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

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].

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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-CBT 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 still thus form a solid basis for improving image quality in CBCT 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 DCT 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.

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