Effect of applicator reconstruction shifting on dosimetric dose-volume histogram parameters during magnetic resonance imaging in brachytherapy for cervical cancer patients

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Abstract

Objective: This study observed the dose-volume histogram (DVH) parameter changes caused by applicator shifting that result from patient movement during image acquisition for magnetic resonance imaging guided brachytherapy for cervical cancer patients.

Materials and Methods: Nine cervical cancer plans with insertion of a Fletcher computed tomography (CT)/magnetic resonance (MR) applicator were retrospectively studied. The MR sequences were T2 fast spin echo on parasagittal, para-axial, and para-coronal planes, respectively. The applicator library was used for applicator reconstruction in each image data set. The tip of the applicator (2 ovoids + 1 tandem) was identified, and the difference from the reference image (axial view) was recorded. The DVH parameters were as follows: D90 of high-risk clinical target volume (HR-CTV) and D2cc of the bladder and rectum for each image data set were compared with the reference image.

Results: The tandem showed less applicator shift on the coronal plane than the reference image. The applicator shifts for tandem were 0.0 ± 0.4, 0.0 ± 1.0, and -0.5 ± 1.0 mm in the left-right, superior-inferior, and anterior-posterior directions, respectively. The mean percentage dose differences in DVH parameters on the coronal and sagittal planes were 3.04% and 1.23% for D90 of HR-CTV, 2.73% and 3.88% for D2cc of the bladder, and 2.60% and 3.49% for D2cc of the rectum, respectively.

Conclusion: An image acquisition time of approximately 15 minutes for three-dimensional MR brachytherapy provided a mean applicator reconstruction shift within 1.3 mm, with minor effects on the DVH parameter of approximately 3%.

Keywords: *Applicator reconstruction, MRI-Brachytherapy, Uncertainty, Applicator library.*

1. Introduction

Cervical cancer is the most common cancer found in Thai women [1]. The current standard treatment is concurrent chemoradiation plus brachytherapy. Brachytherapy is a form of internal radiotherapy often combined with external beam radiotherapy (EBRT). The main advantage of brachytherapy is rapid dose fall-off; surrounding normal tissue can be spared while the gross tumor receives a high dose of radiation. The data recommended in the International Commission on Radiation Units and Measurements (ICRU Report 38) for reporting the standard ICRU bladder and rectal reference points represent the organs most at-risk from high doses of radiation. However, the record normal tissue doses in brachytherapy are varied [2,3].

Our institute started using two-dimensional (2-D) high-dose rate (HDR) brachytherapy in 1995. In 2011, the transition from 2-D to three-dimensional (3-D) brachytherapy began when magnetic resonance (MR) simulation was installed. Groupe European de Curie therapie-European Society for Therapeutic Radiology and Oncology (GEC-ESTRO) has published many guidelines covering all types of 3-D image-guided brachytherapy, including image acquisition, contouring, planning, and evaluation [4,5]. For MR image acquisition for applicator reconstruction and contouring, T2-weighted sequences on para-axial, para-sagittal, and para-coronal planes are recommended. Although the para-axial plane is the main image sequence used for applicator reconstruction, para-sagittal and para-coronal sequences are necessary to for guidance when some para-axial images are not clear. While clinical target volume is clearly visualized on MR imaging (MRI), MR scans are still a source of uncertainty related to dosimetry due to the scanning

duration, internal organ movement, applicator reconstruction shifts and contouring, and so on. As the scan time for each MR sequence is approximately 3 to 5 minutes, patient movement during the MR scan can affect applicator reconstruction with the consequence of dosimetric uncertainty.

The aim of this study was to observe the DVH parameter changes caused by applicator shifting in cervical cancer patients that result from patient movement during image acquisition for MRI-guided brachytherapy.

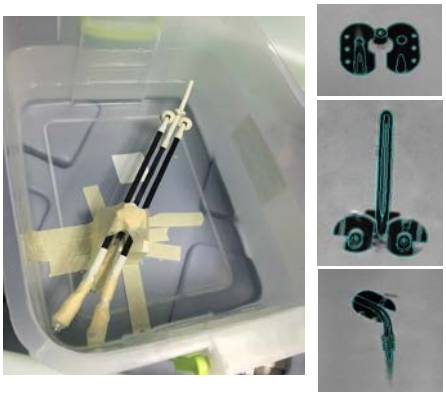
2. Materials and methods

2.1 The phantom study

The geometric distortion of a 1.5-T HDxT MRI scanner (GE Healthcare, Waukesha, WI, USA) was checked by using the Magphan phantom. The distances between the 3-mm holes inside the Magphan phantom were measured at 2, 4, 8, and 10 cm.

A Fletcher CT/MR applicator set combining 2 ovoids and 1 tandem (Nucletron, Veenendaal, The Netherlands) was utilized in this test. The applicator design uses a strong composite fiber tubing and plastic to improve the quality of CT and MR images. The applicator set was fixed in a water bath for the image reconstruction test. An MR line marker was inserted in the applicator lumen. In the MRI bore, a water phantom was placed for 30 minutes before scanning to ensure that the water was still. The water phantom setup with applicator placement and MR images for applicator reconstruction are shown in Figure 1. T2 fast spin echo in the para-sagittal, para-axial, and para-coronal directions were scanned. The coil and parameter setting for the MR scans were the same as those used in a clinical study that included patients (i.e., a 3 mm slice thickness with a 0.3 mm gab for a 20×20 cm field of view [FOV]). The applicator model was located until it perfectly matched the outer applicator surface and was confirmed by using an MR line marker at the applicator lumens. The applicator reconstruction was undertaken in each image data set separately. The tip of each applicator was identified in each coordinate by creating points on the x (left-right), y (superior-inferior), and z axes (anterior-posterior) for the para-axial plane, which was the reference image. The subtraction coordinates *x*, *y*, and *z* of the para-coronal or para-sagittal images from a reference image illustrated the uncertainty of the reconstruction applicators without patient movement.

Figure 1. The phantom water setup and magnetic resonance images for applicator reconstruction shifts



2.2 The clinical study

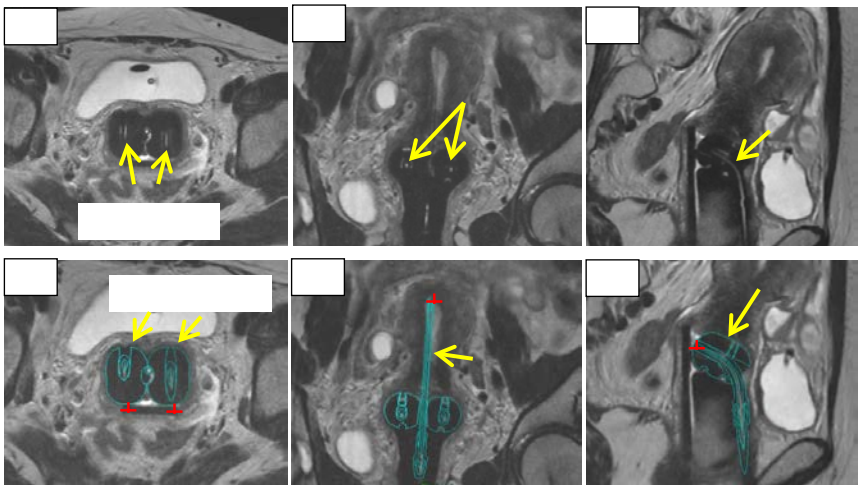
This was a retrospective study conducted that included 9 cervical cancer plans for Fletcher CT/MR applicator set insertion. The treatment schedule involved EBRT for 50.4 Gy in 28 fractions with brachytherapy starting approximately in the fourth week of treatment. After 40-Gy EBRT, an MRI scan was required to design the appropriate applicator insertions for brachytherapy. The dose prescription in brachytherapy was 8 Gy per fraction for a total of 3 fractions in weekly treatments.

The applicators were inserted and clamped, with the patient under spinal anesthesia. A CT/MR applicator clamp with a base plate (Nucletron, Veenendaal, The Netherlands) was used to fix the position of the applicators after placement in the operation room. Intravenous buscopan 20 mg was injected to reduce bowel movement during the MR scans. After drainage of residual urine via Foley's catheter, 50 ml of normal saline was used to fill the bladder before MR scanning and before treatment to control bladder volume. A MR line marker, a small catheter filled with water, was inserted in all applicators to assist in the applicator reconstruction procedure. T2 fast spin echo applied in three main orthogonal planes consisting of parasagittal, para-axial, and paracoronal as per GEC-ESTRO guidelines was performed respectively by using 1.5-T HDxt (GE Healthcare, Waukesha, WI, USA). An HD body array coil with 8

channels was used for visualization of the tumor and organ at risk. The slice thickness used was 3 mm with a 0.3-mm gap for a 20- × 20-cm FOV. The total scan time was about 15–20 minutes.

The image data set was input to the Oncentra treatment planning software program version 4.3 (Nucletron, Veenendaal, The Netherlands) via the Digital Imaging and Communication in Medicine network. The para-axial plane was used for the reference image in this study because it was the main image for radiation oncologist contouring, whereas other planes were used for overview guidance. The applicator reconstruction was performed in each image data set. Applicator models and MR line markers were used for applicator reconstruction. The applicator models imported the physical information that matched the applicator insertion. Three anchor points were placed at the tip of each applicator (2 ovoids + 1 tandem). Rotation and translation were applied until the outer applicator surface fit the black area in the MR images. The accuracy of the applicator reconstruction was confirmed by using the MR line marker that matched perfectly with the applicator lumen. The MR signal of the MR line marker and applicator model placements are shown in Figure 2. After proper alignment of the applicators in each image data set, the point was created at the tip of each applicator to identify the *x* (left-right), *y* (superior-inferior), and *z* (anterior-posterior) coordinates. Applicator error from patient movement during MR scans was defined by subtracting coordinates *x*, *y*, and *z* of the para-coronal or para-sagittal images from a reference image. While the applicators were reconstructed on Oncentra by a medical physicist, structure volumes were contoured on AdvantageSim MD version 4.6 (GE Healthcare, Waukesha, WI, USA) by a radiation oncologist on a para-axial image. These procedures were performed at the same time to minimize the planning time for treatment. The same contour was used for all image data sets. The source location was loaded as 4 positions in both ovoids and all positions in tandem according to uterine length, so the chance for optimization was increased. For each session, a graphical optimization technique was used until the DVH parameters met the acceptable criteria. The physical dose criterion of D_{90} of HR-CTV was 8 Gy, and the D_{2cc} of the bladder and rectum were 7 and 5.4 Gy, respectively. The source position and dwell time were duplicated for coronal and sagittal images. The percent dose difference of the DVH parameters was determined. D_{90} ofHR-CTV and D_{2cc} of the bladder and rectum for each image data set were compared with a reference image.

Figure 2. Magnetic resonance line markers in bright signals



A) axial, B) coronal, and C) sagittal. Applicator library placement (arrows) matched with the applicator insertion and tip of the applicator used for defined applicator displacement (cross): D) axial, E) coronal, and F) sagittal

3. Results

3.1 The phantom study

The average differences between the measured and actual distances were 0.1, 0.3, 0.4, and 0.5 mm for 2, 4, 8, and 10 cm distances, respectively. It means that the geometrical distortion was at the border of the image for a 30×30 cm FOV. This confirms that uncertainty due to the MR itself did not affect our results because a smaller FOV (20 × 20 cm) was used in this study. In addition, the applicator was placed inside the patient at the center of the image, whereas image distortion was shown at the edge of the field. The maximum amount of applicator shift due to applicator reconstruction was 0.7 mm. The result is shown in Table 1. The left side, and superior and anterior directions were defined as positive values from the coordinates.

Table 1. Setup of the applicator reconstruction shifts in water phantom

	Applicator shift (mm)					
	Coronal plane			Sagittal plane		
	Rt. ovoid	Lt. ovoid	Tandem	Rt. ovoid	Lt. ovoid	Tandem
LR shift	0.2	-0.7	0.3	-0.5	-0.3	-0.3
SI shift	-0.5	-0.7	-0.1	-0.4	-0.7	-0.2
AP shift	0.4	-0.2	-0.3	-0.4	-0.4	0.0

Remark: LR, left-right; SI, superior-inferior; AP, anterior-posterior

3.2 The clinical study

The applicator shift values from patient uncertainty during MRI scanning are shown in Table 2. The overall results show random applicator shift for both the coronal and sagittal planes. The maximum mean error was -1.3 mm for the LR direction in tandem with the sagittal plane. However, this result includes the uncertainty from applicator reconstruction, which was within 0.7 mm as verified in water phantom. Applicator reconstruction error-induced percentage dosimetric changes are shown in Table 3. The mean percentage physical dose differences for D_{90} of HR-CTV were 3.04 ± 2.27 and 1.23 ± 1.23 for coronal and sagittal planes, respectively. For the bladder and rectal doses, the sagittal plane had a higher mean percentage dose difference than the coronal plane.

Table 2. Applicator reconstruction shifts during magnetic resonance scanning

	Applicator shift (mm)					
	Coronal plane			Sagittal plane		
	Rt. ovoid	Lt. ovoid	Tandem	Rt. ovoid	Lt. ovoid	Tandem
Mean ± SD						
LR shift	0.0±0.7	-0.2±1.0	-0.0±0.4	0.0±1.2	0.3±1.6	-1.3±1.1
SI shift	-1.0±1.8	-1.0±2.3	0.0±1.0	0.1±1.0	0.7±1.0	0.3±0.7
AP shift	0.5±1.5	1.0±0.8	-0.5±1.0	0.4±1.4	1.0±1.0	0.6±1.2
Range						
LR shift	-1.0 to 0.9	-2.4 to 1.4	-0.8 to 0.4	-1.5 to 1.4	-3.1 to 1.4	-3.5 to 0.2
SI shift	-4.7 to 1.9	-5.5 to 2.9	-1.8 to 1.5	-0.9 to 0.9	-0.8 to 0.2	-1.0 to 1.2
AP shift	-1.9 to 2.5	0.0 to 2.4	-2.5 to 1.1	-1.6 to 2.2	-0.5 to 2.8	-0.8 to 2.9

Table 3. Percentages of the different doses of HR-CTV and organs at risk because of patient uncertainty during magnetic resonance scans

volume	% dose difference (Mean ± SD)	
	Coronal	Sagittal
D_{90} ofHR-CTV	3.04 ± 2.27	1.23 ± 1.23
D_{2cc} of bladder	2.73 ± 2.83	3.88 ± 2.65
$D_{2cc}$of rectum	2.60 ± 3.00	3.49 ± 2.88

4. Discussion

Although the CTV motion was approximately 4.0 mm during MRI scan for 16 minutes; however, thedosimetric parameters changed did not show [6]. Our study considered the degree of applicator reconstruction shift related to dosimetric parameter changes in HR-CTV and the organ at risk. The results indicated that the maximum error of the left ovoid was 5.5 mm on the coronal plane in the superior-inferior direction. The percentage dose difference showed minimal change when the DVH was considered. However, this was not the same as the point dose. If the applicator shifts in a subcentimeter range, it may induce>10% of dosimetric change [7]. The average changes in HR-CTV (D_{90} and D_{100}) were <4% per mm of reconstruction error[8]. The summarized all sources of uncertainty for one intracavitary brachytherapy fraction showed that organ motion has a major impact on dose uncertainties at D90 of HR-CTV (9%) and organs at risk (5–11%)[9]. The applicator reconstruction shift could be related to change in the position of the applicator during MR scanning of up to 5–6 mm in the ventral direction and 3–4 mm cranially[10]. Our study only considered the dosimetric DVH parameter change from the applicator shift during MR scan. The uncertainty of organ movement was not included because of the same contouring by using all image data sets. The range of error of the applicator shifts found in the present study agrees with others studied [9,10]; thus, applicator reconstruction shift occurring during brachytherapy has minor effects on DVH parameters, but organ movement produces a larger uncertainty.

At present, many types of applicators are used in brachytherapy. In some applicator sets, needles can be inserted in the ovoid for increased dose coverage on HR-CTV in patients with large tumors. DVH parameters may be changed more than the changes demonstrated in our study. In addition, our results showed only DVH parameter errors due to the imaging procedure, not including errors from patient transfer, uncertainty of internal organ movement, or planning duration, which produced more errors, and thus, may have an effect on patient dosimetry.

5. Conclusion

The image acquisition time of approximately 15 minutes for 3-D MR brachytherapy gives a mean applicator reconstruction shift of within 1.3 mm, which has only minor effects of approximately 3% on the DVH parameter.

6. References

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