Range Fluctuation Analysis Due To Respiratory Motion in Charged Particle Lung Therapy

Purpose:
Water equivalent pathlength (WEL) variations due to respiration can change the penetration of a charged particle beam, and result in beam overshoot to critical organs or undershoot to the tumor. We have analyzed range fluctuations by analyzing four-dimensional CT (4DCT) data and quantitatively assessing potential beam overshoot.

Methods and Material:
4DCT images were acquired with a multi-slice CT scanner. The maximum intensity volume (MIV) was calculated by temporal maximum intensity projection (MIP) processing. Two targets were designed for charged particle beam therapy. The first target volume calculates the MIV over the entire respiratory cycle (ITV-Rx), while the second target volume is the MIV corresponding to gated radiotherapy (over a 30% phase window around exhale). These targets were used to calculate boli that were then applied to the 4DCT data to estimate beam penetration. Analysis metrics include range fluctuation, overshoot volume, both as a function of gantry angle. We compared WEL fluctuations observed in treating the ITV Vs gated treatment in 11 lung patients. WEL fluctuation and beam overshoot into normal lung are displayed over a beams-eye view display.

Results:
WEL fluctuations were less than 29.8 mm-WEL and 12.0 mm-WEL for ITV-Rx and gated-Rx, respectively for all patients. Gated-Rx reduced beam overshoot volume by approximately a factor of four compared to ITV treatment. Such range fluctuations can affect the efficacy of treatment, and result in excessive dose to a distal critical organ.

Conclusions:
Time varying WEL range fluctuation analysis provides information useful to determine appropriate patient specific treatment parameters in the charged particle radiotherapy. This analysis can also be useful for optimizing planning and delivery.