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Original paper

Dose accumulation of multiple high dose rate prostate brachytherapy treatments in two commercially available image registration systems

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ABSTRACT

Purpose: The purpose of this study was to assess whether deformable image registration (DIR) is required for dose accumulation of multiple high dose rate prostate brachytherapy (HDRPBT) plans treated with the same catheter pattern on two different CT datasets.

Method: DIR was applied to 20 HDRPBT patients' planning CT images who received two treatment fractions on sequential days, on two different CT datasets, with the same implant. Quality of DIR in Velocity and MIM image registration systems was assessed by calculating the Dice Similarity Coefficient (DSC) and mean distance to agreement (MDA) for the prostate, urethra and rectum contours. Accumulated doses from each system were then calculated using the same DIR technique and dose volume histogram (DVH) parameters compared to manual addition with no DIR.

Results: The average DSC was found to be 0.83 (Velocity) and 0.84 (MIM), 0.80 (Velocity) and 0.80 (MIM), 0.80 (Velocity) and 0.81 (MIM), for the prostate, rectum and urethra contours, respectively. The average difference in calculated DVH parameters between the two systems using dose accumulation was less than 1%, and there was no statistically significant difference found between deformably accumulated doses in the two systems versus manual DVH addition with no DIR.

Conclusion: Contour propagation using DIR in velocity and MIM was shown to be at least equivalent to inter-observer contouring variability on CT. The results also indicate that dose accumulation through manual addition of DVH parameters may be sufficient for HDRPBT treatments treated with the same catheter pattern on two different CT datasets.

1. Introduction

High dose rate prostate brachytherapy (HDRPBT) is commonly used in conjunction with external beam radiotherapy (EBRT) for treatment of intermediate and high risk prostate cancer, and has been shown to achieve excellent local control and low toxicity [1–3]. The prescribed dose for both the HDRPBT and EBRT components of the treatment varies considerably in the literature [4], with HDRPBT prescriptions varying from 15 Gy in a single fraction [5] to 24 Gy in four fractions [6]. Both the American Brachytherapy Society (ABS) [7] and European Society for Radiotherapy and Oncology (ESTRO) [4] have produced consensus guidelines for HDRPBT in which prescription doses, fractionation schedules, and organ at risk (OAR) tolerances are described. However, both guidelines acknowledge that given the extreme heterogeneity in published prescription dose and fraction schedules, absolute dose limits for OAR's are difficult to establish [4,7].

For accurate dose reporting of multiple HDRPBT treatments and/or combined HDRPBT and EBRT treatments, dose-volume histogram (DVH) parameters should be combined [8]. The current standard of manual addition of DVH parameters from multiple brachytherapy fractions assumes the 'worst case' scenario, in which the high dose regions occur in the same anatomical location for each fraction [9]. However, manual addition may not be accurate in the presence of anatomical movement and deformation [10–12]. Manual addition does not allow visualisation of the spatial location of hot spots or cold spots which could be accounted for with dose accumulation. In such instances, deformable image registration (DIR) can be utilised to correct for anatomical movement and deformation. Dose accumulation can then be performed through accumulating deformably registered dose distributions [11,12].

Deformable image registration (DIR) is being used increasingly within the radiotherapy community, as evidenced by the recent release of the American Association of Physicists in Medicine (AAPM) Task Group 132 Report, 'Use of image registration and fusion algorithms and

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techniques in radiotherapy' [13]. Qualitative evaluation of DIR can be performed by the end user through assessment of the alignment of anatomical landmarks with the two registered images overlayed on one another.

Quantitative evaluation can be performed by contouring the same structures (e.g. prostate, urethra, and rectum) on both images. For an exact image registration, and perfectly consistent contouring on both images, the contoured structures should overlap entirely. However, in practice, even with a perfect registration contours are never likely to overlap entirely due to variations (both inter and intra-observer) in contouring of structures. Therefore, the overlap of the contours should at least be within the inter or intra-observer contouring variability for the given imaging modality. Quantitative evaluation of DIR is recommended in the AAPM Task Group 132 report to be performed through the use of metrics such as the Dice Similarity Coefficient (DSC) and mean distance to agreement (MDA) [13].

Image registration, including DIR has been applied extensively in the EBRT community for multiple purposes, including: registering multi-modality images in treatment planning [14,15], guiding patient positioning for individual treatment fractions [16], assessing response to therapy [16,17], and performing dose accumulation [18,19].

In the field of brachytherapy dose accumulation has been applied to high dose rate brachytherapy of the cervix where numerous studies have been performed combining multiple brachytherapy treatments [12,20]. Other studies have performed dose accumulation of brachytherapy and EBRT treatment fractions by converting doses to equivalent dose in 2 Gy fractions (EQD2) [21,22]. However, studies performing dose accumulation in HDRPBT are limited to assessment of DVH parameters for organs at risk only, such as the rectum [23].

Changes in prostate and organ at risk volumes have been reported for single HDRPBT implants treated with two fractions separated by up to 24 h [24,25]. Kim, et al. [24] reported an average increase in prostate volume of 7.8% (range 2%–17%) in the time between two treatment fractions separated by an average of 24 h. Meanwhile Simnor et al. [25] showed that catheter.

Displacement corrections between treatment fractions separated by an average of 18 h had a variable effect on the maximum rectal dose. The authors showed that this was due to the rectum suffering from the most internal movement and volume variation between the two fractions due to continual filling and emptying. Currently, to this article's authors best knowledge there have been no studies published on whether deformable image registration (DIR) is required for dose accumulation of multiple HDRPBT plans treated with the same catheter pattern on sequential days. The authors hypothesize that DIR will be required for dose accumulation due to increases in prostate volume and movement of the rectum driving the treatment planning system (TPS) optimizer to deliver high dose regions to different areas within the prostate volume.

In this study, rigid image registration (RIR) and DIR were evaluated through the DSC and MDA for the prostate, urethra and rectum contours. The same registrations were then used to perform dose accumulation across multiple fractions. Finally, DVH parameters obtained using the image registration methods were compared, to manual addition of DVH parameters without image registration.

2. Materials and methods

2.1. High dose rate prostate brachytherapy treatment and contouring

Twenty patients treated with a HDRPBT boost in the period of 2012–2016, who has also received EBRT after the HDRPBT boost were randomly selected for this study. The HDRPBT boost was delivered in 2 fractions in 2 days, with the aim to deliver 18 Gy to the target volume using an Ir-192 source [4,7]. Patients were asked to follow a low fibre, low fat diet from 2 days prior to the procedure. Furthermore they were also given 2 fleet enemas, one the night before the first procedure and one the morning of the procedure to ensure minimal rectal filling. Favourable intermediate risk patients from this study did not receive androgen deprivation therapy (ADT), unfavourable intermediate risk patients (composite Gleason score 4 + 3, PSA $<$ 20, stage $\leq$ T2c) received 6 months of ADT, and high risk patients (Gleason score 8–10, PSA $>$ 10, stage T3-4) received 18–24 months of ADT.

After transperineal insertion of catheters under transrectal ultrasound (TRUS) guidance, a planning CT (2 mm slice thickness) was acquired and treatment planning performed using the Nucletron Oncentra Brachytherapy TPS (Nucletron B.V., Veenendaal, The Netherlands). During treatment planning, the inverse planning simulated annealing (IPSA) optimizer was used to determine dwell positions and times.

The prostate, urethra, and rectum were all contoured by the radiation oncologist at the time of treatment planning. After treatment of the first fraction, the catheters remained in position and the template sutured to the perineum prior to treatment. Prior to the second fraction on the next day, a second planning CT was acquired, new contours drawn and a second plan was produced with new contours. Displacement of catheters were verified prior to each treatment delivery and corrected if the displacement was greater than 3 mm from the planning CT scan [26].

Contours for each fraction were produced by the same radiation oncologist. The prostate contour was defined by the prostate capsule plus any macroscopic extracapsular disease or seminal vesicle involvement identified on diagnostic images and biopsies. The urethra was contoured using a urethral catheter, the contour extended from the bladder base to 10 mm below the prostatic apex. The rectum was outlined using the rectal wall along the same length described for the urethra. Fig. 1 shows an axial slice of typical prostate, urethra and rectum contours with relative dose distribution overlayed in colourwash.

The DICOM radiotherapy treatment plan, CT images, radiotherapy dose, and structure set files for both HDRPBT treatment fractions were retrospectively exported to two image registration systems for comparison in this study.

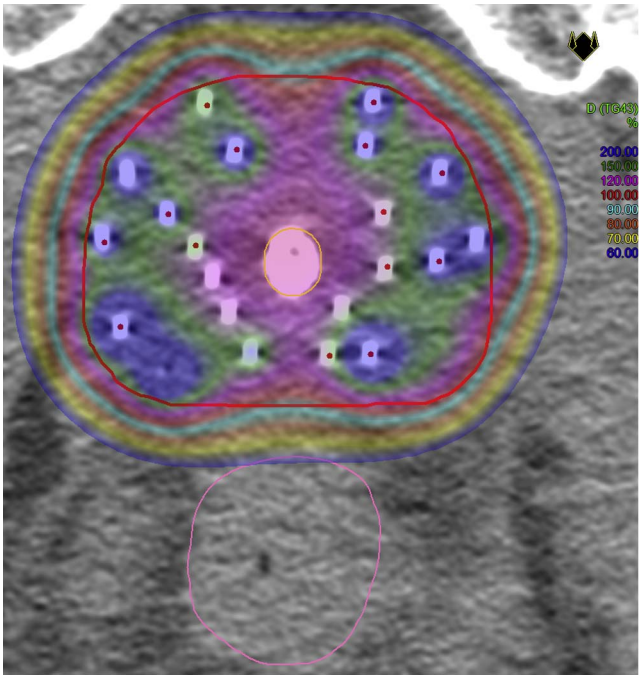

Fig. 1. Axial slice showing typical prostate (red), urethra (yellow) and rectum (pink) contours, along with relative dose distribution overlayed in colourwash. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)