Journal of Medical Imaging and Radiation Sciences 47 (2016) 227-234

Journal of Medical Imaging and Radiation Sciences

Journal de l'imagerie médicale et des sciences de la radiation

www.elsevier.com/locate/jmir

Research Article

Assessment of Adaptive Margins Using a Single Planning Computed Tomography Scan for Bladder Radiotherapy

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ABSTRACT

Introduction: A "plan of the day" (PoD) adaptive radiotherapy approach is presented for bladder cancer. The potential reduction in volumes of normal tissue and bowel bag receiving high-dose radiation is evaluated.

Materials and Methods: Planning computed tomography (pCT) and daily cone beam CT (CBCT) data sets were analyzed for eight previously treated bladder cancer patients. For each patient, a whole bladder clinical target volume (CTV) was delineated on a pCT. Then, the clinical target volume was expanded using five sets of anisotropic or isotropic margins to create five planning target volumes (PTVs). A library of five corresponding treatment PoDs was then created using volumetric modulated arc therapy. Offline PoD selection was performed by three independent radiation therapists (RTs) using daily CBCTs. Dosimetric results were compared between PoD treatments and two conventional treatments using isotropic 1.5- and 2.0-cm margins.

Results: The smallest PTV using 1.0-cm isotropic margins was selected most frequently (70%). Three RTs demonstrated good agreement for daily PTV selections, choosing identical PoDs for 51% of all CBCTs. In addition, acceptable dosimetric coverage of the whole bladder was achieved for all PoD selections, similar to standard treatments. The average volume of bowel bag receiving 45 and 50 Gy and normal tissue receiving 95% prescription dose was significantly ($P < .01$) lower for PoD treatments compared with both conventional treatments.

Conclusions: A PoD strategy using one pCT with isotropic and anisotropic margins can be used to treat bladder cancer and improve sparing of the bowel bag. Minimal dosimetric differences observed between three RTs suggests that PoD strategies are feasible for clinical implementation.

RÉSUMÉ

Introduction : Une approche « plan du jour » (PoD) de radiothérapie adaptative est présentée pour le cancer de la vessie. La réduction potentielle des volumes de tissus normaux et de sac de colostomie recevant une dose élevée de radiation est évaluée.

Matériel et méthodologie : Des ensembles de données de tomodensitométrie planifiée (pCT) et de TDM à faisceau conique (CBCT) quotidienne ont été analysés pour huit patients ayant été traités auparavant pour un cancer de la vessie. Pour chaque patient, un volume cible clinique (CTV) de la vessie entière a été délimité sur une pCT. Le CTV a ensuite été étendu au moyen de cinq ensembles de marges anisotropiques ou isotropiques afin de créer cinq volumes cibles de planification (PTV). Une bibliothèque de cinq PoD de traitement correspondants a ensuite été créée au moyen de l'arcthérapie à modulation de volume(VMAT). Le choix hors ligne des PoD a été fait par trois radiothérapeutes indépendants au moyen de CBCT quotidiennes. Les résultats dosimétriques ont été comparés entre les traitements par PoD et deux traitements conventionnels utilisant des marges isotropiques de 1,5 et 2,0 cm.

Résultats : Le volume cible de planification (PTV) le plus petit, utilisant des marges isotropiques de 1,0 cm a été choisi le plus souvent (70%). Les trois radiothérapeutes ont affiché un bon accord dans le choix des PTV quotidiens, choisissant des PoD identiques pour 51% de toutes les TDM à faisceau conique. De plus, la couverture dosimétrique acceptable de l'ensemble de la vessie a été atteinte pour tous les PoD choisis, comme c'est le cas pour les traitements standard. Le volume moyen de sac de colostomie recevant 45 et 50 Gy et de tissus normaux recevant 95% de la dose prescrite était

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http://dx.doi.org/10.1016/j.jmir.2016.05.001

significativement ($p<0,01$) plus bas avec les traitements PoD qu'avec les deux traitements conventionnels.

Conclusion : Une stratégie PoD utilisant une pCT avec des marges isotropiques et anisotropiques peut être utilisée dans le traitement du cancer de la vessie et améliorer la protection du sac à colostomie. Les écarts dosimétriques minimaux observés entre les trois radiothérapeutes suggèrent qu'il est possible de mettre en œuvre les stratégies PoD en milieu clinique.

Keywords: Adaptive radiotherapy; Bladder cancer; Plan of the day

Introduction

Bladder cancer irradiation is an alternative to life changing cystectomy. A major challenge to bladder irradiation is the large degree of interfraction variation in organ shape and size [1, 2]. The International Commission on Radiation Units & Measurements recommends adding a predefined, population-based margin around the clinical target volume (CTV; ie, bladder) to form a planning target volume (PTV) and reduce risk of geometric miss [2, 3]. Conventional population-based CTV-to-PTV margins for bladder are typically 1.5–2.0 cm [4–6]. These large margins increase dose to nearby normal tissue, leading to more frequent and severe treatment-related toxicity [7]. Current research is aimed at developing new adaptive radiotherapy (ART) strategies to reduce margins when treating bladder cancer.

Introduction of on-board cone beam computed tomography (CBCT) imaging has improved ability to locate soft-tissue organs such as the bladder and rectum immediately before treatment delivery [1, 8, 9]. This has led to new ART techniques for bladder that help reduce planning margins and lower integral dose to healthy tissue [10–15]. For example, Vestergaard et al [16] showed significant improvements in normal tissue sparing in bladder cancer patients when daily online plan reoptimization was used using pretreatment CBCTs. Plan reoptimization workflows, however, need to be streamlined and deformable image registration algorithms further improved before daily plan reoptimization is feasible [16–18]. Adopting a different approach, Shimizu et al [19] demonstrated real-time bladder tumor tracking using implanted gold markers that allowed visualization of the bladder tumor during irradiation, resulting in reduced PTV margins; however, routine whole bladder tracking is technically difficult and requires invasive gold marker implantation.

Several groups have shown that the "plan of the day" (PoD) strategy is well suited for ART of bladder cancer [1, 14, 20, 21]. PoD approaches reduce effective PTV margins using a library of treatment plans, each optimized for different bladder sizes and/or shapes. Before each treatment, on-board CBCTs are used to select the most appropriate PTV and treatment plan as the PoD. PoD selection is based on ensuring full bladder coverage, while minimizing dose to nearby normal tissue. Several PoD studies have investigated strategies to create the PTV and PoD library [12, 13, 22]. For example, Tuomikoski et al [13] used four planning computed tomography (pCTs) scans with different levels of bladder filling to create a library of PTVs reflecting the patient-specific physiological range of bladder shapes. Other groups have explored using one pCT and the initial 4–5 pretreatment CBCTs to construct small, medium, and large PTVs to generate the PoD library [11, 14, 16, 22]. Although these techniques achieved acceptable bladder coverage and lowered normal tissue integral dose, the resources required for contouring and generating Boolean sum volumes are considerable [11, 14, 23]. In some cases, patients must be treated for one week with large conventional PTV margins before the PoD library is finalized [11, 14, 15]. Furthermore, treatments may be interrupted between conventional and ART phases when the PoD strategy relies on CBCTs from initial fractions due to treatment planning and quality assurance of PoDs. These issues have motivated the development of less resource intensive PoD regimes [12, 21] where PTV sizes are generated using just two pCT scans with empty bladder and moderately filled bladder, thus avoiding interruptions associated with planning after treatment begins.

The study by Burridge et al [1] explored the feasibility of using a single pCT to create a PoD library of three 3-dimensional conformal radiotherapy treatment plans. In this study, one PTV consisted of the CTV (ie, whole bladder) expanded with an isotropic 1.5-cm margin and two additional PTVs were created using the CTV plus 1.5-cm margins in all directions except the superior margins were 10 and 5 mm, respectively. This PoD strategy significantly improved sparing of bowel bag in some patients. Most important, Burridge et al concluded that bladder cancer patients could benefit further from additional PoDs using PTVs with anisotropic margins.

The present study further explores the feasibility of using a single pCT to create the required PTVs. The primary aims of this work were to determine which sets of anisotropic and isotropic margins are the most suitable for bladder cancer ART and estimate potential sparing of the bowel bag and normal tissues. In addition, we assessed the interobserver variation in PoD selections among three independent radiation therapists (RTs) and its dosimetric impact. The results of this preliminary study will be used to guide ART-protocol development for bladder cancer RT at our institution.

Material and Methods

Patient Selection

Bladder cancer patients treated between June, 2013 and March, 2015 at our clinic were included in the study. CBCT imaging for bladder cancer patients during this time