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PRESENTATION TITLE
Motion variability in 4D lung treatments for PBS proton therapy using 4DCT(MRI)

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ABSTRACT
Purpose: To investigate the influence of motion variability on dose distributions for PBS proton therapy using motion data extracted from lung 4DMRI.

Materials & Methods: 4DMRI lung data of two volunteers were acquired and reconstructed over multiple respiratory cycles to catch breathing variability. Deformable image registration was used to extract the motion vector fields for five cycles of each volunteer. These vector fields were matched to a full exhale CT of a lung cancer patient. By warping this CT using the 4DMRI deformations, two synthetic 4DCTs (referred to as 4DCT(MRI)) were generated. The resulting motion of the tumour centre has superior-inferior (SI) amplitudes of 9.14+/−0.58 mm for the “large motion” and 1.98+/−0.04 mm for the “small motion” with corresponding periods of 6.9+/−0.6 s and 4.5+/−0.4 s, respectively. The motion patterns in SI and anterior-posterior (AP) are shown in Figure 1. Based on the first breathing cycle of each volunteer, the corresponding geometric ITV (gITV) was generated. On the original full exhale CT, the contour of the gITV was filled with the average density of the CTV for planning purposes. A three-field SFUD plan was optimised on the gITV on this adapted CT. Deforming grid 4D dose calculations (4DDCs) were then performed for both simulated 4DCTs based on five variable breathing cycles. Motion mitigation was introduced by applying 1-9 scans for layered and volumetric rescanning. As a comparison to clinical practice, corresponding 4D dose calculations have also been performed based on the first (repeated) cycle of each dataset. The resulting doses were analysed in terms of CTV coverage and homogeneity as well as mean lung dose.

Results: In the case of small motion amplitude, little dependence of the dose distribution on the motion variability was found. Homogeneity and coverage slightly improved with increased number of rescans, while the free breathing scenarios showed a slightly lower homogeneity than the repeated cycle scenarios (see Figure 2). However, for the large motion case, significant differences in homogeneity and coverage were found for some rescanning regimes. The mean lung dose only marginally depended on the motion irregularity and rescanning scenario. Example dose distributions for the large motion case.
are shown in Figure 3.

**Conclusions:** Considering only one breathing cycle for treatment planning, as is done in clinical practice, can considerably over- or underestimate the effectiveness of a specific rescanning scenario. To ensure an optimal choice of motion mitigation, it is important to also consider motion variability. Our approach of 4DCT(MRI) can be a useful tool for this.

![Figure 1](image1.png) 
**Figure 1** Motion pattern of the tumour centre in superior-inferior (a) and anterior-posterior (b) direction for the two scenarios.

![Figure 2](image2.png) 
**Figure 2** CTV coverage (a) and homogeneity (b) and mean lung dose (c) for all the motion and rescanning scenarios.

![Figure 3](image3.png) 
**Figure 3** Dose distributions for repeated one cycle and free breathing for the large motion case, as well as the dose difference. Left panel: no rescanning, right panel: 4x volumetric rescanning.