Evaluation of Needle Displacement during Prostate HDR Brachytherapy Implant and Treatment

Ziyu Fu[1], Sarath Vijayan[2], Surendra Prajapati[2],
Osama Mohamad[3], Comron Hassanzadeh[3], Michael K Rooney[3], Yusung Kim[2], Zhiqian H. Yu[2]
[1]Department of Imaging Physics, [2]Department of Radiation Physics, [3]Department of GU Radiation Oncology,
The University of Texas MD Anderson Cancer Center, Houston, TX

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ABSTRACT

- **Purpose**: Prostate and perineum edema are known issues for prostate brachytherapy. It could significantly impact the dosimetry for prostate HDR implants with needle displacement since there is a 2-3 hour interval between implant and treatment. The purpose of this project is to determine the patterns of needle displacement and determine practical clinical workflows to minimize this effect and deliver the most accurate treatment plan.
- **Methods**: 13 patients were proactively evaluated during their HDR prostate treatment. Each patient received three CT images: CT1, CT2 and CT3. CT1 was taken right after the implant. CT2 was taken after the plan approval, prior to treatment. Evaluation of needle displacements was performed by rigidly registering the prostate fiducial markers on CT1 and CT2 and measuring the difference in location of the first dwell positions. If the displacements between CT1 and CT2 were greater than 5mm, we replanned using CT2 as new reference image. CT3 was taken immediately after the patient received treatment.
- **Results**: Five out of 13 patients required replanning after CT2 evaluation. Average time difference between CT1 and CT2 were 79±3min; CT3 and CT2 were 72±5min (non-replan), and 130±13min (replan). The average first dwell displacements between CT2 and CT1 were 4.3mm (non-replan), and 9.0mm (replan); between CT3 and CT2 were 3.8mm. A saturating hyperbola model was used to estimate peak displacement rate. Since our typical sim-to-treat time was less than 2 hours, we looked for a time where the rate of displacement is less than 2mm/hour for time interval of 2-3hours, which was predicted to be 100mins.
- **Conclusion**: Our data showed that post-implant needle displacement is an unavoidable issue. However, since the displacement rate is not linear and largest in the first 100min after implant, delaying planning scan by at least an hour may be an optimal workflow to increase delivered dose accuracy.

CONTACT

Ziyu Ben Fu
Department of Imaging Physics
The University of Texas
MD Anderson Cancer Center
zfu1@mdanderson.org

INTRODUCTION

Typical prostate HDR brachytherapy workflow (Figure 1):
- Patient arrives in the morning and is placed under **general anesthesia**
- **Physician performs needle implant** under TRUS guidance
- **Planning CT** acquired **right after implant**
- Physician delineates targets and OARs
- Physics reconstruct catheter channels and defines dwell positions
- HDR treatment plan generated and reviewed
- **Treatment delivery** using HDR afterloader

However, **substantial needle displacement** between planning CT and time of treatment can be observed (Figure 2).

In this study, we propose a modified workflow to **quantitatively investigate the displacement implant needles in HDR brachytherapy**.

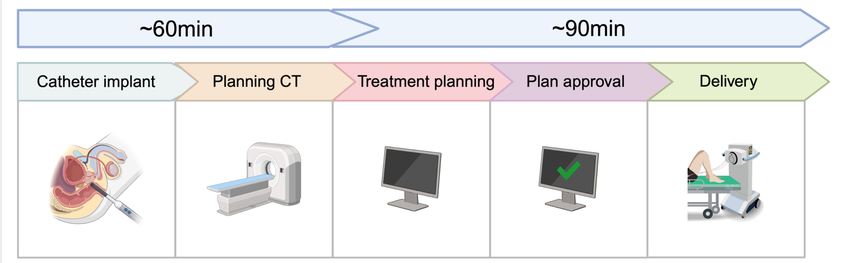
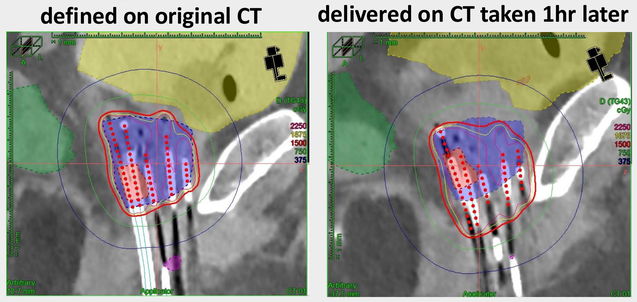


Figure 1. Typical prostate HDR brachytherapy workflow.

Original plan defined on original CT | **Same plan delivered on CT taken 1hr later**



DVH deviations

	Original plan on original CT	Original plan on new CT	Percent difference
HR-CTV V100	97%	86%	-11%
Urethra D10	1684.08 cGy	1856.65 cGy	+10.25%

Figure 2. Example of needle displacement comparing two HDR plans on two CTs taken 1 hour apart.

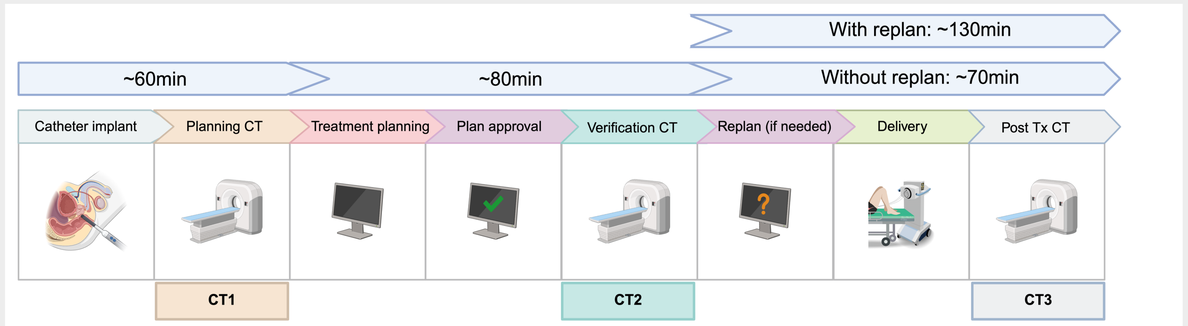


Figure 3. New prostate HDR brachytherapy workflow

RESULTS AND DISCUSSION

3D reconstruction (Figure 4):
- Displacement is visually observed **in all catheter channels**
- Needles did not retrace their original insertion paths
- Visual inspection suggest that displacement is driven by **tissue edema and inflammatory** changes, not mechanical migration

Quantitative modeling (Figure 5):
- **Mean vector displacement** of **all catheter t**ips for each patient are plotted over time (since CT1)
- A **saturated hyperbolic function** was used to model displacement over time per patient
- Greatest rate of displacement observed in the **first ~90 minutes**

Plateau time:
- Defined as when the rate of displacement falls **below 2mm per hour (0.033mm/min)**
- Therefore over the next ~2 hours the expected displacement is <4mm, safely **under the 5mm threshold**.

CONCLUSIONS

- Post-implant needle displacement is an unavoidable issue
- The displacement rate is not linear, and can be modeled using a saturated hyperbolic model
- The displacement rate is largest in the first ~90min
- Delaying planning scan by 90mins may be an optimal workflow to increase delivered dose accuracy

METHODS AND MATERIALS

A **modified workflow** was adopted to investigate the needle displacement (Figure 3):
- Keep **original planning CT** after implant (**CT1**)
- **Verification CT** added **after plan approval** (**CT2**)
- Needle displacement is evaluated, replanning required for displacement > 5mm
- **Post treatment CT** added to further displacement modeling and analysis (**CT3**)

Three CT scans are acquired in total, with **13 patients** included in this preliminary analysis:
- **Reconstruct catheters in all CTs** and define dwell positions (every 5mm from first dwell)
- CT2 and CT3 are **rigidly registered** onto CT1 based on 3-4 implanted gold **fiducials**
- Dwell positions defined on **CT2/3 are transformed onto CT1 coordinates** using the same registration matrix
- **Timestamps of all CTs** are also recorded

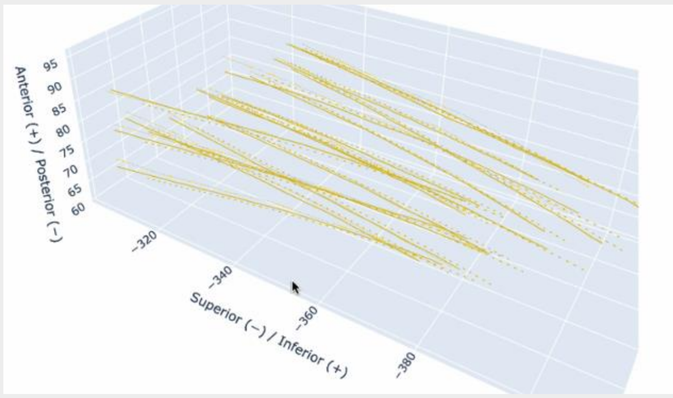


Figure 4. Reconstructed 3D view of all 16 needles in one representative patient.

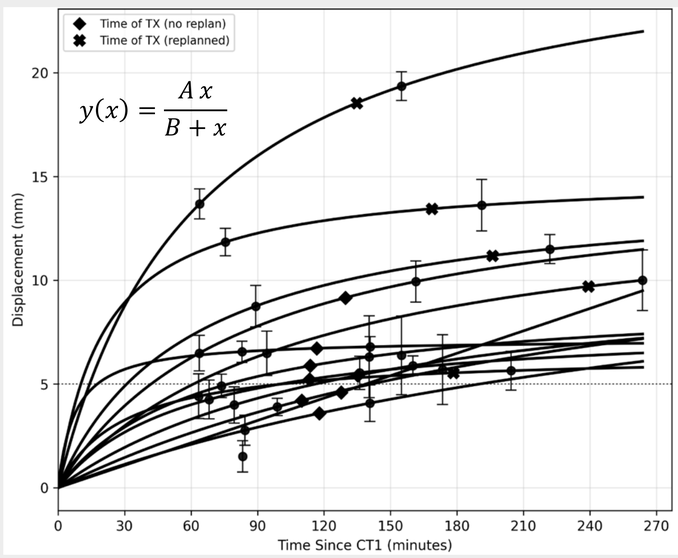


Figure 5. Displacement of catheter tips over time.