Purpose:
To investigate the dosimetric impact of the respiratory motion on lung SBRT treatment when proton beams are used.

Methods:
Ten patients with 4D-CT scans treated by photon SBRT were recruited for this study. To be consistent with the clinical practice, the PTV density override was performed to account for the tumor movement. Intensity modulated proton therapy (IMPT) plans were generated using our MC based dose calculation and optimization system. To quantify the density variation caused by breathing, the average lung density of inhale, exhale and a middle phase was calculated accordingly for every patient. MC simulation was performed to investigate the effects of density variation and the heterogeneity on the SOBP under simple geometry first. The effects of lung density variation on patient dose calculation were investigated subsequently by recalculating the dose distributions of IMPT plans with a different lung density for every individual phase. To investigate the effect of density override, dose distributions of IMPT plans with and without PTV density override were compared.

Results:
The density variation (2.3%-120%,average 22%) and heterogeneity cause SOBP distal edge shift, distortion, and a higher exit dose, which consequently leads to underdosage inside the target and a higher dose to the lung/critical organ in the downstream. In reality, the PTV is composed of solid GTV and lung tissue rather than homogeneous tissue with the unity density set in PTV override. Therefore, in patient treatment, part of the proton beam penetrates deeper than expected. This can significantly increase the dose to the adjacent critical organ.

Conclusion:
The respiratory motion and density variation can significantly affect the critical organ dose and the target coverage, especially for a small tumor with large motion. To encompass the motion, treatment margin and density override should be carefully applied and respiratory gating is necessary for proton SBRT treatment.