ELSEVIER
Journal of Medical Imaging and Radiation Sciences xx (2017) 1-6
Journal of Medical Imaging and Radiation Sciences
Journal de l'imagerie médicale et des sciences de la radiation
www.elsevier.com/locate/jmir

A Dosimetric Evaluation of Threshold Bladder Volumes for Prostate Cancer Radiotherapy

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ABSTRACT

Background: An interfraction variation in bladder filling results in uncertainties of dose received and also has workflow implications for busy departments. This study aims to examine the dosimetric impact of a reduced bladder volume while determining a suitable threshold for treatment.

Materials and Methods: A total of 15 definitive prostate patients were included for this retrospective dosimetry study. Each patient was planned to receive 80 Gy in 40 fractions using intensity-modulated radiation therapy. For each patient, a series of shrunken bladder volumes were created in 50-mL increments. The volume of bladder receiving 65 Gy (V65),70 Gy, 75 Gy, and 80 Gy for each "shrunken" bladder volume were analyzed with paired samples t-tests. The effect of the shrunken volume relative to the established dose-volume constraint (DVC) was then assessed using single sample t-tests.

Results: The mean planning bladder volume was 345.01 ± 138.51 mL. Under maximum bladder shrinkage, mean difference between the percentage dose received and each DVC was seen to be statistically significant ($P < .05$). However, for the majority of patients, DVCs were only violated once the bladder volume shrunk to less than 150 mL. On average, the DVCs were violated once the bladder volume fell below 150 mL for the V75 and V80 constraints, with no violations noted for V65 and V70.

Conclusion: Even under exacerbated bladder shrinkage, bladder DVC violations were found to be rare. A bladder threshold of 150 mL would prove sufficient to meet bladder DVCs in over 90% of patients; however, case-by-case assessment is required to ensure patient suitability.

RÉSUMÉ

Contexte : Une variation d'interfraction dans le remplissage de la vessie entraîne des incertitudes dans la dose reçue et a aussi des répercussions sur le flux de travail dans les services où la charge de travail est élevée. Cette étude se penche sur l'effet dosimétrique d'une réduction du volume de la vessie dans la détermination d'un seuil approprié pour le traitement.

Matériel et méthodologie : Un total de 15 patients ayant un diagnostic définitif de cancer de la prostate ont été inclus dans cette étude dosimétrique rétrospective. Chaque patient devait recevoir 80 Gy en 40 fractions par radiothérapie à modulation d'intensité. Pour chaque patient, une série de volumes de vessie réduits par incréments de 50 mm a été créée. Le volume de vessie recevant 65 Gy (V65), 70 Gy (V70), 75 Gy (V75) et 80 Gy (V80) pour chaque volume de vessie réduit a été analysé par des tests t sur échantillons appariés. Les effets de la réduction de volume par rapport à la contrainte de volume de dose (DVC) établie ont ensuite été évalués à l'aide d'un test t sur échantillon simple.

Résultats : Le volume de traitement moyen planifié de la vessie était de 345 ± 138 mL. Avec la diminution maximale de volume de la vessie, la différence moyenne entre le pourcentage de dose reçue et la contrainte de volume de chaque dose était statistiquement significative ($P < 0.05$). Cependant, pour la majorité des patients, la DVC n'était violée que lorsque le volume de la vessie était ramené à moins de 150 ml pour les contraintes de V75 et V80, sans violation notée pour V65 et V70.

Conclusion : Même avec une forte réduction du volume de la vessie, les violations de DVC de la vessie étaient rares. Un seuil de remplissage de la vessie à 150 mL serait suffisant pour respecter la DVC de la vessie chez plus de 90% des patients, mais une évaluation au cas par cas reste nécessaire pour s'assurer du caractère approprié pour les patients.

Keywords: Bladder DVH; bladder variation; prostate; IMRT

Introduction

The position, size, and shape of the bladder can fluctuate greatly with the patient's hydration levels, diet, medication, and volume of water ingested [1]. As a result of these

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http://dx.doi.org/10.1016/j.jmir.2017.03.003

variations, the planned dose-volume histogram (DVH) is unlikely to represent the true dose delivered during a course of fractionated prostate radiotherapy [2]. Despite the proximity of this radiosensitive organ to the target volume, levels of severe acute and late urinary toxicity in this patient cohort have historically been found to be low [3–5]. This is partly due to technical advances, such as improvements in image guidance.

Image-guided radiotherapy has allowed for online visualization of changes to adjacent radiosensitive structures, giving the radiation therapists additional information when assessing a patient's suitability for treatment. Such advances have also facilitated soft tissue matching to the prostate itself, rendering the impact of bladder volume variations on target coverage minimal [6, 7]. Furthermore, it has been established that variation in treatment bladder volume relative to the planned bladder volume does not significantly impact on prostate position [8–11]. Despite these factors, there is a tendency to "get the patient off the bed" if their bladder volume is less than that of their planning scan regardless of the minimal impact on target coverage [12]. This practice can cause undue stress on patients and also a disruptive workflow for busy treatment units. Currently, there is a lack of data from a planning perspective on the smallest tolerable bladder volume in radiation therapy for localized prostate cancer in the era of Intensity Modulated Radiation Therapy (IMRT). This study aims to determine the dosimetric effect of a decreased bladder volume on the planned DVH and Dose Volume Constraints (DVCs) stipulated by Quantitative Analyses of Normal Tissue Effects in the Clinic (QUANTEC) [13].

Materials and Methods

Patient Selection, Pre-planning Preparation and Volume Delineation

After institutional ethical approval, a convenience sample of 15 consecutive intermediate risk patients were chosen over a fixed period. Inclusion criteria for this retrospective planning study were patients who had received definitive radiotherapy to their prostate and proximal first centimeter of seminal vesicles. As the computed tomography (CT) data were irrevocably anonymized, specific patient characteristics were unknown to the research team. Each patient had a planning CT scan with a comfortably full bladder and bowel preparation as per local protocol [4]. The prostate clinical target volume (CTVp) and proximal first centimeter of seminal vesicles as a clinical target volume (CTVsv) were contoured by the treating radiation oncologist. The CTVp was expanded anisotropically by 0.7 cm and 0.5 cm posteriorly. The CTVsv had a uniform expansion of 0.8 cm. These volumes were then combined to create the planning target volume. Each case was prescribed to 80 Gy in 40 fractions to 95% of the planning target volume. The organs at risk were contoured as per published guidelines [14]. Specifically, the bladder was delineated in its entirety from the base to the dome including the outer bladder wall. In an attempt to decrease observer variability, the organs at risk were contoured by a single radiation therapist with experience in organ at risk delineation.

Treatment Planning and Bladder Volume Manipulation

IMRT plans were created using the Eclipse treatment planning system (TPS; V8.6.23) with the anisotropic analytical algorithm, grid size of 2.5 × 2.5 mm. All plans consisted of a seven field beam arrangement using 6 MV photons. While IMRT planning with higher energies is possible, there is a lack of convincing data to support the use of energies above 6 MV. Although higher energies may reduce dose dumping in unspecified healthy tissue, we were able to manage these regions using the normal tissue objective function in the Eclipse TPS. Plans were optimized to comply with target coverage stipulated in the prescription and organ at risk sparing based on published consensus DVCs, detailed in Table 1 [13, 15].

On completion of all plans, a series of reduced bladder volumes were contoured for each patient. To achieve these reduced bladder volumes, internal margins were created from the original planning bladder volume in the TPS using finite element bladder modelling as a guideline [16]. The original planning bladder was reduced in volume by 50 mL increments down to a volume of 100 mL (Figure 1).

Data Analysis

DVHs were generated for all patients' planning bladders, and each of the subsequent reduced bladder volumes. In the absence of evidence-based DVCs for the bladder, this study adopted the endpoints recommended in the QUANTEC articles for bladder damage [13]. The percentage volume of each bladder structure receiving a dose of 65 Gy (V65), V70 (V70), V75 (V75), V80 (V80) was recorded. The original planning bladder statistics were compared using a range of means. Direct comparisons of dosimetric parameters between the planned bladder volume and the reduced bladder volumes were performed using paired samples t-tests. To analyse the effect relative to QUANTEC DVC of decreasing a patient's bladder volume, a series of single sample t-tests were run

Table 1
Organ at Risk Contouring and Dose Constraints

Organ	Description	Dose Constraint
Rectum	Whole structure rectosigmoid junction to anal verge	V50 < 50%, V60 < 35%, V65 < 25%, V70 < 20%, V75 < 15%
Bladder	Outer wall, dome to base	V65 < 50% V70 < 35%, V75 < 25%, V80 < 15%,
Femoral head	Head, neck, trochanters to ischial tuberosities	V50 < 5%

V80, percentage volume receiving 80 Gy; V75, percentage volume receiving 75 Gy; V70, percentage volume receiving 70 Gy; V65, percentage volume receiving 65 Gy; V60, percentage volume receiving 60 Gy; V50, percentage volume receiving 50 Gy.