Introduction

The purpose of this study is to design an anthropomorphic pediatric spine phantom for use in the evaluation of proton therapy facilities for clinical trial participation by the Imaging and Radiation Oncology Core (IROC) Houston QA Center (formerly the Radiological Physics Center).

Unlike external beam radiotherapy using photons and/or electrons, protons deposit dose over a finite range based on their energy, with a maximum dose deposition at the end of the range. This maximum dose deposition, called the Bragg peak, is useful for treating tumors as it allows for protons to deliver the majority of its dose to the target volume while sparing the surrounding healthy tissue [1,2]

With the number of proton therapy facilities increasing nationwide, it is important to establish accuracy and consistency in the dose delivered in patient treatments. IROC Houston uses anthropomorphic phantoms as a part of the mailable audit program to verify dose delivery for various treatment techniques. The spine phantom includes durable materials that can be used in radiation dosimetry as tissue substitutes when irradiated with protons, along with a simulated spine curvature. The inclusion of multiple tissue substitutes in the phantom increases heterogeneity and the level of difficulty for institutions to conduct a successful treatment.

Materials/Methods

This phantom was designed to perform an end-to-end audit of the proton spine treatment process, including simulation, dose calculation by the treatment planning system (TPS), and proton treatment delivery. The design, shown in Figure 1, incorporated materials simulating the thoracic spinal column of a pediatric patient, along with two thermoluminescent dosimeter (TLD)-100 capsules and radiochromic film embedded in the phantom for dose evaluation.

Results

The materials selected as bone, tissue, and cartilage substitutes were Techron HPV Bearing Grade (blue), solid water (maroon), and blue water (light blue), respectively. Radiochromic film (green) is placed in the sagittal and coronal planes. The spinal curvature is simulated by a wedged piece of solid water. Polystyrene (gray) is added in the superior-inferior direction, extending the length to 50 cm in order to accommodate the beam divergence when using a junction.

Table 1 shows data comparing measured RSP measurements for phantom materials tested at 160 MeV to the RSP calculated by the Eclipse TPS for a given HU. The measured RSP agreed with the RSP calculated by Eclipse within 1.2%.

Preliminary Phantom Evaluation Results

The following attributes were evaluated: absolute dose, junction match and right/left dose profile alignment. Listed are preliminary results from the passive scatter irradiations. Each film plane was evaluated using gamma analysis criteria of 5%/5mm and 5%/3mm with 85% of pixels passing. Table 3 shows the data for each criteria evaluation. Figure 3 shows an example of the gamma analysis in the sagittal plane.

Methods continued

Fourteen potential materials were tested to determine relative proton stopping power (RSP) and Hounsfield unit (HU) values. Each material was CT scanned at 120kVp, and the RSP was obtained from depth ionization scans using the Zebra (IBA) multi-layer ion chamber (MLIC) at two energies: 160 MeV and 250 MeV [3]. To determine tissue equivalency, the measured RSP for each material was compared to the RSP calculated by the Eclipse TPS for a given HU.

Results continued

Table 2 shows the data comparing the relative stopping power measurements at 160 MeV and 250 MeV for each tested phantom material. The largest difference between the RSP at the two proton energies was less than 1.8%.

Table 2 shows the data from each profile. All irradiations successfully passed. Table 4 shows the DTA data with respective criteria evaluation. The following attributes were evaluated: absolute dose, junction match and right/left dose profile alignment. Listed are preliminary results from the passive scatter irradiations. Each film plane was evaluated using gamma analysis criteria of 5%/5mm and 5%/3mm with 85% of pixels passing. Table 3 shows the data for each criteria evaluation. Figure 3 shows an example of the gamma analysis in the sagittal plane.