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Technical note

Positional uncertainty of vaginal cuff and feasibility of implementing portable bladder scanner in postoperative cervical cancer patients

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ABSTRACT

Purpose: To propose a geometrical margin for definition of the vaginal cuff PTV using only CT images of the full bladder (CT_{full}) in postoperative cervical cancer patients.
Methods: Twenty-nine operated cervical cancer patients underwent volumetric arc therapy with a bladder filling protocol. This study assessed bladder filling using a portable bladder scanner and cone-beam computed tomography (CBCT) during the entire treatment period. The measured bladder volumes with a BladderScan® were compared with the delineated volume on CBCT. Titanium clips in the vaginal cuff were analysed to assess geometrical uncertainty and the influence of rectal and bladder volume changes.
Results: BladderScan® showed good agreement with the delineated volume ($R = 0.80$). The volume changes in the bladder have a greater influence on the clip displacements than in the rectum. The 95th percentile of uncertainty of the clips in reference to CT_{full} in the right-left (RL), the superoinferior (SI), and the anteroposterior (AP) was 0.32, 0.65, and 1.15 cm, respectively. From this result and intra-fractional movements of the vaginal cuff reported by Haripotepornkul, a new geometrical margin was proposed for definition of the vaginal cuff planning target volume (PTV): 0.5, 0.9, and 1.4 cm in the RL, SI, and AP directions, respectively.
Conclusions: A new geometrical margin was proposed for definition of the vaginal cuff PTV based on CT_{full}, which will be needless of empty bladder at the planning CT scan. This method allows patients to reduce the burden and efficient routine CT scans can be improved.

1. Introduction

For intermediate- and high-risk early stage uterine cervical cancer patients who underwent radical hysterectomy, postoperative radiation therapy is an established standard treatment with conventional techniques including four-field delivery to the whole pelvis [1,2]. Recently, intensity-modulated radiation therapy (IMRT) has allowed a reduction in unwanted doses to healthy organs within the pelvis, including the small bowel, rectum, bladder, and bone marrow [3–6]. Complication could be possibly reduced with IMRT [7,8]. However, many studies [9–17] reported that a large geometrical uncertainty in the vaginal cuff exists, which was caused by variable volume and positional changes of surrounding organs, such as rectum and bladder. They influence the internal motion of the vaginal cuff region, requiring a greater margin of clinical target volume to planning target volume (CTV-PTV margin) when planning treatment.

Currently, a patient protocol of bladder filling as pre-treatment preparation should be essential in postoperative cervical cancer IMRT and this protocol needs constant bladder filling during a planning CT scan and treatments [9,12,13,15]. This protocol is intended to push the small bowel away from the treated region within the pelvis, which has also allowed reduction in the geometrical uncertainty of the vaginal cuff as well as unwanted dose in the small bowel [18,19]. However, some investigators reported that constant bladder filling was difficult to achieve during entire radiotherapy course, in spite of following the protocols [9,12,13]. Furthermore, the studies showed that bladder volumes vary widely within the population, and control of bladder filling is patient-specific.

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According to the protocol of radiation therapy oncology group (RTOG) 0418 [20] and 1203 [21], clinical trials for post-hysterectomy IMRT, the internal target volume (ITV) of the vaginal cuff is contoured from the fused CT images of the full and the empty bladder for consideration of the vaginal cuff movements. Then, the expansion of 7 mm in all directions is applied to the ITV to create the vaginal cuff planning target volume (PTV). However, such a procedure obliges patients to conduct both empty and full bladder at a planning CT scan. Additionally, if bladder filling is not sufficient at a planning CT scan, which frequently happens because nerves innervating bladder are in some extent damaged during radical hysterectomy [22,23], the ITV could be small and possibly not enough to cover the vagina cuff movements during prolonged treatments. Specifically, the vaginal cuff has a high risk of local recurrences after radical hysterectomy and pelvic lymphadenectomy [24]. From these findings, it is our belief that a geometrical margin of CTV-PTV should be adequate in postoperative cervical cancer IMRT when planning treatment, because such a patient-specific problem remains and stump recurrence must not happened after postoperative pelvic radiation.

Our purpose in this study is to propose a new geometrical margin for definition of the vaginal cuff PTV using a reference CT image of only the full bladder by consideration of the geometrical uncertainty within patient population, which will be needless of empty bladder. This protocol allows patients to reduce the burden and efficient routine CT scans can be improved in clinical practice. Therefore, displacements of clips in the vaginal cuff were analysed to assess the geometrical uncertainty of the vaginal cuff for twenty-nine post-operative cervical cancer patients. Additionally, the relatively new portable bladder scanner was justified by comparison with a known volume in the ultrasound phantom and the delineated bladder volumes on cone-beam computed tomography (CBCT). The measured bladder volumes with the portable bladder scanner were used to assess control of patient's bladder filling during the entire treatment period.

2. Methods and materials

2.1. Patients

Twenty-nine post-operative cervical cancer patients underwent IMRT between February 2011 and May 2016. The characteristics of these patients were represented in Table 1. Patients were treated with supine position and immobilized by vacuum cushions (Engineering System Co., Ltd, Nagano, Tokyo). Patients were instructed to empty the bowel and the rectum, and then drink 300 cm^3 of water one hour before CT scans and each treatment. Two treatment planning CT images with full (CT_{full}) and empty (CT_{empty}) bladder were acquired and transferred to the treatment planning system (Eclipse™, Varian Medical Systems, Palo Alto, CA, USA). Several surgical titanium clips (about 2 mm length and 1 mm diameter) were implanted in the vaginal cuff region and these were used to define the vaginal cuff CTV (mean (1σ) = 2.2 (0.9) for number of clips per patient). The nodal and vaginal cuff CTV were contoured according to contouring guidelines [25,26]. The nodal and vaginal cuff PTV received 50 Gy in 25 fractions and all patients were treated with volumetric arc therapy (VMAT) using 2 arcs and 15 MV x-rays. For all patients, orthogonal images were obtained with the On-Board Imager® (OBI, Varian Medical Systems, Palo Alto, CA, USA) and bony anatomical structures were aligned to the initial CT images prior to every treatments. CBCT scans were also conducted after the orthogonal image acquisitions in the first three fractions and at least once per week to assess the filling of the rectum, bladder, and small bowel. Of 29 postoperative cervical cancer patients, 16 patients underwent bladder volume measurement prior to the orthogonal image acquisitions by a portable bladder scanner, BladderScan® (BVI 6100, Verathon Inc, WA, USA). A mechanical accuracy of the BladderScan® was assessed using an ultrasound phantom before implementation of a clinical practice (supplemental data; appendix A). The measured volume in initial CT scans was used as a reference volume to monitor the bladder filling during treatments. If we have a large difference volume between the reference and daily treatments (approximately 100 cm^3) or bladder filling is determined to be not sufficient by visual assessment of CBCT images, we delay time of the treatments as much as time allow in routine treatments. Treatments were conducted within about 1 h from the time of measuring bladder volume with the BladderScan®.

Table 1
Patient characteristics of 29 post-operative cervical cancer patients.

Median age (range)	43 (27–79)
FIGO stage	
IA	1
IB	1
IB1	14
IB2	8
IIA	3
IIB	2
Cell type	
Squamous cell	19
Adenocarcinoma	9
Adenosquamous	1

2.2. Correlation between vaginal clip displacement and bladder and rectal volume

One radiation oncologist retrospectively delineated bladders, V_{full}, V_{empty}, and V_{CBCT} on the CT_{full}, CT_{empty}, and all of the CBCT images acquired during the treatment period, respectively. On average, each patient had six CBCT scans throughout the treatment course. The longitudinal length of the delineated rectums in the superoinferior direction was defined to be the same in each patient in order to compare volume changes in the rectum among the different treatment sessions. Rectums were typically delineated between the sigmoid flexure and the upper limit of pubic symphysis due to finite sizes of the CBCT scans. The mean (1σ) of the longitudinal length was 4.9 (1.3) cm. Positional variations of vaginal clips in the CBCT images were analysed in three directions: right-left (RL), superoinferior (SI), and anteroposterior (AP). The mean positional clip displacements were derived in reference to the clip positions in the CT_{full}.

2.3. Analysis

Bladder volumes measured with the BladderScan® (V_{BS}) were compared with the delineated bladder volumes on the CBCT images (V_{CBCT}) and a Bland-Altman plot was used to examine the consistency of bladder volume in the BladderScan® for 16 of 29 cervical cancer patients (mean 6.3 measurements per patient; total measurements 89). The correlation coefficient was calculated. A Wilcoxon signed rank test was used to examine the significant difference between the two bladder volumes as a non-parametric test. We also examined the relationships between V_{full}, V_{empty}, V_{CBCT}, and V_{BS} at the different treatment days. A paired Student's *t*-test was used to examine the significant difference between V_{full} and mean values of V_{CBCT} during the treatments as a parametric test.

The various statistics for geometrical uncertainty of the vaginal cuff were reported such as mean, median, range, systematic, random uncertainty, and 95th percentiles [9–17]. From these reports, such statistics were also analysed for geometrical margin of the vaginal cuff from a reference of CT_{full} in this study. The mean of all patients' mean (M), systematic (Σ) and random (σ) were calculated by using the following equations,

$$M = \frac{1}{N_p}\sum_i m_i \quad (1)$$