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3D-Printed Phantom to Simulate Ultrasound-Guided High-Dose-Rate (HDR) Interstitial Prostate Brachytherapy for the Training of Medical Physics Residents

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INTRODUCTION

High-dose-rate (HDR) interstitial prostate brachytherapy is a technically demanding procedure requiring proficiency in imaging, catheter localization, contouring, treatment planning, and quality assurance under time-constrained operating room conditions. Training opportunities are limited because instruction is typically tied to live clinical cases, where patient safety and workflow constraints restrict repetition of key skills. Low-cost, reproducible training phantoms designed for medical physics education are scarce, leaving learners with limited opportunities for hands-on practice.

To address this gap, we developed a low-cost, fully reproducible prostate phantom that replicates key procedural, imaging, and treatment-planning elements of HDR interstitial prostate brachytherapy. The phantom enables repeated practice of catheter reconstruction, contouring, and treatment planning outside the clinical environment, supporting proficiency-based skill development.

METHODS AND MATERIALS

A hollow cylindrical housing with a flattened side was designed in TinkerCAD and 3D printed in modular sections (final dimensions ~28 × 20 × 21 cm, ~8 L internal volume). The sections were bonded with polyurethane adhesive and sealed with waterproof and rubber coatings for durability. A custom 3D-printed prostate cradle ensured consistent positioning within the housing.

A three-dimensional prostate and urethra model (STL file) was used to create a custom three-piece mold for casting two ballistic gel (10% NATO formulation) prostate halves enclosed in a thin silicone shell. A silicone-coated Foley catheter was embedded centrally to simulate the urethra and bladder.

The assembled prostate was secured in the cradle, and the housing was filled with water and fine sea salt (~300 g) to approximate tissue-equivalent attenuation (**Figure 1.**)The Foley balloon was inflated (10 mL) to represent the bladder and reduce buoyancy-induced displacement (**Figure 2.**).

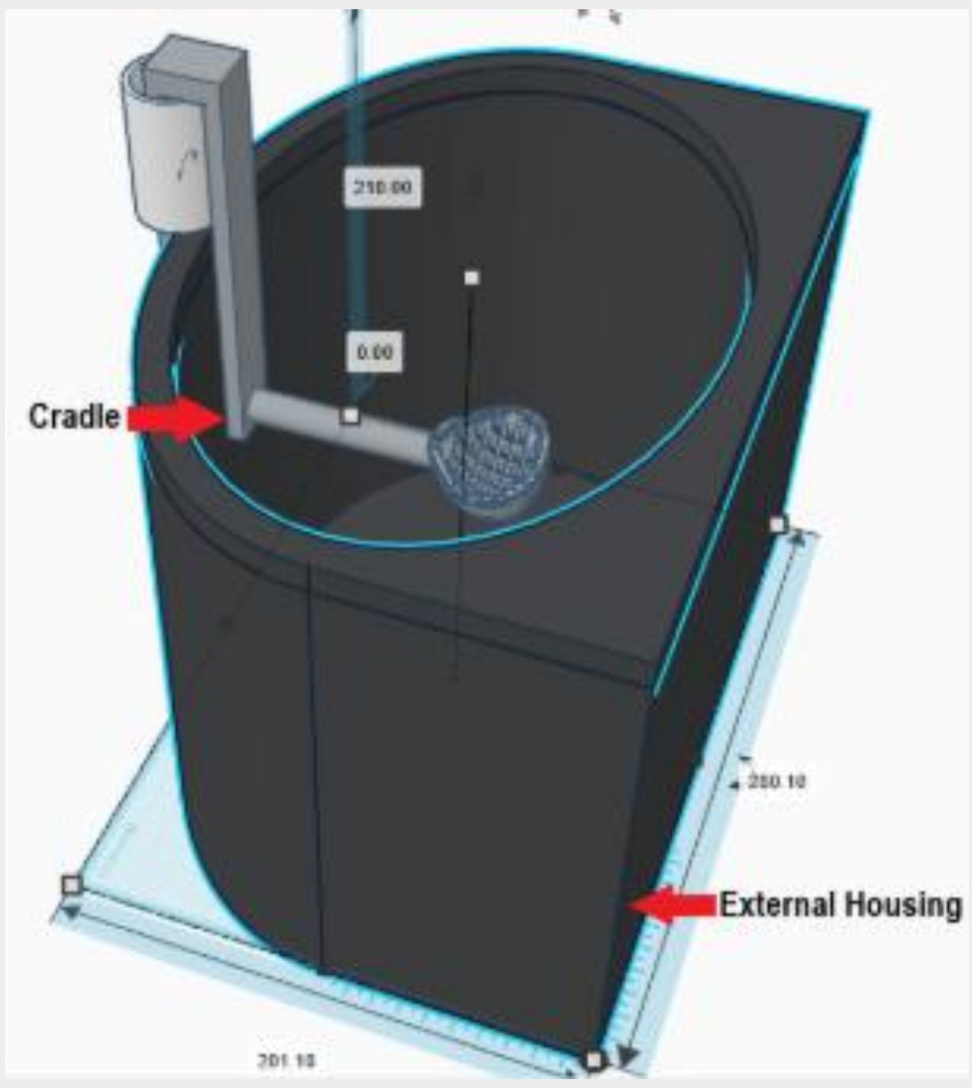

Figure 1. *Visual of external housing and prostate cradle from the TinkerCAD design workspace*

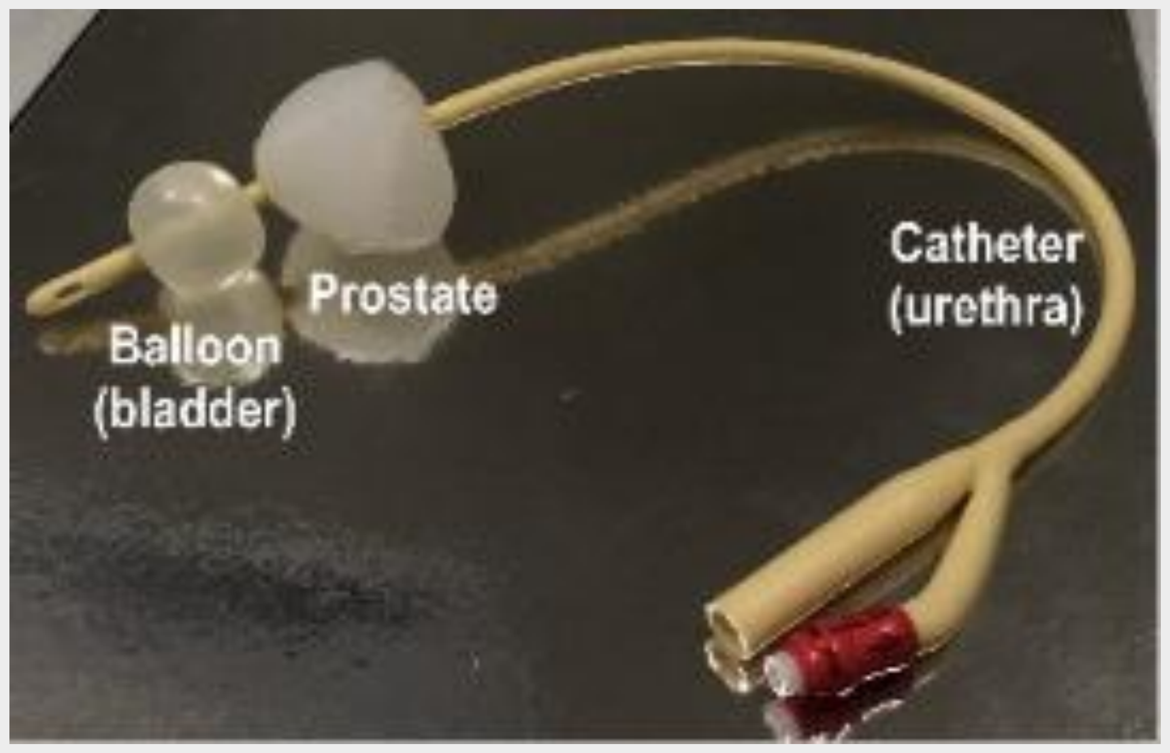

Figure 2. *Silicone encased gelatin prostate structure with the embedded catheter and expanded balloon.*

RESULTS

A BK ultrasound probe mounted on a clinical stepper was inserted into the saline-filled phantom, and the stepper-mounted template guided and confirmed catheter positions (**Figure 3**). Probe orientation was adjusted to evaluate visualization in both axial and sagittal planes.

Axial imaging demonstrated well-defined prostate boundaries, a clearly visible simulated urethra, and distinct hyperechoic needle tips at template positions b3.0, D3.0, and E4.0 (**Figure 4**). Sagittal imaging showed increased noise but maintained clear posterior prostate boundaries with consistent visualization of the catheter and balloon.

During a simulated HDR interstitial prostate brachytherapy procedure, catheter insertion and removal were reproducible, and the phantom supported realistic imaging, contouring, catheter reconstruction, and treatment planning.

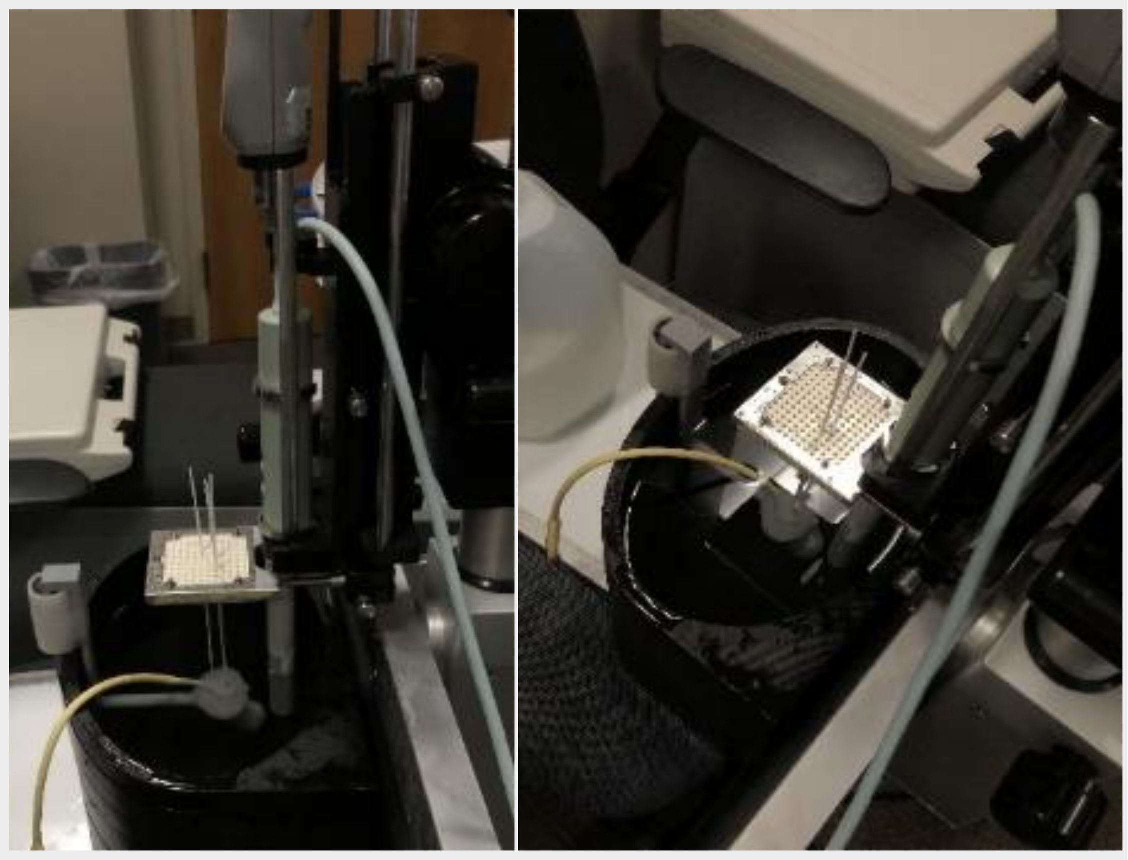

Figure 3. *Imaging setup with ultrasound probe, stepper, and template; needles placed at b3.0, D3.0, E4.0.*

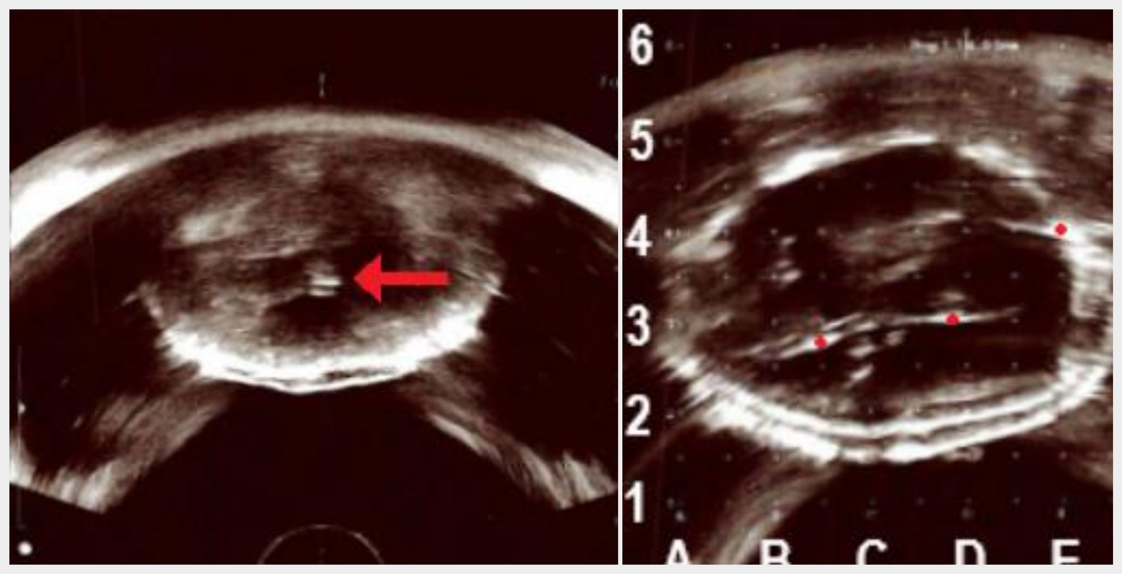

Figure 4. Axial ultrasound images of prostate phantom with defined catheter borders (Left) and needle tips (Right)

CONCLUSIONS

This phantom enables repeated hands-on practice of imaging, needle placement, contouring, and treatment planning outside of the operating room, supporting deliberate skill acquisition without relying on clinical cases. By providing a realistic platform compatible with standard imaging and treatment-planning workflows, it can enhance confidence and procedural readiness for HDR interstitial prostate brachytherapy. Because it was created with inexpensive materials and accessible fabrication methods, this low-cost model may lower financial and logistical barriers and support the initiation or expansion of training programs — including in resource-limited settings and lower-income regions where commercial phantoms are often prohibitively expensive.

REFERENCES

1. Pfeiffer, D., Sutlief, S., Feng, W., Pierce, H.M. and Kofler, J. (2008), AAPM Task Group 128: Quality assurance tests for prostate brachytherapy ultrasound systems. Med. Phys., 35: 5471-5489. https://doi.org/10.1118/1.3006337

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