Modeling lung respiration with emphysema regions in left lung for use in virtual imaging trials

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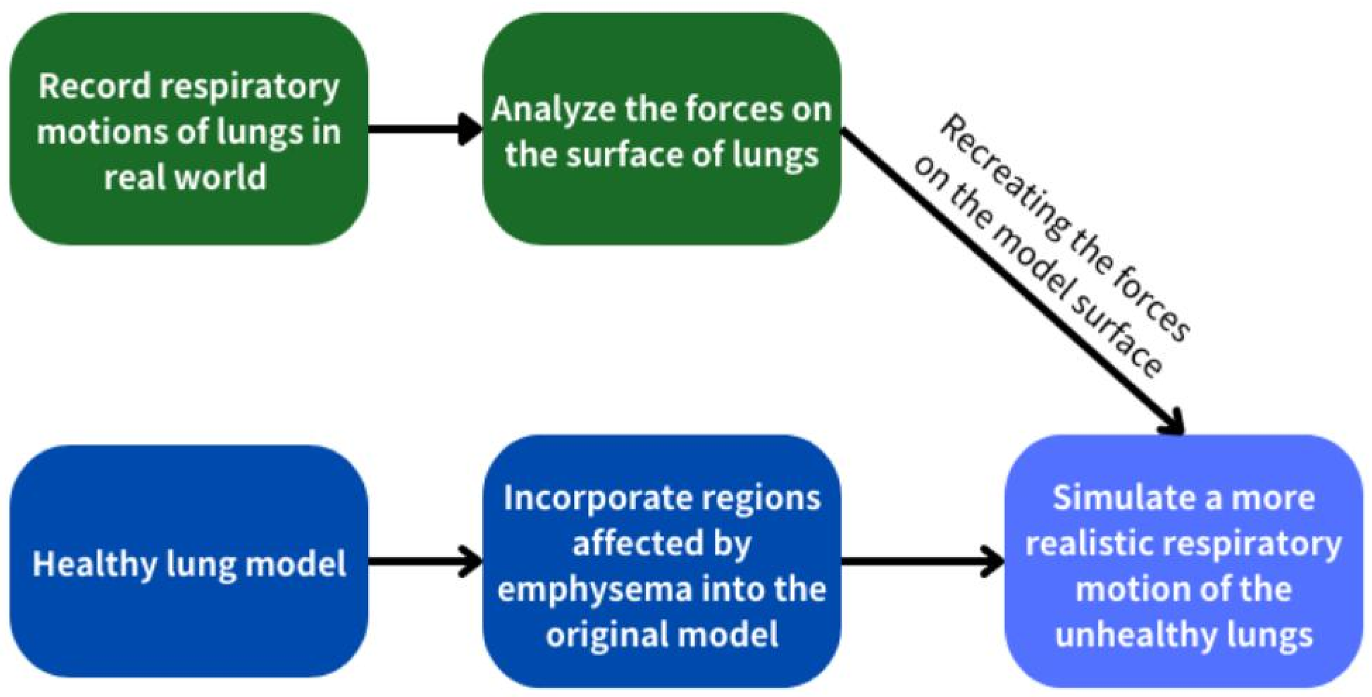
Introduction

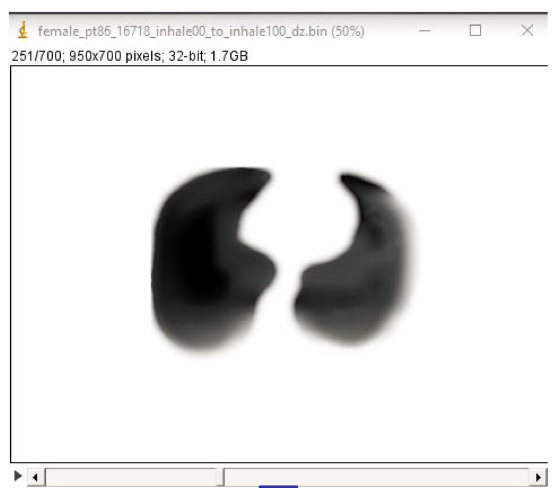
Purpose: In this research, we purposed to simulate the respiration movement of unhealthy lung with emphysema regions inside in ABAQUS. To make the respiration movement more realistic, we aimed at analyzing the magnitude and direction of the forces on the lung surface in the real breathing movement and restoring these forces to the model in ABAQUS as much as possible.

Introduction: Emphysema is a lung disease where alveoil lose elasticity, causing breathlessness and reduced oxygen exchange. To advance research on emphysema, we utilized ABAQUS to construct a lung model. We substitute healthy regions within the lung model with unhealthy portions affected by emphysema to rudimentarily simulate the unhealthy lung afflicted with emphysema. By conducting force analysis on actual respiratory movements, we extracted the magnitude and direction of forces at each point on the lung surface. Subsequently, we applied the force data to the corresponding locations on the surface of model lung, achieving a more realistic simulation of respiratory motion.

Process Overview

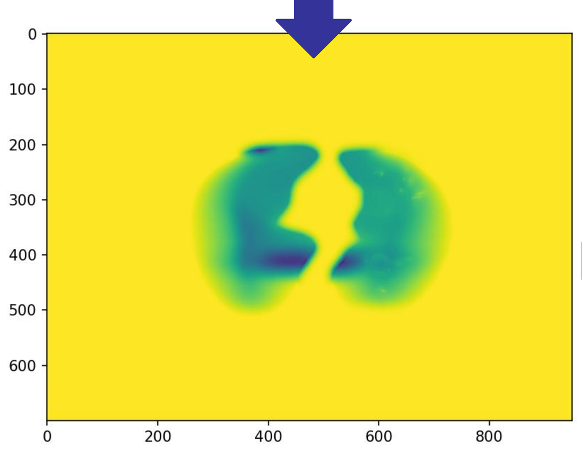


Force Analysis



Observe the force distribution in actual lung respiratory movements from three perspectives (x, y, z). Record and save data in the .nrb format.

Figure 1. Use NotePad++ to directly read .nrb file; Darker colors indicate higher forces.



Using Numpy to read force vectors in x, y, and z directions separately.

Figure 2. Use matplot library to display a force slice in z direction, visualized using Python.

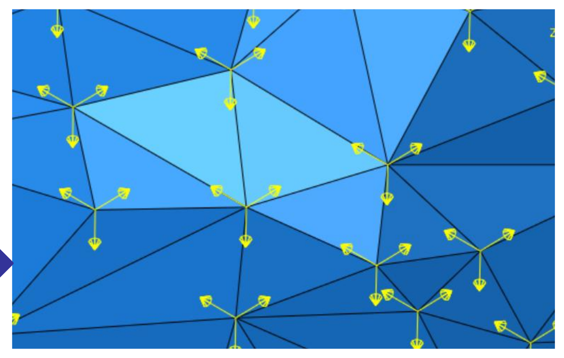
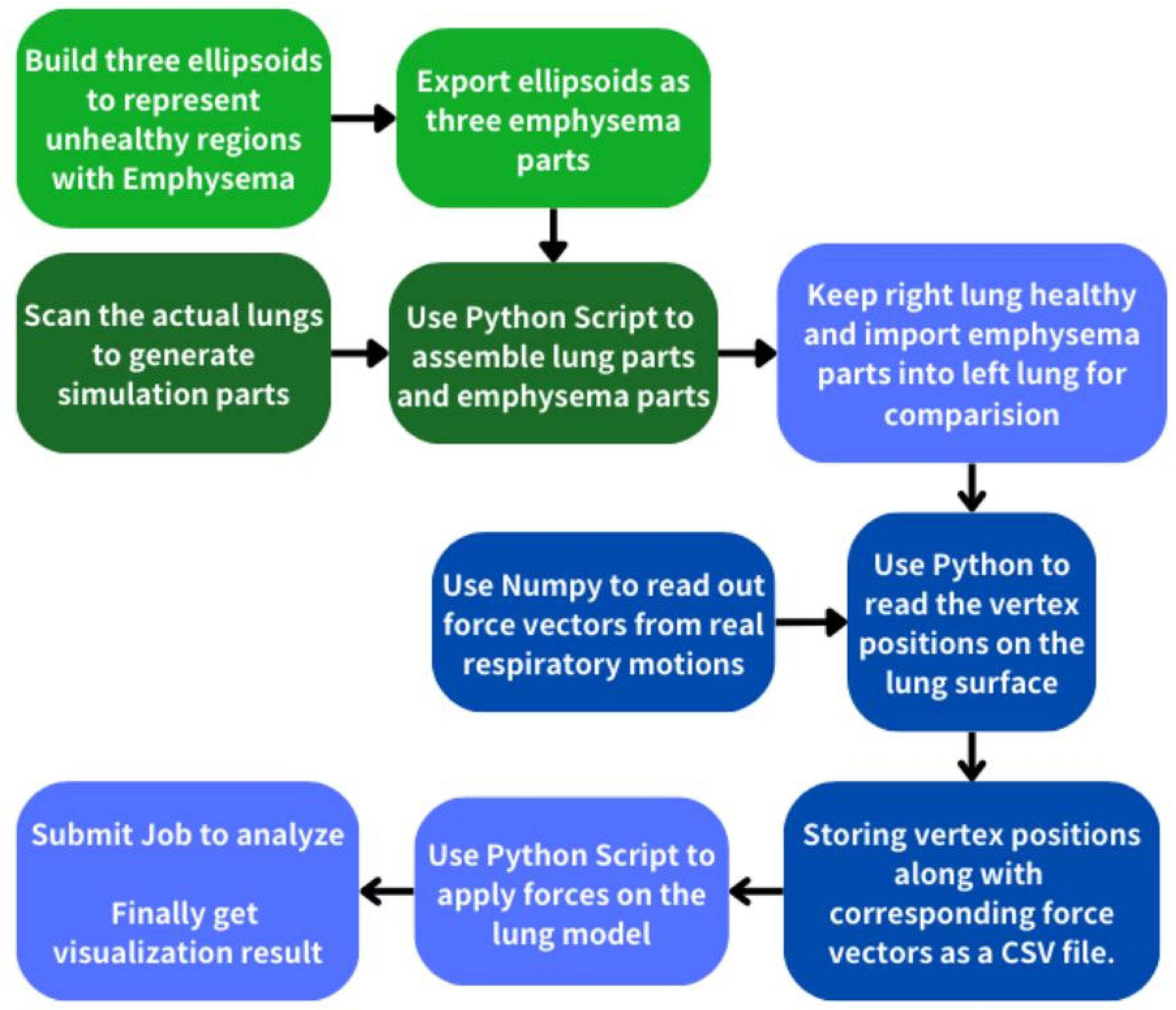


Figure 3. Applying concentrated forces to corresponding vertices, with each point having force information in three directions.

ABAQUS Scripting

Scripting Process:



Simulation Results

After submitting the job in ABAQUS, the software provides visualized respiratory motion animations. Screenshots from the ABAQUS visualization section are shown below:

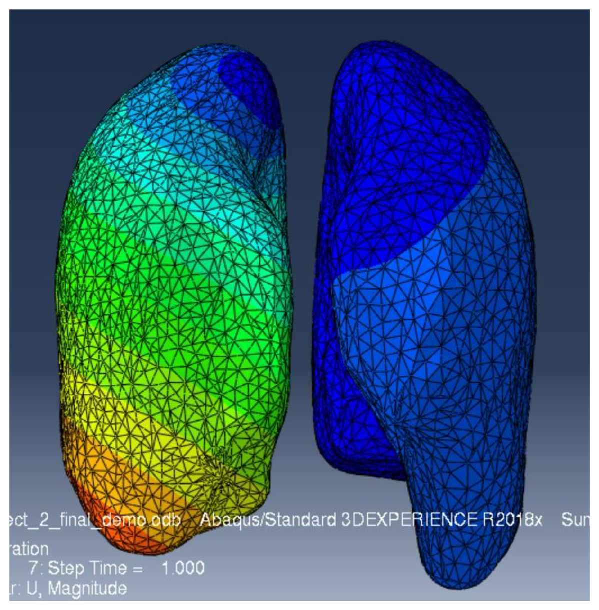


Figure 4 (left figure). The colors represent the displacement magnitude of nodes during the respiration. From blue to red, the magnitude of displacement increases. The right lung is healthy while the left lung has emphysema. Figure 4 shows that the displacement in the left lung is significantly smaller than that in the right lung, indicating lower elasticity in the left lung, which consistent with the characteristics of emphysema.

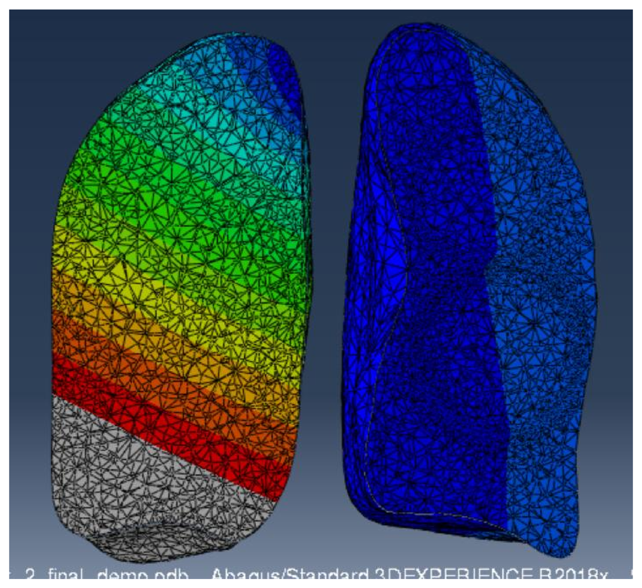


Figure 5 (right figure). Similar to Figure 4, but showing a cross-section in y direction. It provides a clearer view of a circular boundary in the middle of the left lung (right side in the image), representing the unhealthy region affected by emphysema.

Figure 6 (left figure). Display the force magnitude at vertices on the lung surface. The transition from blue to red indicates an increasing force. It is noticeable that the vertices on the bottom of the lung experience stronger forces, providing a reasonably simulation of the force distribution in real respiratory motion.

Quantitative Results

Nodes moving plot:

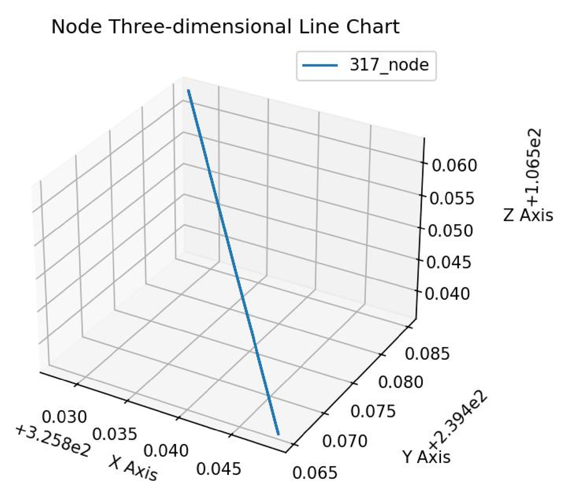


Figure 7. illustrates the trajectory of Node with label 317 during a single expiration moving, located in the left lung affected by emphysema.

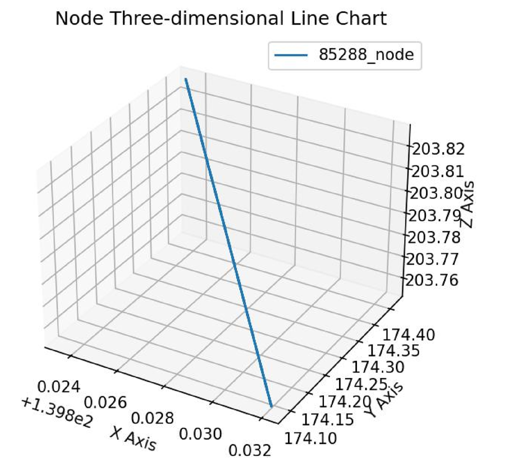


Figure 8. illustrates the trajectory of Node with label 85288 during a single expiration moving, located in the healthy right lung.

The moving paths of these two points exhibit minor displacements.
To get the moving path of any desired node, users can change the input value of point's label in the Python script.

Volume differences:

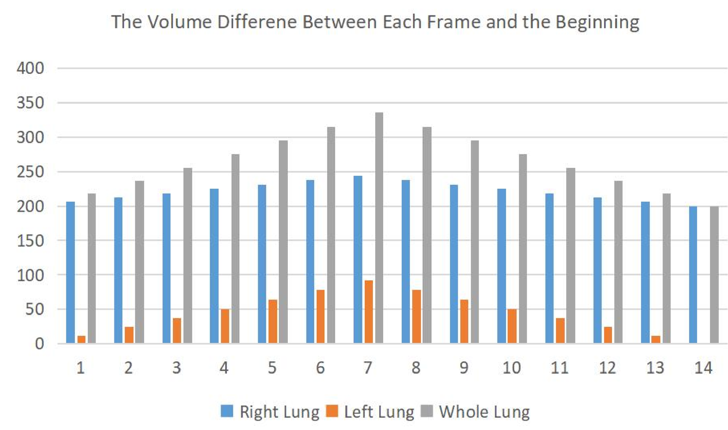


Figure 9. Describe the volume differences in the left lung, right lung, and the whole lung during an entire respiratory motion. The data reveals that the volume change in the left lung, represented by the orange bar chart, is significantly smaller than that in the healthy right lung. This table aligns with the characteristic of unhealthy lung effected with emphysema, that the elasticity of the lung should reduce.

Conclusions

This experiment demonstrates the feasibility of using Abaqus to roughly simulate the respiratory motion of lungs afflicted with emphysema, by inserting unhealthy regions into a healthy lung model. Additionally, precise forces can be applied to vertices on the lung model surface in the x, y, and z directions, which offers a more accurate representation of respiratory motion in real life.
However, there are areas for improvement in this research. Due to various constraints, when simulate the lung model with emphysema, we used larger ellipsoids to represent unhealthy regions with emphysema inside, instead of accurately modelling each tiny emphysema. This simplification resulted in a coarse approximation in the simulation results.

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