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Feasibility of out-of-field dosimetry in photon, proton, and neutron therapies using a 3D-printed patient-specific phantom

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INTRODUCTION

Currently treatment planning systems used in external beam radiation therapy do not accurately take into account dose contributions outside the field of radiation (i.e., 50% isodose surface).[1] However, out-of-field dosimetric evaluation is necessary for radiosensitive sites that lie outside the treatment field which could experience detrimental effects due to stray radiations (e.g., fetus or pacemaker).

Evaluation of these sites is carried out through a variety of methods. Most commonly seen is the use of water equivalent blocks, water tanks, analytical models, Monte Carlo simulations, and anthropomorphic phantoms.[2] To date, a whole body 3-D printed, patient-specific anthropomorphic phantom has not been tested for out-of-field dosimetry.

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2, Kry SF, Bednarz B, Howell RM, et al. AAPM TG 158: Measurement and calculation of doses outside the treated volume from external-beam radiation therapy. *Medical Physics*. 2017;44(10):e391-e429. doi:10.1002/mp.12462

AIM

To test the feasibility of using a 3D-printed, patient specific phantom for out-of-field dosimetry in photon, proton, and neutron external beam radiation therapy systems.

METHOD

Louisiana State University 3D printed a 5'4" female research subject as a shell to be filled with water and used for out-of-field dosimetry. A PVC rod ran along the central axis of the phantom entering through the top of the head and exiting through the pelvic floor. This rod allowed for the insertion of a variety of radiation detectors at predetermined locations throughout the body. For out-of-field measurements in this study, we utilized a farmer chamber for photon therapy and an IC-30 filled with tissue equivalent gas for neutron and proton therapies.

The isocenter was located in the cranium and was placed around the intersection of the planes of the eyes, ears, and PVC pipe. Left-lateral intracranial fields of 2.8x2.8, 5.3x5.3, 7.8x7.8, 10.3x10.3, and 12.8x12.8 cm^2 were delivered using clinical photon, proton, and neutron external beam radiation therapy systems. Out-of-field dosimetric measurements were taken in the locations of the thyroid, esophagus, fetus, and pacemaker for each external beam therapy. Photon therapy was delivered with a 100 cm SAD setup on a Varian Novalis Tx (6 MV) and Elekta Versa HD (6 MV, 6 FFF). Pencil beam proton therapy was delivered using a maximum beam energy of 170 MeV and SOBP of 10 cm. Neutron therapy was delivered using the Clinical Neutron Therapy System which employs a 50.5 MeV proton beamline impinging on a 10.5 cm thick Beryllium target to generate a fast neutron beamline with a depth dose profile similar to that of a 6 MV photon beam. All out-of-field data was reported as absorbed dose, D (cGy), per absorbed dose prescribed at isocenter, D_{Rx} (Gy).

Figure 1. Photograph of 3D printed phantom shell. Labeled on the phantom are the approximate radiation detector placement locations for Isocenter (A), Thyroid (B), Esophagus (C), Fetus (D), and Pacemaker (E). Beams were delivered using left lateral fields of 2.8x2.8, 5.3x5.3, 7.8x7.8, 10.3x10.3, and 12.8x12.8 cm^2 for clinical photon (6 MV, 6 FFF), proton (170 MeV, 10cm SOBP), and neutron therapy. Detectors were placed inside the PVC pipe that lies along the central axis of the phantom for all measurements excluding the pacemaker. Buildup caps were employed for measurements taken at the pacemaker, giving an approximate depth of 5 mm.

RESULTS

All therapies excluding neutron therapy demonstrated that having a larger volume irradiated led to a higher out-of-field absorbed dose. This was coupled with a decreased absorbed dose with an increased distance from the field edge.

The modality with the lowest out-of-field absorbed dose was pencil beam scanning proton therapy followed by the Elekta Versa HD 6 FFF, Elekta Versa HD 6 MV, Varian Novalis Tx 6 MV, and neutron therapy.

For photon therapy, the Elekta Versa HD 6 FFF produced the lowest out-of-field dose, and in comparison to the Elekta Versa HD 6 MV, it was on average 25%, 15%, 25%, and 45% lower in the thyroid, pacemaker, esophagus, and fetus, respectively.

Comparing out-of-field absorbed dose for proton therapy to the Elekta Versa HD 6 FFF, we found that on average photon therapy was 60% and 30% higher in the thyroid and pacemaker, respectively.

Beyond the pacemaker, the out-of-field dose from proton therapy was indistinguishable from background for each field size.

Neutron therapy showed the highest absorbed dose for all locations with smaller field sizes having the largest out-of-field dose contribution.

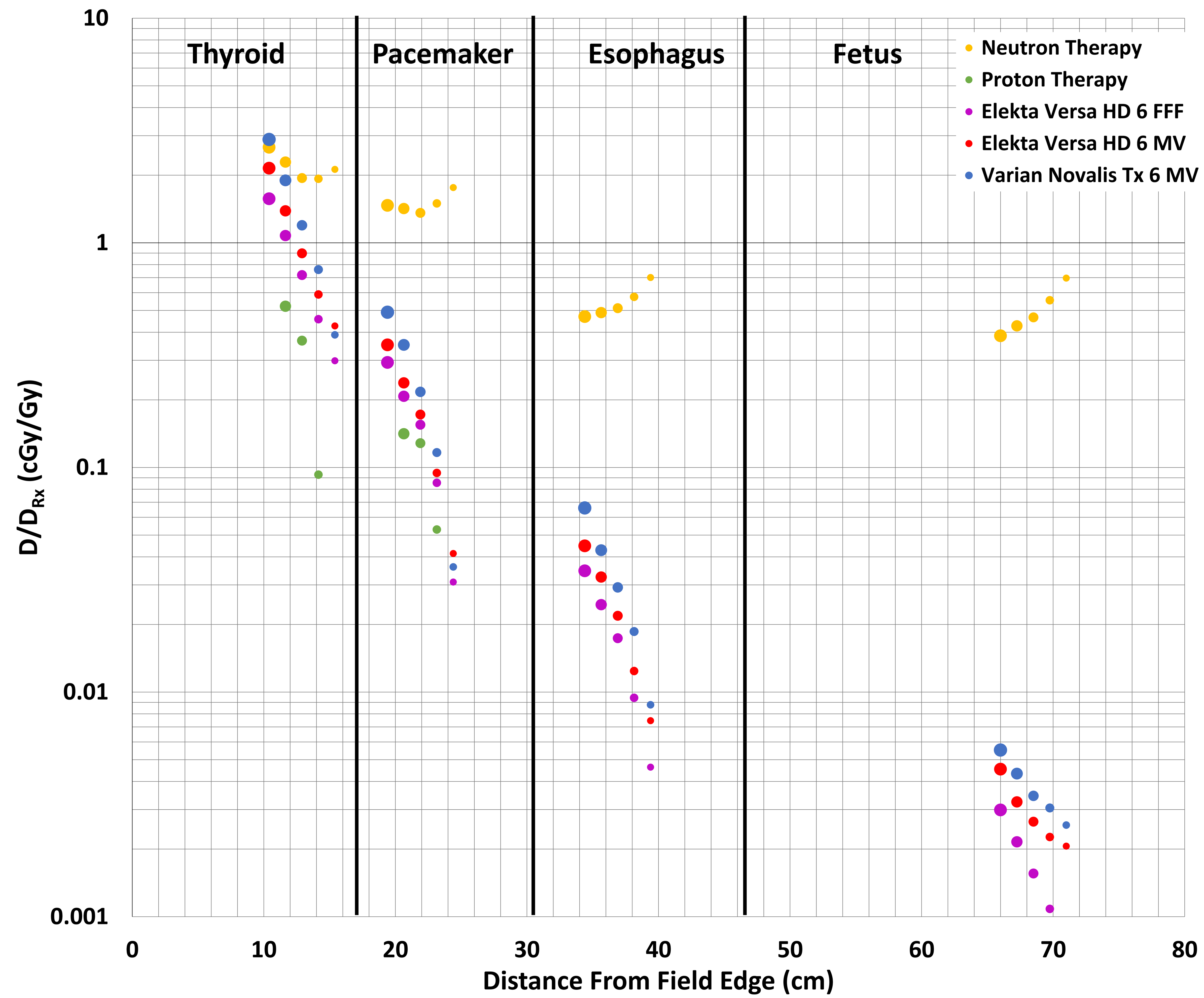

Figure 2. Graph of absorbed dose per dose prescribed (D/D_{Rx})(cGy/Gy) versus distance (cm) from the field edge for 6 MV Elekta 6 FFF (purple), 6 MV Elekta (red), 6 MV Varian (blue), proton (green), and neutron (yellow) external beam therapies. Solid black lines denote the general location of Thyroid, Pacemaker, Esophagus, and Fetus. Data points vary by field size and region with field sizes of 2.8x2.8, 5.3x5.3, 7.8x7.8, 10.3x10.3, and 12.8x12.8 cm^2. Smaller data points indicate smaller field sizes (2.8x2.8 cm^2) and larger data points indicate larger field sizes (12.8x12.8 cm^2).

CONCLUSIONS

We demonstrated the feasibility of utilizing a 3D printed phantom for out-of-field dosimetry in a variety of external beam radiation therapies. This study also highlighted the considerable reduction of out-of-field dose by utilizing pencil beam scanning proton therapy.

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