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Use of 3D transabdominal ultrasound imaging for treatment planning in cervical cancer brachytherapy: Comparison to magnetic resonance and computed tomography

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ABSTRACT

PURPOSE: To evaluate if the addition of 3D transabdominal ultrasound (3DTAUS) imaging to computed tomography (CT) can improve treatment planning in 3D adaptive brachytherapy when compared with CT-based planning alone, resulting in treatment plans closer to the ones obtained using magnetic resonance imaging (MRI)-based planning.

METHODS AND MATERIALS: Five patients with cervical cancer undergoing brachytherapy underwent three imaging modalities: MRI, CT, and CT-3DTAUS. Volumes were delineated by a radiation oncologist and treatment plans were optimized on each imaging modality. To compare treatment plans, the dwell times optimized on MRI were transferred on CT and CT-3DTAUS images and dose parameters were reported on volumes of the receiving imaging modality. The plans optimized on CT and CT-3DTAUS were also copied and evaluated on MRI images.

RESULTS: Treatment plans optimized and evaluated on the same imaging modalities were clinically acceptable but statistically different ($p < 0.05$) from one another. MR-based plans had the highest target coverage (98%) and CT-based plans the lowest (93%). For all treatment plans evaluated on MRI, the target coverage was equivalent. However, a decrease in target coverage (V100) was observed when MR-based plans were applied on CT-3DTAUS (6%) and CT (13%) with $p < 0.05$. An increase in the rectum/sigmoid dose (D2cc) was observed with both CT-3DTAUS—based (0.6 Gy) and CT-based planning (1 Gy) when compared with MR-based plans, whereas bladder dose stayed similar.

CONCLUSIONS: When compared with CT-based planning, the addition of 3DTAUS to CT results in treatment plans closer to MR-based planning. Its use reduces the high-risk clinical target volume overestimation typically observed on CT, improving coverage of the target volume while reducing dose to the organs at risk.

Keywords: Cervix; Ultrasound; Magnetic resonance imaging; Computed tomography; Treatment planning; 3D

Introduction

Over the last decade, brachytherapy treatment for cervical cancer has evolved, progressing from 2D to 3D treatment planning. Improvements in imaging have allowed treatment planning to move from radiograph point dose prescription to image-guided adaptive brachytherapy (IGABT) on magnetic resonance imaging (MRI). Volumetric prescription dose is now formalized by the ICRU 89 (1), which was preceded by GEC-ESTRO (2, 3) and ABS recommendations (4, 5). Those changes allow

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personalized treatment plans adapted to the patient anatomy and a better control on dose delivery, with the possibility to improve both target coverage and the dose to the organs at risk (OARs).

MRI is considered the gold standard in IGABT due to its excellent soft tissue contrast (3). However, this imaging technique is expensive and time consuming, especially if the device is not located within the radiotherapy department. To overcome the cost and delays of MRI, many clinics use computed tomography (CT) images to delineate the high-risk clinical target volume (HR-CTV) and the OARs (6) for brachytherapy treatment planning. However, CT overestimates the HR-CTV volume (7). This overestimation increases the delivered dose to healthy tissues as well as the dose given to OARs.

Over the last few years, ultrasound has been evaluated for use as a real-time applicator insertion guidance modality (8) as well as for volume definition in GYN brachytherapy (9−12). Ultrasound acquisition and interpretation are associated with a steep learning curve (9). However, once all professionals are comfortable with the technique, ultrasound is an interesting imaging modality to explore. VanDyk *et al.* (10, 11) have proven that the accuracy of 2D transabdominal ultrasound is comparable to MRI for cervix and uterus anteroposterior measurements. Schmid *et al.* (12) have studied a 3D transrectal ultrasound (3DTRUS) and has also shown that the HR-CTV can be measured accurately. A treatment workflow including a CT-3DTRUS has been recently presented by Nevsacil *et al.* (13), as well as a first patient planned with CT-3DTRUS images. However, they reported some limitations to its usefulness. First, the uterus fundus can hardly be seen on 3DTRUS due to rectum length. Also, they reported being unable to insert the probe beyond the applicator ring for one of their patients. To date, no one has studied the impact of adding 3D transabdominal ultrasound to CT to determine if it improves planning quality.

Thus, the goal of this work is to determine if 3D transabdominal ultrasound (3DTAUS) imaging combined with CT (CT-3DTAUS) can improve treatment planning over CT alone.

Methods and materials

Patients

Between August 2015 and June 2016, all patients diagnosed with cervical squamous cell carcinoma, who underwent MRI at the time of brachytherapy and did not require interstitial implant, were included in this study; because of the limited access to MRI, only five patients met all these criteria. All patients underwent external beam radiation therapy treatment of 45 Gy in 25 fractions before brachytherapy, followed by four brachytherapy fractions of 7 Gy planning-aim dose each. Patients, with median age of 49 (30−55) and staged from IB-IIB according to FIGO guidelines (1), were treated with intracavitary brachytherapy. For the first fraction, tandem insertion was performed within the brachysuite, under general anesthesia. CT and 3DTAUS were acquired while patients were still asleep. Patients were then woken and brought to the imaging department for MRI acquisition. They were brought back to the brachysuite to be treated. All patients were treated with 3D-CT−based plans, using MRI images with the applicator in place for image fusion to help for volume definition. Treatment plans involving 3DTAUS were created offline and were not used to treat patients.

Patient imaging

After applicator insertion (Cervix Rotterdam Applicator, Elekta Brachytherapy, Veenendaal, The Netherlands), a 3D-CT (Sensation Open Sliding, Siemens, PA) using helical 2 mm slice thickness, 120 kVp, 217 mA, and 230 mAs scan parameters, and a 3DTAUS system (research prototype based on Clarity AutoScan, modified for GYN brachytherapy—Elekta Clarity, Montreal, Canada) with 0.65 mm continuous slice thickness were acquired in the same treatment position in the brachytherapy unit. The patient was then transferred to the imaging department and underwent multiplanar T2WI-weighted Magnetic Resonance Imaging (MRI—Signa Excite, GE Healthcare, Milwaukee, WI) with 5 mm slice thickness. Fusion between CT and 3DTAUS was made (CT-3DTAUS) using the Clarity AFC Workstation 4.0 (Elekta, Montreal, Canada). Before each image acquisition, the bladder was filled with 198 cc of saline water NaCl 0.9% and 2 cc of Visipaque contrast agent. All image sets were exported using DICOM-RT protocol to the Oncentra Brachy Treatment Planning System 4.3 (OCB; Elekta Brachy, Veenendaal, The Netherlands). The high-risk clinical target volume (HR-CTV) and the OARs (bladder and rectum/sigmoid) were contoured on all imaging modalities by one radiation oncologist based on GEC-ESTRO definition (2). Because no HR-CTV definition is given for 3DTAUS, the ABS recommendation for CTV delineation on CT was used with slight modifications: the HR-CTV extended from the cervical stopper to the indented portion of the uterus, with a typical minimal height of 3 cm. In our experience, laterally, the differentiation between the cervix and tumor was not possible. Therefore, the gray/white interface was used to identify the lateral borders of the CTV (7, 14). As the rectum and sigmoid could not be distinguished on 3DTAUS, it was decided that they could be contoured together. The D2cc of the rectum/sigmoid contour limit tolerated for the optimization is 4.5 Gy instead of 4.5 Gy for both. This choice lead to more severe dose limits for these OARs.

Treatment planning

The applicators were reconstructed on each imaging modality (MRI, CT, and CT-3DTAUS) using the TPS