A training phantom for ultrasound-guided needle insertion and suturing

Team 18: Tracy Kao
Mentors: Carmen Kut (MD/PhD); Emad M. Boctor, PhD; Akila Viswanathan, MD, MPH, M.Sc; Younsu Kim (PhD)

Citation:
Review of Project Goals

- There is a clear need to differentiate the cervical tumor mass from surrounding normal tissues e.g. the rectovaginal septum during brachytherapy.
- Placement of a hydrogel spacer to minimize radiation dose to normal anatomical structures is a challenging procedure, and inaccurate needle placement can lead to complications such as accidental perforation of the bowel and rectum.

We want to develop an ultrasound-compatible phantom to assist training on localizing and visualizing a needle for hydrogel space injection during the preparation of a patient for brachytherapy.
Rationale for Paper Selection

1. Addresses the same issue.
2. Detailed account of construction process.

This will be very beneficial as a reference and point of comparison for this project’s design and testing results.
“The purpose of this study was to design and evaluate a gynecologic gelatin phantom to be used for gynecologic BT (brachytherapy) training.”

**Significance:** There are no existing gynecologic phantoms that can be constructed in a medical or research laboratory that is useful for training medical residents in gynecologic brachytherapy. This improves on the traditional learning model, where residents observe senior physicians within a very limited field of view in a limited number of cases with anatomical variability.

**Uses:** BT procedures such as the *transrectal US image-guided insertion of needles*, suturing the cervical lip, placing a suture on the vaginal wall to secure a BT tandem, etc.

**Specifications:**
- Transparent for external visualization
- Realistic contrast under computer tomography (CT) and ultrasound (US) imaging.
- Realistic tactile and material properties.
- Resistant to usage and storage.
- BONUS: Cheaper than the costly commercially available phantoms.
Resulting Product
Materials Used

Materials:

- 2x Acrylic sheet (20.3 cm × 12.7 cm × 0.6 cm).
- Acrylic sheet (10.8 cm × 21.0 cm × 0.6 cm).
- Acrylic sheet (10.8 cm × 12.7 cm × 0.6 cm).
- Acrylic sheet (13 cm × 15 cm × 0.3 cm).
- Cylinder (13 mm dia × 18 cm).
- Cylinder (6 mm dia × 15 cm).
- Cylinder (44 mm dia × 13 cm).
- Fast set acrylic bonding agent, SCIGRIPŽ (IPS Corporation, Gardena, CA).
- **Liquid rubber coating**, Performix Co. (Houston, TX).
- **Industrial grade porcine gelatin**, Sigma-Aldrich Corporation (St. Louis, MO).
- Clay.
- Plastic wrap.
- Water (2 L).
- 70% Ethanol solution.

Equipment:

- Drill.
- **Refrigerator** (8°C).
- Electric stove or similar heating source.
- C-clamps (size/s).
- Computer-aided design (CAD) software*.
- **3D printer***.
- Stirring spatula.
- 2 L pot.
- Thermometer.

*Optional.
General Procedure: Manufacture

STEP ONE: Vaginal Cavity and Uterus Preparation
- CAD + 3D Print mold (ZP 150 High Performance composite printing material)
- Gelatin mix: 100 mL H₂O:12 g gelatin, 50°C under stirring for over 10 minutes.
- 4.5 hour cooling and refrigeration (8°C).
- Rubber coating on Uterus.

STEP TWO: Housing Assembly
- 5 sided acrylic box.
- Two holes at front for vaginal cavity and rectal cavity.
- Sealed with acrylic bonding agent and clay.

STEP THREE: Gelatin Preparation
- Gelatin mix: 100 mL H₂O:12 g gelatin, 50°C under stirring for over 10 minutes.
- 2 L of gelatin prepared.
- Can add thimerosal for longevity (optional).

STEP FOUR: Phantom Assembly
- Structures suspended with tight seal in casing.
- Gelatin poured until uterus submerged.
- Cooled for 4 hours then refrigerated for solidifying.
- Structures removed manually and with water.
Images of Manufacturing Process

<< (left): CAD Models for Vaginal Cavity and Uterus

<< (left top): 3D Printed molds. (left bottom): Coating with Rubber

(right) >>: Set-up prior to gelatin insertion.
General Procedure: Evaluation Strategy

STEP FIVE: Determine Speed of Sound in Gelatin
- Pulse echo measurements in water (500 PR Pulser).
- Sample cured gelatin of 5, 15, and 20 mm thickness.
- Placed between 2 ultrasound transducers 67 mm apart, 4.5 MHz center frequency.
- Analog input displayed on 54600 A oscilloscope.

STEP SIX: Durability Test
- Rectal wall: Transrectal US probe inserted and removed 50 times.
- Cervix: puncture wall 20 times with suture needles.
- Qualitative assessment: fissures/change in texture of gelatin.
- Longevity: Up to 2 mm of gelatin liquefaction.

STEP SEVEN: CT + US Image Contrast
- Siemens SOMATOM Sensation spiral CT (120 kVp)
- BK Medical 2102 Hawk EXL transrectal US Probe
- Qualitative assessment of contrast.

STEP EIGHT: Physician Testimony
- Used by attending BT physician to demonstrate gynecologic suturing and BT needle insertion to medical residents.
- Qualitative feedback.
Images of Test Results/Evaluation

<< (left): CT images of the phantom. Axial and sagittal cross sections.

(right) >>: Attending brachytherapy physician testing phantom using transrectal ultrasound probe.

^^ (top): Suturing needles were used repeatedly to test durability.
Results:

"Medical students confirmed that the procedures with the phantom were realistic, the phantom helped increase their skills in GYN BT, and that they felt more comfortable in the operating room after using the phantom."

Measured speed of sound in gelatin:

1495 ~ 1506 m/s

<table>
<thead>
<tr>
<th>Medium</th>
<th>Velocity (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>1450</td>
</tr>
<tr>
<td>Water</td>
<td>1480</td>
</tr>
<tr>
<td>Soft tissue</td>
<td>1540</td>
</tr>
<tr>
<td>Kidney</td>
<td>1560</td>
</tr>
<tr>
<td>Blood</td>
<td>1570</td>
</tr>
<tr>
<td>Muscle</td>
<td>1580</td>
</tr>
<tr>
<td>Bone</td>
<td>4080</td>
</tr>
</tbody>
</table>
Discussion:

DURABILITY:
- Phantom lasted 2 weeks in refrigeration (8°C). 2mg thimerosal:1 mL liquid gelatin extends lifetime to 6 weeks, but is a Level 3 Health Hazard (~CO, LH₂, Ca(ClO)₂, etc.)
- Probings on rectal wall show no degradations. Probing with suturing needle show slight softening of texture of phantom cervix. Needle tracks visible on subsequent ultrasound scans.

MANUFACTURE:
- Total Time: 3 hours of active participation and 2 days including curing time.
- Material cost was under $200. Significant component was 3D printing.
- Phantom can be built without CAD/3D Printer through external sources. Alternatively, use sturdy pottery clay/traditional molding. *STL files available upon email request.

PHYSICIAN FEEDBACK:
- Suturing was similar to a real case; texture resembles human tissue. However, gelatin was more fragile than human tissue and didn’t represent regular uterine motion during bimanual examination.

FUTURE ENDEAVORS:
- Adjustable parameters: Modifications of length/shape, concentration of gelatin, choice of material.
- Possible improvements: Quantitatively determine material properties (e.g. acoustic and x-ray attenuation, propagation, backscatter) to adjust to achieve optimal contrast for multiple modalities.
## Assessment

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Paper detailed for repeatability.</td>
<td>● No quantitative analysis of imaging.</td>
<td>● Model phantom for project (standard).</td>
</tr>
<tr>
<td>● Recommended sources for 3D print and alternatives (clay).</td>
<td>● No detailed analysis of user study -- could compare outcomes.</td>
<td>● Could look at multi-modality phantom model.</td>
</tr>
<tr>
<td>● Authors willing to provide STL files upon request.</td>
<td>● Not durable (lifetime 2 weeks with refrigeration).</td>
<td>● Evaluation protocol.</td>
</tr>
<tr>
<td>● Material used are compatible with medical/research lab environment.</td>
<td>● Long curing time.</td>
<td>● Adapt for hydrogel injection.</td>
</tr>
<tr>
<td>● Relatively low cost</td>
<td>● Needle tracks visible on ultrasound.</td>
<td>● Consider a more durable material to resist reuse.</td>
</tr>
<tr>
<td>● Simple geometry.</td>
<td>● No gradation in contrast for CT and ultrasound.</td>
<td>● Can 3D print structures for molding.</td>
</tr>
<tr>
<td></td>
<td>● Geometry is not anatomically correct.</td>
<td>● Simple geometry is sufficient.</td>
</tr>
</tbody>
</table>
References:
