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Development and implementation of an anthropomorphic pediatric spine phantom for the assessment of craniospinal irradiation procedures in proton therapy

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Abstract

Purpose: 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 RPC).

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 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. Fourteen potential materials were tested to determine relative proton stopping power (RSP) and Hounsfield unit (HU) values. Each material was CT scanned at 120 kVp, and the RSP was obtained from depth ionization scans using the Zebra multi-layer ion chamber (MLIC) at two energies: 160 MeV and 250 MeV. 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: The materials selected as bone, tissue, and cartilage substitutes were Techron HPV Bearing Grade (Boedeker Plastics, Inc.), solid water, and blue water, respectively. The RSP values did not differ by more than 1.8% between the two energies. The measured RSP for each selected material agreed with the RSP calculated by the Eclipse TPS within 1.2%.

Conclusion: An anthropomorphic pediatric proton spine phantom was designed to evaluate proton therapy delivery. The inclusion of multiple tissue substitutes increases heterogeneity and the level of difficulty for institutions to successfully treat the phantom. The following attributes will be evaluated: absolute dose agreement, distal range, field width, junction match and right/left dose profile alignment. The phantom will be tested at several institutions using a 5% dose agreement criterion, and a 5%/3mm gamma analysis criterion for the film planes.

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Innovation/Impact: With the number of proton therapy facilities increasing nationwide, it is important to establish accuracy and consistency in the dose delivered in patient treatments. The IROC Houston QA Center (formerly the RPC) uses anthropomorphic phantoms as a part of the mailable audit program to verify dose delivery for various treatment techniques. This new phantom is an improvement over the current proton spine phantom. The current spine phantom contains a deteriorating skeleton, causing air pockets that can lead to inaccurate gamma analysis calculations. The design of the

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current spine phantom also causes curvature of the film when positioned, causing additional difficulties in the analysis. The new design includes durable materials that can be used in radiation dosimetry as tissue substitutes when irradiated with protons, along with a simulated spine curvature that does not affect the film dosimeters. The inclusion of multiple tissue substitutes in the phantom increases heterogeneity and the level of difficulty for institutions to conduct a successful treatment.

TABLE 1: Data comparing relative stopping power measurements for phantom materials tested at 160 MeV and 250 MeV

Material Name	RSP at 160 MeV	RSP at 250 MeV	Mean RSP	Percent Difference (%)
Gammex Inner Bone	1.614	1.598	1.606	0.99
Gammex Cortical Bone	1.092	1.078	1.085	1.29
B200 Bone	1.102	1.092	1.097	0.92
* Techron HPV Bearing Grade	1.298	1.281	1.289	1.34
Ketron PEEK GF30	1.406	1.387	1.396	1.38
Polyester PETP Ertalyte TX	1.364	1.341	1.353	1.72
Ketron HPV Bearing Grade	1.346	1.325	1.336	1.
† Polyester PETP Ertalyte	1.302	1.279	1.291	1.75
Duratron T4301 PAI	1.359	1.341	1.35	1.31
Concrete	Beam didn't penetrate sample	1.856	1.856	Incalculable
Crayola Clay	1.605	1.605	1.605	1.38×10^{-14}

*This data corresponds to the bone tissue substitute selected for the phantom.
†The largest difference between the RSP at two proton energies was calculated for this material.

TABLE 2: Data comparing measured relative stopping power measurements for phantom materials tested at 160 MeV to the relative stopping power calculated by the Eclipse treatment planning system for a given HU.

Material Name	Theoretical RSP at 160 MeV	Measured RSP at 160 MeV	Percent Error (%)
Blue Water	1.0711	1.0679	0.3
Solid Water	1.009	1.004	0.6
Techron HPV Bearing Grade	1.3139	1.2981	1.2

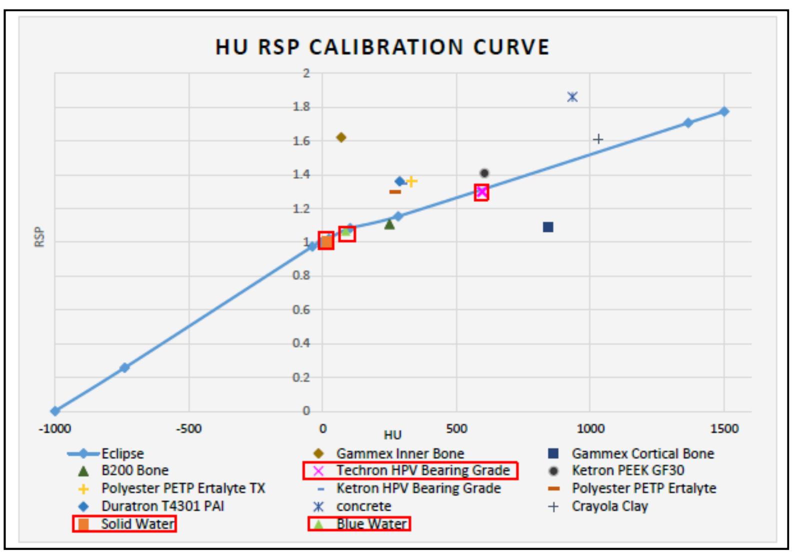

FIG.1: Relative Stopping Power (RSP) versus Hounsfield unit calibration curve comparing tested materials with Eclipse treatment planning system

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