ARTICLE IN PRESS

Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

Use of an in-house Monte Carlo platform to assess the clinical impact of algorithm-related dose differences on DVH constraints

A. Wagner [a], F. Crop [a], X. Mirabel [b], C. Tailly [a], N. Reynaert [a]

[a] Department of Medical Physics, Centre Oscar Lambret and University Lille 1, France
[b] Academic Department of Radiation Oncology, Centre Oscar Lambret and University Lille 2, France

ARTICLE INFO

Article history:
Received 30 December 2016
Received in Revised form 18 April 2017
Accepted 18 May 2017
Available online xxxx

Keywords:
Treatment planning
Monte Carlo
QA
Dose constraints

ABSTRACT

Purpose: The aim of the present work is to evaluate a semi-automatic prescription and validation system of treatment plans for complex delivery techniques, integrated in a Monte Carlo platform, and to investigate the clinical impact of dose differences due to the calculation algorithms, by assessing the changes in DVH constraints.

Methods: A new prescription module was implemented into the *Moderato* system, an in-house Monte Carlo platform, with corresponding dose constraints generated depending on the anatomical region and fractionation scheme considered. The platform was tested on 83 cases treated with Cyberknife and Tomotherapy machines, to assess whether dose variations between the re-calculated dose and the Treatment Planning System might impact the dose constraints on the sensitive structures.

Results: Dose differences were small (within 3%) between calculation algorithms in most of the thoracic, pelvic and abdominal cases, both for the Cyberknife and Tomotherapy machines. On the other hand, spinal and head and neck treatments presented a few significant dose deviations for constraints on small volumes, such as the optic pathways and the spinal cord. These differences range from −11% to +6%, inducing constraint violations of up to 8% over the dose limit.

Conclusions: The *Moderato* platform offers an interesting tool for plan quality validation, with a prescription module highlighting crucial features in the structures list, and a Monte Carlo dose re-calculation for complex modern techniques. Due to the high number of warnings appearing in some situations, display optimization is required in practice.

1. Introduction

In radiotherapy, the treatment chain consists of several steps that can introduce errors, and workflow is an essential aspect in the quality management of a department. The number of different actors and the numerous steps in a patient course before treatment require very fast and flexible tools, and much effort has been put into the automation and optimization of the processes in our department, as introduced in [1]. An important step is the prescription performed by the physician. If it is not clear enough or lacks some elements when the patient file reaches the dosimetry step, additional interaction is needed between the physicist or dosimetrist and the physician, which inevitably slows down the process. Sometimes an unusual fractionation scheme is adopted, which requires new constraints to be calculated. The validation step of a treatment plan can also be very time-consuming, as it implies both the physicist and the physician reviewing the quality of the plan, including a number of regions-of-interest (ROI) to make sure these are all spared (or covered) adequately. This manual verification is one of the last checkpoints before a patient receives his or her first treatment session, and an error or oversight during this step might have serious consequences. All these aspects support the need for a system that would speed up the process while preserving its quality and safety aspects, as well as guaranteeing that no element is overlooked.

As introduced in [2], *Moderato* is an independent treatment QA platform that allows for dose re-calculation of complex radiation therapy techniques. It consists of a Monte Carlo (MC) based platform designed to be used in the daily clinical routine as most of the processes are automated: the Dicom files (images, structures and dose) are converted and simulations are launched without user interaction, and a graphical interface allows for a quick visual comparison of the dose distributions and Dose-Volume Histogram (DVH) data. The Cyberknife and Tomotherapy machines were modeled [4] and validated based on dose profiles, depth-dose curves and simple phantom geometries. It is generally recognized that

http://dx.doi.org/10.1016/j.ejmp.2017.05.062
1120-1797/

Please cite this article in press as: Wagner A et al. Use of an in-house Monte Carlo platform to assess the clinical impact of algorithm-related dose differences on DVH constraints. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.05.062

Monte Carlo algorithms provide a higher precision for dose distributions calculated in complex geometries, where many material interfaces are involved [5]. The main drawback of the use of Monte Carlo codes in routine has been their computation time, but this issue has been addressed in *Moderato*. This allows to use it on a much larger scale and to systematically re-calculate all patient plans.

The aim of the present work is to implement a semi-automated Prescription/Validation module into our existing *Moderato* platform, allowing for an improvement of the process in terms of speed and safety. As doses are re-calculated using a high-precision MC engine, our second objective is to evaluate the clinical impact of the calculation algorithms on the dose constraints for the different anatomical structures considered.

2. Materials and methods

The *Moderato* platform, which is originally based on MCDE [6] is introduced in detail in Reynaert et al. [2]. Calculations for the patients considered in this study were based on BEAMnrc [7] and DOSXYZnrc [8] (other codes are available). The modeling of the Tomotherapy is partly based on Chen et al. [3], whereas the Cyberknife modeling was validated earlier in our centre [4]. Standard MC calculation parameters are defined in the system and can be modified if necessary. The number of histories was set to result in an uncertainty of 2% in 95% of the Planning Target Volume (PTV). This corresponds to approximate calculation times between 15 and 45 min. The image value to density table and tissue composition are based on a stoichiometric calibration method [9,10].

A new *Prescription* module was implemented into the system, consisting of a graphical interface where the physician first selects a "model", which corresponds to an indication (e.g. head and neck, thoracic, pelvis), the desired dose level and number of fractions. All OAR constraints are automatically displayed based on the anatomical region and the fractionation scheme. The physician can add or remove structures from the list and modify the dose constraints if necessary, depending on the clinical specificity of the patient considered (priority between target coverage and close OAR, re-irradiation case, etc.)

Treatment planning is realized using the dedicated commercial Treatment Planning System (TPS). Upon completion, the dose is re-calculated in *Moderato* with standard simulation parameters (which can be modified if necessary), and a tag is activated in the patient flow system [1] to indicate the plan is ready for validation. The system displays the isodoses and the Dose-Volume Histograms in a manner similar to a conventional TPS (Fig. 1). In addition, the system creates a table containing all the DVH points of interest (corresponding to dose constraints), both according to the TPS and to the MC calculation. The first structures shown are those where constraints are violated, either in the TPS calculation, the Monte Carlo calculation, or both. Three different color codes are associated with the magnitude of the deviation (0–3%, 3–5%, >5%). Next, structures fulfilling all constraints are displayed. Finally the table shows the structures usually associated to the selected model, but that could not be found in the structures list. This allows the physician to verify whether some structure was omitted during the contouring phase.

The structure display is illustrated in Table 1. Here the first constraint on the oral cavity, V15 Gy < 80%, is violated. The table shows the dose actually delivered to 80% of the organ, and highlights it as it deviates by approximately 7% from the limit. Although this display might seem less intuitive than showing directly the volume percentage, it is more logical as the comparison focuses on the dose calculation from both algorithms, and not the volume. The choice was made not to modify the constraints list as the form Vx < Y% is most common in the literature and is the one used by the physicians in our department.

Twenty-seven Cyberknife (CK) patients and fifty-six Helical Tomotherapy (HT) patients were included in this work. The CK cases consisted of 8 head and neck, 5 thoracic, 6 spine, 3 liver, and 5 pelvic treatments. The distribution of patients treated with HT was 20 head and neck, 5 thoracic, 14 breast, 4 abdominal, and 13 pelvic cases. No selection criteria were used and the relative proportions of indications simply reflect the database of each machine at the time of the study. All OARs were reviewed to look

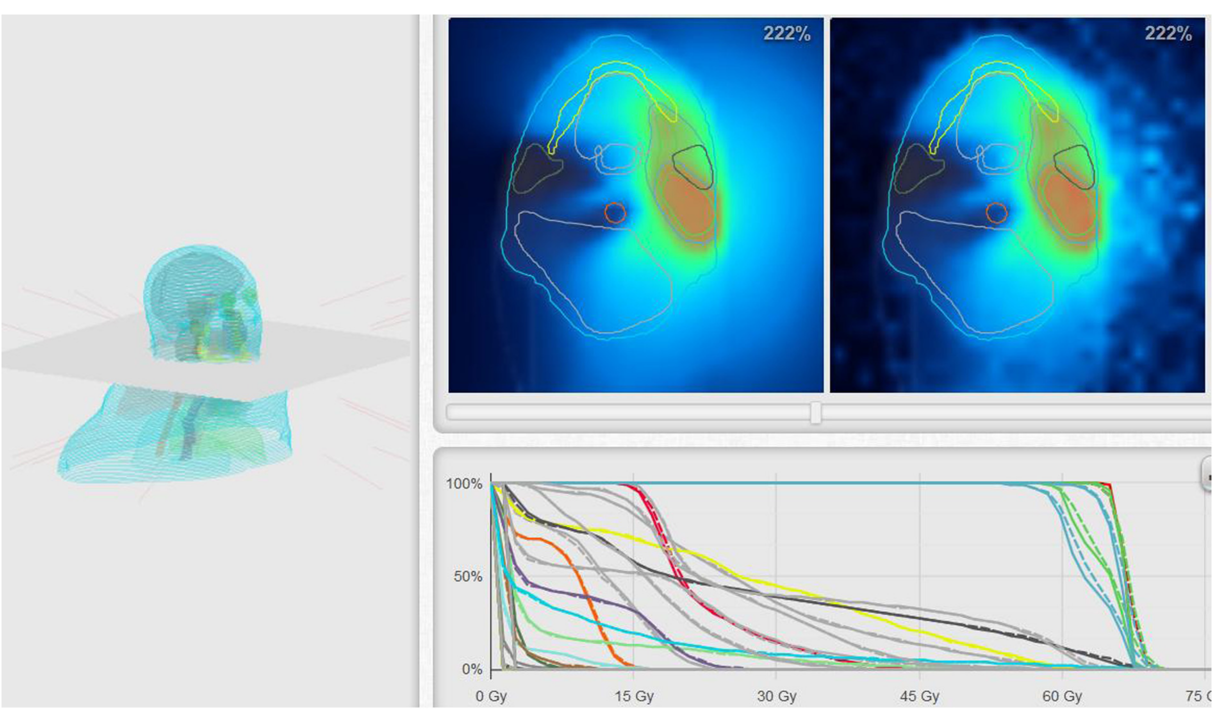

Fig. 1. The DVH and isodose visualization of *Moderato*.

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