Document: **Critical Review of Seminar Paper**
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Project: **Ultrasound-Compatible Female Pelvic Phantom for Hydrogel Spacer Injection during Brachytherapy Training**
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Citation:

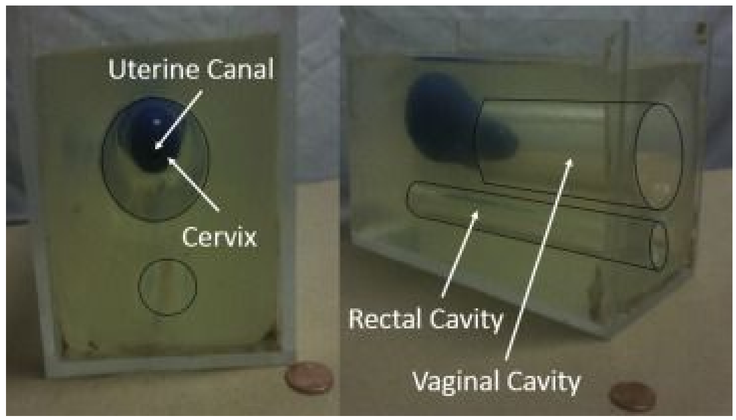
Nattagh, Khashayar, et al. "A training phantom for ultrasound-guided needle insertion and suturing." *Brachytherapy* 13.4 (2014): 413-419.

Phantoms are simplified, physical models of anatomy that are often used for medical research, training, and quality assurance. The material, geometry, and other properties of the phantom are used in order to best capture a realistic aspect of the anatomy, in order to simulate interaction in a real clinical situation. Phantoms serve critical roles in the training of medical staff in performing highly skilled procedures, and can also benefit technicians adapt to operating new technology. Phantoms present clear advantages over the traditional training model, where medical residents learn procedures by observing senior physicians through a limited few of view and with minimal amount of case experience.

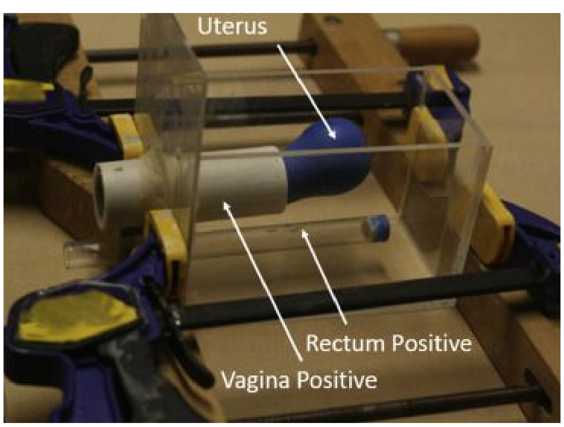
In the case of gynecology, the female pelvis presents specific difficulties to training and research. The anatomy, which is deep to the surface and difficult to access, can be a tripping point for medical professionals in training as they learn to recognize landmarks and manipulate tools in this enclosed space. Thus, for a number of gynecologic applications, phantoms present a convenient and possibly cost-efficient opportunity for training. A particular need has been noted for the case of gynecologic brachytherapy, a type of high dose internal radiation used to treat cervical or endometrial cancer, typically done by inserting a “tandem and ovoid” applicator or a “tandem and ring” applicator to address the site of the tumor. During a brachytherapy procedure, a number of tools need to be placed in the small vaginal cavity accurately in order to deliver the optimal dosage of radiation and minimize complications. Additionally, needle insertion for hydrogel spacing (radiation attenuation to protect vulnerable tissue) is also a common task performed in preparation for the brachytherapy procedure that presents technical difficulties due to limited imaging potential and the delicate structure of the septum layers between cavities.

The paper under review is the product of a joint collaboration between the Department of Radiation Oncology from University of California, San Francisco, and the Department of Physics from University of California, Berkeley. In recognizing the existing need for better gynecologic training, the paper describes an effort to design and evaluate a female pelvic gelatin phantom to be used for gynecologic brachytherapy training procedures such as suturing the cervical lip, placing a suture on the vaginal wall to secure a tandem, and image-guided insertion of needles into the cervix. The design had specific goals: to mimic tactile and material properties of the tissue, to look realistic under computer tomography (CT) and ultrasound (US) imaging, and to be resistant to usage and storage. The group proposed a gynecologic phantom that is unique in its specific training purposes at significantly lower cost to durable, long-lasting, and expensive commercial alternatives.

The resulting phantom design comprises of the following relevant structures: uterus, cervix, caginal cavity, uterine canal, and rectum. The vaginal and rectal cavities open to the "front", simulated by cylindrical shafts that run to the opposite end of an acrylic enclosure. The inner facing end of the vaginal cavity connects directly to the uterus, which is coated by rubber to simulate the skin texture. All tissue is made using industrial grade porcine gelatin. The resulting structure can be seen in the Figure to the right. In the paper, Nattagh et al. also describes in considerable detail the process of their manufacturing to promote repeatability. The procedure for the construction comprises four major parts: 1. Vaginal cavity and uterus preparation, 2. Housing Assembly, 3. Gelatin Preparation, and 4. Phantom Assembly.



The uterus (pear shaped, 8.2 cm long and 4.8 cm wide at its maximum) and vaginal cavity (4.4 cm in diameter and 13 cm in length) were created with CAD technique to simulate dimensions typical to the anatomy. STI files for the positive vaginal cavity cylinder and negative uterus mold were exported for 3D printing then cooled to 8°C. These structures were used to create molds for the gelatin positive structures. The material used was industrial grade porcine gelatin mixed in a ratio of 100mL of room temperature water to every 12 g of gelatin powder cooked above 50°C under stirring for over 10 minutes. This is a manufacturing condition that their selected choice of ZP 150 high performance composite printing material can withstand. The gelatin was poured into the mold held together by C-clamps, with a rod passing through to act as the canal and hold the structure. The cooling took 30 minutes at room temperature then refrigeration for 4 hours. The gelatin uterus was coated in liquid rubber for an hour to provide US and CT contrast and prevents melting of the gelatin.



To make the housing, five acrylic sheets were held together using acrylic bonding agent. On the front side, 4.4 cm and 1.3 diameter holes were drilled to allow placement of the vaginal cylinder positive and 1.3 cm rod. The former represented the vaginal cavity, while the latter the rectal cavity, placed 3.2 cm apart. These structures were tightly fit together then suspended manually and sealed with clay until the gelatin provided buoyant support. The figure to the left describes the set-up.

The remaining space was filled from 2 liters of gelatin mixture, enough to submerge the uterus, then left for 4 hours to cool before refrigeration. To remove the molds, they were gyrated repeatedly and water was used to diminish adhesion.

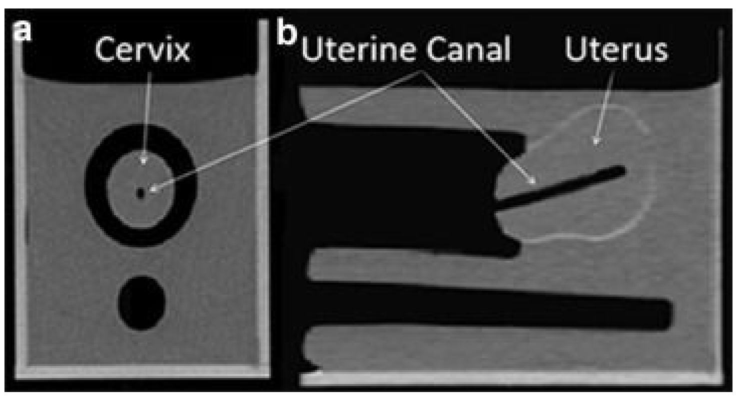
The proposed manufacturing process and choice of materials has a number of benefits. First, the materials used are generally low cost, with the main component being the 3D printing (under $200) though the prints were reusable. The authors recommend online sources for 3D printing, or using sturdy pottery clay and traditional molding techniques as alternatives. The gelatin preparation also does not present a number of difficulties and is compatible with the 3D printed material. The temperatures at which the manufacturing occurs are not so extreme as to damage any material. The geometries are also simple to deal with. However, gelatin is a vulnerable material that degenerates easily and has limited durability. The ease of manufacture might be a balancing factor to the gelatin degradation, but the need to repeatedly manufacture the phantom is a weakness of this choice of material. The authors defined phantom mortality as 2 mm of gelatin liquefaction on any phantom surface. The cylinders needed to be sprayed with 70% ethanol, wrapped, and stored in a 8°C for prolonged use. The authors note that the phantom lasted 2 weeks under refrigerated conditions. To increase longevity, the authors recommended thimerosal, though they also recognized its potential for a health hazard. With thimerosal, the longevity was extended to six weeks. The total length of the manufacturing process took 3 hours of active participation and 2 days of curing time, a significant time sink due to the cooling time.

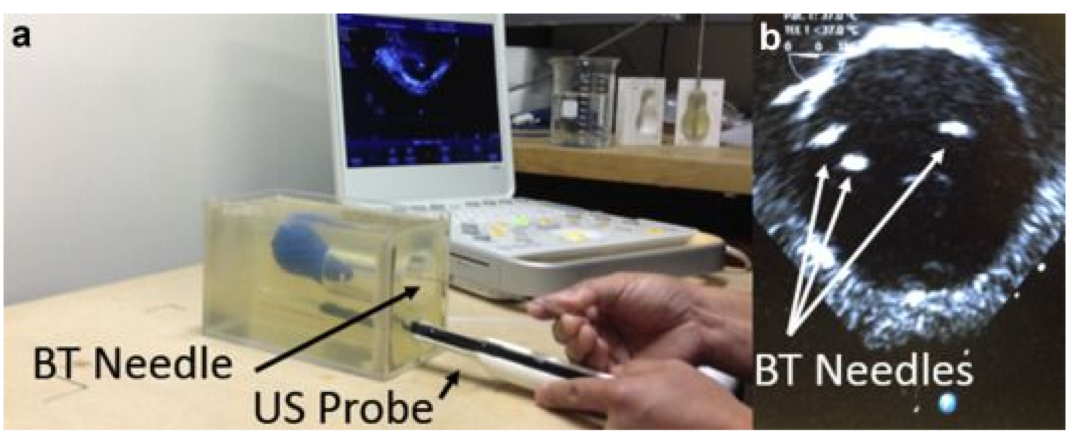
Durability was tested by inserting structures. For the rectal wall, ta transrectal US probe was placed inside 50 times without damage in fissures or change in texture. The durability of the cervix was evaluated through 20 upunctures using suturing needles. Speed of sound in gelatin samples of thickness 5, 15, and 20 mm was measured using pulse echo measurements from a 500 PR pulser between two planar US transducers, one transmitting and one receiving, at a fixed distance 67mm away with center frequency of 4.5 MHz. The speed was determined to be 1495 to 1506 m/s, demonstrating the acoustic property of the material. In comparison, the table below demonstrates the speed of sound of various tissue.

Medium	Velocity (m/sec)
Fat	1450
Water	1480
Soft tissue	1540
Kidney	1560
Blood	1570
Muscle	1580
Bone	4080

To test the validity of the phantom under computer tomography and ultrasound conditions, contrast between the uterus and uterine canal and the uterus and gelatin matrix was generated using a SOMATOM Sensation spiral CT. The phantom was also used to guide a brachytherapy needle into the uterus using a transrectal-US probe. The resulting figures from these imaging modalities are shown below. While the images were showing, a quantitative analysis of the images would provide a better assessment of how representative these structures are of actual anatomical tissue.

Testing revealed some weakness in the design. As a result of repeated insertion of tools, gelatin that was not coated with rubber was shown to tear, and the stiffness of the material was described as not being representative of uterine motion during bimanual examinations in real cases by a practicing physician. The needle tracks left by the gelatin material were also visible on subsequent ultrasound scans. The author suggests future work into adjusting manufacturing parameters to optimize the acoustic and x-ray attenuation coefficients for multi-modality treatment planning. In general, however, the authors comment that the medical residents confirmed that the procedures with the phantom were realistic, that the phantoms helped them develop skills, and theat following training on the phantom they were more comfortable carrying out the procedures on a real patient.





Overall, this study demonstrates that it is possible to make cheaper alternatives to the costly, ephemeral market models. Using materials that can be acquired with relative ease to the layperson today, this phantom is one model worth considering for training programs. Medical students and residents might find that they want to construct this themselves, as the limited longevity of the material chosen in this design can lead to difficulties coordinating publicly usable phantoms. Despite apparent weaknesses in the design, some of these parameters can be investigated through a search into the optimal material for this design. The use of alternative materials may lead to better durability, more realistic texture, more representative image modalities, and better simulation of the actual procedure.

This paper provides detailed construction instructions and lessons learned that I can reference in my own construction of a gynecologic phantom. The testing plan implemented by Nattagh's team is also something I can consider in the development of my phantom. It is comforting to know that there is precedence in successfully creating low cost phantoms that are beneficial to assisting with transrectal US-guided needle injection of the cervical area. Though my application is specifically to ultrasound, there are clear areas that I can improve on compared to this design.

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