Knowledge of endoscopic ultrasound-delivered fiducial composition and dimension necessary when planning proton beam radiotherapy

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ABSTRACT

Background and study aims Little consideration has been given to selection of endoscopic ultrasound-guided fiducials for proton radiotherapy and the resulting perturbations in the therapy dose and pattern. Our aim was to assess the impact of perturbations caused by six fiducials of different composition and dimensions in a phantom gel model.

Materials and methods The phantom was submerged in a water bath and irradiated with a uniform 10 cm × 10 cm field of 119.7 MeV monoenergetic spot scanning protons delivered through a 45 mm range shifter. The proton "Bragg Peak" was evaluated.

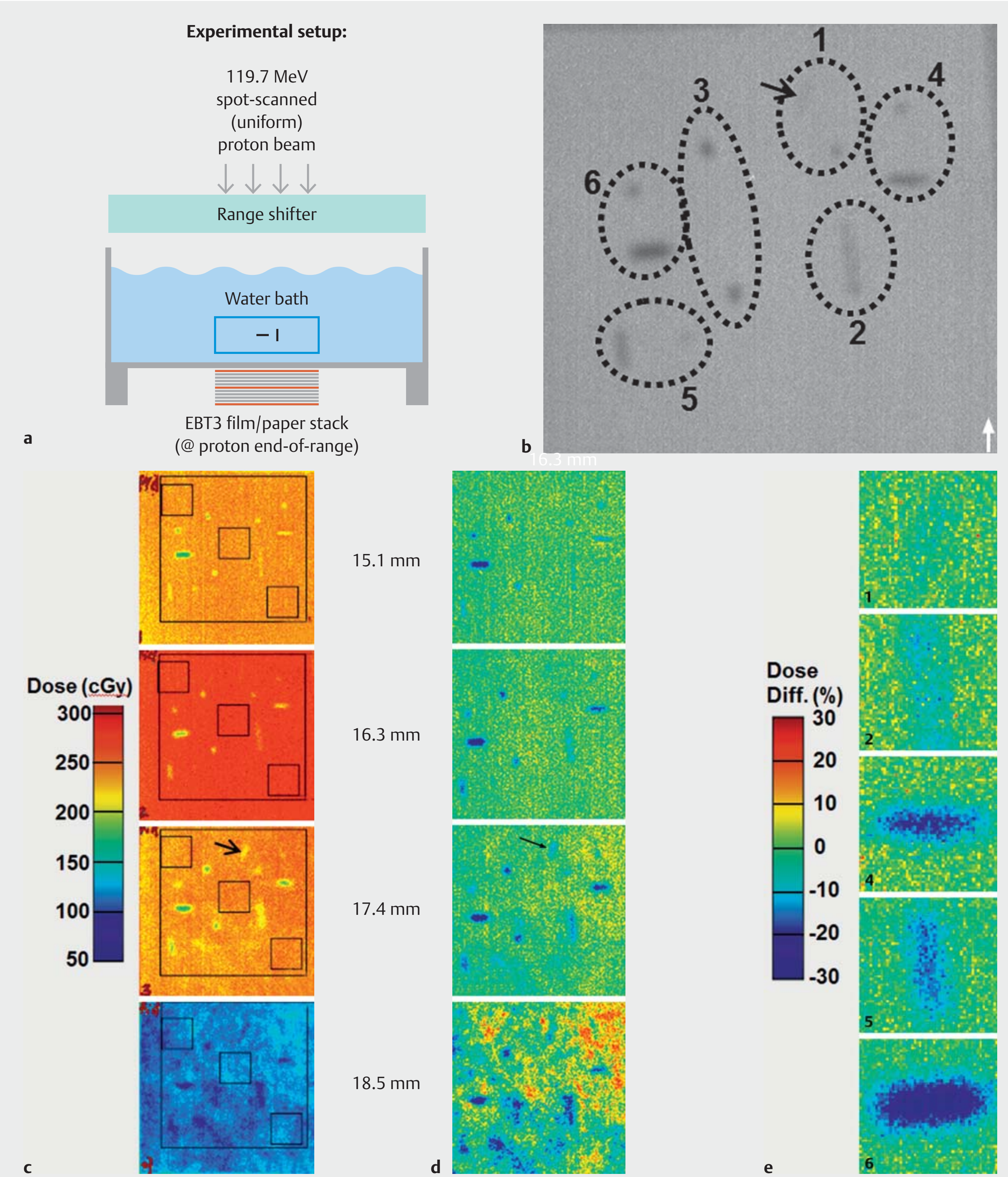
Results Dose perturbations manifesting as dose reductions up to 30 % were observed. A carbon composite (1 × 5 mm) and gold (0.4 × 10 mm) fiducial with backload potential rather than dedicated EUS pre-loaded gold fiducial needles had the best performance in terms of minimizing the dose perturbation.

Conclusions Our data demonstrate that a carbon composite fiducial has a less untoward effect on proton therapy dose distribution than dedicated EUS pre-loaded gold fiducial needles. Such information is important to consider when selecting fiducials specifically for proton therapy.

Introduction

Proton radiotherapy (RT) is a form of external beam RT (EBRT) that is of increasing interest, as it is associated with a reduction in normal tissue radiation exposure when compared with conventional photon RT. EBRT in soft tissue regions may be guided radiographically using implanted fiducial markers composed of a high atomic number (Z) material such as gold or other metallic alloys. Ideal markers whether placed by interventional radiology or by endoscopic ultrasound (EUS) should have good radiographic visibility, not migrate, display minimal artifacts on computed tomography or magnetic resonance imaging used for treatment planning and, in particular, not distort the delivered dose of the treatment beam. Conventional photon beams are relatively insensitive to presence of fiducial markers, but the same does not apply to proton beams; the perturbation in dose distribution for proton RT is strongly influenced by fiducial composition [1 – 3]. As the role and utility of proton RT is clinically increasing for gastrointestinal malignancies, interest in EUS-guided fiducial placement for pancreas ductal adenocarcinoma proton RT is gaining momentum. Currently available options include back loading of individual fiducials into an EUS needle and sealing with bone wax or use of newly introduced EUS pre-loaded devices that contain several gold fiducials [4, 5].

In the current study, we sought to assess the "worst case" dosimetric impact of perturbations caused by six commercially available carbon composite or gold fiducial markers of different composition and dimensions in a phantom gel model, as potential radiopaque markers for use in proton RT.



▶ **Fig. 1** **a** Schematic of experimental setup: a gel phantom containing fiducial samples was submerged in a water bath and irradiated with a uniform 10 × 10 cm^2 field of 119.7 MeV protons using discrete spot scanning. Exiting the water bath, the protons stopped in a paper stack arrangement interleaved with four EBT3 (Gafchromic) films spaced approximately 1.1 mm apart (water-equivalent spacing). **b** Digitized EBT3 film (16.3 mm behind fiducial plane, closest to the Bragg Peak) identifying the set of fiducial samples included in the present study. Note that an edge-on example for Sample 2 was not incorporated in the gel phantom. The side-on example for Sample 2 is difficult to visualize and therefore black arrows are included as a guide-to-eye (in **b**, **c**, and **d**). **c** Dose in cGy for a set of EBT3 films exposed to the end-of-range region, with water-equivalent depths behind the fiducial plane as shown. The small ROIs indicate the regions used for nominal (or background) dose sampling (for normalization) and the large ROIs designate the cropping regions for **d**. **d** Dose difference (from background) in % for corresponding cropped film regions from **c. e** Dose differences observed nearest the Bragg Peak (16.3 mm film) for zoomed (6.4 × 6.4 mm^2) ROIs affected by the five given side-on samples (#1, #2, #4 – 6).

Materials and methods

The fiducials with back load potential, were carbon composite or gold measuring 1 × 5 mm (#1), 0.4 × 10 mm (#2) and 0.28 × 10 mm in a clustered arrangement (#3), respectively: all with 22G needle potential. The EUS pre-loaded gold fiducial needles (#4 – #6) were either 0.43 × 5 mm (#4 and #5) via a 22G needle (EchoTip Ultra Fiducial Needle, Cook Medical or Beacon FNF Pre-loaded Needle, Medtronic) or 0.75 × 5 mm (#6) via a 19G needle (Beacon FNF Pre-loaded Needle, Medtronic). A gel phantom containing the aforementioned fiducials placed in both side-on and edge-on orientation relative to the beam axis for all samples except #2 and #3 was submerged in a water bath and irradiated with a uniform 10 cm × 10 cm field of 119.7 MeV monoenergetic spot scanning protons delivered through a 45-mm range shifter. Radiation-sensitive, self-developing Gafchromic EBT3 films (Ashland Advanced Materials, Bridgewater, New Jersey, United States) were placed in a sandwich-stack arrangement incorporating paper spacers of known proton stopping power with approximate water-equivalent film spacing of 1.1 mm and positioned immediately downstream of the water bath. The bath depth was adjusted such that the film stack sampled the region of maximum dose deposition known as the proton "Bragg Peak."

Results

Dose perturbations manifesting as dose reductions up to 30 % were observed. The magnitude and size of the observed dose reductions are likely clinically relevant. ▶ **Fig. 1** represents both a qualitative and quantitative summary of our findings. We noted an apparent correlation with both fiducial composition and diameter. Edge-on configurations resulted in generally smaller dose perturbations than side-on configurations. As demonstrated by ▶ **Fig. 1e**, the side-on 0.75 × 5 mm fiducial (#6) gave the largest perturbation in terms of both magnitude and size. Fiducials #1 and #2 had the best performance in terms of minimizing the dose perturbation. The clustered fiducial (#3) configuration did not compare favorably to #1 and #2. The results for samples #4 and #5 were generally similar in magnitude to #3.

Discussion

The dosimetric effects of polymer-based or biodegradable esophageal stents is less than that of self-expanding metal stents and attributed mainly to the stent mesh density [6]. Dose perturbation changes have also been demonstrated for fiducials composed of carbon, plastic-coated stainless steel and conventional gold fiducials for patients with prostate cancer undergoing proton RT, favoring carbon composite markers [7]. For endosonographers, there is growing call to place fiducial markers to guide treatment planning and delivery of proton RT. However, there has been little consideration regarding the composition and diameters of fiducials and the resulting perturbations in the dose and pattern of therapy. Resulting decrements in radiation dosage result in a less effective tumor cell death, and conversely secondary dose escalations risk injury to healthy tissues. Our data demonstrate that carbon composite (1 × 5 mm) and gold (0.4 × 10 mm) fiducials, both with needle back loading capabilities, have less untoward effects on proton RT dose distribution than the dedicated EUS pre-loaded gold fiducial needles. Such information is important to consider when working with our radiation oncology partners and selecting fiducials to guide RT and for industry when considering product development.

Competing interests

None

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