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Dosimetric Evaluation of Systematic Source Position Uncertainty Along the Source Path During MRI-guided Gynecological HDR Interstitial Brachytherapy

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ABSTRACT

Purpose:
To assess the dosimetric impact of systematic source position uncertainty along the source path during MRI-guided gynecological high-dose-rate (HDR) interstitial brachytherapy (ISBT) treatment planning.

Methods:
Treatment plans from 11 cervical cancer patients treated using interstitial brachytherapy were retrospectively analyzed. Uncertainty in the source position along the source path was modeled by systematically shifting the source position at the increment of 1mm in the -5mm to +5mm range along the source path in original treatment plans. Dosimetric parameters HRCTV_D90 as well as D_{2cc} for organs at risk (OARs) were computed for each source position. Statistical significance was evaluated using the Wilcoxon signed-rank test.

Results:
Dosimetric changes were significant for all OARs (all shift positions; p≤0.003). HRCTV_D90 was also significantly affected at all source position shifts (p≤0.033) except −1 and −2mm. HRCTV_D90 decreased by up to 11.9%, and the OARs D_{2cc} increased by up to 17.2%, 3.0%, 7.6%, and 13.8% for bladder, bowel, rectum, and sigmoid, respectively.

Conclusion:
Systematic source position shift can significantly influence dosimetry in MR-guided gynecological HDR interstitial brachytherapy. This indicates that treatment plan re-optimization strategies may be necessary to minimize this effect.

INTRODUCTION

- Brachytherapy is an integral part of gynecological cancer treatment.
- Dose delivery accuracy depends on the consistency of source position within the applicator between treatment planning and delivery.
- Source position uncertainty within straight applicators like tandem has been reported up to 2.3mm [1,2].
- A change in the length of the source drive cable has been reported up to 1mm [3].
- Applicator tip reconstruction uncertainty in MR images has been observed to be up to 3.3mm [4–6].
- Steep dose gradients in BT necessitate the assessment of the dosimetric impact of source position uncertainty.
- This study evaluates the dosimetric effect of systematic source position uncertainty (within applicators) up to ±5mm for MRI-guided cervical interstitial HDR brachytherapy.

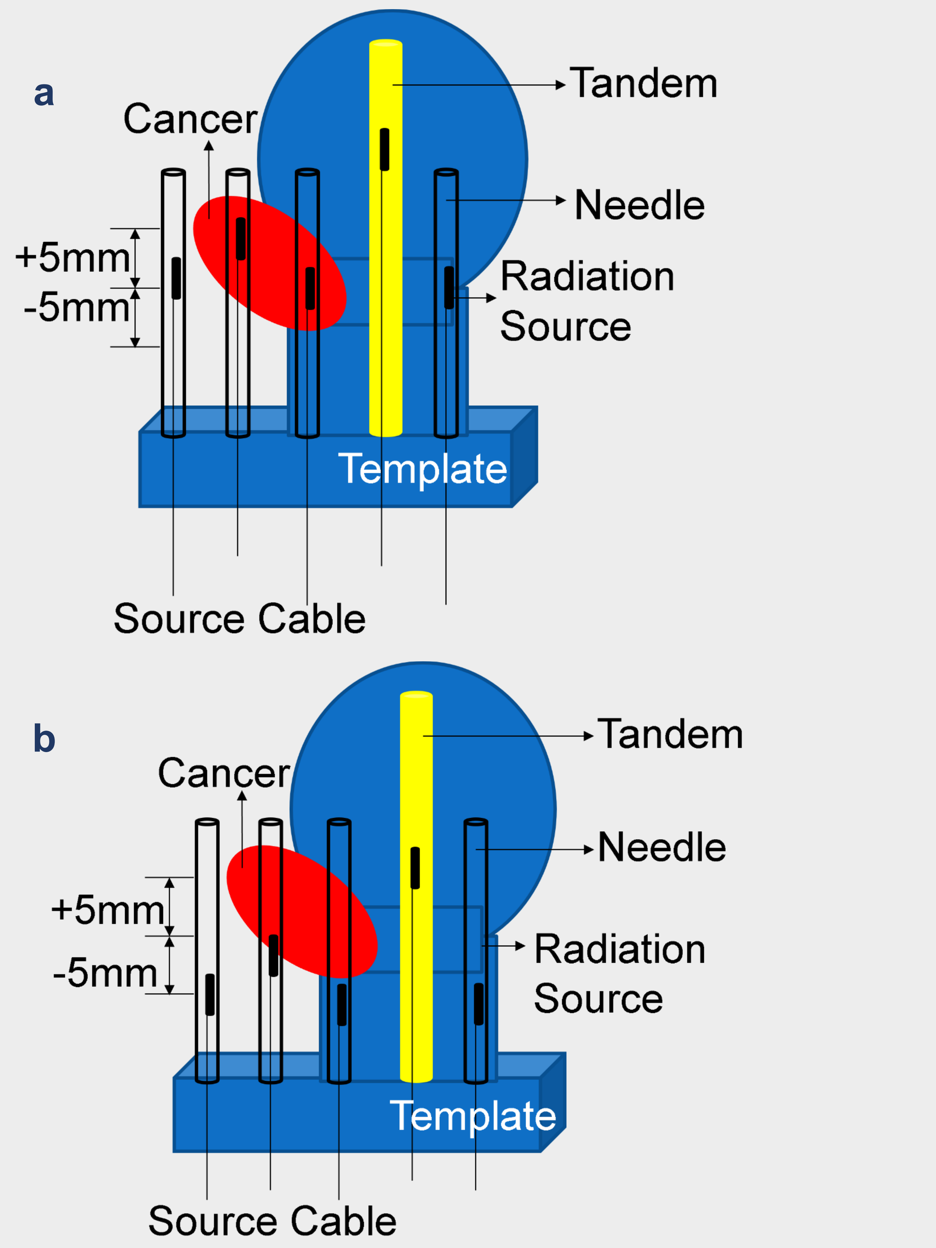

Figure 1. Schematic diagram representing the treatment scenario (a) without source position uncertainty and (b) with source position uncertainty within applicators.

METHODS AND MATERIALS

- Treatment plans from 11 cervical cancer patients (with intact uterus) treated using interstitial brachytherapy were retrospectively analyzed.
- Uncertainty in the source position along the source path was modeled by systematically shifting the source position within the treatment planning system at the increment of 1mm in the -5mm to +5mm range along the source path in original treatment plans.
- HRCTV_D90 and OARs (bladder, bowel, rectum, and sigmoid) D_{2cc} were computed for each source position, and cumulative dosimetric parameters were calculated.
- Statistical significance of dosimetric differences for each shifted source position with respect to the original source position was evaluated using the Wilcoxon signed-rank test.

RESULTS

- Variation in HRCTV_D90 is non-linear with respect to source position uncertainty (Figure 2).
- Figure 2 shows that with increasing uncertainty for more patients, dose falls below the planning aim.
- Dosimetric variations were statistically significant (p≤0.033) at all source positions except at -1mm and -2mm.

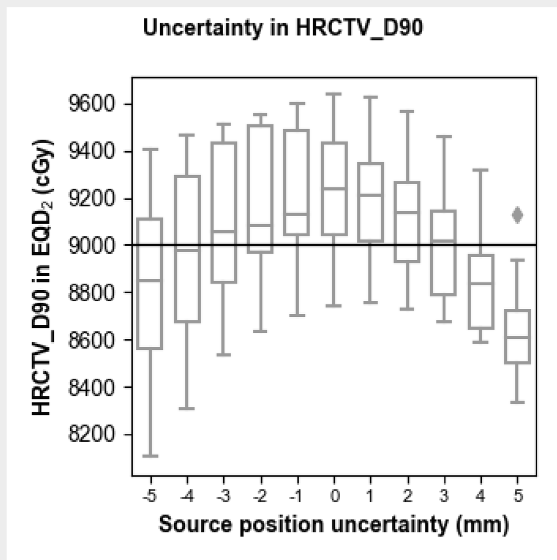

Figure 2. Uncertainty in HRCTV_D90 (EQD_2) based on systematic source position uncertainty within tandem and interstitial needles. The solid lines within each box indicate the median. The solid line in the figure represents the planning aim. The plot construction detail provided here also applies to Figure 3.

- Graphical representations of D_{2cc} variations for OARs (bladder, bowel, rectum, and sigmoid) are presented in figure 3.
- Variation in D_{2cc} for all OARs was linear with respect to source position uncertainty.
- Bladder and rectal D_{2cc} were increasing with an increase in negative uncertainty in source position, whereas bowel and sigmoid D_{2cc} were increasing with positive source uncertainty.
- Dosimetric variations for all OARs were statistically significant (p≤0.003) at all source positions.

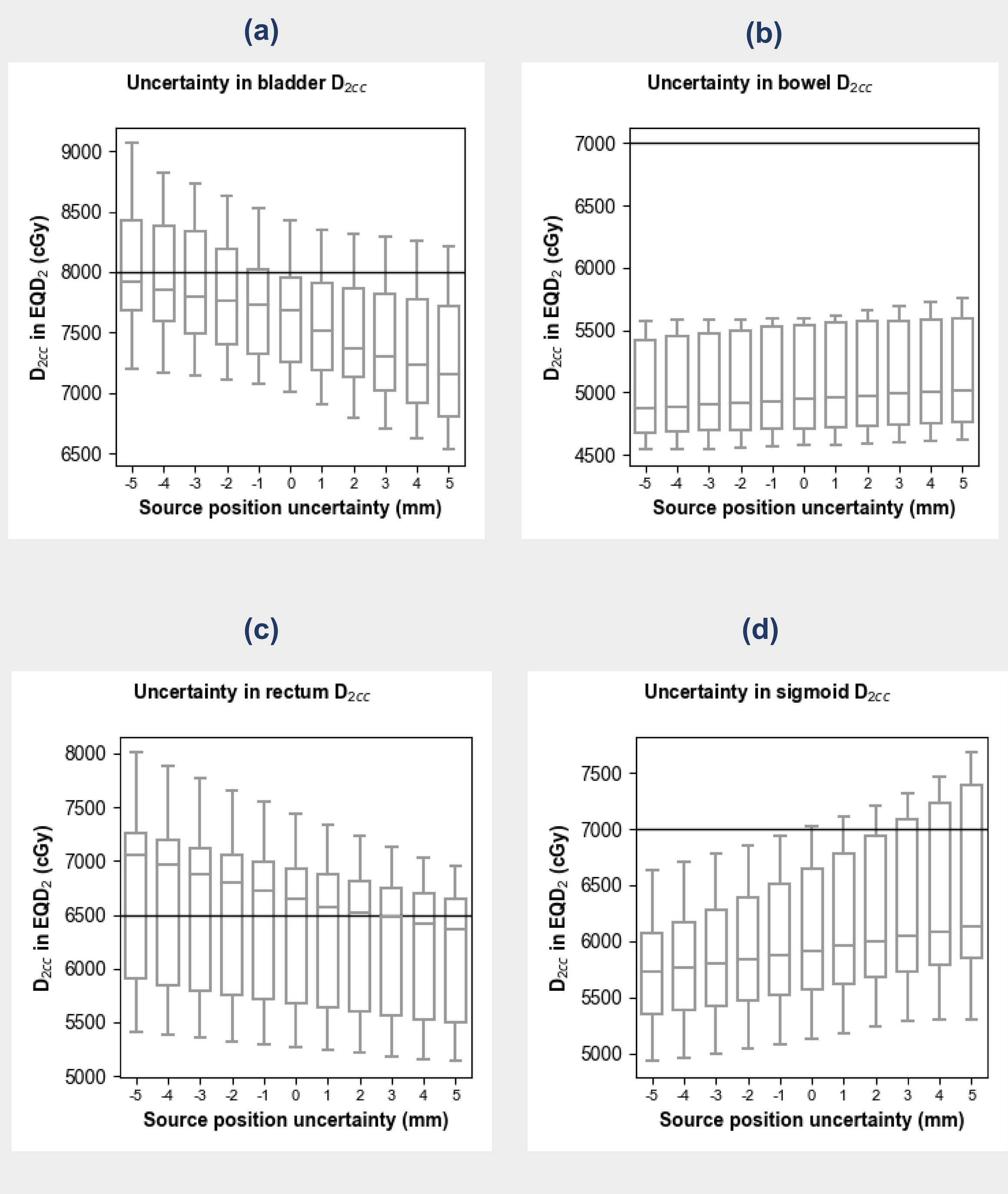

Figure 3. Uncertainty in $D_{2cc}(EQD_2)$ based on systematic source position uncertainty within tandem and interstitial needles for: (a) Bladder (b) Bowel (c) Rectum (d) Sigmoid

DISCUSSION

- An average decrease in HRCTV_D90 was 4.5±3.7% and 6.2±1.4% at -5mm and +5mm, respectively, with the largest drop of 11.9% for an individual patient at -5mm.
- The average D_{2cc} increased by 5.2±4.6% and 4.6±2.5%, with a -5mm shift for bladder and rectum.
- For bowel and sigmoid, the average D_{2cc} increased by 1.3±0.9% and 6.6±3.6% at +5 mm uncertainty, respectively.
- The largest increases in D_{2cc} for bladder and rectum were 17.2% and 7.6%, respectively, at -5 mm, whereas they were 3.0% and 13.8% for bowel and sigmoid, respectively, at +5mm.
- Highest individual variations indicate that the treatment plan where HRCTV_D90 is at planning aim 9000cGy may underdose HRCTV.
- If OARs D_{2cc} is close to the corresponding planning limit, then the OAR D_{2cc} may exceed the planning limit in the presence of uncertainty, which could result in soft tissue complications.

CONCLUSIONS

- A systematic source position shift can significantly influence dosimetry in MR-guided gynecological HDR interstitial brachytherapy.
- Patients with OAR dose close to the limiting dose are at risk of overdosing.
- Treatment plan re-optimization strategies may be necessary to minimize the impact of source position uncertainty.

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