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Deformable image registration for cervical cancer brachytherapy dose accumulation: Organ at risk dose−volume histogram parameter reproducibility and anatomic position stability

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ABSTRACT

PURPOSE: The purpose of this study was to determine the effect of deformable image registration (DIR) on cumulative organ at risk dose−volume histogram (DVH) parameter summation for more than three brachytherapy fractions. The reproducibility of different methods of DIR was tested. DIR was then used to assess the stability of the anatomic position of the DVH parameters within the bladder and rectum.

METHODS AND MATERIALS: DIR was completed for 39 consecutive cervical cancer brachytherapy patients' planning CTs. Accumulated DVH parameters (D_{2cc} and $D_{0.1cc}$) for bladder and rectum were compared with dose summation without DIR. Reproducibility of DIR results was assessed for different methods of implementation based on adding contour biases added to the DIR algorithm. Vol_{D2cc} and $Vol_{D0.1cc}$ structures were created from the overlap of the D_{2cc} and $D_{0.1cc}$ isodose and the bladder or rectum, respectively. The overlap of Vol_{D2cc} and $Vol_{D0.1cc}$ structures was calculated using the Dice similarity coefficient.

RESULTS: DIR accumulated D_{2cc} and $D_{0.1cc}$ decreased by an average of 2.9% and 4.2% for bladder and 5.08% and 2.8% for rectum compared with no DIR. DIR was most reproducible when the bladder or rectum contour was masked. The average Dice similarity coefficient was 0.78 and 0.61 for the bladder D_{2cc} and $D_{0.1cc}$ as well as 0.83 and 0.62 for rectal D_{2cc} and $D_{0.1cc}$, respectively.

CONCLUSIONS: Dose decreases were observed for accumulated DVH parameters using DIR. Adding contour-based biases to the algorithm increases the reproducibility of D_{2cc} and $D_{0.1cc}$ accumulation. The anatomic position of Vol_{D2cc} was more stable than $Vol_{D0.1cc}$.

Keywords: Cervix; Deformable image registration

Introduction

A brachytherapy boost is a standard part of treatment for locally advanced cervical cancer. The Groupe European de Curietherapie-European Society for Therapeutic Radiology and Oncology working group and the American Brachytherapy Society have produced a series of recommendations for dose reporting and prescribing in volume-based image-guided brachytherapy for locally advanced cervical

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cancer, based on three-dimensional image-guided treatment planning (1–4). Doses to organs at risk (OAR) are reported using dose–volume histogram (DVH) parameters, such as the requirement to report the minimum dose in the most irradiated tissue volume of 2 cc (D_{2cc}) and 0.1 cc ($D_{0.1cc}$). Studies have found that higher DVH parameter values (D_{2cc}, D_{1cc}, and $D_{0.1cc}$) for the bladder and rectum correlated with Grade 2 or higher late side effects (5, 6).

Currently, OAR DVH parameters for high-dose-rate (HDR) brachytherapy are accumulated assuming 100% of the prescribed dose from external beam radiotherapy (EBRT) is received by the entire organ. All doses are converted to the equivalent dose in 2 Gy fractions (EQD2) during accumulation. When accumulating fractionated HDR brachytherapy DVH parameters over a treatment course, a worst-case scenario assumption is made that the hot spots occur in the same anatomic position each fraction (2). The accuracy of this assumption may be affected by organ deformation and movement. A study of the dosimetric effects of anatomic structure variations relative to the fixed applicator geometry found that the bladder had the lowest dose uncertainty of all structures studied (7). This is in line with the basic anatomy of pelvic organ mobility, with the posterior inferior bladder wall being relatively fixed in relation to the applicator. Another study found the topographical position of the bladder D_{2cc} volume to remain stable (8). Kim *et al.* (9) analyzed the location of the D_{2cc} hot spots relative to the applicator, finding it was positioned anterior and superior to the cervix, near the plane perpendicular to the tandem containing Point A. Factors that affected the anatomic position of the D_{2cc} hot spots for standard loading plans included uterine wall thickness, uterine tandem position, fibroids, bladder filling, bowel gas, and vaginal packing.

Deformable image registration (DIR) algorithms have been introduced to map voxels between different image data sets. The same deformation map can then be applied to the dose distribution. Despite the potential uncertainties related to DIR based on image intensity algorithms, previous studies have used these algorithms for gynecologic brachytherapy dose summation, although no recommended validation method currently exists and DIR-based dose accumulation should not be used clinically without further validation (10–14). Constraints can be added to DIR algorithms based on selected contours. In addition, selected contours can be masked to a higher Hounsfield unit before performing DIR. This biases the optimization in the image registration algorithm to focus on that structure (13).

This work used MIM Maestro (Version 6; MIM Software, Inc, Cleveland, OH) for DIR, which uses an image intensity free-form algorithm for DIR. In this study, the cumulative DVH brachytherapy OAR parameters were used to assess the reproducibility of the DIR algorithm as additional biases were added based on the bladder contour. To assess the anatomic stability of the DVH parameter hot spots, structures were created from the overlap of the D_{2cc} and $D_{0.1cc}$ isodoses and the bladder or rectum. The overlap of the structures was calculated using the Dice similarity coefficient (DSC).

Method

Thirty-nine consecutive patients between 2009 and 2013 (Federation of Gynecology and Obstetrics Stage IB–IV), who had received EBRT before a brachytherapy boost, were retrospectively selected for this study. EBRT was delivered using a conformal four-field box technique using 18 MV photon beams. Thirty-two patients received 45 Gy in 25 fractions, one 50 Gy in 25 fractions, two 50.4 Gy in 28 fractions, and four 54 Gy in 30 fractions, varying according to boost requirements to different volumes of primary and nodal disease. Following international recommendations, it was assumed the OAR volumes being investigated received 100% of the prescribed dose from the EBRT treatment (1–4).

An HDR brachytherapy boost was delivered in three fractions, with a planning aim dose of 87 Gy total EQD2 to the high-risk clinical target volume (HR-CTV), limited by OAR D_{2cc} doses of 90 Gy to the bladder and 70 Gy to the rectum. Brachyvision (Version 11; Varian Medical Systems, Inc, Palo Alto, CA) was used as the brachytherapy treatment planning system (TPS). Treatment was delivered using a Varisource iX afterloader (Version 11; Varian Medical Systems, Inc, Palo Alto, CA) with an iridium-192 source and a titanium Fletcher–Suite–Delclos tandem (Version 11; Varian Medical Systems, Inc, Palo Alto, CA) and ovoid style applicator with flexible geometry. No interstitial needles were used for patients in this study. The applicators were inserted under ultrasound guidance.

After recovery from the applicator insertion procedure, CT (GE Lightspeed) images of slice thickness 1.25 mm were taken for treatment planning purposes. The most recent 28 patients also had a 1.5 T MRI scan (Signa HDx; GE Medical Systems, Milwaukee, WI) for the first fraction only. A Foley catheter was inserted into the bladder before applicator insertion. The bladder was free draining for three-dimensional imaging and treatment.

The MR and CT were fused using rigid registration (based on the applicators). All plans were performed on the CT, with the MR only used for HR-CTV definition to maintain consistency across all fractions. Patient images were imported into the TPS where the OAR and CTV were delineated, the applicators reconstructed, and a treatment plan calculated in the TPS. Standard plans were optimized using both inverse planning and graphical optimization. The planning aim dose was the D_{90} of the HR-CTV. The dose to Point A was reported but used for prescription. The D_{2cc} and $D_{0.1cc}$ bladders were calculated and converted to EQD2 to ensure that OAR dose tolerances (incorporating the external beam dose) were not exceeded and CTV doses were also within acceptable limits.

For this study, the planning CT images, structure sets, radiotherapy plan, and radiotherapy dose digitial imaging and communications in medicine files were exported from the TPS into the DIR software package, MIM Maestro