



3D Printed Respiratory Motion Phantom

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Overview

- Problem Statement
- Background
- Competing Solutions
- Design Specification
- Preliminary Designs
- Design Matrix
- Testing and Results
- Future Work
- References and Acknowledgments



Figure 1: Design team picture

Problem Statement

Problem Statement:

- Problem statement: Design and Fabricate a 3D-printed respiratory motion phantom that simulates two tumors with realistic density and structure.

Goals:

- Accurately validate real-time tumor tracking during radiotherapy.
- Cheap, cost effective method

Background

- 1.8 million annual lung cancer-related deaths worldwide [1]
- Difficulty tracking tumors due to breathing
 - Radiation to surrounding healthy tissue
- Evolving technologies to **track tumor movement and adjust radiation** in real time
 - Four-dimensional cone beam computed tomography to show tumor regression [2]
 - Validation is important
- QUASAR system to validate tumor-tracking and radiotherapy technologies

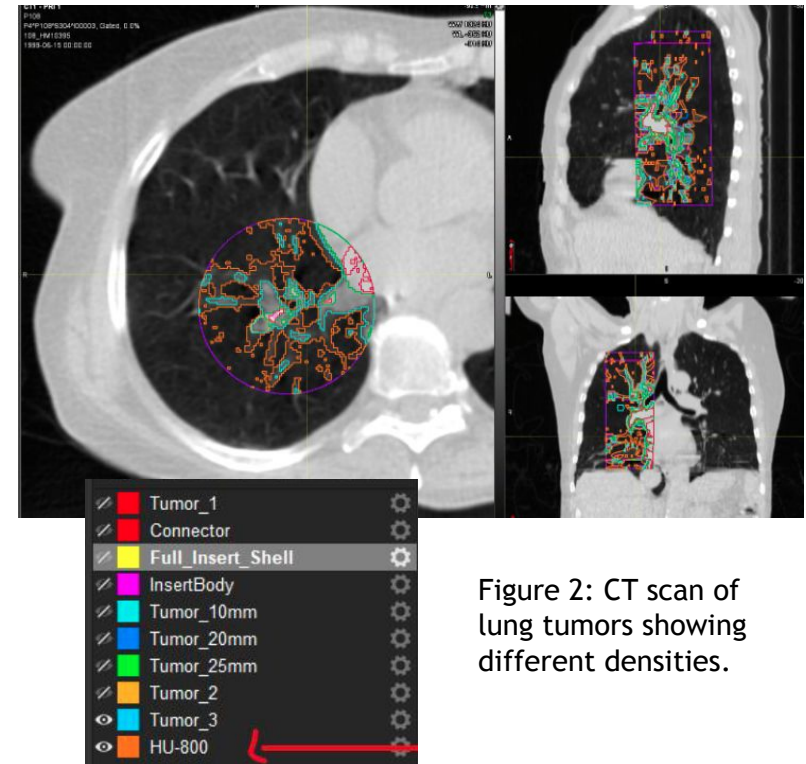


Figure 2: CT scan of lung tumors showing different densities.



Background

QUASAR respiratory motion phantom

- Applies breathing motion to the phantom during tracking and radiation
- Various phantom inserts for different purposes
 - Ion chamber
 - Radiochromic film



Figure 3: QUASAR respiratory motion phantom [3].



Figure 4: Wood Phantom Inserts



Figure 5: Phantom in motion [4]

Competing Solutions

- **Dynamic 3D-Printed Thorax Phantom (Didier Lustermans) [5]**
 - Dynamic 3D-printed thorax phantom with realistic lungs, bronchi, and ribs.
 - Contained 3 lung tumors at different locations.
 - Developed for 4DCT and motion-management QA
- **Sun Nuclear Dynamic Thorax Phantom [6]**
 - More anatomically realistic thorax, including lung- and bone-equivalent materials.
 - Designed to mimic patient anatomy and imaging conditions more closely.
 - Better suited for studying how anatomy affects image quality and tracking performance.

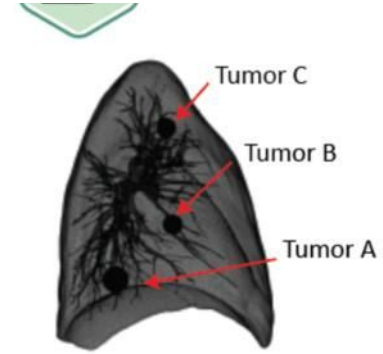


Figure 6: Design Graphic [5]

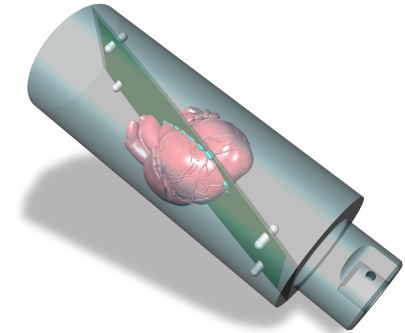


Figure 7: Sun Nuclear Phantom [6]



Design Specifications

- **Anatomically Accurate Tumors**
Realistic tumor size, shape, and location.
- **Realistic Respiratory Motion**
Simulates patient breathing and tumor movement.
- **Tumor Tracking Validation**
Quantifies tracking accuracy during treatment.
 - a. Material density
- **Multiple Tumor Support**
Accommodates ≥ 2 anatomically accurate lesions.

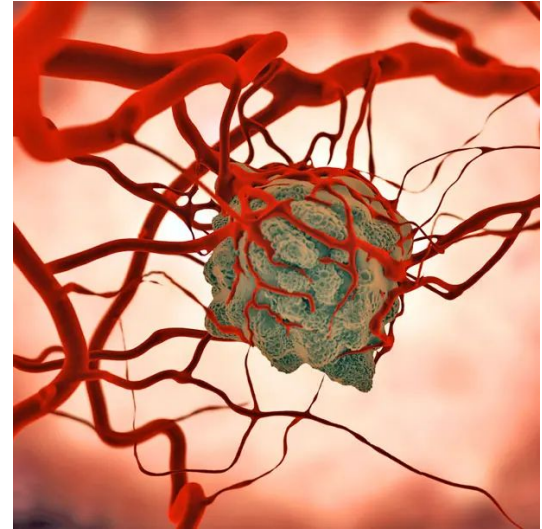


Figure 8: Realistic Lung Tumor [7]

Nesting Doll Inserts

- Different sized casings for tumors
- Holes in cylinder to hold casing
- Infill material to close air gaps
- Magnet to attach to machine
- End cap to close cylinder

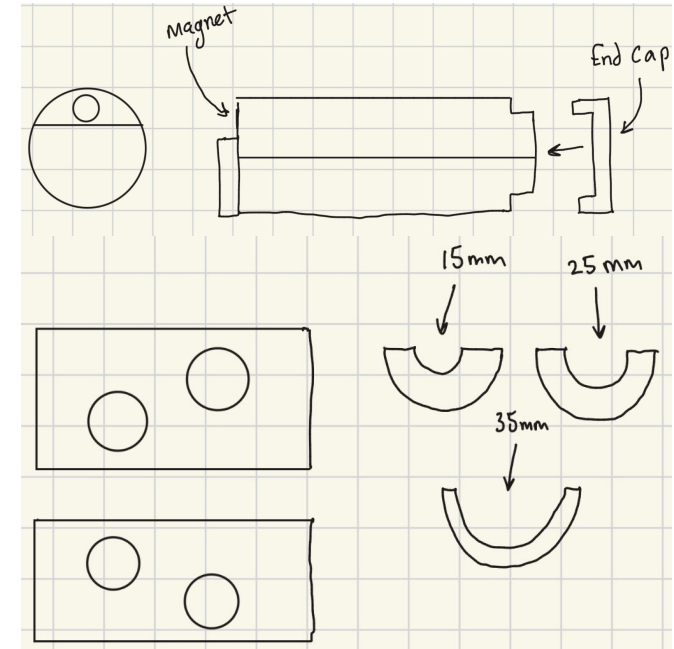


Figure 9: Nesting doll design sketch

Foam Infill

- 3D printed plastic shell halves
- Dense foam infill layer to hold tumor
- Slits in foam for varying location
- Multiple sizes of tumor supported

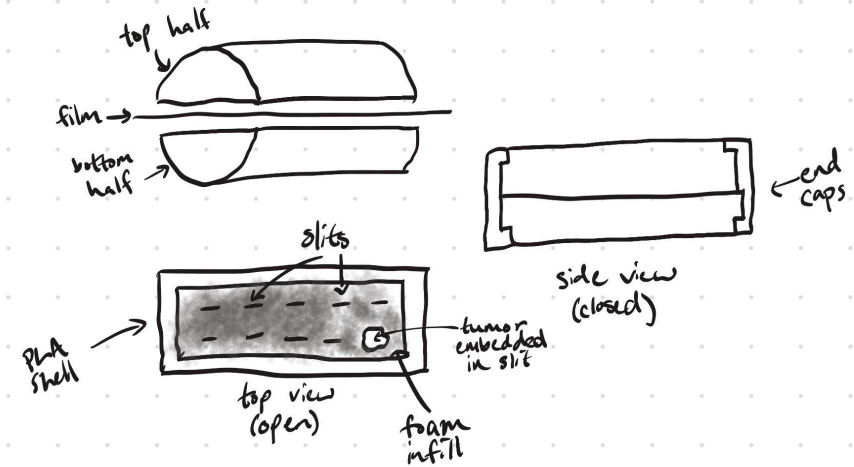


Figure 10: Foam infill design sketch

Automated Standardized Insert System

- Prepare tumor Model - 3D Slicer
- Create standardized insert - CAD
- Prepare model for manufacturing
- Manufacture and assemble - 3D printing
- Place inserts into standardized holes in Phantom

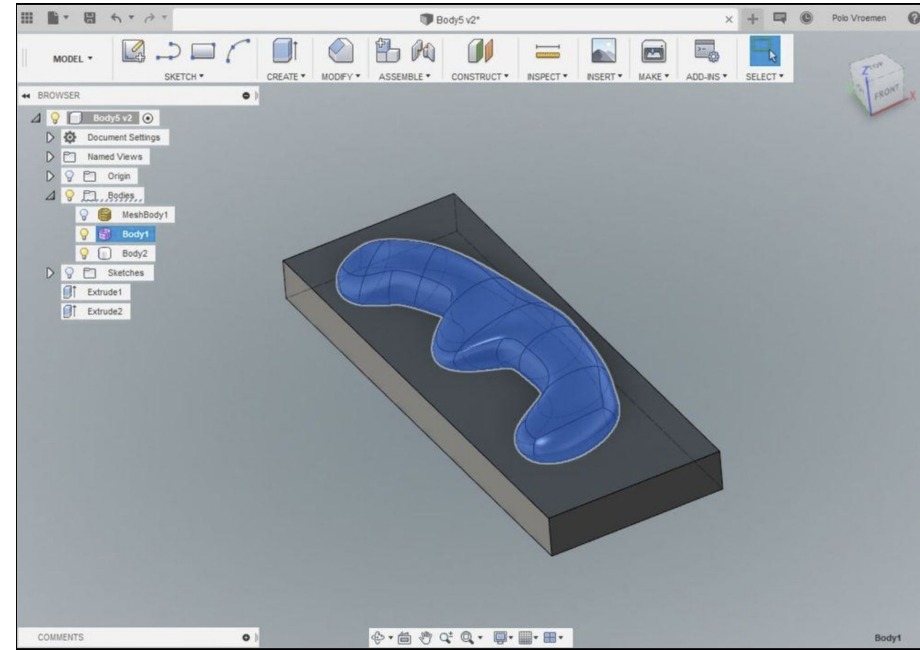
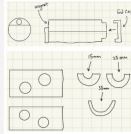
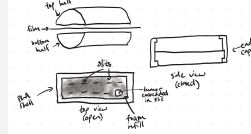
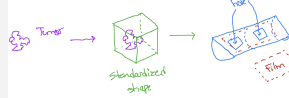


Figure 11: Standardized Shape with tumor like insert [8]

Design Matrix

- Criteria selection
- Design 1
 - Overall fit
- Design 2
 - Multiple 5/5's
- Design 3
 - Highs and low

Table 1: Design matrix for Motion Phantom

		Design 1: Nesting Doll		Design 2: Foam Infill		Design 3: Automated Standardized Insert System	
							
Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Modularity	25	4/5	20	5/5	25	5/5	25
Differentiability	25	5/5	25	3/5	15	4/5	20
Stability	15	4/5	12	5/5	15	5/5	15
Durability	10	4/5	8	3/5	6	3/5	6
User Friendliness	10	4/5	8	5/5	10	3/5	6
Ease of Fabrication	10	4/5	8	4/5	8	1/5	2
Cost	5	4/5	4	4/5	4	3/5	3
Total (Out of 100):		89		83		77	

Testing and Results

- Material Density & Infill Testing
 - PLA-CF at 18% infill
 - PLA at 85% infill
- Failure Modes
 - Motion testing checks for seam separation
 - Motion testing verifies tumor remains in place
- QUASAR System
 - Fits within QUASAR parameters
 - Structural integrity

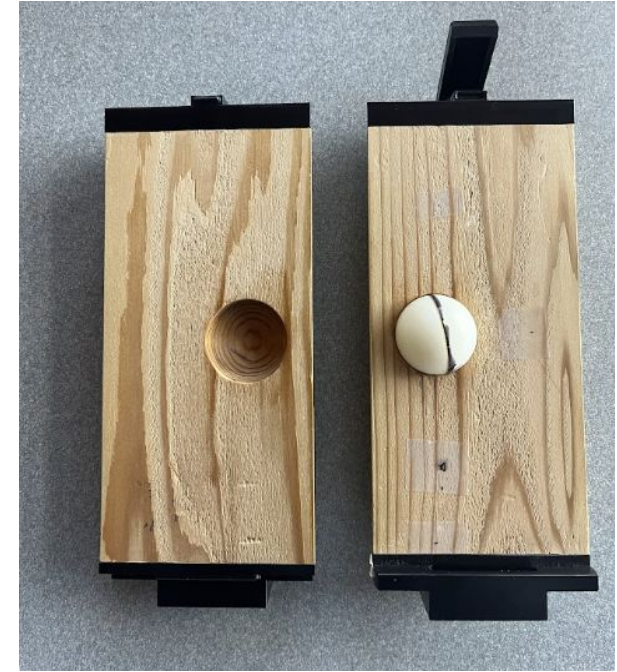


Figure 12: Wood Phantom with spherical tumor Insert

Future Work

- Material CT Scan Validation
 - Print test samples
 - Verify Hounsfield Unit output against real tissue benchmarks
- Tumor Integration
 - Acquire tumor STL file
 - Verify tumor geometry
- Prototype Fabrication
 - Print phantom and modular inserts
 - Print end cap
 - Attach magnet

Acknowledgments

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References

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