Tools for Development of 4D Proton CT

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Introduction

Proton CT is a promising image modality for improving the accuracy of relative stopping power determination in proton or ion treatment planning. While this modality has been explored with simulation studies and first experimental prototypes have been developed, the concept of 4D proton CT with single-proton data acquisition synchronized with a breathing model has never been explored. The goal of the research and development presented in this abstract is to develop tools for exploring methods and algorithms for 4D proton CT of lung patients.

Methods

A suitable patient with a tumor in the right lower lobe was selected from a group of patients that underwent the 5DCT imaging protocol[1]. The acquired fast helical CT images together with the simultaneously recorded breathing surrogate signals allowed for the construction of patient breathing model that can generate volumetric images at each breathing phase. The images were imported into the TOPAS Monte Carlo simulation platform for simulating an experimental proton CT scan with 45 projections spaced by 4 degree intervals. Each projection acquired data for 2 seconds followed by a gantry rotation for 2 seconds without acquisition. The scan covered 180 degrees with individual protons passing through a 9-cm slab of the patient's lung covering the moving tumor. An initial proton energy sufficient for penetrating the patient from all directions was determined. Proton particles were sourced from rectangular field of uniform intensity. The geometry of the proton CT scanner was modified to allow for the coverage of the thoracic region and the higher energy required for penetrating patient anatomy. Performing the proton CT simulation, TOPAS provided the exit proton energy and coordinates registered in two planes before and after the patient, respectively. The set of projection data was then used with an iterative reconstruction algorithm to generate a volumetric proton CT image set of the static reference image and the image obtained under breathing motion, respectively.

[1]Low et al. "A novel CT acquisition and analysis technique …", Physics in Medicine and Biology, 58, 11, L31 2013

Results

For the exploration of 4D proton CT with moving patient objects, the Monte Carlo simulation kit TOPAS was utilized. The geometry of an existing proton CT head scanner was modified in order to fit a patient that was selected from a database of 17 lung tumor patients that had been scanned with a fast helical x-ray CT scanning protocol previously. From the x-ray CT data and the breathing model, an artefact-free 4D model of the patient chest was reconstructed and imported into TOPAS after converting the CT Hounsfield values to human tissue materials, thus providing a realistic model of a breathing lung tumor patient.

Figure 1 shows that an energy of 200 MeV, which has been suggested for head and neck proton CT scans is not sufficient, while 230 MeV provides sufficient residual energy for all projection angles.

Figure 2 shows the proton CT reconstruction of a static proton CT reference image. Notice that the relative stopping power difference between bone and soft tissue is much less than that for the relative x-ray attenuation, reducing the bone-soft tissue contrast. An efficient 4D proton CT reconstruction algorithm taking into account of the motion state is under development.

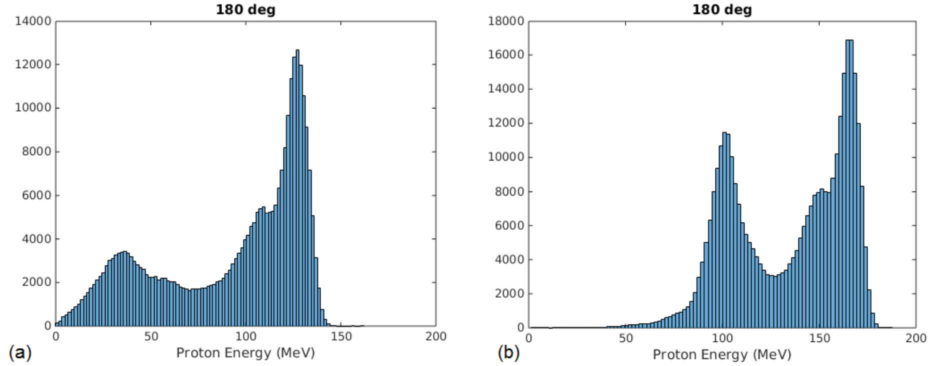

Fig. 1. Histogram of outgoing proton energies provided by simulation of a proton CT scan with a) 200 MeV and b) 230 MeV initial energy respectively.

Fig. 2. Reconstruction of a static reference image obtained from a fixed patient geometry

Conclusions: We have developed tools to perform studies of proton CT in the presence of lung motion based on the TOPAS simulation toolkit. This will allow to optimize 4D reconstruction algorithms by synchronizing the acquired proton CT data with a breathing signal and utilizing a breathing model obtained prior to the proton CT scan.