Dosimetric Impact of Different Bladder Volumes on Sparing Organs at Risk in CT-based Cervix HDR Brachytherapy

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Introduction

High-dose-rate (HDR) brachytherapy is pivotal in cervical cancer management, delivering targeted radiation to the tumor while aiming to spare organs-at-risk (OAR), such as the bladder, rectum, sigmoid, and bowel. Although bladder volume (BV) is hypothesized to influence OAR dosimetry, prior studies have lacked consensus, often comparing across different patients or implants, introducing variability. This study introduces a novel approach by evaluating BV effects within the same patient and implant, using two CT scans with distinct BVs per session. This intra-patient and implant design isolates BV as the variable, offering a unique perspective on its dosimetric impact.

Methods and Materials

This retrospective study analyzed 42 CT scans from 21 HDR brachytherapy implants in 15 cervical cancer patients. Patients presented with FIGO stages IB1 to IIIC2 and histology including squamous cell carcinoma, adenocarcinoma, and neuroendocrine tumors. All received prior pelvic external beam radiation therapy (EBRT) to 45 Gy in 25 fractions via VMAT with concurrent weekly cisplatin-based chemotherapy.

Following EBRT, intracavitary brachytherapy was administered using mainly the Geneva tandem and ovoid applicator. Treatments ranged from 28-30 Gy in 4-5 fractions. Applicator insertions were performed under anesthesia, with patients prepped via rectal enemas and bladder emptying. Each implant was imaged with two CT scans at different BVs (62cc–467cc). One scan guided clinical treatment, while the second, with altered BV, was used for research. Both CTs were imported into RayStation for organs-at-risk (OAR) contouring and HR-CTV transfer via tandem and ovoid point registration. Applicator reconstructions and plan generation were performed in Oncentra TPS, using the same dwell times and positions from clinical plans. Dosimetric dose values for each plan were recorded and normalized to consistent HR-CTV coverage, except when analyzing HR-CTV variation itself (see Fig. 2. and Fig. 3.).

Statistical analysis included Pearson correlation, linear regression, Kruskal-Wallis, and Mann-Whitney U tests to compare BV groups (low, medium, and high). Delta analysis assessed the relationship between BV change and dosimetric variation. An interquartile range (IQR) approach identified the optimal BV range minimizing OAR dose while maintaining HR-CTV coverage (see Fig 1.).

Data Collection

Acquired two CT scans with different BV. Contoured OARs, fused images for HR-CTV transfer, reconstructed HDR implant and replicated dwell times. Dose for OARs and HRCTV recorded.

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Statistical Analysis

OAR D2cc values were normalized to HR-CTV D90 to isolate BV effects. Person correlation, linear regression, Kruskal-Wallis, and Mann-Whitney U tests were performed.

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Evaluation

Bladder dose is significantly affected by BV, with an optimal range of 73-100 mL. This minimizes bladder dose, lowers urotoxicity risk, and maintains stable OAR and HR-CTV coverage.

Fig. 1. Workflow of study

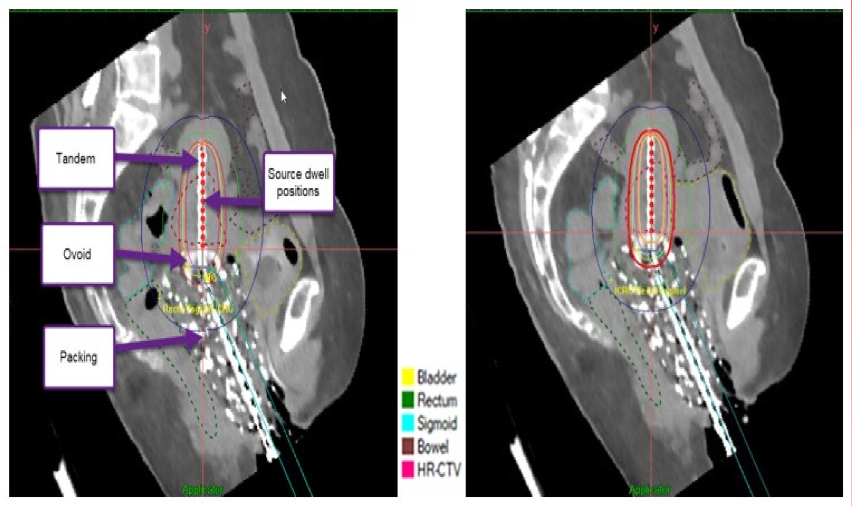

Fig. 2. Shows a mid-sagittal view of the intracavitary applicator for the same patient, same implant but different bladder volumes, with dose distribution to the target. Smaller bladder volume (left) and larger bladder volume (right). This Figure is a single case for the illustration purpose without normalizing the HR-CTV D90 coverage

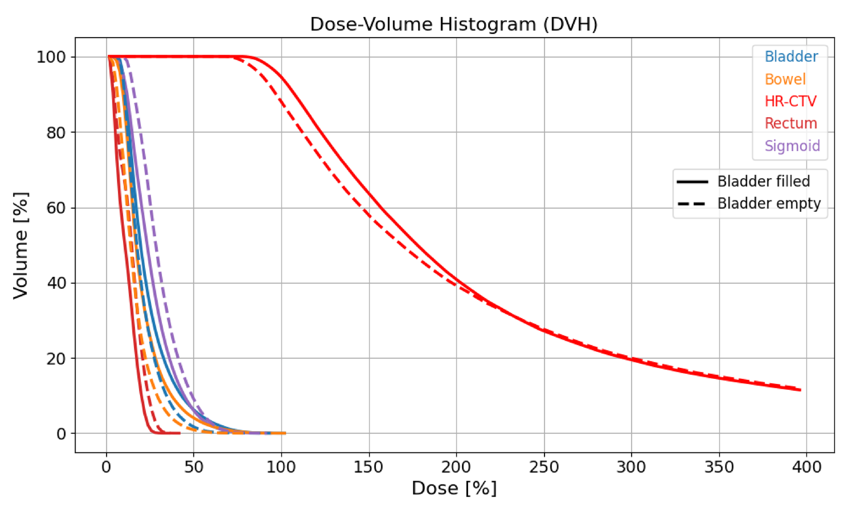

Fig 3. DVH plot for the smaller bladder volume and larger bladder volume. This Figure is a single case for the illustration purpose

Results

A significant positive correlation emerged between BV and bladder D2cc (r = 0.556, p = 0.00013), while rectum (p = 0.803), sigmoid (p = 0.638), bowel (p = 0.942), and HR-CTV (p = 0.266) doses showed no significant BV dependence (see Table 1.). Delta analysis reinforced this, revealing a strong correlation between BV changes (ΔBV) and bladder dose changes (ΔBID; r = 0.8512, p < 0.000001), with negligible effects on rectum, sigmoid, bowel, (ΔRD, p = 0.7053; ΔSD, p = 0.9070; ΔBoD, p = 0.4290) and HR-CTV (ΔHR-CTV, p = 0.2610) doses (see Table 2.). Patients stratified into low, medium, and high BV groups demonstrated significantly lower bladder D2cc in the low BV group (p = 0.0094) versus medium (p = 0.1904) and high (p = 0.0022) groups. Linear regression hinted at a slight, non-significant bowel dose decrease (slope = -0.0120) and potential HR-CTV coverage reduction (slope = -0.0526) with higher BVs.

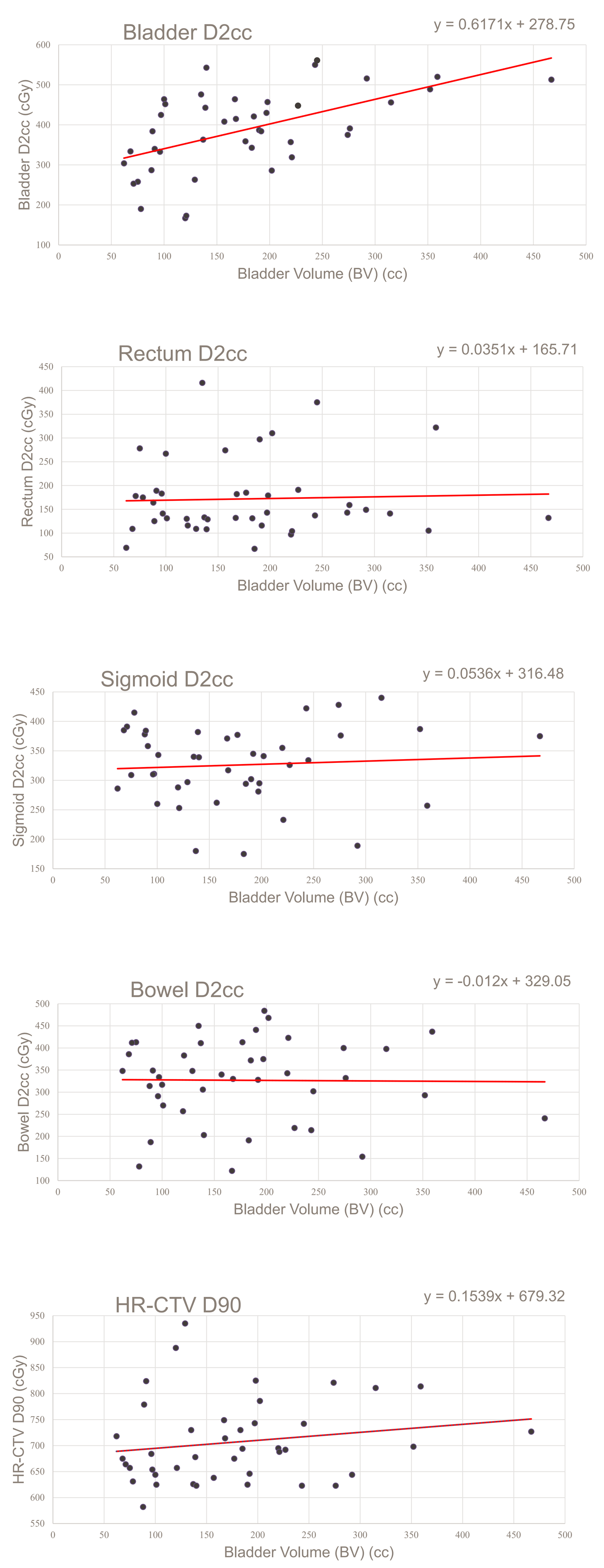

Fig. 4. Scatter plots of BV (cc) and D2cc (cGy) of OAR and D90 (cGy) of HR-CTV with OAR normalized to comparable HR-CTV D90 between two CT scans of the same patient and implant with different bladder volumes.

Table 1. Statistical analysis of 42 CT scans using Pearson correlation, linear regression, Kruskal-Wallis test for differences across Low, Medium, and High BV groups, and Mann-Whitney U test for pairwise group comparisons.

Analysis Test	Bladder D2cc	Rectum D2cc	Sigmoid D2cc	Bowel D2cc	HR-CTV (D90)
Pearson Correlation and p-value	r 0.556 p-value 0.00013	r 0.040 p-value 0.803	r 0.075 p-value 0.638	r -0.012 p-value 0.942	r 0.176 p-value 0.266
Linear Regression	Slope 0.6171 p-value 0.00013	Slope 0.0351 p-value 0.803	Slope 0.0536 p-value 0.638	Slope -0.0120 p-value 0.942	Slope 0.1539 p-value 0.266
Kruskal-Wallis Test	p-value 0.0024	p-value 0.8392	p-value 0.3233	p-value 0.7391	p-value 0.3447
Mann-Whitney U Test	Low vs Medium: p-value 0.0094 Medium vs High: p-value 0.1904 Low vs High: p-value 0.0022	No significant differences in pairwise comparisons	No significant differences in pairwise comparisons	No significant differences in pairwise comparisons	No significant differences in pairwise comparisons

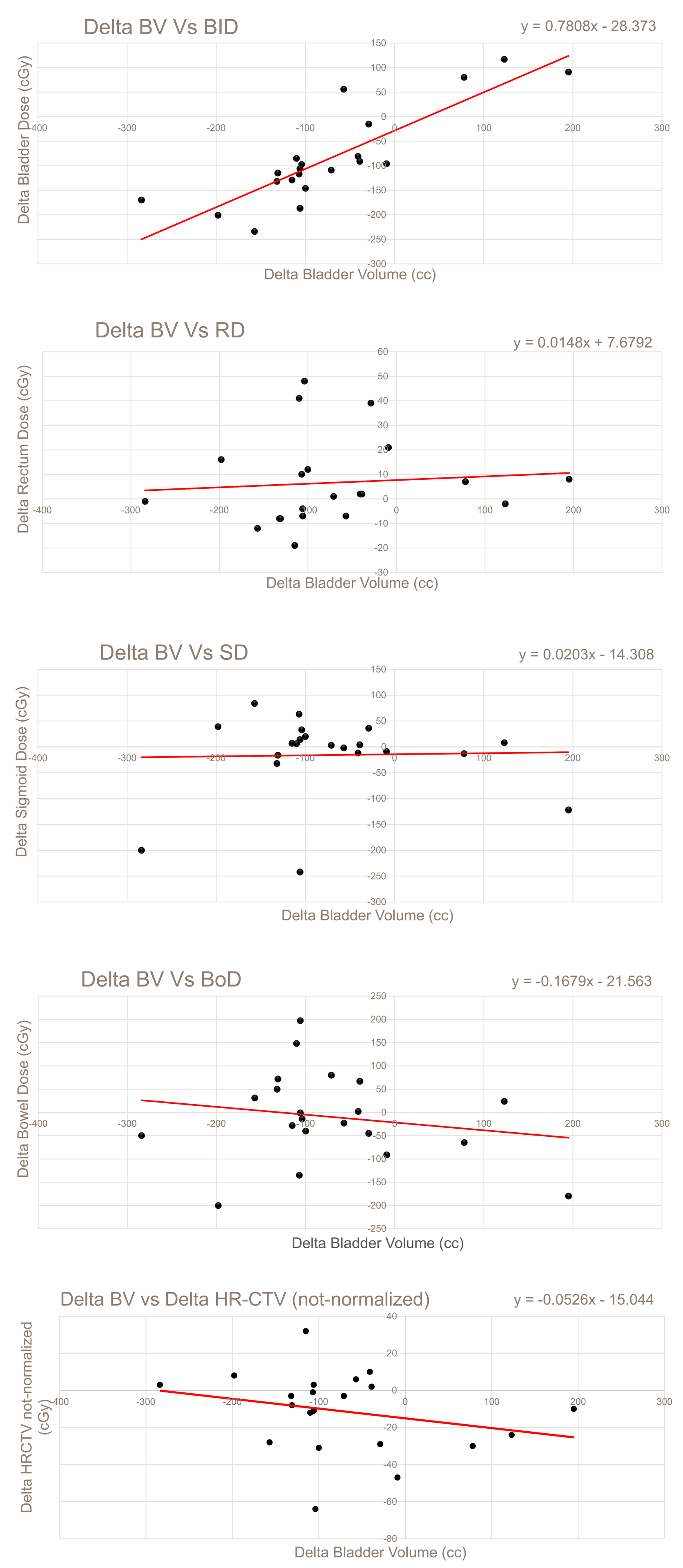

Fig. 5. Scatter plots show the relationships between Delta BV (Bladder Volume Change) and the OAR dose changes: D2cc for Delta BID, Delta RD, Delta SD, Delta BoD, and D90 for Delta HRCTV, along with their respective trendlines and equations.

Table 2. Shows delta bladder dose (BID) is significantly influenced by bladder volume changes, with a strong positive correlation (r = 0.8512). Delta rectal (RD), delta sigmoid (SD) and delta bowel (BoD) dose changes are weakly associated with bladder volume variations, showing negligible relationships.

Analysis Test	Delta Bladder D2cc	Delta Rectum D2cc	Delta Sigmoid D2cc	Delta Bowel D2cc	Delta HR-CTV (D90%)
Pearson Correlation and p-value	r 0.8512 p-value 9.99E-07	r 0.0877 p-value 0.7053	r 0.0272 p-value 0.9070	r -0.1823 p-value 0.4290	r -0.2568 p-value 0.2610
Linear Regression	Slope 0.7808 p-value 9.99E-07	Slope 0.0148 p-value 0.7053	Slope 0.0203 p-value 0.9070	Slope -0.1679 p-value 0.4290	Slope -0.0526 p-value 0.2610
Kruskal-Wallis Test	p-value 0.0036	p-value 0.2372	p-value 0.6624	p-value 0.5341	p-value 0.3994
Mann-Whitney U Test	Low vs Medium: p-value 0.209 Medium vs High: p-value 0.007 Low vs High: p-value 0.0023	No significant differences in pairwise comparisons	No significant differences in pairwise comparisons	No significant differences in pairwise comparisons	No significant differences in pairwise comparisons

Discussion

This study examines the impact of BV on OAR dosimetry in HDR brachytherapy using a novel intra-patient design, comparing two CT scans within the same implant to isolate BV as a variable.

Results showed a significant positive correlation between BV and bladder D2cc (r = 0.556; Δ-analysis r = 0.8512), while doses to the rectum, sigmoid, bowel, and HR-CTV coverage remained stable (see Fig. 4. and 5.). An optimal BV range of 73–100 cc was identified to minimize bladder dose without compromising target coverage.

These findings are consistent with Patel et al., who also demonstrated increased bladder D2cc with larger BV and decreased rectal and bowel doses using a similar dual-scan approach, though they included applicator position analysis, which this study did not.[1]

Xu et al. also reported higher bladder D2cc with increased BV but noted a drop in HR-CTV coverage, likely due to their adjustments for BMI, corpus angle, and applicator length—factors not included in this analysis.[2]

Ye et al. observed no significant BV effect on bladder D2cc but did find reduced sigmoid dose; this difference may relate to their inclusion of patients with more advanced disease and longer tandems.[3]

Chakravarty et al. found no significant BV correlation and questioned the reliability of ICRU reference points, though their study assessed inter-fraction rather than intra-implant variability.[4]

Our intra-patient methodology eliminates inter-fraction and inter-patient variability, offering a more controlled assessment of BV's effect on dosimetry. Future studies should incorporate confounding anatomical factors and assess applicator stability to further refine bladder management guidelines in brachytherapy.

Conclusion

Uniquely, this study's same-patient, same-implant methodology eliminates inter-patient and inter-implant variability, pinpointing an optimal BV range of 73–100 cc. This range minimizes bladder D2cc, reducing risks of urotoxicity and cystitis, while maintaining stable doses to other OAR and consistent HR-CTV coverage. These findings provide a robust, patient-specific framework for optimizing bladder filling protocols in cervical HDR brachytherapy.

References

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