



Radiographic Radiomics Phantom Development

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Biomedical Engineering 200/300

Section 302

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Function

Radiomics, the extraction and analysis of high-dimensional quantitative texture features from medical images, has shown promise in oncology for prognosis, treatment response assessment, and outcome prediction. However, radiomic features are highly sensitive to image acquisition specifications and hardware-specific characteristics. In simpler terms, models developed on one imaging platform cannot be reliably applied to another without proper validation and benchmarking. This benchmarking requires a phantom containing a variety of heterogeneous, tissue-like textures; however, commercially available phantoms lack a sufficient range of materials and are not designed for this purpose. -

Dr. Jennie Crosby requires a phantom that incorporates multiple clinically relevant texture patterns, is compatible with imaging protocols for both small anatomy (e.g., head) and large anatomy (e.g., abdomen) parts, and is constructed from materials that can maintain mechanical stability over a multi-year period to support longitudinal radiomic feature evaluation across radiographic imaging systems.

Client Requirements

- I. Dr. Jennie Crosby outlined several key specifications for the development of the Radiographic Radionomics Phantom.
 1. Incorporate a variety of different textures to represent the variability and nonhomogeneous characteristics of real human tissue.
 2. Size similar to that of a human abdomen, and the inner core should resemble the size of a human head.
 3. Withstand research usage for multiple years and ideally provide consistent results

through repeated usage.

4. The approximate size of the outer, abdomen shell should have a diameter of 38cm and a height of 20cm, and the head should have a diameter of approximately 16cm and have a height of 25cm.

Design Requirements

1. Physical and Operational Characteristics:

a. Performance Requirements:

- i. Each phantom part should replicate the body part's mechanical properties with tissue texture. The non-homogeneous nature of the phantom material should be visible and representable in the imaging done by clinical CT imaging systems.
- ii. The phantom should have a long lifespan, meaning that the material shall not have noticeable degradation over the intended period of usage time (around five years; see section d. Life in Service). The material for emulating the texture of a phantom body part should reliably maintain its texture for at least “a couple of years.”

b. Safety:

- i. The phantom must contain materials that are safe to use under normal clinical conditions and must not contain any radioactive materials that could cause harm to the user or be left as residue on the machine [1].

- ii. The user should be able to easily and manually transport the phantom through a typical indoor, sterile laboratory environment.
- iii. All sharp edges and exposed hazardous materials should be either removed or concealed before handing over to the client. All components must be identified clearly without instruction and easily assembled, with a removable core that remains stable and prevents movement during scanning.

c. Accuracy and Reliability:

- i. Fabrication and Manufacturing reliability
 - 1. The phantom must maintain consistent dimensions and placement of materials between scans, maintain consistent dimensions and placement of materials between scans, and produce repeatable CT texture characteristics.
 - 2. Manufacturing inconsistencies should be minimized, and controlled material compositions should be used to improve reproducibility.
- ii. Testing reliability and accuracy
 - 1. The phantom should be tested repeatedly in CT scans to determine consistency and accuracy. The assembly of the outer shell should also contain no gaps or voids in the assembly of material, as this can cause errors in images and false data.

d. Life in Service:

- i. At least 5 years. The phantom must maintain its geometry, material

composition, and imaging performance during repeated use over an extended period of time. Existing CT phantoms are intended for long-term clinical and research use. Competing designs have acquired consistent and accurate scans after a 7-month period [2].

e. Shelf Life:

- i. The phantom must maintain its physical and imaging properties during storage in recommended conditions. In reference to the above section d., the phantom should last for a duration of approximately 5 years in service. To achieve this, materials that do not significantly degrade, wear out, or change during normal storage should be used to create all parts of the phantom.

f. Operating Environment:

- i. The phantom must be suitable for an indoor laboratory environment and hospital imaging. Repeated handling of the phantom must be taken into account, as well as the ability to easily place and remove the phantom from the imaging equipment during practices.
- ii. Dr. Crosby will be the intended user of this phantom and will be storing it in her lab. Possible transportation of the phantom to other labs is anticipated.

g. Ergonomics:

- i. The phantom should be designed for safe and easy handling, staining, and removal of the core by the user when possible. The removable pieces of the phantom should have an easily accessible grasping and positioning

feature that prevents any harm to the device itself.

- ii. The shape of the phantom also must be considered with reason of ergonomics, since an abnormal shape or cut of any section may require repositioning to acquire a proper image. An elliptical cylinder will be the main form of the phantom, as it should decrease any physical labor associated with moving and positioning the phantom on the CT machine.

h. Size:

- i. Multiple different scales of human anatomy should be represented. The phantom should be able to approximately represent a human head as the core and a human torso as the width/outer diameter dimensions.

Dimensions shall be selected based on the anthropometric and medical image references [3].
- ii. The clients requested the following dimensions for the phantom: The head should have a diameter of 16 cm by 25cm height, and the abdomen should have a diameter of 38cm by 20cm height.

i. Weight:

- i. There are no specified weight requirements for the device, other than that it must be movable by the client. This limit should not be met as long as we use standard materials and follow the current sizing guidelines. The density of the material should be roughly that of water (1 g/mL) [1].

j. Materials:

- i. Materials must be cost-effective, corresponding to the size of the design and our budget. However, the material must maintain all shaping and

mechanical properties even after handling for its entire life of service.

- ii. The main material options for the base of the phantom are acrylic and PLA 3D-printed polymer. The 3D printing approach is a cost-effective and time-efficient solution; however, it is not as standard and reputable as acrylic [2]. The final design will likely be composed of acrylic.
- iii. The tissue-replicating material should have an electron density similar to water to help mimic tissue under CT scanning.

k. Aesthetics, Appearance, and Finish:

- i. The finish of the phantom should be clean and smooth. There must be no gaps or voids in the assembly of any modules to prevent errors in scanning.
- ii. The removable core of the phantom should be uniform in size and free of harsh edges.
- iii. The entire system should be as simple and organized as possible for ease of use, without sacrificing functionality. The entire phantom should look cohesive and should carry a professional aesthetic.

2. Product Characteristics:

a. Quantity:

- i. Only one phantom will be fabricated and provided to the client upon completion. The one phantom will have multiple uses and can be used to mimic a range of different human anatomy depending on the client's imaging goals.

b. Target Product Cost:

- i. With consideration of the various components required for the phantom already available at the university, and an evaluation of prices for additional material, a target cost for the project is approximately \$400 [4]. The main cost factor of this design is the acrylic base of the phantom.
- ii. There are other materials with similar properties and behaviors that are sold at a less steep price, and our ultimate selection of material may significantly change the estimated cost. This figure is a summation that includes the \$50 stipend given for the project by the department as well as further monetary support that will be provided by the client if and when required.
- iii. Possible project specifications can be pivoted to lower cost to fit budget if necessary

3. Miscellaneous:

- a. **Standards and Specifications:** The texture phantom design will need to be modular across various CT systems. To ensure that the quality of medical and R&D decisions based on these CT images are sound, the phantom design will need to comply with the following standards:
 - i. ASTM E1935-26, which details the procedures and requirements for calibrating and measuring material densities from CT images. [5]
 - ii. IEC TS 62558:2011, which details phantom specifications for artificial cyst testing and tissue mimicry [6].
- b. **Customer:**

- i. The users of this device will be Dr. Jennie Crosby in the Department of Medical Physics at the University of Wisconsin-Madison. This device is for research and testing purposes with imaging/radiographic technology.

c. Patient-Related Concerns:

- i. Degradation reduces the quality of medical decisions. Therefore, it is important that we ensure the phantom is able to last for a long time with no degradation while also being able to mimic various body parts. Any changes in the phantom should be easily identifiable for clients.
- ii. Modules should be safe for handling. No toxic materials. The weight of each module should be easy to handle.

d. Competition:

- i. This radiomic phantom should last longer and provide more consistent results in CT imaging than biological phantoms [7].
- ii. CT phantoms on the market tend to hold a five-year warranty. Such phantoms are typically constructed from acrylic or lower-density common plastics such as low-density polyethylene [8].

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