**1604**

Poster Discussion

# Evaluation of a novel anthropomorphic thorax phantom with a dynamic lung using 4DCT

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## Purpose/Objective:

Four-dimensional computed tomography (4DCT) has revolutionized the radiation therapy field by allowing visualization and tracking of movements in the target volume and organs at risk, leading to more accurate treatment procedures. However, the image quality and accuracy of quantitative information could be affected by severe artifacts arising from regular or irregular breathing and motion artifacts. These image quality measurements are mostly performed using phantoms, which do not represent entirely the complexities and motion of patients. Recently, the 3D-printing technology has been introduced into radiotherapy that allows for increased customization and generating anthropomorphic dynamic/deformable phantoms. This study aims to evaluate the 4DCT image quality and proof-of-concept of an in-house developed realistic dynamic/deformable phantom in terms of tumor trajectory and motion artifacts, which allows for more realistic motion evaluation than with more commonly used simplistic phantoms.

## Material/Methods:

A novel anthropomorphic thorax phantom (Figure 1A) was manufactured with fused deposition modeling (FDM) printing by using tissue-equivalent materials that represented soft tissue, lung tissue and bone. These materials were selected based on the effective atomic number and relative electron density. The soft tissue structure was based on CT images of a real patient with, in addition, tissue-equivalent bone such as spine and ribs and a deformable and compressible lung, including bronchi and tumors with accurate mechanical properties for realistic compression. The compression was performed by a developed electronic lung compression system (LCS), that simulated realistic respiration induced breathing motion. This system was connected to a static chest movement system (CMS; Figure 1B). The latter system was used to connect the ANZAI belt and allowed to track the breathing phases by the 4DCT system. A snippet of the respiratory curve is shown in Figure 2A. Images were acquired in static 3DCT (reference volume) and 4DCT. The image acquisition was performed on a SOMATOM Definition Drive CT scanner (Siemens Healthineers) with a tube voltage of 120 kVp (Qr40). This scanner used a phase-based sorting algorithm to reconstruct at specific breathing phases (0% inhale, 25% inhale, 50% inhale, 75% inhale, 100% inhale, 75% exhale, 50% exhale, 25% exhale). The scan parameters for the 4DCT were chosen based on clinical practice and included a pitch of 0.14 s, a field-of-view of 500 mm and a CTDIvol of 22 mGy. In addition, reconstruction was performed with 3 mm slice thickness. In evaluation, two tumors that had different volumes(tumor 1 and 2; Figure 1A) were assessed by quantifying the center of mass and volume between the respiratory phases. In addition, the amplitude between the different tumors was evaluated to demonstrated the realistic motion induced by the LCS.

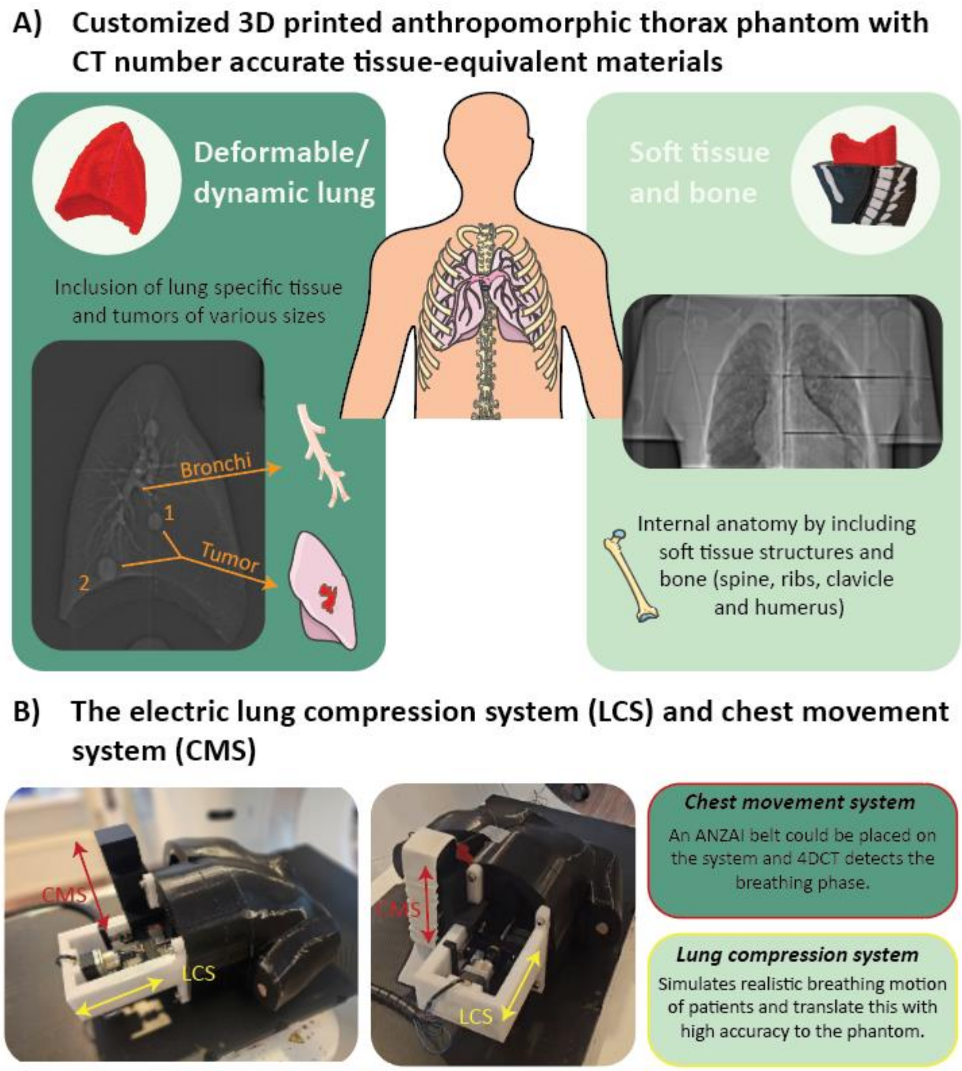


**Figure 1:** A) Visualization of the anthropomorphic thorax phantom with the deformable lung (left) and the soft tissue/bone (right). The compressible lung included structures of bronchi and various tumors (tumor 1 and 2 shown in topogram). B) Visualization of the electronical lung compression system and the chest movement system that are connected to the phantom. The lung compression system moves in superior-inferior direction and simulates accurate patient breathing motion (yellow arrow). The chest movement system is connected to the lung compression system and moves in anterior-posterior direction (red arrow) and represent the simplified static thorax motion and is connected with an ANZAI belt. The 4DCT can track the breathing phase.

**Results:**

The two independent motors were able to accurately mimic breathing and tumor motion. Compared to the reference, tumor 2, placed in the lower region of the lung showed higher amplitudes (6.7 – 20.2 mm) than tumor 1 (2.1 – 10.4 mm). This demonstrates that the linear motion of the LCS was dampened throughout the dynamic lung and generated different motion in various lung regions, as is seen in patients. The tumor displacements were in both cases seen in superior-inferior direction and only small displacements were visible in anterior-posterior direction (Figure 2A). Breathing phases were detected properly by the 4DCT based on the ANZAI belt connected to the CMS and image quality was preserved, without motion artifacts (Figure 2B).

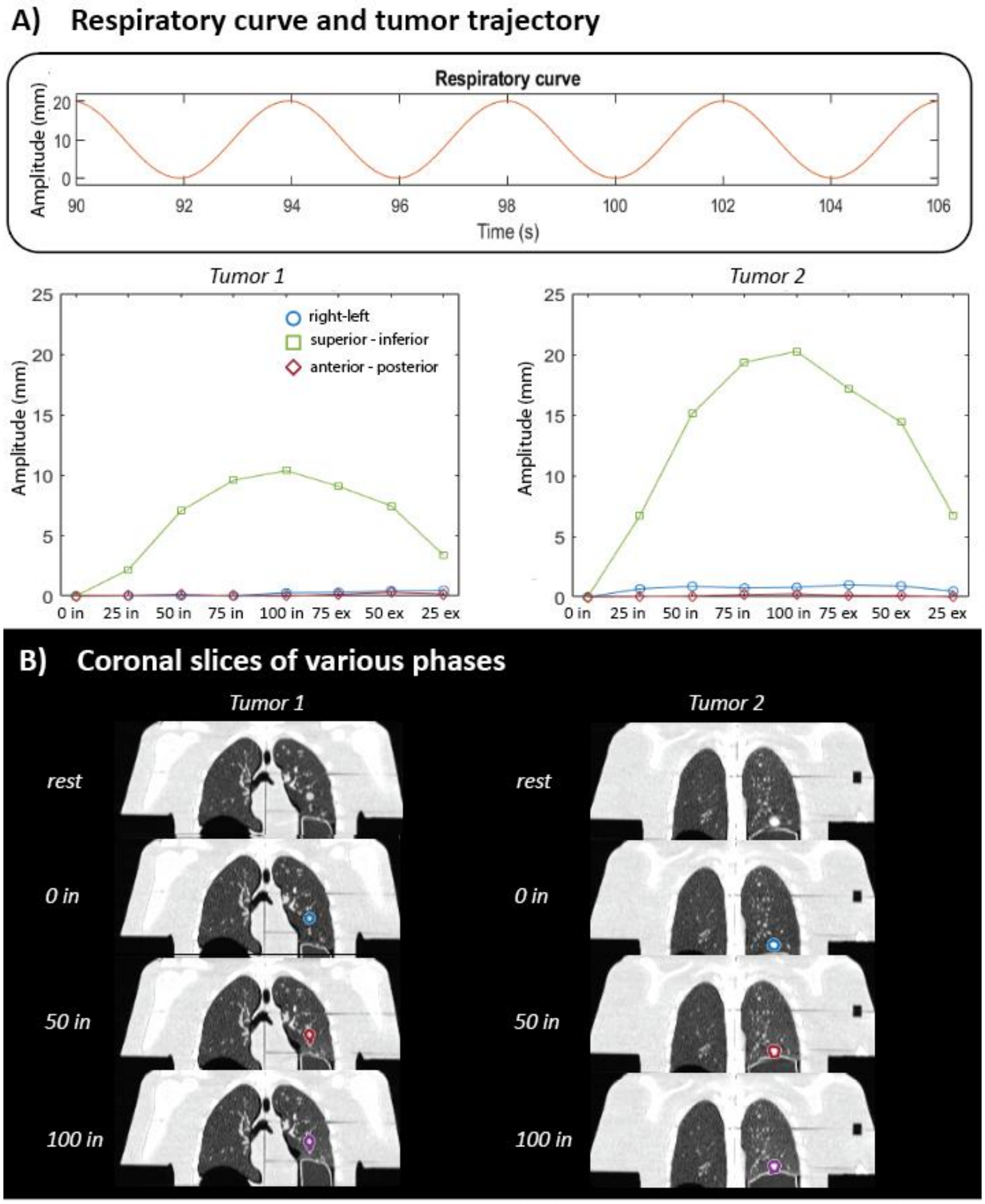


**Figure 2:** A) Representation of the respiratory curve (top) of the simulated breathing motion. In addition, tumor trajectory curves were established of tumor 1 and 2 for the right-left (blue), superior-inferior (green) and anterior-posterior (red) movements. B) Coronal images of the thorax phantom with two tumors and acquired in different breathing phases. Abbreviations: in-inhale, ex-exhale.

**Conclusion:**

This study shows a novel thorax phantom with a dynamic/deformable lung model using 4DCT by providing realistic motion and preserving image quality. The phantom can be customized by changing the lung and tumor (shape and position) and it can reproduce real tumor/breathing curves. Additionally, it will allow further 4DCT imaging optimization, and could also be employed for dosimetry, as it is comprised of tissue-equivalent materials.

**Keywords:** 4DCT, 3D-printing, 4D imaging phantom