Design and Manufacture of Anatomically Realistic, Actuated, Elastic Lung Inserts for PET/CT Phantom Studies with Respiratory Motion

D Black[1], Y Oloumi Yazdi[1], J Wong[1], R Fedrigo[1,3], C Uribe[2], I Klyuzhin[3], A Rahmim[3],

1. **Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada**
2. **BC Cancer, PET Functional Imaging, Vancouver, Canada**

(3) British Columbia Cancer Research Centre, Vancouver, Canada

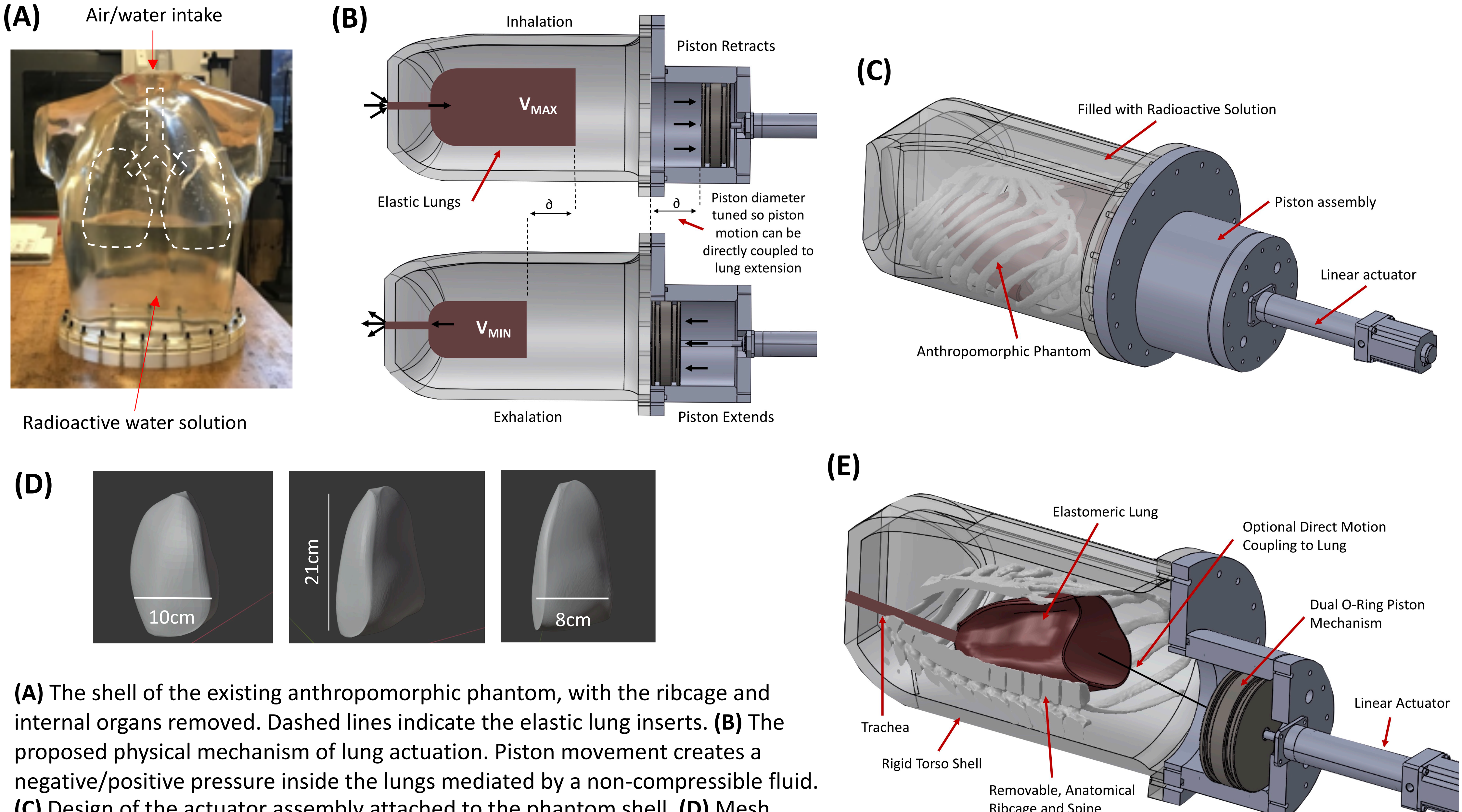
Purpose: To build realistically-shaped, elastic lung inserts with an actuation mechanism, for an anthropomorphic phantom for quantitative analysis of PET/CT images affected by respiratory motion.

Methods: An anthropomorphic phantom that models a stationary human PET scan (Kadrmas et al.) was modified to add accurate respiratory motion. The phantom's outer shell is cast as a single component with an open base, sealed by an acrylic plate and O-ring. The thorax features a spine, ribs, lungs, and liver. The internal space and organs are filled with radioactive water solutions (17300mL) to model natural tracer distribution in the body.

Realistically shaped lungs were manufactured by rolling a silicone elastomer (Chlorosil-35, Ottobock, Germany) onto a 3D-printed mold that was derived from CT scans and mesh-optimized using Blender. A water-tight base was constructed for the phantom that includes a Delrin piston mechanism, mounted onto a waterjet-cut polycarbonate base plate. The piston mechanism is driven by a programmable linear actuator (Tolomatic Inc., USA) with encoder feedback to create a pressure differential inside the phantom, causing the lungs to inflate and deflate (mediated by incompressible fluid). The lung volume and respiration rate are controlled using a closed-loop Proportional Integral Derivative algorithm on a Raspberry Pi via a custom software, and can be set to a range of values (up to 1.5L tidal volume and 30+ breaths per minute).

Results: While all the components have been designed and fabricated, assembly and testing are still underway. Initial tests show the breathing mechanism to be realistic and reliable, with no leaks or risk of failure. Mechanical simulation has shown the actuator force to be about 300N. At 0.5L tidal volume (relaxed breathing for adult male), the lungs extend 3cm axially, which is anatomically realistic. At very large tidal volumes (>1L), extension is larger than is realistic due to lack of ribcage expansion from intercostal muscle contraction, which in reality causes additional lateral expansion.

Conclusion: The existing anthropomorphic phantom was retrofitted with custom-designed, actuated lungs that have realistic shape and motion. The improved phantom can model various waveforms and rates of the respiratory cycle. The phantom can facilitate quantitative analysis of the impact of respiratory motion on the appearance and detectability of cancer lesions in PET images.



(A) The shell of the existing anthropomorphic phantom, with the ribcage and internal organs removed. Dashed lines indicate the elastic lung inserts. **(B)** The proposed physical mechanism of lung actuation. Piston movement creates a negative/positive pressure inside the lungs mediated by a non-compressible fluid. **(C)** Design of the actuator assembly attached to the phantom shell. **(D)** Mesh model of the 3D-printable mold to manufacture the lungs. **(E)** Internal assembly of the piston, lungs, ribcage, and the actuation mechanism.