2-21-2024

Utilizing 3D Printed Lung Phantoms for Patient-Specific History Storage, Follow-Up, and Lesion Visualization in CT Scanning

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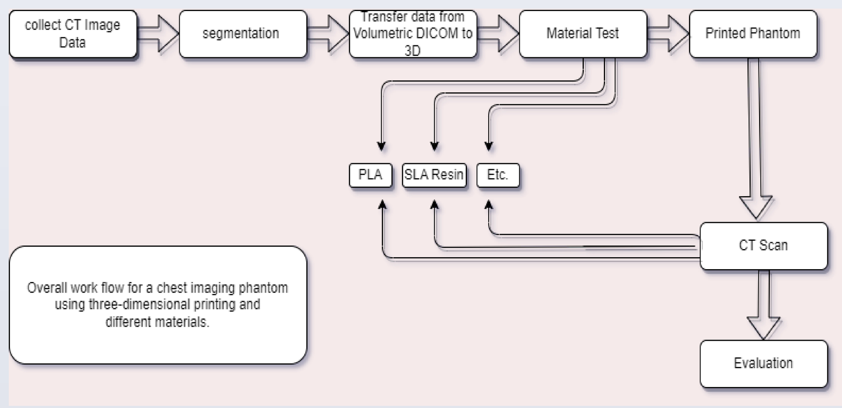
Introduction

- This research proposes an innovative solution using 3D printing technology to create lung tissue phantoms for improved COVID-19 visualization and diagnosis.
- A dataset of 100 CT scans, including 60 COVID-19 positive cases, was utilized for lung tissue segmentation via 3D Slicer software.
- Segmentation isolated regions within a specific Hounsfield Unit range to accurately represent lung tissue characteristics.
- Lung tissue phantoms were fabricated using Stereolithography (SLA) and Fused Deposition Modeling (FDM) printing techniques.
- These phantoms faithfully replicate ground-glass opacities (GGO), a key feature of COVID-19 pneumonia, aiding in detailed lung visualization.
- The potential of these phantoms extends to telemedicine applications, enabling remote consultations and preserving patient-specific information for efficient diagnosis and treatment planning.



Graphical abstract showing overall work of flow for a chest imaging phantom using 3D printing and different materials

Objectives

- Validate the presence of Ground Glass Opacity (GGO) in CT lung scans of COVID-19 patients using 3D printing technology.
- Employ Fused Deposition Modeling (FDM) and Stereolithography (SLA) printing techniques to create 3D-printed lung phantoms, enabling precise anatomical replication.
- Contribute to the validation of patient diagnoses and disease prognosis through the identification of GGO using 3D printed phantoms.
- Showcase the efficacy of additive manufacturing techniques, particularly 3D printing with FDM and SLA technologies, in confirming GGO diagnoses.
- Highlight the importance of careful selection of modeling software and appropriate threshold parameters for enhancing diagnostic precision in GGO-related pulmonary conditions.

Methodology

Data Collection:

- Conducted High-Resolution Computed Tomography (HRCT) lung scans on ten patients diagnosed with COVID-19 and five with normal lung conditions.
- Utilized Multi-detector Computed Tomography (MDCT) following a routine helical CT protocol for image acquisition.
- Employed the TOSHIBA Aquilian Lightning version CT scanner for suspected cases of COVID-19.
- Obtained CT lung images by downloading them from Picture Archiving and Communication Systems (PACS).

Data Post Processing:

- Utilized ITK-SNAP, 3D SLICER, and Radiant software for manual segmentation of chest CT images available in DICOM format.
- Accounted for the wide range of Hounsfield Units (-1000 to -500 HU) within lung tissue due to varying densities of air, water, fat, and nodules as shown in Table 1.
- Isolated specific regions within defined Hounsfield Unit ranges to accurately represent lung tissue characteristics (Figure 2).
- Generated three-dimensional digital models of the patient's lung region through manual segmentation, subsequently exported as Stereolithography (STL) files.

Table 1 Relationship between different lung anatomy area and the measured house field unit (HU)

Substance	HU
Air	−1000
Lung	−500
Fat	−100 to −50
Water	0
CSF	15
Kidney	30
Blood	+30 to +45
Muscle	+10 to +40
Grey matter	+37 to +45
White matter	+20 to +30
Liver	+40 to +60
Soft Tissue, Contrast	+100 to +300
Bone	+700 (cancellous bone) to +3000 (dense bone)

Slicing and 3D printing:

- Creating flat lung tissue phantoms using Stereolithography (SLA) and Fused Deposition Modeling (FDM) techniques to identify optimal CT scanning parameters
- Fabricated lung tissue phantoms utilizing Stereolithography (SLA) and Fused Deposition Modeling (FDM) techniques.
- Ensured precise replication of ground-glass opacities (GGO) observed in COVID-19 pneumonia within the fabricated phantoms.
- Explored the feasibility of utilizing the fabricated phantoms for telemedicine applications, particularly for remote consultations.

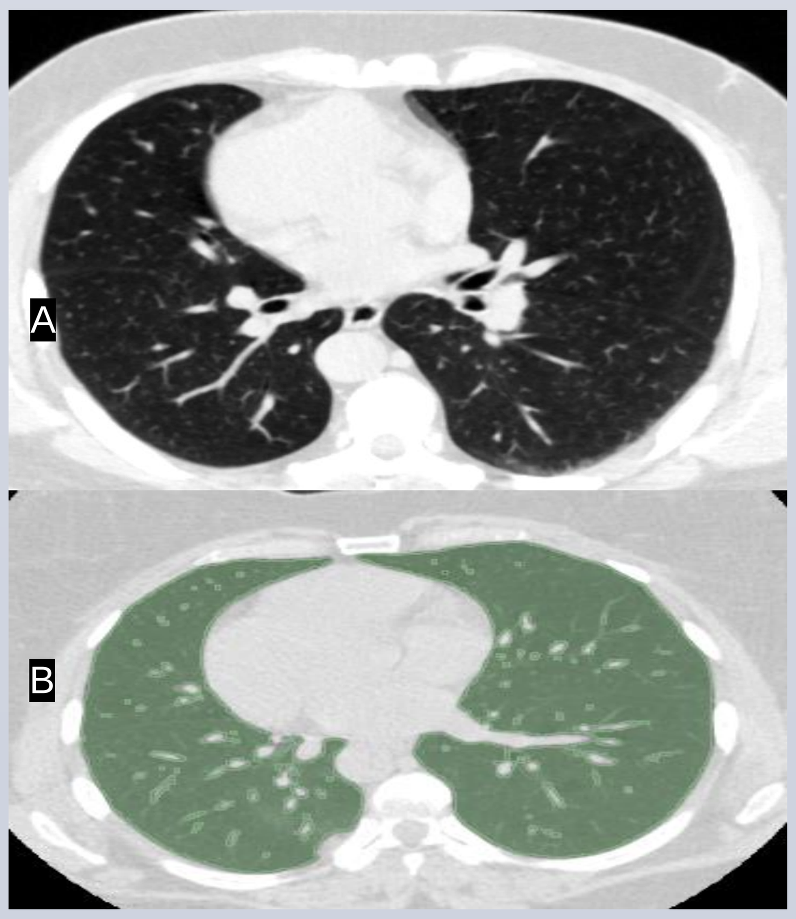


Figure 1 One axil CT scan Real DICOM before Segmentations (A). One axil DICOM Image after Segmentations (B).

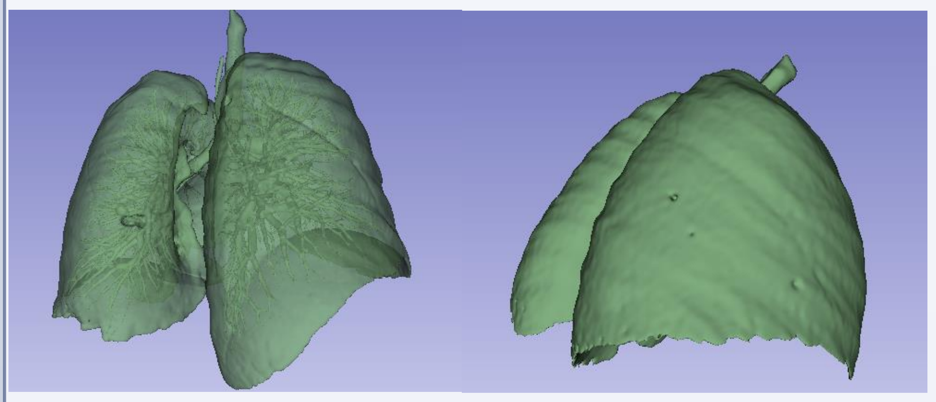


Figure 2 3D image of lung after segmentation process

Results

- Successful segmentation of diverse pulmonary tissue from CT scans, capturing various anomalies.
- Fabrication of accurate lung tissue phantoms reflecting different pulmonary conditions, including GGO.
- Initial evaluation demonstrating the potential of phantoms in improving visualization and diagnosis of pulmonary diseases.
- Exploration of telemedicine applications showing promising prospects for remote consultations across diverse pulmonary conditions.
- Initial validation of the effectiveness of 3D printed phantoms in enhancing pulmonary disease diagnosis.

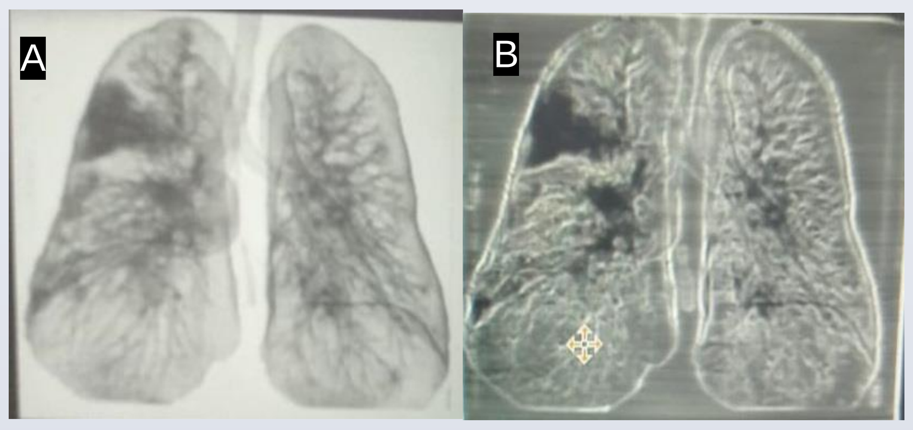


Figure 3 Lung X-ray DICOM image from printed SLA printed flat phantom (A). Lung X-ray DICOM image from printed FDM printed flat phantom (B).

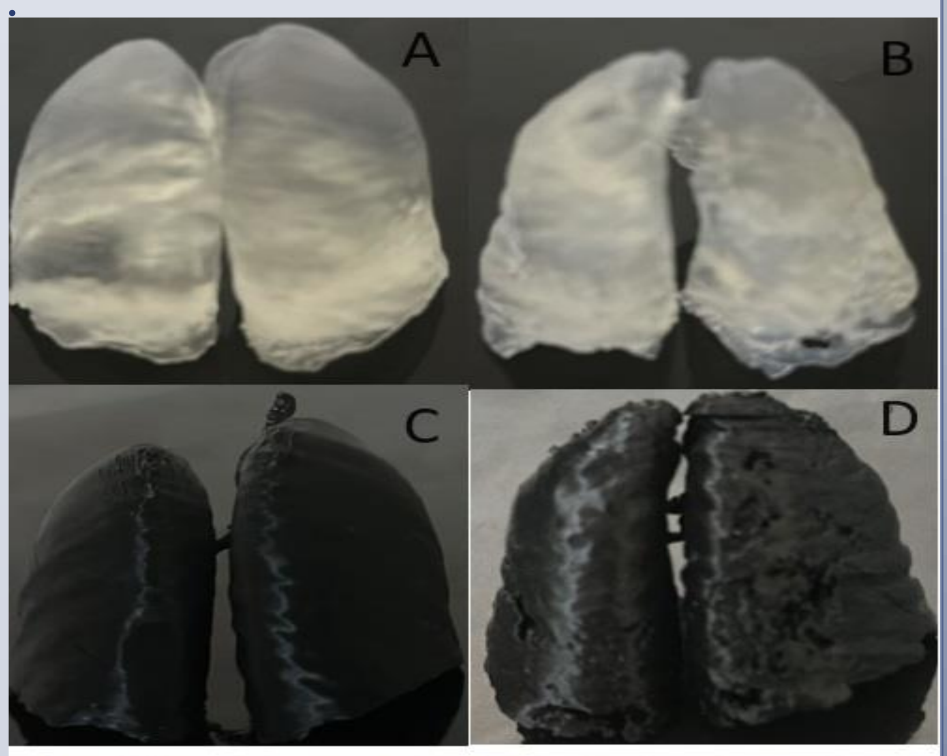


Figure 4 A) SLA printed healthy lung phantom, B) SLA printed GGO infected lung phantom, C)FDM printed healthy lung phantom, D) FDM printed GGO infected lung phantom.

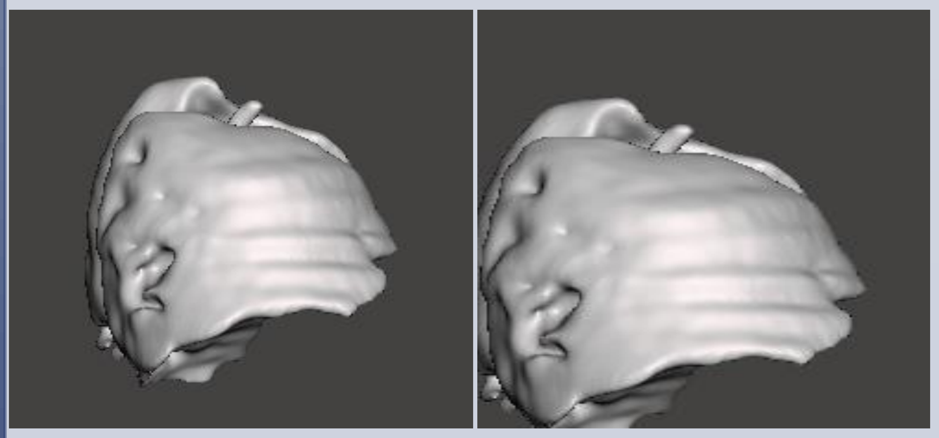


Figure 5 3D manual reconstruction for SLA phantoms after CT scanning.

In Progress

- Continued refinement and validation of the fabricated lung tissue phantoms across various pulmonary conditions.
- Completion of CT scanning of the fabricated phantoms to further assess their accuracy and characteristics.
- Calculation of Hounsfield Units (HU) for the segmented lung tissue phantoms to ensure precise representation.
- Exploration of additional applications and potential advancements in telemedicine utilization in pulmonary healthcare.
- Collaboration with healthcare professionals for real-world testing and implementation across diverse pulmonary diseases.
- Continuation of research efforts to optimize the use of 3D printed phantoms in pulmonary disease diagnosis and treatment.

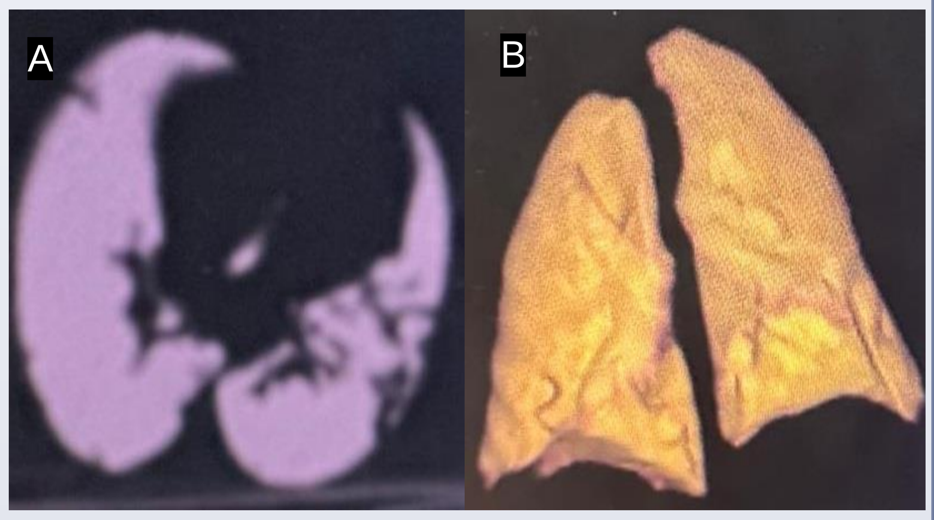


Figure 6 One axial slice for SLA phantoms after CT scanning(A). 3D automated reconstruction for SLA phantoms after CT scanning. (B).

Conclusions

- 3D printed lung tissue phantoms offer a promising solution for improving visualization and diagnosis across diverse pulmonary conditions (1).
- Successful segmentation and fabrication processes demonstrate the feasibility of the proposed approach (2).
- Initial evaluations suggest significant potential in enhancing pulmonary disease diagnosis and treatment planning (3).
- Further research and collaboration are essential for refining and implementing this technology across diverse pulmonary diseases (4).
- Continued efforts in this direction hold promise for advancing healthcare delivery in pulmonary medicine beyond specific diseases (5).

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