Cancer/Radiothérapie 15 (2011) 270–278

Disponible en ligne sur ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com

Original article

Dosimetric uncertainties related to the elasticity of bladder and rectal walls: Adenocarcinoma of the prostate

Incertitudes dosimétriques relatives à l'élasticité de la paroi rectale et vésicale : adénocarcinome de la prostate

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ARTICLE INFO

Article history:
Received 14 July 2010
Received in revised form
22 November 2010
Accepted 21 December 2010
Available online 15 April 2011

Keywords:
IGRT
DGRT
Prostate
Setup error
Margin
Organ motion
Rectum
Bladder
Radiotherapy
Pelvis

ABSTRACT

Purpose. – Radiotherapy is an important treatment for prostate cancer. During treatment sessions, bladder and rectal repletion is difficult to quantify and cannot be measured with a single and initial CT scan acquisition. Some methods, such as image-guided radiation therapy and dose-guided radiation therapy, aim to compensate this missing information through periodic CT acquisitions. The aim is to adapt patient's position, beam configuration or prescribed dose for a dosimetric compliance.
Methods. – We evaluated organ motion (and repletion) for 54 patients after having computed the original ballistic on a new CT scan acquisition. A new delineation was done on the prostate, bladder and rectum to determine the new displacements and define organ doses mistakes (equivalent uniform dose, average dose and dose–volume histograms).
Results. – The new CT acquisitions confirmed that bladder and rectal volumes were not constant during sessions. Some cases showed that previously validated treatment plan became unsuitable. A proposed solution is to correct dosimetries when bladder volume modifications are significant. The result is an improvement for the stability of bladder doses, D50 error is reduced by 25.3%, mean dose error by 5.1% and equivalent uniform dose error by 2.6%. For the rectum this method decreases errors by only 1%. This process can reduce the risk of mismatch between the initial scan and following treatment sessions.
Conclusion. – For the proposed method, the cone-beam CT is necessary to properly position the isocenter and to quantify bladder and rectal volume variation and deposited doses. The dosimetries are performed in the event that bladder (or rectum) volume modification limits are exceeded. To identify these limits, we have calculated that a tolerance of 10% for the equivalent uniform dose (compared to the initial value of the first dosimetry), this represents 11% of obsolete dosimetries for the bladder, and 4% for the rectum.

Mots clés :
IGRT
DGRT
Prostate
Erreur de positionnement
Marges
Mouvement des organes
Rectum
Vessie
Radiothérapie
Pelvis

RÉSUMÉ

Objectif de l'étude. – La radiothérapie est un traitement important du cancer de la prostate. Durant les séances, les réplétions rectales et vésicales sont difficiles à quantifier, une unique scanographie initiale ne peut procurer cette information. Des méthodes comme la radiothérapie guidée par l'image ou la dose, ont pour but de compenser cette perte d'information, en utilisant des acquisitions scanographiques périodiques. La finalité étant de proposer une radiothérapie adaptative et plus réelle.
Méthodes. – Nous avons évalué le mouvement (et la réplétion) des organes de 54 patients, après avoir calculé la balistique initiale sur une nouvelle tomodensitométrie. De nouvelles délinéations ont été effectuées pour la prostate, la vessie et le rectum afin de déterminer les déplacements occasionnés, ainsi que les erreurs de doses générées sur les différents organes (*equivalent uniform dose* [EUD], dose moyenne et histogramme dose–volume).

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1278-3218/$ – see front matter
doi:10.1016/j.canrad.2010.12.006

Résultats. – Les nouvelles acquisitions confirment que la vessie et le rectum ne sont pas de volume identique durant les séances. Dans certains cas, la dosimétrie validée initialement n'est plus correcte et doit être revue. Une solution proposée ici est de ne s'attarder que sur les importantes modifications de volume vésical (5 % des patients). Avec cette méthodologie, on constate une nette amélioration concernant la stabilité des doses vésicales, l'erreur sur la D50 (dose délivrée à 50 % du volume) est réduite de 25,3 %, la dose moyenne de 5,1 % et l'erreur sur l'EUD de 2,6 %. Pour le rectum, cette méthode diminue toutes les erreurs de 1 %. Ce processus tend à réduire le risque de non-respect de la dosimétrie validée, entre la simulation et les séances de radiothérapie.

Conclusion. – La méthode proposée nécessite l'utilisation de la tomographie conique pour bien positionner les volumes cibles mais aussi pour quantifier les variations de volume du rectum et de la vessie. Les distributions de dose sont retravaillées dès que les volumes vésicaux ou rectaux sont considérablement modifiés (limite fixée d'après la présente étude). Nous avons identifié que pour une tolérance de 10 % concernant les EUD (comparées à la valeur initiale établie sur la première scanographie), cela correspondait à 11 % de dosimétries obsolètes pour la vessie et 4 % pour le rectum.

1. Introduction

Prostate cancer is the most frequent cancer affecting men over 50 years of age and second in terms of men mortality (25% of diagnosed cancers in France). Radiotherapy is an important treatment for prostate cancer. In some cases, it is the exclusive type of therapy. The current practice is dose escalation, which limits tumour development. The dosimetric limiting factor is the dose received by non-cancerous tissues, especially the organs at risk, such as the bladder, the rectum, femoral heads, the small intestine or the penis bulb [1–4]. In practice, rectum or bladder complications (late effects) often reduce the dose to the prostate. Dose escalation is really possible when the clinical target volume (CTV) motion during radiotherapy sessions (daily displacements or modifications) is controlled. The proposed study aims to, first, determine the mechanisms of organ interactions in the pelvic area and, second, estimate the consequences of these interactions on prostate treatment by radiation. In fact, for all the different methodologies used in prostate cancer treatment (conformation, intensity modulation, arc-therapy, etc.), dosimetry planning uses data from the initial simulation alone [5–7]. To take into account organ repletion and internal morphology variation during treatment sessions, there are control methods such as image-guided radiation therapy and dose-guided radiation therapy requiring periodic CT acquisitions [8,9]. The purpose is to adapt patient's position, beams and prescription doses. These techniques decrease errors due to patient positioning and ensure the proper location of targets and organs at risk. In the proposed study, we chose to concentrate on the dosimetric consequences generated by bladder and rectum morphological changes. The first consequence is that initial skin markers (often tattoos for pelvic treatment) are no longer adapted and generate a loss of tumour control [10–12]. The same process can occur to tissues near the prostate. The physician and physicist validations (isodoses, organ dose, dose–volume histograms, etc.) related to the toxicity to organs at risk cannot be adapted to the reality of treatment. The stochastic transformations, which caused these patient setup errors, are essentially related to the repletion of the bladder and rectum. These organs have a particular visco-elasticity that the radiotherapy team must quantify and control in order to increase the therapeutic dose (dose escalation). Elasticity is the quality of an object to be deformed and then resume its original shape when the applied stress disappears. These transformations are observable on pelvic organs, especially bladder or rectum muscles [13,14]. Firstly, we will describe the tools used and the clinical trials implemented. Then, we will reveal the statistical interaction between ballistic parameters and dosimetric values. Thirdly, we will consider clinical solutions proposed to select the morphological modifications requiring a new dosimetry. Lastly, we will look at the impact of daily CT acquisitions and the time required to control the dose to the organs.

2. Materials and methods

2.1. Methodology

The CT scan is a random snapshot of a changing patient. Organ position and repletion are fixed arbitrarily. One method of adaptive radiotherapy is the use of multiple scans (preferably one a day) to estimate organ position and to adapt the beams. To protect the patient from excessive irradiation, we have only taken two CT scans per patient. One made during the treatment and another during the simulation, before the treatment began (necessary for treatment planning). With the new scanner, we evaluated the impact of time on dosimetry, and verified that the ballistic was still appropriate. It is evident that, as van Herk et al. have shown with analyses of organ motion from repeated CT, the intrinsic error of the dose on irradiated volume has two distinct origins: one systematic and the other random [15]. They suggest a necessary patient setup margin which ensures a minimum CTV dose of 95% for 90% of the patient population, calculated as $2.5\Sigma + 0.7\sigma$ (Σ is the standard deviation of the patient mean errors, and σ the quadratic mean of the patient standard deviations). In the proposed study, the error due to movement is more "macroscopic" and the difference between the random (Σ) and the systematic (σ) term becomes negligible. As shown in Fig. 1, evaluating organ motion and patient setup errors is done after computing the original ballistic on the new anatomical configuration; the dose to different organs can then be evaluated. The phase following acquisition is the delineation on the new scan of prostate, bladder and rectum by a well-trained person who has already delineated the first scan.

2.2. Patients' eligibility and ballistics

From 2008 to 2009, 54 patients with organ-confined prostate cancer were prospectively enrolled on a conformational radiation treatment in the radiotherapy centre of Ajaccio, the CHD Castelluccio. Each patient was assigned a pretreatment (virtual simulation) with a CT scan of 2 mm slice thickness, followed by a three-dimensional treatment plan. The initial clinical target volume (CTV1) included the prostate and seminal vesicles and the second target volume (CTV2) included the prostate only. The PTV1 and PTV2 margins were done with CTV with a 1 cm uniform margin and 0.5 cm in posterior. The PTV-to-field-edge margin was 7 mm everywhere else, but 12 mm at the superior and inferior borders of the PTV. These margins take into account the dosimetric penumbra of the multileaf collimator and jaws. The selection criteria for