Medical Systems), the chosen treatment plan was delivered. The full team was present during the adaptive sessions, including two RTTs, a radiation oncologist, a medical physicist and a technical physicist. Treatment time and fraction doses were compared.

Results
All patients completed treatment without any ≥ grade 2 CTCAE v5.0 toxicities. From CBCT acquisition to end of treatment delivery, the mean treatment time ± standard deviation was 17.4±1.9 minutes (range: 10.8-28.8 minutes). For all fractions, the adapted plan was preferred over the scheduled plan, because of increased target coverage (183/220 fractions) or a combination of increased target coverage and superior bladder and/or rectum sparing (37/220 fractions). In 14/220 fractions the increased target coverage of the adapted plan resulted in a violation of the V60Gy constraint of the bladder and/or rectum. Typical comparisons of scheduled and adapted plans are shown in Figure 1.

Conclusion
CBCT-guided oART for prostate cancer patients is feasible within twenty minutes with a dedicated team. Future steps include the implementation of an RTT-led workflow and oART for more indications in the pelvic region.

OC-0480 Range probing as a quality control tool for CBCT based synthetic CTS: an in vivo demonstration