

Purpose: To identify fiducial markers that are good candidates for use in proton therapy of the prostate by evaluating each marker based on three criteria: radiographic visibility on kV portal images, minimal perturbation of therapeutic dose in a clinical proton beam ($\leq 10\%$ near the middle of the SOBP and $\leq 15\%$ near the end of range), and no streak artifact production in CT treatment planning images.

Methods: Twelve total fiducials, one that is routinely used at our institution and eleven prototype, non-commercially available markers, were evaluated. The radiographic visibility of each marker was verified by acquiring kV plane radiographic images of the fiducials in a pelvic RANDO® phantom using an on-board imager (OBI) kV imaging system. CT images of the pelvic phantom containing the markers were also acquired and analyzed in order to quantify the CT streak artifacts caused by each marker. To measure the dose perturbations caused by each fiducial, the fiducials were loaded into a PMMA phantom along with radiochromic film and irradiated using a clinical proton beam (225 MeV, 10 cm SOBP). Measurements were taken with the fiducials located at the middle of the SOBP as well as near the end of range.

Results: Five prototype fiducials along with the clinical fiducial, met our criteria for clinically acceptable fiducials markers; all of the passing markers were composed of carbon-coated ZrO₂.

Conclusions: This work indicates that carbon-coated ZrO₂ is a judicious choice for fiducial markers in proton therapy because this material represents a good compromise between two conflicting requirements, radiographic visibility and minimal dose perturbations. Furthermore, several general recommendations can be extracted from this study (mid-Z material, minimize mass thickness while maintaining good radiographic visibility) that can be applied to the design of more exotic fiducials as well as novel applications of fiducial markers in radiation therapy.