Unique Considerations Associated with Neutron Ambient Dose Equivalent Measurement for a Gantry-Mounted Synchrocyclotron

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INTRODUCTION

Synchrocyclotrons deliver radiation in distinct macro pulses with high instantaneous dose rate that distinguish them from isochronous cyclotrons and synchrotrons. The relatively high instantaneous dose rates associated with synchrocyclotrons require special consideration in measurement of the neutron dose [1]. The objective of this work is to measure the out-of-field neutron ambient dose equivalent (H*(10)) and assess the fetal dose due to secondary neutrons for a gantry-mounted synchrocyclotron proton therapy system when an intensity modulated proton therapy (IMPT) brain treatment is delivered with the dynamic aperture (DA), static aperture (SA), and no aperture (NA).

METHOD

IMPT plans were created to treat a spherical brain target with 6 cm diameter. Out-of-field neutron ambient dose equivalent was measured at several distances using a WENDI-II and a LUPIN-BF3-NP rem-meter [1].

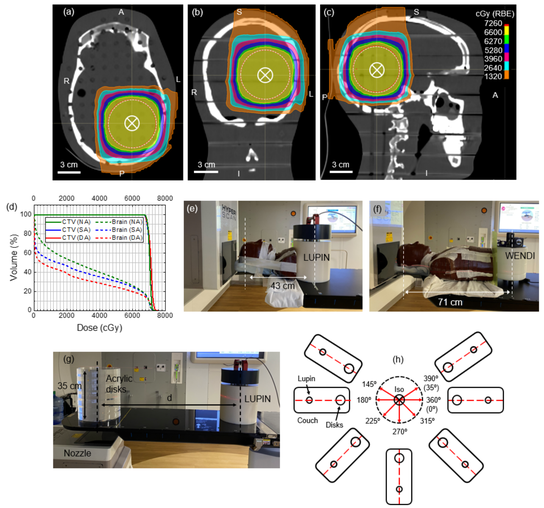

Figure 1. (a-d) Dose distribution and DVHs. Measurement geometry using LUPIN-BF3-NP and WENDI-II with (e-f) an anthropomorphic and (g-h) cylindrical phantoms.

RESULTS

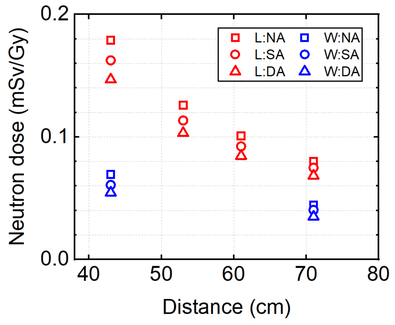

Figure 2. Measured neutron dose, normalized by the proton dose (2 Gy, RBE-weighted), using LUPIN (L) and WENDI (W) as a function of distance from the isocenter for plans with static aperture (SA), dynamic aperture (DA), and with no aperture (NA). Error bars are within the symbols. WENDI suffers from dead-time and underestimates the dose by ~2-3 times.

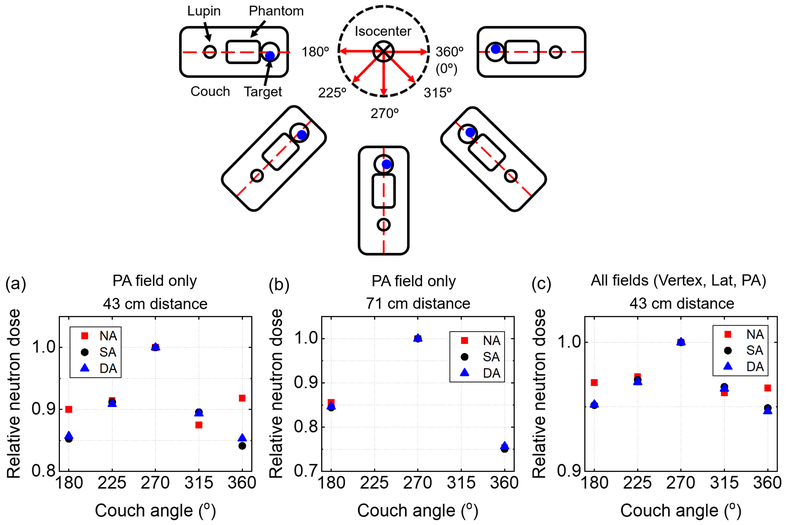

Figure 3. Measured relative neutron dose from the PA field at (a) 43 and (b) 71 cm distance using LUPIN as a function of couch angle for plans with static aperture (SA), dynamic aperture (DA), and with no aperture (NA). (c) Measured neutron dose at 43 cm distance from all fields as a function of couch angle. The neutron dose in each panel was normalized to the maximum at the corresponding panel. Insets show schematic of the measurement geometry for the PA field in which the proton beam emanates perpendicular to the plane of the paper towards the viewer. The target was located at the isocenter in each case.

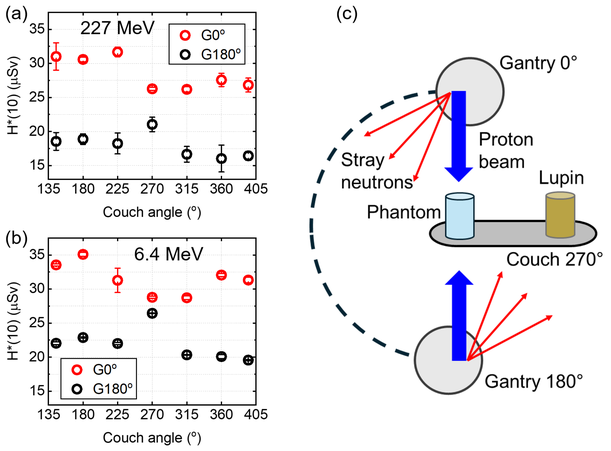

Figure 4. Measured neutron dose from a single spot with 300 MU and (a) 227 MeV and (b) 6.4 MeV energy delivered at 0º (red symbols) and 180° (black symbols) gantry angle at various couch angles. (c) Schematic explanation of the local minimum (maximum) at 270° couch angle for 0º (180°) gantry angle based on the directionality of the stray neutrons emanating from the accelerator.

CONCLUSIONS

Temporal radiation output structure of the proton therapy machines must be carefully considered to choose the proper neutron rem-meter for neutron dose assessment. Synchrocyclotrons, due to their pulsed nature, overwhelm conventional rem-meters such as WENDI leading to a significant under-estimation of the dose. In gantry-mounted synchrocyclotron systems, due to the proximity of the range shifter plates to the patient, neutron dose is higher than that in machines in which the accelerator is located far away from the isocenter. The neutrons from the gantry-mounted accelerator have asymmetrical directionality leading to asymmetry in the neutron dose with respect to the couch angle.

REFERENCES

[1] A. Darafsheh et al., "First multi-institutional systematic comparison of the neutron ambient dose equivalent produced by proton therapy systems," Physics in Medicine & Biology, (2025).

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