Physica Medica 32 (2016) 506–511

Contents lists available at ScienceDirect

Physica Medica

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

Invited Paper

Bladder dose–surface maps and urinary toxicity: Robustness with respect to motion in assessing local dose effects

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ARTICLE INFO

Article history:
Received 4 December 2015
Received in Revised form 29 February 2016
Accepted 3 March 2016
Available online 1 April 2016

Keywords:
Bladder
Dose–surface maps
Inter-fraction motion

ABSTRACT

The purpose of this study was to quantify the impact of inter-fraction modifications of bladder during RT of prostate cancer on bladder dose surface maps (DSM).

Eighteen patients treated with daily image-guided Tomotherapy and moderate hypofractionation (70–72.8 Gy at 2.5–2.6 Gy/fr in 28 fractions and full bladder) were considered. Bladder contours were delineated on co-registered daily Megavoltage CT (MVCT) by a single observer and copied on the planning CT to generate dose–volume/surface histograms (DVH/DSH) and bladder DSMs. Discrepancies between planned and daily absorbed doses were analyzed through the average of individual systematic errors, the population systematic errors and the population random errors for the DVH/DSHs and DSMs.

In total, 477 DVH/DSH and 472 DSM were available. DSH and DVH showed small population systematic errors of absolute surfaces (<3.4 cm^2) and volumes (<8.4 cm^3) at the highest doses.

The dose to the posterior bladder base assessed on DSMs showed a mean systematic error below 1 Gy, with population systematic and random errors within 4 and 3 Gy, respectively. The region surrounding this area shows higher mean systematic errors (1–3 Gy), population systematic (8–11 Gy) and random (5–7 Gy) errors.

In conclusion, DVH/DSH and DSMs are quite stable with respect to inter-fraction variations in the high-dose region, within about 2 cm from bladder base. Larger systematic variations occur in the anterior portion and cranially 2.5–3.5 cm from the base.

Results suggest that dose predictors related to the high dose area (including the trigone dose) are likely to be sufficiently reliable with respect to the expected variations due to variable bladder filling.

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Introduction

Bladder is a hollow and flexible organ exposed to high doses in RT for prostate cancer and it is well known, in literature, that its impairment can be cause of toxicities that highly affect the patient quality of life even many years after the treatment [1,2].

Acute and urinary toxicities were found related with the planned dose in various works [1–7] however, due to the deformable nature of bladder, estimating the deviations of daily-absorbed dose from the planned dose becomes a major issue [8–13].

In order to investigate the robustness of planned dose, appropriate dose descriptors should be employed. The dose–volume histograms (DVH) are well-established descriptors commonly employed in treatment planning, however, various works have suggested that other tools that are surrogate of the dose absorbed by the bladder wall, like the dose–wall histograms or dose–surface histograms, should be more appropriate when we describe the dose absorbed by an empty organ [10,14,15].

However, it is well known that all the previous dose descriptors reduce the spatial dose information into a single parameter (i.e.: the dimension of the region absorbing a given dose) while more advanced techniques should better preserve the information of

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http://dx.doi.org/10.1016/j.ejmp.2016.03.006
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dose distribution on the surface of an empty organ, like the dose surface maps, applied with success in rectum toxicity studies [16,17] and, recently, to bladder toxicity studies [18].

In this work we decided to make use of the dose surface maps (DSM), appropriately normalized and aligned, in order to compare the dose received by the patient in each daily fraction with the planned dose and to estimate the magnitude of systematic and random deviations of the absorbed dose for a population of patients treated with full bladder and daily image guided Tomotherapy for the treatment of prostate cancer. Other dose descriptors, like DSH and DVH, were also used for comparison.

Materials and methods

Patient cohort

We selected a cohort of 18 prostate cancer patients treated with daily Image Guided Radiotherapy with radical intent. The treatment followed a modified version of a Phase I–II protocol testing moderate hypo-fractionation [19]: the prescribed dose was 70/72.8 Gy at 2.5/2.6 Gy/fr in 28 fractions. Intermediate and high risk patients had simultaneous irradiation of seminal vesicles with different doses (range: 56–61.6 Gy); high risk patients had also simultaneous pelvic nodes irradiation to 49 Gy at 1.75 Gy/fr.

Patients were treated with Helical Tomotherapy and daily image-guidance: first a rigid registration of the bones between planning kVCT and the daily megavoltage CT (MVCT) was performed, then fine adjustments were done if necessary to take into account the motion of the prostate with respect to the bony anatomy, as reported in Fiorino et al. [20].

Details including patient preparation, contouring, planning optimization and image guidance strategies can be found elsewhere [19–21]. Regarding bladder, the planners tried to keep the maximum dose below 105% of the prescribed dose and to spare as much as possible the bladder outside PTVs: no other specific constraints were applied. Patients were asked to maintain full bladder during the CT simulation and treatment: with this aim, patients were asked to drink 400–500 ml of water one hour before simulation and before each fraction.

Estimation of daily-absorbed dose

Daily-absorbed dose was estimated by making use of the pre-treatment MVCT that was rigidly registered to the planning kVCT as described in the previous section.

Bladder contours were then delineated on each registered MVCT by a single observer and copied on the planning CT, the planned dose distribution was then employed to estimate the daily dose absorbed by bladder: the procedure was previously reported to be sufficiently representative of the dose absorbed by the bladder compared to a full dose re-calculation due to a substantial invariance of the dose distribution with respect to anatomical changes during a radiotherapy course [22].

MVCT with partial bladders were excluded from the analysis.

For each patient, all the planning data (planning CT, dose distribution and organ contours) along with the pre-treatment MVCT bladder contours were uploaded on a dedicated software that allowed the extraction of dose–volume histograms (DVH) and dose–surface histograms (DSH) for each patient for both the planned and daily contours (VODCA, MSS Medical Software Solutions, Hagendorn, Switzerland [14,23]).

Dose surface maps

A dedicated VODCA module was employed for generating the planning and daily bladder dose surface maps (DSM).

A three-dimensional polygonal mesh of each bladder was made first by connecting, through triangulation, the vertices of the bladder contours and, subsequently, by associating each face of the resulting bladder polygon with the planned doses through a trilinear interpolation. The polygonal surface doses were then unfolded on a 2D plane by anteriorly cutting the bladder at the points intersecting the sagittal plane (M) passing through its center of mass. In this way, the posterior bladder corresponded to the central region of the map, while the anterior one was located laterally, see Fig. 1.

A rectangular map for each patient was generated in order to allow map superpositions: the lateral dimension was normalized assuming a "roughly" constant number of endothelial cells at each transversal cut of bladder (in analogy with a similar concept previously used for rectum analysis [24]), while the cranial–caudal direction was maintained in absolute units. The last choice was performed because we did not want to artificially compress or enlarge isodoses at the bladder base when we compare different bladder fillings.

The laterally normalized DSM is then rasterized into a matrix of pixels with a resolution of 0.5% along the lateral dimension and of 1 mm along the vertical extension.

In order to allow map comparison, the inferior posterior point (I/P) intersecting the sagittal plane M was chosen as the DSM origin for each patient and fraction, as it corresponds to a stable portion of the bladder (relative to bladder filling and prostate position) receiving the highest doses during prostate cancer irradiation. Moreover, the normalized DSMs were cut at the smallest vertical extension present in the sample: given the considered population, the analysis was then restricted to a bladder cranial length of 34 mm.

Statistical analysis

Discrepancies between the planned and daily-absorbed doses were evaluated for each patient by calculating the individual systematic errors (mean of daily deviations from the planned histograms) and random errors (standard deviation of daily deviations from the planned histograms) of absolute surfaces and absolute volumes for DSH and DVH, respectively.

After that, the mean of individual systematic errors, the population systematic errors (standard deviation of individual systematic errors) and the population random errors (average of individual random errors) were computed for both DSH and DVH.

In a similar way, the maps of mean and population systematic errors (systematic deviations in dose at each pixel) and that of population random errors (average of individual random errors in dose at each pixel) were created.

Results

Data of 18 patients were available, with 477 DSHs/DVHs (459 daily histograms + 18 TPS histograms) and 472 dose surface maps (454 daily maps + 18 TPS maps) of bladders: on average, we considered 26 (18–29) and 25 (18–28) daily MVCT per patient for DVHs/DSHs and DSMs respectively.

In Table 1 we report the planning parameters of the considered population. Note that there is a small but not negligible overlap between the bladder and the prostate PTV volumes, which has a mean value of 15.2 (6.4–27.6) cm^3 and that the bladder receives on average maximum doses (at 1% of its volume) equal to 73.7 (71.2–77.1) Gy that are comparable with those received by the prostate, that are equal to 74.3 (72.0–77.5) Gy.

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