Purpose: This study sought to develop a head phantom for the Radiological Physics Center (RPC), to be used for credentialing of institutions wishing to participate in clinical trials involving proton therapy. This phantom is one of the first designed at the RPC for proton therapy credentialing and in the assessment of proton therapy facilities.

Proton therapy has become an increasingly common method of radiation therapy, with the dose sparing to distal tissue making it an appealing option, particularly for treatment of brain tumors [1, 2]. As there is much variability in the make, model, and maintenance of proton therapy facilities, it is imperative to ensure the treatment procedures at each institution are accurate and comparable. Phantom audits are a way of testing a facility’s treatment process from start to finish: treatment simulation, treatment planning, and treatment delivery. We developed a head phantom that improves upon previous phantom models by using materials that better match human anatomy based on the stopping power-Hounsfield unit (HU) calibration curve that is used by proton treatment planning software.

Materials/Methods: The phantom was designed using a solid Alderson material cast around a human skull. The Alderson material has stopping power and HU values very near to water (relative stopping power: 1.00, HU: 16 ± 5), which is approximately tissue equivalent. The HU-RSP curve used with various phantom materials included is shown in Figure 1.

![Figure 1. The HU-RSP calibration curve for the Eclipse treatment planning system, with phantom materials plotted](image)

Both MR- and CT-compatible inserts were created, with the aim of replicating real-life simulation of brain tumor patients. The phantom was imaged with MRI using a water-filled cylindrical insert containing a spherical target of 2 cm in diameter. It was then imaged with CT using the solid polyethylene (RSP: 0.997, HU: -34) dosimetry insert, containing Radiochromic film and TLD-100 capsules. The phantom and inserts are shown in Figure 2.

![Figure 2. Head phantom with dosimetry insert (L) and imaging insert (R)](image)

The MRI and CT image sets were fused in the Eclipse proton treatment planning system and used to delineate the target and create a plan. A passive scatter plan was created for a prescribed dose of 5.4 Gy delivered with three fields: Left Vertex, Right Vertex, and Posterior-Anterior. Isodose distributions can be observed in Figure 3a. The modulated spot scanning plan was created for a prescribed dose of 4.9 Gy with just two beams: Left Vertex and Right Vertex. Isodose distributions can be seen in Figure 3b.

![Figure 3a. Eclipse treatment planning posterior snapshots for (a) passive scattering and (b) modulated spot scanning](image)

The treatment plans were delivered with the dosimetry insert loaded with Radiochromic film in the sagittal and coronal planes, and TLD-100 capsules in the right anterior and left posterior quadrants. Each plan was delivered three separate times.

![Figure 3b. Coronal film gamma analysis for Trial 1 of the passive scattering plan](image)

After delivering each treatment plan three separate times, we analyzed the absolute doses, dose distributions, and distance to agreement of the treatments, utilizing the TLD and Radiochromic film from the dosimetry insert. Using gamma analysis, with a pixel passing for γ ≤ 1 and failing if γ > 1, we compared the film profiles with the treatment plan dose profiles. We examined agreement criteria of both ±5%/3mm and ±5%/5mm for the gamma analysis. An example of the gamma analysis for one of the passive scatter trials is illustrated in Figure 3, showing 91.5% agreement with criteria of 5%/3mm.

![Figure 3. Coronal film gamma analysis for Trial 1 of the passive scattering plan](image)

The passive scattering plans had average gamma pixel pass rates of 91.9% for 5%/3mm agreement, and 97.4% for 5%/5mm agreement. The modulated scanning plans had average gamma pixel pass rates of 90.4% for 5%/3mm agreement, and 98.4% for 5%/5mm agreement. The data for each proton delivery system and both gamma criteria is shown in Table 1.

![Table 1. Gamma analysis pass rates for 5%/3mm and 5%/5mm criteria for passive scattering, modulated scanning beams](image)

Table 2. Point dose comparisons between treatment planning calculated doses and TLD-measured doses for passive scattering and modulated spot scanning plans

Distances to agreement (DTAs) were calculated for each trial of each beam delivery system. These were done by comparing the linear regressions of the profiles of the treatment planning system and the film measurements in the dose falloff region. The DTAs were averaged over each trial in the superior, inferior, anterior, posterior, right, and left directions. Results for the DTA measurements are shown in Table 3. For both the passive scattering and spot scanning plans, shifts were within the 3mm margins on all sides of the target dose profile except the right side, which we suspect was caused by a rotation of the phantom due to a loose leveling screw.

![Table 3. Average DTAs for each direction for both treatment systems](image)

Discussion: While the distance-to-agreement shifts in the R-L direction were larger than desired, these DTAs represent just one slice of a plane of data, and the overall shifts demonstrated by the phantom were acceptable. The phantom showed good pixel pass rates for the more thorough gamma analysis with both the 5%/3mm and 5%/5mm criteria, and had a reproducibility within the RPC’s 3% criteria. The head phantom has been deemed acceptable for the integration into the RPC phantom audit program.

References:


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