Physics and Imaging in Radiation Oncology 6 (2018) 12–13

Contents lists available at ScienceDirect

Physics and Imaging in Radiation Oncology

journal homepage: www.elsevier.com/locate/phro

Editorial

Quantitative computed tomography in radiation therapy: A mature technology with a bright future

ARTICLE INFO

Keywords:
Radiotherapy
CT imaging
Treatment preparation

1. Introduction

Computed tomography (CT) imaging is a cornerstone of radiation treatment planning, serving as the main source of quantitative volumetric information for the majority of patients. CT is currently the clinical workhorse for three-dimensional patient modelling, both for delineation and dose calculation, and is continuously being improved to perform these tasks to a higher level of accuracy. In the associated special virtual issue of *Physics and Imaging in Radiation Oncology* several papers on various parts of the radiotherapy workflow are assembled, clearly demonstrating that CT is still an important and lively active field of research leading to new and improved clinical applications. Numerous new technological improvements are currently under development at research institutes, in industry as well as in start-up companies. Partly driven by the need in routine diagnostic imaging to lower the dose burden as well as to improve spatial resolution and speed, the spin-off from the field of radiology to radiotherapy is evident.

In this virtual special issue of Physics and Imaging in Radiation Oncology focusing on CT imaging for radiotherapy, the selection of papers provides a snapshot of the areas currently investigated in the field of radiotherapy CT research. In this editorial we will introduce and classify these papers in broad general categories, and present a perspective on their potential role in current state-of-art radiotherapy.

2. CT imaging for treatment preparation

Standard CT imaging is still the starting point for many radiotherapy workflows. The calibration method that has been in place for many years is a conversion of the CT numbers (CT#) or Hounsfield Units (HU) into electron density (or for some dose calculation algorithms into mass density). A novel reconstruction method to reconstruct CT images directly into electron densities was evaluated by van der Heyden et al. [1]. In this paper a commercially available CT reconstruction algorithm was evaluated which bypasses the classical HU to electron density calibration curve of the treatment planning system by directly providing the electron density for dose calculation. This simplifies the current workflow in such a way that tube potential selection (kVp) can easily be optimized, allowing departure from the ubiquitous 120 kVp setting. As a case in point, see also the paper by Chen et al. [2] which investigated the optimal CT acquisition parameters, including different tube potentials (ranging from 70 to 140 kVp).

3. Dual energy CT imaging for proton therapy

Proton therapy is an area where the accuracy of CT# conversion to stopping power ratios (e.g. the quantity needed for proton therapy dose calculations) leaves much to be desired, as attested by the comprehensive survey of proton clinics from Taasti et al. [3], which includes a summary of the importance of upcoming techniques. In that survey dual energy CT (DECT) has been identified, along with improved dose calculation techniques, as the most important development. The technique can better estimate electron density and thus proton stopping power, as illustrated in Vilches-Freixas et al. [4], and leads to clinically relevant differences in range calculation when compared to conventional CT [5]. Given the growing evidence from animal tissue based validation studies showing the superior accuracy of DECT for stopping power estimation [6–10], these differences suggest DECT may bring clinical improvements. There has however recently been a number of DECT papers presenting alternative DECT formulations, often to little benefit over existing methods, which is the topic of another article in this special issue [11]. While the survey of Taasti et al. alludes to the competition between DECT and the pre-clinical concept of proton CT, where stopping power is measured directly to a high accuracy [12], an innovative paper from Vilches-Freixas et al. [13] proposes their combination as a novel means of directly imaging the mean excitation energy, or I-value, a non-negligible source of uncertainty in proton therapy [14].

https://doi.org/10.1016/j.phro.2018.04.004

4. Cone beam CT imaging

In the field of cone beam CT (CBCT) imaging, many clinics are investigating dose calculation based on this modality. There has been a strong interest from proton clinics, where the devices are making their way in the form of C-arm [15], gantry [16], nozzle or couch mounted imagers [17]. Dose computation [16,18,19] or monitoring of water equivalent thickness changes [20] is of particular interest in proton therapy. For improved scatter estimation and beam hardening correction strategies, Zöllner et al. [21] showed the feasibility of prior-CT based scatter correction by comparing to a physical model using accelerated Monte Carlo simulations. Another paper from this special issue by Thing et al. [22] evaluates a model-based artefact correction strategy to improve the Hounsfield Unit reconstruction in the context of dose calculation accuracy. Theoretical and simulation work thus still form a solid basis for improving image quality in CT based imaging. In the paper by Hansen et al. [23], a fast acquisition technique of around 60 s followed by all 4D image reconstruction of the CBCT is an example of the progress made in this field. Such correction strategies and reconstruction frameworks may allow future extension of the use of CBCT imaging for patient set-up purposes to a dose evaluation strategy, together with automatic segmentation or contour propagation enabling a comprehensive adaptive radiotherapy strategy.

5. Future perspectives

Although CT technology has been around for several decades, current work in this special issue shows the progress still made for radiotherapy imaging procedures, with improvements ranging from practical image quality optimization to exotic imaging of the mean excitation potential. The interest in DECT based dose calculation, in particular in proton therapy where devices are making their way into the clinic [9], also opens a new avenue for optimizing the image quality for improved delineations. Proton therapy has a particularly high demand for precision and improved target and OAR delineations, and improved CT imaging might be one of the factors in successfully improving accuracy of treatments. Adaptive strategies, for both conventional and proton therapy, demand more accurate procedures and workflow improvements, and require a renewed view on clinical goals.

Conflict of interest statements

None declared.

References

[1] van der Heyden B, Öllers M, Ritter A, Verhaegen F, van Elmpt W. Clinical evaluation of a novel CT image reconstruction algorithm for direct dose calculations. Phys Imag Radiat Oncol 2017;2:11–6.

[2] Chen G-P, Noid G, Tai A, Liu F, Lawton C, Erickson B, et al. Improving CT quality with optimized image parameters for radiation treatment planning and delivery guidance. Phys Imag Radiat Oncol 2017;4:6–11.

[3] Taasti VT, Bäumer C, Dahlgren C, Deisher A, Ellerbrock M, Free J, et al. Inter-centre variability of CT-based stopping-power prediction in particle therapy: survey-based evaluation. Phys Imag Radiat Oncol 2018. [accepted for publication].

[4] Vilches-Freixas G, Taasti VT, Muren LP, Petersen JBB, Létang JM, Hansen DC, et al. Comparison of projection- and image-based methods for proton stopping power estimation using dual energy CT. Phys Imag Radiat Oncol 2017;3:28–36.

[5] Taasti VT, Muren LP, Jensen K, Petersen JBB, Thygesen J, Tietze A, et al. Comparison of single and dual energy CT for stopping power determination in proton therapy of head and neck cancer. Phys Imag Radiat Oncol 2018. [accepted for publication].

[6] Xie Y, Ainsley C, Yin L, Zou W, McDonough J, Solberg TD, et al. Ex vivo validation of a stoichiometric dual energy CT proton stopping power ratio calibration. Phys Med Biol 2018;63:055016.

[7] Mohler C, Russ T, Wohlfahrt P, Elter A, Runz A, Richter C, et al. Experimental verification of stopping-power prediction from single- and dual-energy computed tomography in biological tissues. Phys Med Biol 2018;63:025001.

[8] Bar E, Lalonde A, Zhang R, Jee KW, Yang K, Sharp G, et al. Experimental validation of two dual-energy CT methods for proton therapy using heterogeneous tissue samples. Med Phys 2018;45:48–59.

[9] Wohlfahrt P, Möhler C, Hietschold V, Menkel S, Greilich S, Krause M, et al. Clinical implementation of dual-energy CT for proton treatment planning on pseudo-monoenergetic CT scans. Int J Radiat Oncol Biol Phys 2017;97:427–34.

[10] Taasti VT, Michalak GJ, Hansen DC, Deisher AJ, Kruse JJ, Krauss B, et al. Validation of proton stopping power ratio estimation based on dual energy CT using fresh tissue samples. Phys Med Biol 2017;63:015012.

[11] Möhler C, Wohlfahrt P, Richter C, Greilich S. On the equivalence of image-based dual-energy CT methods for the determination of electron density and effective atomic number in radiotherapy. Phys Imag Radiat Oncol 2018;5:108–10.

[12] Giacometti V, Bashkirov VA, Piersimoni P, Guatelli S, Plautz TE, Sadrozinski HF, et al. Software platform for simulation of a prototype proton CT scanner. Med Phys 2017;44:1002–16.

[13] Vilches-Freixas G, Quinones CT, Letang JM, Rit S. Deriving the mean excitation energy map from dual-energy and proton computed tomography. Phys Imag Radiat Oncol 2018. [accepted for publication].

[14] Andreo P. On the clinical spatial resolution achievable with protons and heavier charged particle radiotherapy beams. Phys Med Biol 2009;54:N205–15.

[15] Hua C, Yao W, Kidani T, Tomida K, Ozawa S, Nishimura T, et al. A robotic C-arm cone beam CT system for image-guided proton therapy: design and performance. Br J Radiol 2017;90:20170266.

[16] Veiga C, Janssens G, Teng CL, Baudier T, Hotoiu L, McClelland JR, et al. First clinical investigation of cone beam computed tomography and deformable registration for adaptive proton therapy for lung cancer. Int J Radiat Oncol Biol Phys 2016;95:549–59.

[17] Stock M, Georg D, Ableitinger A, Zechner A, Utz A, Mumot M, et al. The technological basis for adaptive ion beam therapy at MedAustron: status and outlook. Z Med Phys 2017.

[18] Park YK, Sharp GC, Phillips J, Winey BA. Proton dose calculation on scatter-corrected CBCT image: feasibility study for adaptive proton therapy. Med Phys 2015;42:4449–59.

[19] Veiga C, Alshaikhi J, Amos R, Lourenco AM, Modat M, Ourselin S, et al. Cone-beam computed tomography and deformable registration-based “dose of the day” calculations for adaptive proton therapy. Int J Part Ther 2015;2:404–14.

[20] Wang P, Yin L, Zhang Y, Kirk M, Song G, Ahn PH, et al. Quantitative assessment of anatomical change using a virtual proton depth radiograph for adaptive head and neck proton therapy. J Appl Clin Med Phys 2016;17:427–40.

[21] Zöllner C, Rit S, Kurz C, Vilches-Freixas G, Kamp F, Dedes G, et al. Decomposing a prior-CT-based cone-beam CT projection correction algorithm into scatter and beam hardening components. Phys Imag Radiat Oncol 2017;3:49–52.

[22] Thing RS, Bernchou U, Hansen O, Brink C. Accuracy of dose calculation based on artefact corrected Cone Beam CT images of lung cancer patients. Phys Imag Radiat Oncol 2017;1:6–11.

[23] Hansen DC, Sørensen TS. Fast 4D cone-beam CT from 60 s acquisitions. Phys Imag Radiat Oncol 2018;5:69–75.

Wouter van Elmpt

Department of Radiation Oncology (MAASTRO), GROW – School for Oncology and Developmental Biology, Maastricht University Medical Centre, Dr. Tanslaan 12, NL-6229 ET Maastricht, The Netherlands

E-mail address: wouter.vanelmpt@maastro.nl

E-mail address: wouter.vanelmpt@maastro.nl.

Guillaume Landry

Department of Medical Physics, Faculty of Physics, Ludwig-Maximilians-Universität München (LMU Munich), Garching b. München, Germany