MRI Phantom Report

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Introduction

In the biomedical research community, medical imaging phantoms are objects used as stand-ins for human tissues to ensure that systems and methods for imaging the human body are operating correctly.[1] There are types of phantoms that can serve different purposes for testing magnetic resonance imaging (MRI). Resolution phantom can test the spatial performance of the MRI and help people know the range of size of objects that can be tested. On the other hand, anatomical phantoms are created to stimulate human body parts. In this way, people can check if the imaging process is correct and use them when conducting medical research. As phantoms play a significant role in MRI testing, our group aims to create an anatomical phantom to help evaluate the imaging process. Specifically, we designed a phantom that mimics human wrists, and it contains imitated tissues, skins, and two bones.

Methodology

This methodology outlines the process of designing and fabricating a wrist phantom for MRI testing, using mineral oil for soft tissue and durable resin to simulate bone and skin. The phantom will be printed as a single unit, integrating both skin and bone.

1. Design & Planning

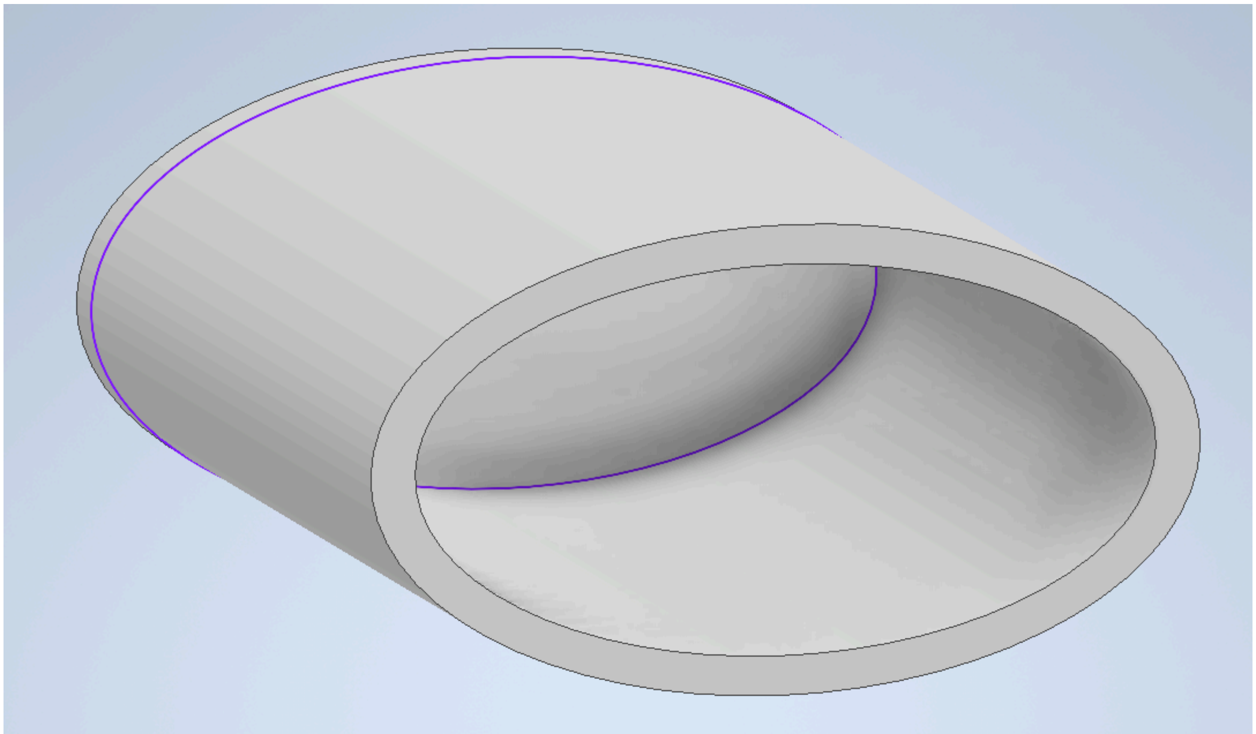
   1.1. Anatomical Reference

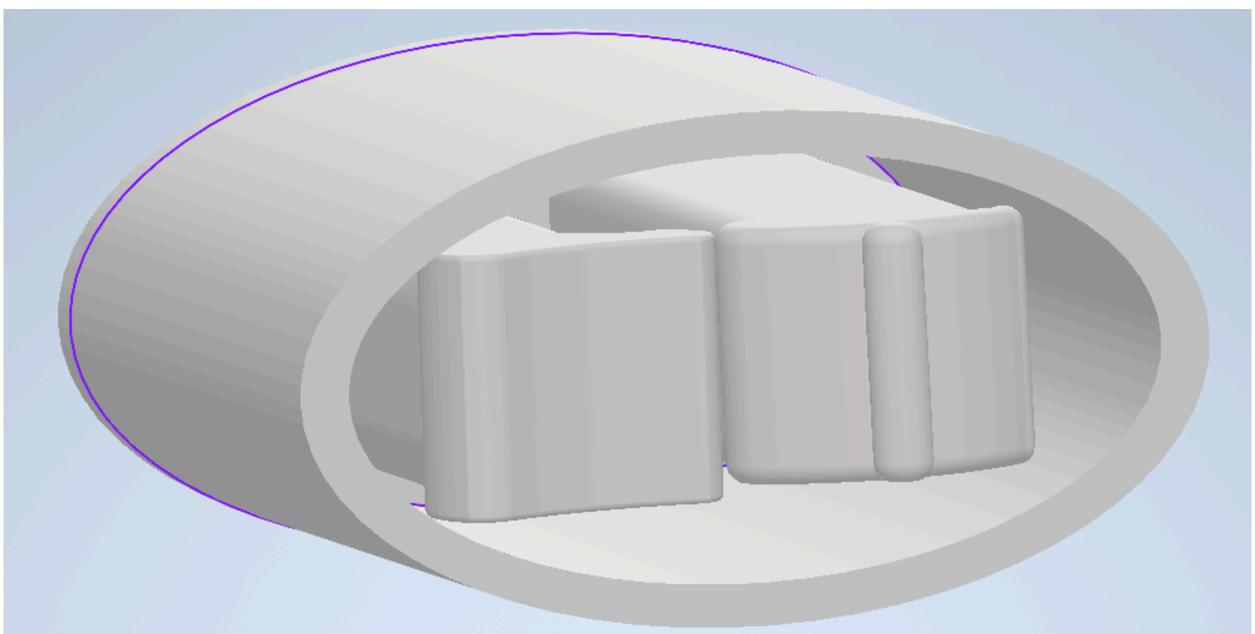
- Goal: Develop a realistic model of the human wrist for MRI testing.
- **Procedure:**
  - Acquire medical images (CT or MRI) of a human wrist.
  - Model the anatomical structures of interest: skin, bones, and soft tissues, using software like 3D Slicer, Mimics, or Materialize.

   1.2. Model Preparation

- Software: Use 3D modeling software (Autodesk Inventor Pro) to generate a combined model of the skin, bones, and cavities for the soft tissue.
- Details:
  - Create independent models of the skin and bones.
  - Design internal hollow spaces to represent soft tissue regions where mineral oil will be injected.
  - Integrate the bones within the skin model, ensuring accurate anatomical dimensions.
  - The skin layer should have a thickness of around 0.138 inches.

[1] "What Are Imaging Phantoms? | NIST." NIST, 24 Jan. 2024





2. Material Selection

    2.1. Bone and Skin Simulation

- Resin Type: Use a single durable photopolymer resin for both skin and bones.
- Properties: Select a resin with high mechanical strength to replicate bones and sufficient flexibility for the skin layer.

- Printer Compatibility: Ensure the resin works with stereolithography (SLA) or Digital Light Processing (DLP) 3D printers.
    - Soft Tissue Simulation: Use mineral oil to simulate soft tissue.
    - MRI Compatibility: Mineral oil is ideal for soft tissue regions due to its high hydrogen content, which provides contrast in MRI, and is easy to use as an anatomical filling.

Anatomical Phantom (Human wrist/forearm)		
Usage	Material	Size
Tissue	Mineral oil	length 3 inch Circumference 16-18 cm
Bone	Durable Resin	Ulna: We are taking 3 inches for the Ulna . Radius: We are also taking 3 inches for the Radius.
Skin/coating	Durable Resin	One layer coating the tissue.

3. 3D Printing

Single-Print Model:

- Print the entire wrist phantom as a single unit, combining the bones and skin structure in one go.
- Ensure the bones are embedded within the skin layer, and internal cavities are designed for soft tissue.
- Use supports for complex overhangs if needed and ensure hollow cavities are properly formed for later mineral oil injection.

3.1. Internal Cavities:

Ensure that internal hollow spaces for soft tissue are maintained during the print and are free of any supports or blockages.

4. Soft Tissue Injection

4.1. Preparation

- Clean and dry the internal hollow cavities to ensure optimal filling with mineral oil.
- Remove all support structures made during the printing process.

- Paint oil-proof materials on the phantom. Place extra materials in places with printing flaws.

4.2. Mineral Oil Filling

- Procedure:
  - Using a pipet, fill the hollow spaces with mineral oil to simulate soft tissue.
  - Seal phantom with a plastic lid and hot glue to prevent leakage.
  - Slowly turn the phantom over to observe any potential leakages and seal them if found.

5. Post-Processing

5.1. Curing

- UV Curing: Cure the resin phantom under UV light
- Surface Finishing
  - Smoothing: Polish the skin surface if necessary to achieve a texture that closely resembles human skin and ensure smoothness for accurate MRI imaging.

6. Testing and Validation

6.1. MRI Compatibility Testing

Goal: Validate the phantom's performance in MRI.

- Procedure:
  - Conduct MRI scans to evaluate image quality, focusing on:
  - The contrast provided by mineral oil for soft tissue regions.
  - The clarity and distinguishability of the resin bones.
  - Ensure no air pockets or defects affect imaging.

6.2. Phantom Adjustments

- If needed, adjust the design or fabrication process to address any issues with MRI imaging quality.

7. Documentation and Future Use

- Keep detailed records of the design files, materials, and fabrication process for future replication or refinement.

Discussion

While the human wrist phantom our group designed achieves its goal of testing the MRI system, some problems are being noticed. Firstly, the 3D-printed skin is too rigid, so it cannot entirely mimic the properties of human skin. Also, after the wrist is printed, some supporting parts are hard to remove. As a result, some supporting structures might remain inside the wrist phantom, which could affect the imaging results. Lastly, when members used hot glue guns to stick materials, they melted outer-surface gels. It makes the phantom oily. If the surface is not cleaned completely, the oil will affect the result as well.

To mitigate these problems, some potential solutions could be worked on in the future. To make the mimicked skin less rigid, we can use more flexible materials like TPU to print the skin. Also, instead of designing the skin and bones together, we can craft them separately. In this way, we can not only use different materials respectively but also make it easier to remove the supporting parts of 3D printing. Lastly, to solve the problem of melting some gels on the surface, we can look for tools other than hot glue guns to help us stick parts together.

Results

The 3D-printed wrist phantom was successfully fabricated using durable photopolymer resin to simulate both bone and skin, with mineral oil representing the soft tissue. The skin, tissues, and bones are indicated differently under MRI imaging. The design is not difficult to produce or replicate. The single-print approach tended to ensure that the anatomically correct congruence of the embedded bones with the surrounding skin was maintained. The hollow cavities, designed to hold the mineral oil, remained during printing and were easily injectable with the soft tissue simulant without entrapment of air. After curing and surface treatment, it resulted in a very smooth skin-like exterior.

MRI scans confirmed that the phantom performed well under imaging conditions. The mineral oil provided clear contrast, mimicking the soft tissue regions effectively, while the resin bones were clearly distinguishable from the surrounding structures. No significant defects, such as air bubbles or print deformities, were observed, and the phantom remained structurally intact throughout the imaging process. The results indicate that the phantom is suitable for repeated MRI use and offers a realistic, durable model for future testing and experimentation.

References

- “What Are Imaging Phantoms? | NIST.” NIST, 24 Jan. 2024, www.nist.gov/physics/what-are-imaging-phantoms.