Ultrasound-Compatible Gynecologic Training Phantom for Hydrogel Injection

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Introduction

This project **aims to create an ultrasound-compatible training phantom** for medical professionals to visualize the needle and to perform **accurate hydrogel spacer placement** under image guidance. **Deliverables** include: phantom & needle design (*minimum)*, Phantom with realistic texture (*expected*), and ultrasound-compatible phantom (*maximum)*. This project expanded to include an anatomically correct phantom compatible with cervical exam maneuvers.

The Problem

Cervical cancer is the third most common cancer among women worldwide. The current standard of care for locally advanced cervical cancer includes brachytherapy, the insertion of a radiation source directly into the cancerous tissue. There is a clear need to **minimize radiation dose** to surrounding normal tissues, particularly the rectum and the bladder. During brachytherapy planning, one technique that has gained recognition is to **provide rectum and bladder spacing using a hydrogel** compound. It is a challenging procedure, and inaccurate **needle placement** can lead to complications including perforation of the bowel and rectum.

The Solution

Phantom Creation: Phantoms were created by PVC plastisol **[Ref 3]**. Realistic tissue textures were created by mixing various ratios of softener and hardener. The plastic was heated to temperatures above 180 ^{0}C then cooled to room temperature in glass containers. Colored powder was added to differentiate between anatomical structures. Realistic acoustic properties were created with varying densities of 75 µm glass beads **[Fig. 1]**.

First Prototype (Realistic Texture): The vaginal canal and rectum were molded using metal pipes (at 16.6 mm OD, 5 mm thickness, and 65 mm length) at 4:1 (plastisol: softener). The uterus was molded using a wine glass with 4:1 ratio also. Surrounding tissues were created with a glass using a 2:1 (plastisol:softener) **[Fig. 2a]**.

0.6951% 0.2157% 0.04551%

Fig 1. Ultrasound image of 3 different echogenicities (by % weight).

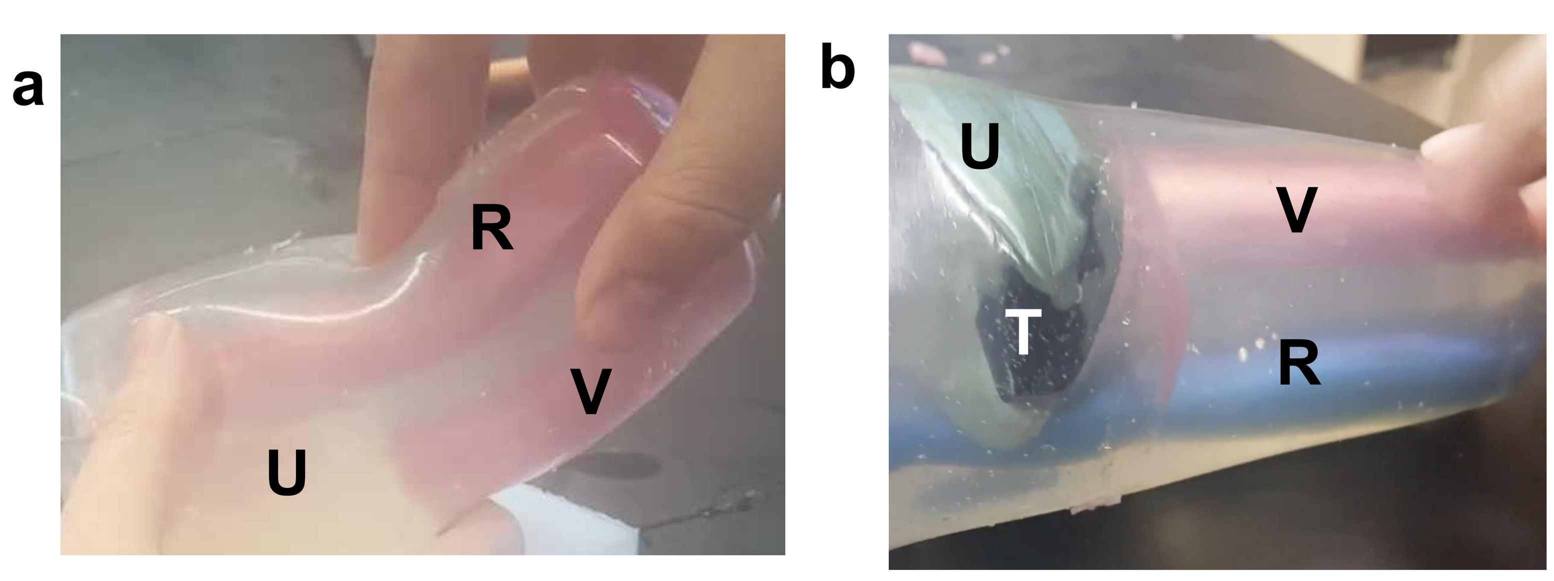

Fig 2. (a) 1st prototype has a rectum (R), vaginal canal (V), & uterus (U). (b) 2nd prototype has a tumor (T) and is ultrasound-compatible.

The Solution

Second Prototype (Ultrasound Compatibility): A spherical 'tumor' made with 2:1 (Plastisol: Hardener) was embedded in the 'uterus.' The microbead density by weight is 0.22% for tumor, 0.69% for organs (vagina, rectum & uterus), and 0.05% for residual tissue **[Fig. 2b]**.

Third Prototype (Anatomical Accuracy): PLA/ABS 3D models were created based on manual segmentation of a patient MRI using 3D Slicer **[Fig. 3a-b]**. A bladder (2:1 Plastisol: Softener) was included. Microbead densities are 0.2% for tumor, 0.05% for bladder, 0.7% for vagina, rectum, & uterus, and 0.35% for surroundings **[Fig. 3c]**.

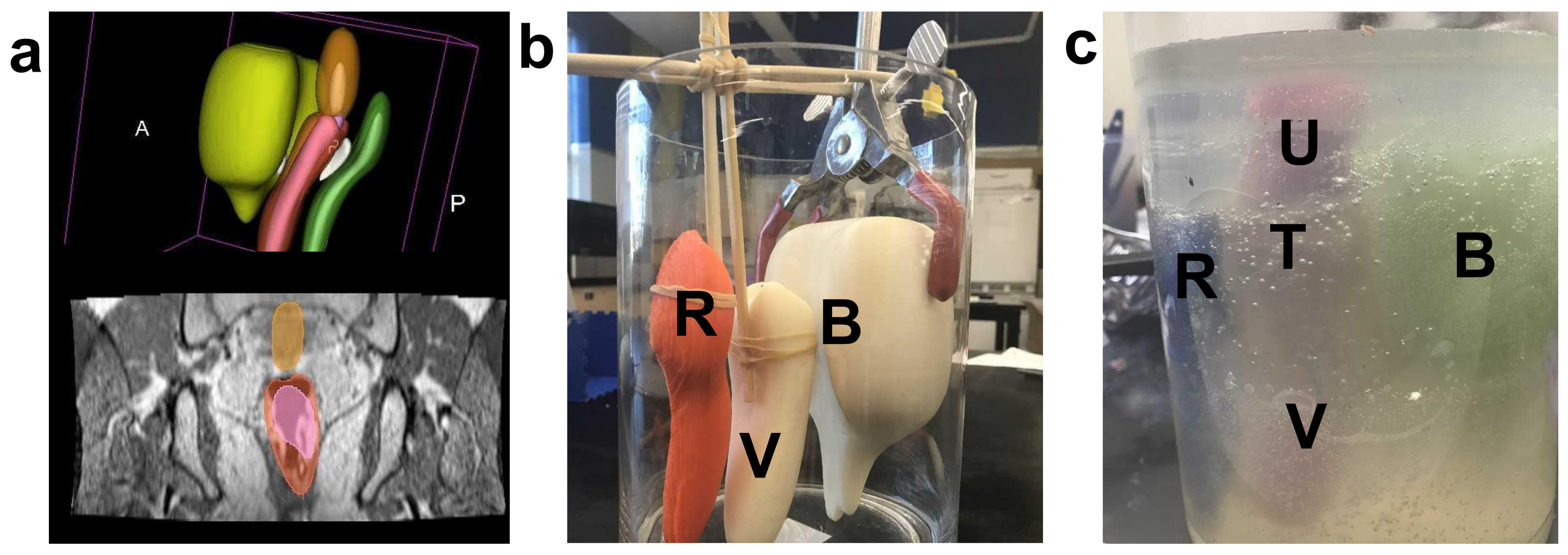

Fig 3. (a) Segmentation in 3D Slicer. (b) Bladder (B), rectum (R), vaginal cavity (V) & uterus (U) 3D prints used in 3rd prototype. (c) 3rd prototype is compatible for ultrasound and cervical exam maneuvers.

Outcomes and Results

The resulting phantoms demonstrated realistic texture, echogenicity, and anatomy **[Fig. 4]**.

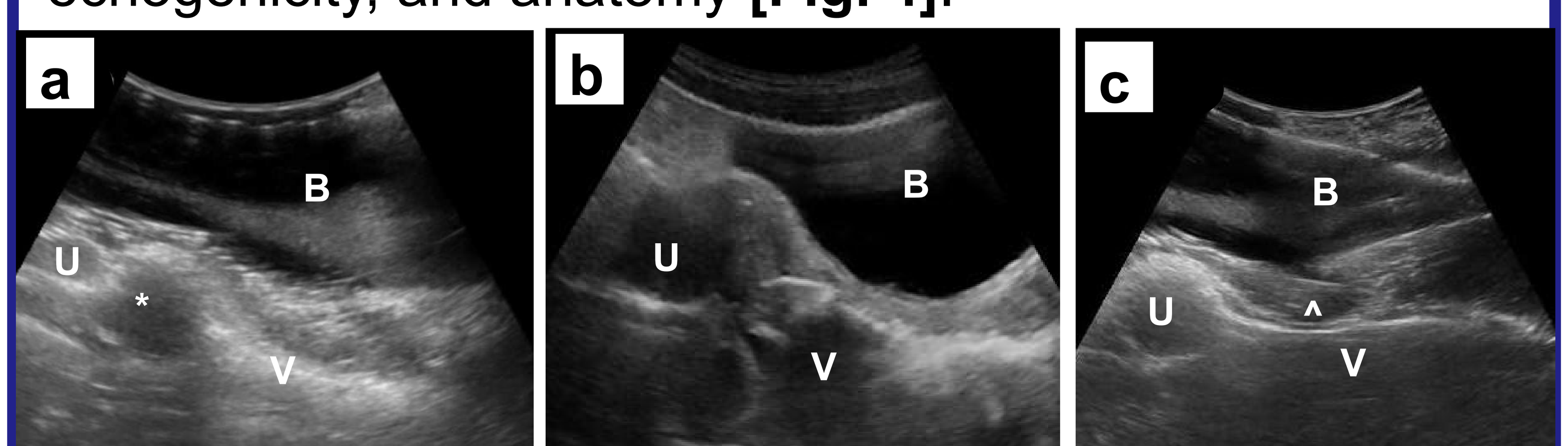

Fig 4. Pelvic anatomy on ultrasound with bladder (B), rectum (R), vaginal cavity (V) & uterus (U) shown.3rd prototype is compatible for ultrasound and cervical exam maneuvers. Images were obtained from 3rd prototype(a, c) with tumor (*) and needle (^) and from a patient scan.

Future Work

Further areas to explore include: method to eliminate bubbles, size adjustment to fit tools, extraction/absorption of injected compound, and conducting a user study for evaluation.

Lessons Learned

Development requires iterative trials to explore unexpected contributing factors and to improve manufacturing skills.

References

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