Experimental validation of single detector proton radiography with scanning beams

Cezarina Chirvase1,2, Kevin Tro2, Roger Barlow3, El Hassane Bentefour3

1International Institute for Accelerator Applications, The University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK
2Department of Radiation Oncology, University of Pennsylvania, Philadelphia, PA, USA
3Advanced Technology Group, Ion Beam Applications s.a., Louvain-la-Neuve, Belgium, EU

Introduction and Objectives:
Contrary to the traditional concept of proton radiography [1] (Fig. 1a) which uses multiple detectors and a single beam energy, the Proton Energy Resolved Dose imaging method (PERDi) uses a single detector and multiple beam energies (Fig. 1b). The concept of PERDi was demonstrated by Bentefour et al. [2]. In this study, we perform end to end experimental evaluation of PERDi. Using multiple phantom configurations, we evaluate the method’s accuracy to determine the Water Equivalent Path Length (WEPL) and the Relative Stopping Power (RSP), in addition to testing it with a heterogeneous anthropomorphic phantom.

Materials and Method:
To perform the PERDi evaluation experiments we used the following materials:
• a commercial 2D detector (Lynx, IBA-Dosimetry, Schwarzenbruck, Germany) which has an active surface area of 300 × 300mm2 with an effective resolution of 0.5mm.
• an imaging field with a size of 30 x 30cm2 and multiple combinations of beam sets with energies between 226MeV and 100MeV is used to deliver a uniform dose. The dose per spot for each beam of the imaging field is 0.1MU (~ 1eV/cm2).

The experimental workflow shown in Fig. 2, consists of the following steps:
• a. The imaging field is first delivered on a wedge shaped water phantom (Fig. 2a) to produce a calibration library of Energy Resolved Dose Functions (ERDFs) between 0 cm and 30 cm (Fig.2b).
• b. The imaging field in (ii) is delivered respectively on configurations (Fig. 2c): configuration 1 is a stack of solid water stairs like used to test the WEPL accuracy of the method. Configuration 2 is a CIRS phantom with multiple tissue surrogate plugs used to test the method’s accuracy to measure the RSP and configuration 3 is a head phantom used as heterogeneous test case.
• c. By retracing the signal from every pixel j of the detector (i) against the beam energies of the imaging field (ii), we obtain an ERDF, as shown in Fig. 2d.
• d. By performing a least square fit of the ERDF against the calibration library measured from step (a) we obtain the WEPL of the phantom along the axis vertical to pixel j.

Experimental Results:

Configuration 1: stairs like phantom

(a) Experimental set-up
(b) Example of a WEPL map
(c) Comparison of measured and expected WEPL profiles
(d) WEPL accuracy for various imaging doses

Figure 3 shows: (a) the experimental set-up: stacks of solid water placed in a stairs like shape with steps of thicknesses between 1mm and 50mm and a total thickness between 70 mm and 230 mm; (b) is the measured WEPL map of the solid water stacks; (c) compares the measured and expected WEPL profiles and (d) shows the WEPL accuracy against the number of layers of the imaging fields: ± 1mm WEPL accuracy is achieved for an imaging field with 10 layers or more.

Configuration 2: CIRS phantom

(a) Experimental set-up
(b) Example of a WEPL map
(c) Summary of RSP values and the estimated error in %
(d) RSP accuracy for various imaging doses

Figure 4 shows: (a) the experimental set-up: a CIRS phantom with tissue surrogate plugs; the inserts mimic 9 tissue types with densities between 0.2 g/cm3 to 1.5 g/cm3; (b) the measured WEPL map; (c) a summary of the measured RSP values for a case of imaging field with 26 layers; (d) the average accuracy for all tissue surrogates vs the imaging dose. A 2% RSP accuracy is achieved for all homogeneous tissue surrogate plugs for imaging fields with 10 layers or more.

Configuration 3: head phantom

(a) Experimental set-up
(b) WEPL maps for an imaging field with (m) 47 layers and (m) 10 layers
(c) Comparison of the cumulative WEPL profile of the forehead of the head
(d) Comparison of the cumulative WEPL profile of the posterolateral of the head

Figure 5 shows: (a) the experimental set-up: a head phantom; (b) the measured WEPL maps for an imaging field with (m) 47 layers and (m) 10 layers, respectively; (c) a comparison of the cumulative WEPL profiles for the maps (m) and (m) over pixels X=480:580 and (d) a comparison of the cumulative WEPL profiles for the maps (m) and (m) over pixels X=50:175. The compared profiles are in good agreement with a 2mm systematic error, which may be due to the choice of the beam energies of the 10 layers imaging field.

Conclusion
Proton radiography with single detector using energy resolved dose measurement shows potential for clinical use in PBS setting. The achieved WEPL and RSP accuracies are encouraging. Further studies, with a more sensitive detector are needed to optimize the imaging dose and the clinical workflow.

References