Study on the compatibility of tissue equivalent phantoms for use in proton beam therapy QA

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INTRODUCTION

The main goal for external radiation therapy is to deliver dose to tumor while keeping surrounding healthy tissues none or less affected by the delivered dose. This can be done by monitoring dose during treatment. Although there is a way to measure the dose in-vivo during treatment, this is not practical for the patient health and there is a difficulty in the setup. Another way is to find or manufacture materials which are closer to body in dosimetric properties in which dose measurements is practical and less complicated. In that respect, it is recommended by many protocols to use water as a material for reference dosimetry (ICRU 59, IEAE TRS 398, AAPM TG-21, AAPM TG-51). But dosimetry measurements setup in water is very tedious work and not very practical. So water is used generally for machine calibration in monthly or annual QA , not day to day application. On the other hand, manufactured tissue equivalent phantoms which can mimic the properties of water or body tissues can be used for dose estimation. Those phantoms manufactured to mimic tissues should have been in agreement with actual absorbed dose within accepted uncertainty (ICRU 44, 1989). In other words the materials should be selected carefully to be equivalent to tissues in terms of radiation dosimetry.

Proton therapy offers physical advantages over conventional therapy (Sandison et al 2000, Hong et al 1996, Petti 1992,Schneider et al 1994). In order to fully utilize what has been offered by proton therapy, absorbed dose should be carefully measured. Normally, proton beam characteristics such as beam range in water, lateral flatness and penumbra are carefully measured in QA process. Many tissue equivalent phantoms are used in that QA process. While electron density is main focus in conventional therapy to manufacture tissue equivalent phantoms, stopping power of proton beams in those phantoms plays important role in proton therapy. So 3D stopping power map should be acquired through proton CT. But this is still in ongoing research area. Instead, Human tissues are visualized as electron densities with the help of CT scanner. Then these electron densities, namely CT numbers imported into treatment planning system. So, there should be conversion curve from CT numbers to stopping powers in order to use this proton modality for patient treatment. But many authors mentioned uncertainties caused by conversion process up to 5% (Shaffner et al 1998, Schneider et al 1996). These uncertainties motivate many researchers to look into uncertainties caused by tissue equivalent phantoms used in proton beam therapy (Schenider et al, 2002).

The aim of this study is to analyze the compatibility of tissue equivalent phantoms in proton therapy with the help of Proton Loss (PL) model. We have used following CIRS Inc. (Norfolk, VA) tissue equivalent media : PW® (Plastic Water-original), PW® -DT (Plastic Water Diagnostic Therapy), PW® -LR (Plastic Water Low Range), AB (Average Bone), ST (Soft Tissue), CB (Cortical Bone).

METHOD AND MATERIALS

Range (R) and Energy (E) relationship of proton beams can be defined by Bragg-Kleeman rule (1905) as shown in the following formula, $R=\alpha E^p$ where α and p are Atomic number dependent and energy dependent constant, respectively. These constants can be obtained by curve fitting on energy-range relationship of proton beams (See Figure 2). The energy-range data were imported from Ziegler et al.[2]. We used Bragg additivity rule to calculate stopping power and range for the materials which are not listed in data from Ziegler et al. The spreadness and field sizes of proton beams in tissue equivalent slab phantoms were calculated using Proton loss model (Sandison et al, 2000). We implemented WET depth concept into proton beam lateral spreadness calculation. The fluence, field size increase and WET measurements were carried out at HUPTI (Hampton University Proton Therapy Institute). The radiographic films were used to measure the field size at 5 cm and 10 cm WET depth. We intended to deliver 28cm pristine Bragg peak so that we were able to measure field size within the flat region of depth doses. WETs were measured using MLIC (Multi-layer ionization chamber) system. WET measurements were performed in two different settings, with and without slab phantoms introduced in front of MLIC system. The shift in the range measurement is equal to WET as MLIC measures the dose through WET depths. The WET calculation through TPS is performed by using Philips Big Bore PET/CT. Those tissue equivalent phantoms are scanned then imported to Eclipse treatment planning software where WET is calculated. See (Figure 1)

Figure 1: Experimental design for proton beam WET measurements with MLIC (left) and tissue equivalent phantoms are scanned through Philips Big Bore PET/CT (right) to calculate WET in TPS.

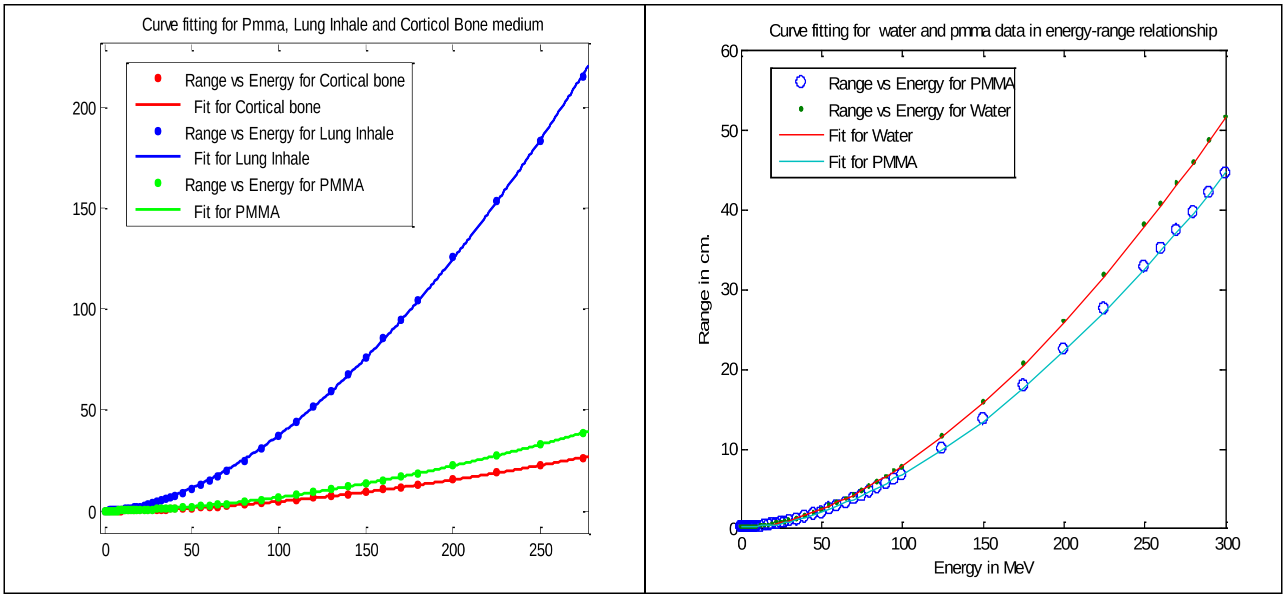

Figure 2: Curve fit for different tissue equivalent media. The data for range of proton beams were taken from Ziegler et al.

RESULTS

We found that measurements and calculations for WETs of those media are in good agreement within 1% accuracy except CB case which is ~1.3 %. Also, field size of PW with PL Model is in good agreement with field size measurement. Moreover, we found that WES of proton beams with respect to water is giving constant value throughout the range at the same WET depth. On the other hand, the calculated WET and WET from Treatment Planning System (TPS) are not in good agreement (See: Table3). PL model is in good agreement with MCNPX Monte Carlo calculation for field size measurement. PL model is also predicting field size of proton beam in PW medium. The film measurements for PW phantom is in good agreement with our model which is less than 1 mm.

WET cm	**Calculated 152.98 MeV**	**Measured 152.88 MeV**	**Difference %**	**WET cm**	**Calculated 211.88 MeV**	**Measured 211.88 MeV**	**Difference %**
PW 5cm	4.973	4.963	0.193	**PW 10cm**	9.942	9.951	-0.089
PWDT 5cm	4.987	4.943	0.886	**PWDT 10cm**	9.974	9.905	0.698
ST 5cm	5.155	5.131	0.476	**ST 10cm**	10.308	10.291	0.166
PWLR 5cm	4.964	4.952	0.242	**PWLR 10cm**	9.992	9.993	-0.010
AB 5cm	7.309	7.258	0.696	**AB 10cm**	14.630	14.495	0.929
CB 5cm	-	-	-	**CB 10cm**	16.786	17.010	-1.317

Table 1: WET values for different CIRS Inc (Norfolk) phantoms. The calculated and measured WET values are in good agreement for all cases except Cortical Bone (CB) which is higher than 1%. Dashes mean that there is no data available.

WER	Calculated 152.98	Measured 152.98	% difference Calc. vs Meas.	Calculated from TPS	% difference Calc vs TPS
PW 5 cm	0.995	0.993	0.193	1.060	6.790
PWDT 5 cm	0.997	0.989	0.886	1.000	1.153
ST 5 cm	1.031	1.026	0.476	1.028	0.175
PWLR 5 cm	0.993	0.990	0.242	0.999	0.868
AB 5 cm	1.462	1.452	0.696	1.356	-6.586
CB 5 cm	-	-	-	-	-

Table 2: WER values for different CIRS Inc (Norfolk) phantoms. TPS calculated WET values are in agreement except AB and PW case. Dashes mean that there is no data available.

WER	Calculated 211.88	Measured 211.88	% difference Calc. vs Meas.	Calculated from TPS	% difference Calc vs TPS
PW 10 cm	0.994	0.995	-0.089	1.060	6.522
PWDT 10 cm	0.997	0.990	0.698	1.000	0.964
ST 10 cm	1.031	1.029	0.166	1.028	-0.102
PWLR 10 cm	0.999	0.999	-0.010	0.999	-0.030
AB 10 cm	1.463	1.450	0.929	1.356	-6.451
CB 10 cm	1.679	1.701	1.293	-	-

Table 3 : WER values for different CIRS Inc (Norfolk) phantoms. TPS calculated WET values are in agreement except AB and PW case. Dashes mean that there is no data available.

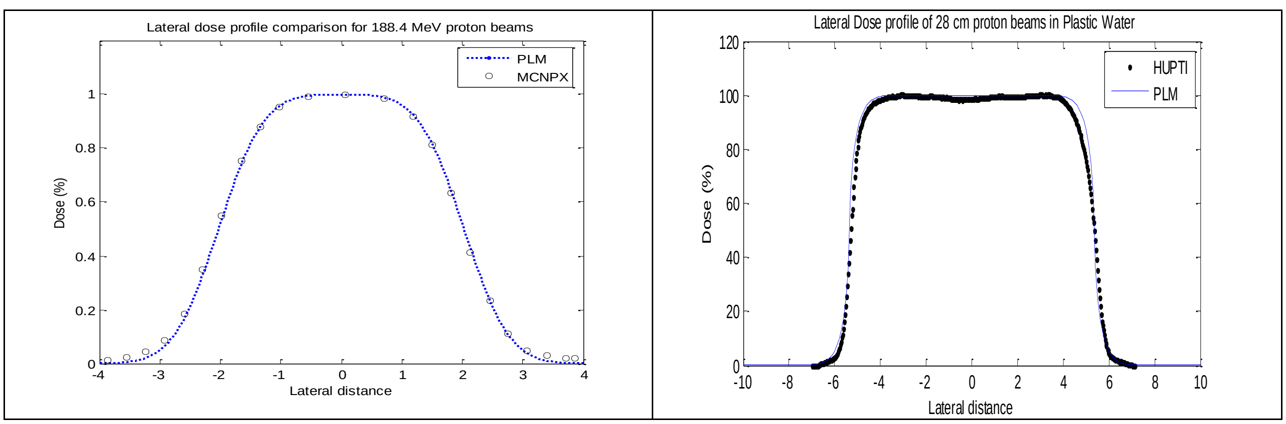

Figure 3: Field size measurement and calculation in water (Left). The MCNPX data are taken from Ciangaru et al (2005). Field size measurement and calculation in PW (Right).

CONCLUSIONS

It was found that calculated WETs of tissue equivalent media are in good agreement with calculations with Bragg-Kleeman rule and measurements. On the other hand, WET values from TPS which is calculated by CT calibration are giving discrepancies more than 5% for PW and AB case. This is due to Z^2/A (Z: atomic number and A: atomic weight) which is part of Bethe-Bloch stopping power formula. Moreover, PW does not provide a water equivalent response at typical CT energies, particularly it gives approx 80HUat 120 kVp as indicated by manufacturer. We believe that PWDT and PWLR are much more suitable for proton therapy in daily and Patient QA purposes.

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