Dosimetric Properties of a Liquid Embolic System in the Context of Proton Radiosurgery

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Objectives: Mayo Clinic in Arizona has recently initiated a proton beam-based radiosurgery program with an emphasis on arteriovenous malformations (AVMs). The technology used is spot scanning proton beam therapy in conjunction with brass apertures inserted into a specially designed aperture holder. In this paper we report on the relative proton stopping power (RSP) measurement of a commercially available embolization agent used in the treatment of AVMs. This embolization agent includes Tantalum (atomic number 73) powder to increase its radiological visibility. The impact of the Tantalum on the proton beam is unclear, requiring the RSP measurement. We report on the measurement technique, as well as on the use of the information gained in treatment planning.

Methods: A sample of the Onyx 18 Liquid Embolic System (eV3 Neurovascular, Irvine, CA) was extruded into a small cylindrical vessel filled with water, causing rapid polymerization of the Onyx agent and forming a heterogeneous, spongy cylindrical plug, similar to the embolus produced in vivo by the Onyx system in the treatment of an AVM. The RSP of this plug was determined by measuring the range difference of a proton beam passing through it. The water-equivalent range of a 200.4 MeV clinical proton beam was measured using a detector consisting of a block of organic plastic scintillator and a calibrated camera. The light produced by the proton beam in the scintillator was measured by the camera, which provided the beam range via its internal calibration and through precisely-spaced marks on the scintillator surface. This system had a spatial resolution of 0.2 mm, and it had been previously validated by comparison with proton beam range measurements in a water tank and a multi-layer ionization chamber. The proton beam range was measured with and without passing the beam through the cylindrical Onyx plug. The measured beam range difference gave the water-equivalent thickness of the plug, which was then divided by the plug's physical thickness to give the RSP of the Onyx material. The plug's physical thickness is not perfectly representative of the material thickness due to its heterogeneous, sponge-like structure. Therefore, the plug's physical thickness was scaled by the ratio of the plug's physical volume to its external volume. The physical volume was measured by immersing the plug in water in a graduated cylinder. The embolus plug was scanned with a CT scanner with high dynamic range, providing an accurate image intensity without saturation.

Results: The measured water-equivalent thickness of the Onyx plug was 3.5 mm using the scintillator detector, and its physical thickness was 5 mm, with a volume fill ratio of 44%. The resulting relative stopping power was 1.6 (relative to water). The areas of Onyx embolization in our patient saturated our clinical CT scanner, providing no useful corresponding RSP. However, the embolus plug was scanned on a CT scanner with 16-bit dynamic range, resulting in a heterogeneous image with a range of image intensities from 6,000 to 18,000 Hounsfied Units (HU). According to our HU to RSP calibration curve, this range of HU corresponds to a range of proton RSP from 3 to 5.5. The discrepancy between the measured RSP and that predicted by the CT scanner led us to override the HU in the patient's CT scan. The areas of Onyx embolus detected in the patient's CT were overridden with the appropriate HU's to select the measured RSP by means of the CT scanner's HU to RSP conversion table.

Conclusion(s): Embolization procedures are an accepted treatment method for AVMs, including embolization materials such as Onyx, which incorporate high-Z materials to enhance their visibility in x-ray radiography. Radiation therapy is also a common treatment for AVMs, and it is expected that radiation therapy AVM patients will at times have residual embolization material in or adjacent to the treatment field. The presence of high-Z materials in the emboli may lead to inaccurate RSP determination, which can lead to serious errors in proton dose calculation. Our measurements demonstrate that, while the small concentration of Tantalum powder has a large impact on radiographic contrast and CT numbers, it has a minimal impact on the proton RSP. We found the Onyx emboli to have a RSP of 1.6. This is similar to dense bone, which has a RSP of 1.46.