J. Lee, C. Kim, B. Min, J. Kwak, S. Park, S-B. Lee, S. Park and S. Cho, Sparse-view proton computed tomography using modulated proton beams, *Medical Physics*, Vol. 42, pp. 1129-1137, (**2015**). DOI:10.1118/1.4906133.

Abstract

PURPOSE: Proton imaging that uses a modulated proton beam and an intensity detector allows a relatively fast image acquisition compared to the imaging approach based on a trajectory tracking detector. In addition, it requires a relatively simple implementation in a conventional proton therapy equipment. The model of geometric straight ray assumed in conventional computed tomography (CT) image reconstruction is however challenged by multiple-Coulomb scattering and energy straggling in the proton imaging. Radiation dose to the patient is another important issue that has to be taken care of for practical applications. In this work, the authors have investigated iterative image reconstructions after a deconvolution of the sparsely view-sampled data to address these issues in proton CT.

METHODS: Proton projection images were acquired using the modulated proton beams and the EBT2 film as an intensity detector. Four electron-density cylinders representing normal soft tissues and bone were used as imaged object and scanned at 40 views that are equally separated over 360°. Digitized film images were converted to water-equivalent thickness by use of an empirically derived conversion curve. For improving the image quality, a deconvolution-based image deblurring with an empirically acquired point spread function was employed. They have implemented iterative image reconstruction algorithms such as adaptive steepest descent-projection onto convex sets (ASD-POCS), superiorization method-projection onto convex sets (SM-POCS), superiorization method-expectation maximization (SM-EM), and expectation maximization-total variation minimization (EM-TV). Performance of the four image reconstruction algorithms was analyzed and compared quantitatively via contrast-to-noise ratio (CNR) and root-mean-square-error (RMSE).

RESULTS: Objects of higher electron density have been reconstructed more accurately than those of lower density objects. The bone, for example, has been reconstructed within 1% error. EM-based algorithms produced an increased image noise and RMSE as the iteration reaches about 20, while the POCS-based algorithms showed a monotonic convergence with iterations. The ASD-POCS algorithm outperformed the others in terms of CNR, RMSE, and the accuracy of the reconstructed relative stopping power in the region of lung and soft tissues.

CONCLUSIONS: The four iterative algorithms, i.e., ASD-POCS, SM-POCS, SM-EM, and EM-TV, have been developed and applied for proton CT image reconstruction. Although it still seems that the images need to be improved for practical applications to the treatment planning, proton CT imaging by use of the modulated beams in sparse-view sampling has demonstrated its feasibility.