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

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INTRODUCTION
Patient motion during Positron Emission Tomography (PET) scans can be a detrimental factor to image quality, leading to quantification errors and radiologists potentially missing malignant lesions. In order to analyze the impact of motion on image quantification and lesion detection, anthropomorphic phantoms with accurate anatomy and realistic motion are needed. In this work we present such a phantom, which builds off the state of the art in humanized phantom anatomy by adding elastic lungs with a highly controllable, realistic breathing mechanism to an existing, proven anatomically accurate phantom.1

RESULTS
All the components excluding the lungs have been fabricated, assembled and tested. Initial tests show the breathing mechanism to be realistic and reliable, with no leaks and little risk of failure. Tidal volumes of up to 1250ml can be achieved at up to 25 breaths per minute. At full tidal volume (relaxed breathing for adult male), the lungs extend 3cm axially, which is anatomically accurate. At very large tidal volumes (>1L), extension is slightly larger than is realistic due to lack of ribcage expansion from intercostal muscles, which in reality causes additional lateral expansion. Due to COVID-19, lung fabrication has been delayed but is currently underway as restrictions are easing in British Columbia.

AIM
To build realistically-shaped, elastic lung inserts with an actuation mechanism for an anthropomorphic phantom for analysis of the effect of respiratory motion on quantification of PET/CT images.

METHOD
- A static anthropomorphic torso phantom was modified to add accurate respiratory motion.
- The phantom's outer shell is cast as a single component with an open base, sealed by a polycarbonate plate and O-ring.
- The internal space and organs (excluding the lungs) are filled with radioactive water solutions to model natural tracer distribution in the body.
- Realistically shaped lungs were manufactured by rolling a silicone elastomer, ChloroSil-35 P, onto a 3D-printed mold.
- A water-tight base was constructed for the phantom that includes a Dielin piston mechanism, mounted onto a waterjet-cut polycarbonate base plate.
- The piston mechanism is driven by a programmable linear actuator to create a pressure differential inside the phantom, causing the lungs to inflate and deflate.
- A Python interface and control system were developed to simulate custom respiratory waveforms with the phantom via a Raspberry Pi.

CONCLUSIONS
The existing anthropomorphic phantom was retrofitted with actuated lungs that have realistic shape and motion. The improved phantom can model a wide variety of respiratory waveforms, thus facilitating quantitative analysis of the impact of respiratory motion on the quantification and detectability of cancer lesions in PET images.

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REFERENCES
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