Simulation-based analysis of dosimetric uncertainty due to catheter reconstruction error in TRUS-guided prostate HDR brachytherapy

Kurtis H. Dekker[1], Chandra P. Joshi[1,2], Andrew Kerr[1,2]
[1]Medical Physics Department, Cancer Centre of Southeastern Ontario, Kingston, Ontario, Canada
[2]Departments of Physics and Oncology, Queen's University, Kingston, Ontario, Canada

Background

Geometric error in catheter reconstruction impacts target coverage and OAR sparing in brachytherapy

Study Aim

To assess robustness of our HDR prostate procedure *via* simulation of errors and re-calculation of target and OAR dose

Methods

Fast Dose Calculation

- TG-43U1 implemented in NVIDIA CUDA-C for rapid parallel execution ($\sim 25\times$ speedup vs. CPU)
- Validated by comparison to clinical treatment planning system (Oncentra Brachy)

Patient Cases

- 31 TRUS-guided HDR prostate single fraction boost cases (prescription dose = 1500 cGy) anonymized
- Dose recalculated under simulated catheter errors (systematic and random errors)
- DVH curves / GEC-ESTRO key metrics recorded

Ultrasound-derived catheter error estimates

- Catheter profiles (axial and lateral) measured on US
- FWHM used to define a spatially-varying Gaussian error distribution to sample (Figure 1)

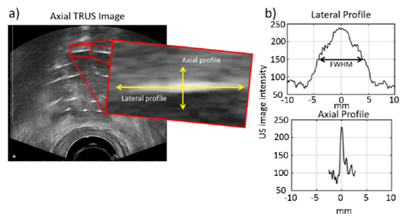
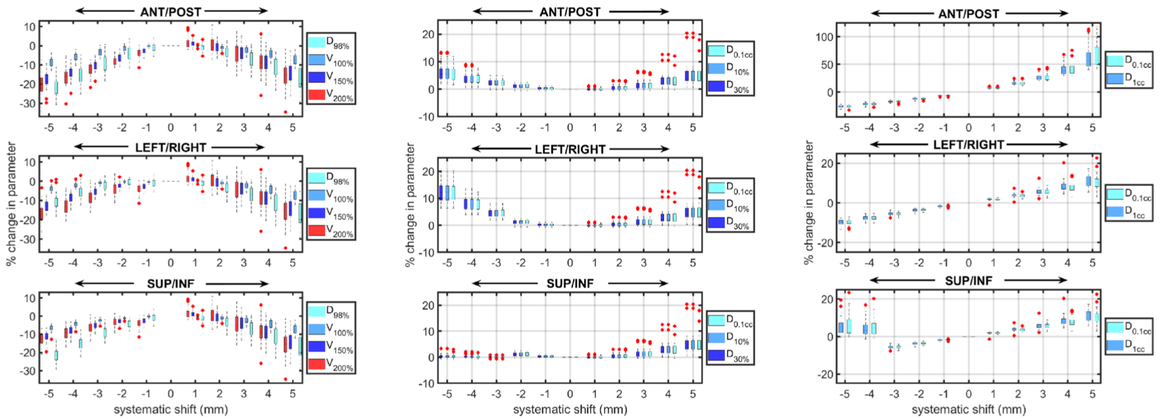


Figure 1: a) US image of prostate with implanted catheters. b) Lateral and axial profiles measured from ultrasound.

Results - Systematic Shifts

- Systematic shifts of [1-5 mm] applied to all catheters in ANT/POST, LEFT/RIGHT, and SUP/INF directions, simulating mis-calibration or misalignment of equipment
- GEC-ESTRO DVH reporting parameters calculated for each simulated shift



(a) Prostate (b) Urethra (c) Rectum

Figure 2: Change in GEC-ESTRO DVH parameters (for all cases) for (a) **prostate**, (b) **urethra**, and (c) **rectum** as a function of introduced systematic errors. Boxplots show the mean and interquartile range, while red dots show outlying cases.

- Systematic errors of ≤ 2 mm result in $\leq 2\%$ change in target $V_{100\%}$, $\leq 5\%$ change in $D_{98\%}$ and acceptable urethra dose variability
- Rectal dose criteria very sensitive to posterior shifts - validates conservative rectal dose limits in planning

Results - Random Errors

- Image-derived Gaussian error distributions in probe axial and lateral directions sampled via Monte Carlo technique
- Dose and DVH parameters recalculated for 1000 iterations per case (sample shown in Figure 3)
- Parameters are compared for the prostate, CTV (prostate + margin), urethra, and rectum

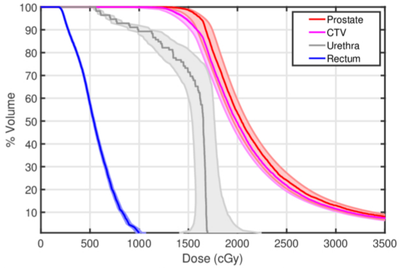


Figure 3: Confidence-interval DVH curves for a single case. The solid line denotes the clinical plan, while the shaded region indicates the 95% confidence interval from Monte Carlo simulations.

- Small mean changes to $V_{100\%}$ for targets, larger changes in $D_{98\%}$
- Very small changes in OAR DVH parameters

Structure	Parameter	Mean % Change
Prostate	$D_{98\%}$	-7.0 ± 2.4
	$V_{100\%}$	-0.6 ± 0.9
	$V_{125\%}$	-1.7 ± 6.2
CTV	$D_{98\%}$	-12.5 ± 1.6
	$V_{100\%}$	-1.1 ± 0.9
	$V_{125\%}$	-8.8 ± 4.2
Urethra	$D_{0.1cc}$	+1.6 ± 3.7
Rectum	D_{2cc}	-0.1 ± 1.1

Table 1: Mean and standard deviation of difference, in percent, of GEC-ESTRO reporting parameters relative to clinical plans.

Conclusions

- Systematic errors of less than 2 mm result in less than 2% change in target $V_{100\%}$ and less than 5% drop in $D_{98\%}$
- Conservative image-derived random errors result in small changes in prostate $V_{100\%}$ and $V_{125\%}$, but significant change in $D_{98\%}$
- OAR dose criteria relatively unaffected by random errors
- Rectal dose impacted by systematic ANT/POST shifts
- QA tolerances of 2 mm are reasonable, and implant and planning strategy is robust against random geometric errors
- Developed software will be useful in evaluation of automatic catheter segmentation methods

References

1. Rivard, M. J. *et al.* Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. *Medical Physics* **31,** 633–674 (Feb. 27, 2004).
2. Batchelar, D. *et al.* Validation study of ultrasound-based high-dose-rate prostate brachytherapy planning compared with CT-based planning. *Brachytherapy* **13,** 75–79 (Jan. 2014).
3. Poder, J. *et al.* Derivation of in vivo source tracking error thresholds for TRUS-based HDR prostate brachytherapy through simulation of source positioning errors. *Brachytherapy* **18,** 711–719 (Sept. 2019).
4. Whatman, Z., Peca, S., DeVries, D. & Joshi, C. *An Open-Source Quality Assurance Software Program for Independent Verification of Brachytherapy Treatment Plans* in *MEDICAL PHYSICS* **45** (2018), E496–E496.

Contact Information

Kurtis.Dekker@KingstonHSC.ca

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