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Original Article

Pelvic Organ Motion during Radiotherapy for Cervical Cancer: Understanding Patterns and Recommended Patient Preparation

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Abstract

Aims: Minimisation of organ position variation during pelvic radiotherapy is vital for accurate treatment. We analysed bladder and rectal filling during radiotherapy to understand variation reduction methods.

Materials and methods: Cone beam computed tomography scans (CBCTs) taken twice weekly during three-dimensional conformal radiotherapy were retrospectively analysed for 10 cervical cancer patients. Bladder and bowel preparation was followed. Two independent clinicians outlined bladder, rectum and the primary clinical target volume (CTV) on each CBCT. Effects of time, chemotherapy and drinking time on bladder and rectal volume were analysed. CTV coverage impact was investigated using fixed effect logistic regression modelling.

Results: Ten planning scans and 109 CBCTs were reviewed. The bladder volume was 45–578 cm^3 during radiotherapy and 73–664 cm^3 at planning. The bladder volume increased (4 cm^3/min) with waiting time, decreased (average 4 cm^3/day) through treatment and was larger (about 50 cm^3) after chemotherapy. A bladder volume difference $>$ 130 cm^3 from planning led to the planning target volume (PTV) not covering the CTV. The probability of the PTV covering the CTV for every cm^3 deviation from the planning volume reduced by 1.9%, predominantly affecting the uterus. Planning bladder volumes $>$ 300 cm^3 were not reproducible during treatment. The rectal anterior-posterior diameter correlated with volume. No pattern was displayed through treatment. The probability of the PTV covering the CTV with every mm deviation from the planning anterior-posterior diameter reduced by 5.8%, predominantly affecting the cervix. The risk of the PTV not covering the CTV is higher if the rectum is larger during treatment than planning. As bladder volume decreased rectal anterior-posterior diameter increased.

Conclusion: Our data suggest an ideal planning bladder volume of 150–300 cm^3, a shorter waiting time on post-chemotherapy days and adequate hydration throughout treatment. Laxatives at planning and throughout treatment may also be beneficial. Even with these measures, regular imaging is vital when implementing advanced radiotherapy techniques for gynaecological cancers.

Key words: Bladder preparation; cervical cancer; organ motion; radiotherapy

Introduction

Pelvic intensity-modulated radiotherapy (IMRT) reduces the irradiated small bowel volume compared with three-dimensional conformal radiotherapy [1], thus reducing toxicity [2]. It is therefore increasingly used to treat cervical cancer. Margins applied to the clinical target volume (CTV) aim to account for uncertainties, including organ motion. Appreciation of the extent of this motion and contributing factors is important to ensure adequate target coverage. Many studies have attempted to quantify cervical and uterine movements during radiotherapy, finding movements up to 4–6 cm [3–10]. Adequate margins to account for this would negate the benefits of more conformal radiotherapy and are therefore not applicable [10]. Bladder and rectal filling affect this motion, but no published guidelines on bladder or bowel preparation exist. Most centres aim for a ‘comfortably full bladder’ to push the bowel out of the radiation field. However, a full bladder leads to unacceptably large set-up errors [7,9]. Analysis of a cohort of patients who underwent magnetic resonance imaging scans on two consecutive days led Taylor and Powell [8] to conclude that asymmetrical margins of maximum 15 mm would be adequate to cover uterine and cervical motion. This may not represent the changes that

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occur during a course of radiotherapy. Jadon *et al.* [10] systematically reviewed the available literature of organ motion in 2014. They identified 39 heterogeneous studies, 12 of which were conference abstracts. Eleven reviewed cervical motion, five uterine, two nodal, 11 analysed the impact of bladder filling and five the impact of rectal filling. Each study used different methods to characterise motion and established slightly different conclusions. None of these defined clear guidance for bladder and bowel preparation despite detecting patterns in bladder and rectal filling and an effect on CTV coverage. Proposals to compensate for observed changes include daily tissue imaging, adaptive radiotherapy with variable bladder filling scans, or individualised margins [11]. Adaptive radiotherapy does not account for rectal changes and requires significant resources and training to be implemented safely. Further validation is necessary before adopting any of these strategies. The aims of this study were to analyse bladder and rectal filling patterns throughout a course of cervical chemoradiation, assess the effect on CTV coverage and attempt to produce some proposals for patient preparation.

Materials and Methods

Ten consecutive patients undergoing cervical chemoradiation were analysed. Patients were prescribed laxatives (Movicol or sodium docusate) for a minimum of 5 days before planning and treatment to achieve a Bristol stool chart type 5 stool. On arrival in radiotherapy, patients emptied their bladder then drank 3 cups of water 30 min before both the planning computed tomography scan and each daily treatment.

Twice weekly cone beam computed tomography (CBCT) scans as per the agreed departmental imaging protocol were acquired, one of which was 1 day after chemotherapy. Varian on-board imaging acquired a 16 cm length CBCT with 2 mm slices around the isocentre, shifted to ensure the entire bladder and rectum were captured. A retrospective review was carried out on Eclipse v11 Contouring and ARIA Offline Review v11. In addition, the actual bladder filling time was recorded.

Bony matching to the planning computed tomography scan was carried out to eliminate set-up errors. CTV1 (cervix, tumour, bilateral parametria, entire uterus and upper vagina), CTV2 (pelvic nodes), bladder and rectum were outlined by experienced clinicians on the planning computed tomography scan. No internal target volume (ITV) was created. The planning target volume (PTV) was created by adding 8 mm to CTV2 and 15 mm to CTV1 except laterally where 10 mm was added. The rectum, bladder and CTV1 were outlined on all CBCTs by two independent clinicians. These two outlines were summed to create a final CTV1. Along the uterine axis, the upper two-thirds represents the uterus and the lower third represents the cervix. Where the CBCT failed to capture the entire bladder (10% of CBCTs) the planning bladder volume was used to complete the outline. This ensured a total bladder volume was calculated for these 11 CBCTs.

Bladder filling time and volume, rectal volume, length, and maximum anterior-posterior diameter, and whether the PTV covered the entirety of CTV1 were recorded for all scans (planning and CBCTs). Where the CTV was not fully covered by the PTV the maximum distance (mm) from the PTV edge to the CTV was recorded. The deviation from planning was calculated for bladder volume and rectal anterior-posterior diameter. The mean, standard deviation and 95% confidence intervals were calculated following QQ plots review confirming normality using IBM SPSS Statistics 22. Scatter plots and Pearson's correlation were analysed for overall patterns. *P* values were derived from one sample *t*-tests and independent samples *t*-tests assuming equal variance. Linear mixed regression modelling was used to analyse patterns through time. Fixed effects binary logistic regression was used to assess the organ size effect on CTV1 coverage resulting in odds ratios.

Results

In total, 10 planning computed tomography and 109 treatment CBCT scans (between nine and 12 per patient) were analysed. The actual bladder filling time was recorded for 98 scans.

Bladder volume ranged from 45 to 664 cm^3 overall, mean 200 cm^3. The bladder volume at planning was 73–664 cm^3, mean 289 cm^3, and through treatment was 45–578 cm^3, mean 192 cm^3. During radiotherapy, the bladder volume was on average smaller by 96 cm^3, 95% confidence interval 9–184, $P = 0.031$. For individual cases, the range of bladder volume through radiotherapy varied between 116 and 416 cm^3, mean 306 cm^3. Nine of 10 had a minimum bladder volume less than 100 cm^3 (Table 1).

Bladder volume increased with increased interval after drinking by about 4 cm^3 per minute.

Bladder volume decreased with time through treatment by 3.6 cm^3 per day (Figure 1), leading to an approximate total average 150 cm^3 decrease throughout treatment. This decrease was larger (5 cm^3/day) in patients with a planning bladder volume > 300 cm^3. On individual case analysis, bladder volume reduced through treatment in 9/10 cases, 1–8 cm^3/day. One case, which had a small bladder volume in general, ranging from 60 to 176 cm^3, displayed a stable volume through treatment (95% confidence interval +3 to −1 cm^3/day) (case 9 Table 1).

The mean bladder volume on non-chemotherapy days was 170 cm^3 and 219 cm^3 on the first day after chemotherapy; a 49 cm^3 increase (95% confidence interval 1–96 cm^3, $P = 0.045$). Analysing each case independently, the mean bladder volume difference between post-chemotherapy and non-chemotherapy days ranged from 0 to 115 cm^3. Therefore, all patients had a larger mean bladder volume on post-chemotherapy days.

Figure 2(a–c) displays bladder volume deviation from planning (*y* axis) against whether CTV1, uterus (upper CTV1) or cervix (lower CTV1) are covered by the PTV (*x* axis). In all cases where deviation from the planning volume exceeded 130 cm^3 CTV1 was not covered by the