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The Effect of Dose Grid Resolution on Dose Volume Histograms for Slender Organs at Risk during Pelvic Intensity-modulated Radiotherapy

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ABSTRACT

Purpose: There are enduring uncertainties regarding the optimal dose grid resolution for use with pelvic intensity-modulated radiotherapy (IMRT) plans in which the adjacent organs at risk are slender and transect the field edge. Therefore, this study evaluated the effect of dose grid resolution on bladder wall dose-volume histogram (DVH) calculations for prostate IMRT plans.

Materials and Methods: The planning computed tomography scans and clinical plans from 15 prostate cancer patients were included in this analysis. For each study computed tomography, the entire inner and outer bladder surfaces were delineated. Nine versions of the clinical plan were created, varying interval between the dose grid calculation points uniformly in three dimensions, whereas all other plan parameters were kept constant. The dose grid increments tested were 1–10 mm. The plans were recalculated and the bladder wall DVH compared against the study benchmark (1 mm grid).

Results: All the dose grid increments evaluated resulted in a systematic overestimation of the bladder wall volume receiving low doses and an underestimation of the volume receiving high doses. Grid increments <2.5 mm all resulted in mean volume differences less than 1 cm^3 across the whole DVH. Grid increments >5.0 mm resulted in mean volume differences greater than 2 cm^3. Individual patient analysis revealed that only the 1.5 mm increment resulted in maximum volume differences ≤ 1 cm^3 for every patient across the full length of the DVH curve. Bladder wall thickness ranged from 1.7 to 4.4 mm and displayed no correlation with the magnitude of the dose grid effect.

Conclusions: For an accurate DVH calculation for bladder wall during IMRT planning for prostate cancer, a 1.5 mm dose grid increment is recommended. This finding was unaffected by a normal range in bladder wall thickness. It is suggested that the application of any new treatment planning technique or organ delineation method be accompanied with an evaluation of optimal dose grid resolution.

RÉSUMÉ

Objet: Il existe des incertitudes persistantes concernant la résolution optimale de la grille de posologie (dose grid) pour les plans de radiothérapie par modulation d'intensité (RTMI) du pelvis, où les organes à risque sont minces et recoupent la bordure du champ. Par conséquent, cette étude évalue les effets de la résolution de la grille de posologie sur les calculs de DVH sur la paroi de la vessie pour les plans de RTMI de la prostate.

Matériel et méthodes: Les TDM de planification et les plans cliniques pour 12 patients atteints d'un cancer de la prostate ont été examinés dans le cadre de cette étude. Pour chaque examen TDM, la totalité des parois internes et externes de la vessie a été délimitée. Neuf versions du plan clinique ont été créées, variant l'intervalle entre les points de calcul de la grille de posologie de façon uniforme dans les trois dimensions, tous les autres paramètres étant constants. Les incréments testés allaient de 1 mm à 10 mm. Les plans ont été recalculés et le DVH sur la paroi de la vessie comparé aux données de base de l'étude (grille de 1 mm).

Résultats: Tous les incréments de grille de posologie évalués ont entraîné une surestimation systématique du volume de la paroi de la vessie recevant une dose faible et une sous-estimation du volume recevant une forte dose. Les incréments inférieurs à 2,5 mm ont tous entraîné des différences de volume moyen inférieures à 1 cm^3 sur l'ensemble du DVH. Les incréments supérieurs à 5,00 mm ont entraîné des différences de volume moyen supérieures à 2 cm^3. L'analyse individuelle des patients montre que seul l'incrément de 1,5 mm a produit une différence de volume maximale égale ou inférieure à 1,5 cm^3 pour tous les patients sur l'ensemble de la courbe de DVH. L'épaisseur de la paroi de la vessie variait entre 1,7 mm et 4,4 mm et n'affiche aucune corrélation avec la magnitude de l'effet sur la grille de posologie.

Conclusions: Pour un calcul exact du DVH sur la paroi de la vessie durant la planification de la RTMI pour le cancer de la prostate, l'incrémentation de la grille de posologie à des intervalles de 1,5 mm est

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recommandée. Cette conclusion n'est pas influencée par la plage normale d'épaisseur de la paroi de la vessie. Il est suggéré que l'application de toute nouvelle technique de planification du traitement ou méthode de délimitation des organes s'accompagne d'une évaluation de la résolution optimale de la grille de posologie.

Keywords: Dose grid; penumbra; bladder; intensity-modulated radiotherapy

Introduction

Dosimetric variations from inaccurate dose calculations have a marked impact on dose-volume histograms (DVHs) [1, 2]. Three major factors influence the ability of radiotherapy treatment planning systems to accurately report the dose received by an organ at risk: the use of tissue density heterogeneity correction, dose calculation algorithm, and dose grid resolution. There is expert consensus regarding the use of tissue density corrections and the accuracy of common dose calculation algorithms [3, 4], but the identification of the optimal grid resolution for three-dimensional dose calculation matrices is a complex issue, which often involves compromise [5–8]. The choice of optimal grid resolution for DVH calculation depends on the expected dose gradient, the dimensions of the organ of interest, and the maximum acceptable error [3].

Intensity-modulated radiotherapy (IMRT) is used to create high-dose gradients to spare organs at risk. A 4 mm grid increment may be sufficient for conventional pelvic radiotherapy [9], but controversy over the optimal grid increment for IMRT persists because most theoretical evaluations of grid resolution assume low-dose gradients [4, 7, 10]. It has also been suggested that a 4 mm increment accurately describes the dose to adjacent normal tissue structures for head and neck IMRT [11], yet figures in that article clearly showed clinically important differences between the spinal cord DVH at various dose grid resolutions, particularly for volumes traversed by high-dose gradients. A more detailed analysis of the dose grid effect on head and neck IMRT plans indicated that using a 4 mm grid increment will result in dose discrepancies of ~4% [12], and grid sizes of ~1.5 mm were necessary for an accurate prediction of dose compared with film dosimetry. In fact, it has been postulated that a dose grid increment $\leq$1 mm is necessary to nullify any dosimetric errors related to this effect [9, 12], but the use of grid increments that small is often clinically impractical.

For modern pelvic radiotherapy, most organs at risk are immediately adjacent to the target and are often transected by the field borders. Thus, they are simultaneously just inside and just outside the irradiated area, making them subject to the highest-dose gradient. If a widely spaced calculation grid (~5 mm) is used in the penumbra region, the dose calculated may be >2% different from the actual dose [1, 13]. The resultant DVH will suffer from both an underestimate at the high-dose region and an overestimate at the low-dose region [7, 9]. Moreover, if the organ at risk is "slender" (ie, the cross-section is small, such as bladder wall), then there is the potential to greatly underestimate the dose received by that organ during the calculation [8, 14–16].

In summary, there are enduring uncertainties regarding the optimal dose grid resolution for use with pelvic IMRT plans in which the adjacent organs at risk are slender and transect the field edge. This has necessitated the design of a study to evaluate the effect of dose grid resolution on bladder wall DVH calculations for prostate IMRT plans.

Methods and Materials

This was a single-centre, prospective, quasiexperimental study with local research ethics board approval. The radiotherapy planning computed tomography (CT) data sets of 15 prostate cancer patients were included in the analysis. These were selected consecutively (reverse chronologically) from a cohort of more than 400 available patients all treated according to departmental policy. Study inclusion criteria were as follows: received 78 Gy in 39 fractions to prostate-only clinical target volume, IMRT plan (7-field coplanar, static field, step-and-shoot fields) achieved departmental dose constraints, received "comfortably full" bladder preparation instructions, and no positive or negative contrast in the pelvis.

The planning CT scans and clinical plans from these 15 patients were copied into a treatment planning system research directory (Pinnacle, ver. 9.0, Elekta). These images were then deidentified. For each study CT, the entire inner and outer bladder surfaces were manually delineated using standard Pinnacle tools by a single observer. The borders of the dose calculation grid were automatically defined by adding a 3 cm margin around the bladder contours plus the clinical target volume (dose prescribed to minimum clinical target volume dose). Then, 9 identical versions of the clinical plan were created for each study CT. In each plan version, the interval between the dose grid calculation points was varied uniformly in three dimensions, whereas the dose grid origin and all other plan parameters were kept constant. The dose grid increments (mm) tested were 1, 1.5, 2, 2.5, 3, 4, 5, 7, and 10. The dosimetry of the plans was then recalculated using the collapsed cone convolution/superposition algorithm with tissue heterogeneity correction.

To aid in the interpretation of findings from this study, a previously validated method to approximate the average thickness of the bladder wall was applied to each patient [17]. Briefly, a uniform contraction (in 0.1 mm increments) was applied to the outer bladder contour until the volume of the structure created was equivalent to the volume of the manual inner bladder contour (in cm^3). The magnitude of that uniform contraction was then used as an approximation of the bladder wall thickness.