EVALUATING CLINICAL STOPPING POWER ESTIMATION FROM A RADIOTHERAPY DUAL ENERGY CT SCANNER*

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The use of dual energy computed tomography (DECT) is increasingly considered in particle therapy (PT) to reduce the range of uncertainties attributed to the conversion of X-ray linear attenuation coefficients into relative stopping power (RSP). DECT scanners equipped with clinically available image conversion software can now be found in PT centers. In this work, RSP calculated on the basis of clinical DECT scanner software (syngo.via) was compared to a validated published procedure (Hudobivnik) for calibration and pediatric head phantoms. Based on material inserts, the average difference between RSP values calculated using syngo.via (Hudobivnik) against reference values were 1.0% (0.7%). This difference excludes the lung inserts as the syngo.via method does not provide Z_{eff} values for CT numbers < -500 HU. An analysis of the head phantom showed overall a good agreement with all RSP differences within 1% between the syngo.via and Hudobivnik methods. The use of clinically available syngo.via provides equivalent accuracy as a validated RSP calculation method.

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1. Introduction

Range uncertainties in proton therapy (PT) [1] are partially attributed to the conversion of X-ray linear attenuation coefficients obtained from computed tomography (CT) scans to relative (to water) proton stopping power (RSP), which is used for treatment planning. Currently, RSP uncertainties from single energy CT (SECT) are estimated at 3.5% [2]. The use of dual energy CT (DECT) to separate the contributions of the Compton scattering and photoelectric absorption to photon attenuation provides RSP values with 1% accuracy [3, 4] via relative electron density (ρ_e) and effective atomic number (Z_{eff}) estimation. While several methods for RSP estimation have been published [3–7], few are currently available clinically. DECT scanners have been recently installed at PT facilities [8] and clinical software allowing (ρ_e) and (Z_{eff}) calculation from DECT images has been made available. Differences in scanner and software performance suggest that careful validation is necessary before using a clinical DECT scanner [9]. In this study, the RSP accuracy from a clinical DECT scanner equipped with such software was evaluated against the validated DECT RSP evaluation methods of Hudobivnik *et al.* [6].

2. Material and methods

A Siemens SOMATOM Definition Open AS scanner with sequential DECT capability (Siemens Healthineers, Forchheim, Germany) installed at the Loyola University Medical Center in Maywood, IL, USA was employed to scan a custom made calibration phantom and a pediatric head phantom. The calibration phantom consisted of a 15 cm diameter PMMA cylinder centrally housing the tissue mimicking inserts of the Gammex RMI 467 electron density calibration phantom (Gammex, Middleton, WI, USA). The inserts' mass density ρ, ρ_e, Z_{eff}, mean excitation potential I, and RSP are found in Table I and were calculated using the elemental compositions and equations from [6]. The pediatric head phantom, model 715 HN from CIRS (Norfolk, VA, USA), is constructed of materials simulating bone and soft tissue. DECT scans of both phantoms were performed with sequential 80 kVp and 140 kVp acquisitions. CT number (CT#) images were reconstructed with the H20f kernel. The scanner software (syngo.via) was used to obtain (ρ_e) and (Z_{eff}) images. The Z_{eff} was calculated with exponent 3.1 using equation (2) from [6]. Alternatively, the low and high kVp CT# images were converted to (ρ_e) and (Z_{eff}) using the methods presented in [6]. Subsequently, the Bethe equation was used to calculate RSP, following conversion of (Z_{eff}) to the logarithm of I using the piecewise linear fits from [3]. RSP from the calibration phantom inserts and from homogeneous parts of the pediatric phantom were obtained using elliptical regions of interest (ROI) and used to compare the two methods.

TABLE I

Reference values for the Gammex phantom inserts. RSP is calculated for 175 MeV protons using $I_{\text{water}} = 75$ eV. ρ was taken from the inserts' calibration sheet.

Insert	ρ [g/cm^3]	ρ_e	Z_{eff}	I [eV]	RSP
LN-300 lung	0.27	0.261	7.36	76.3	0.261
LN-450 lung	0.42	0.409	7.49	73.8	0.410
AP6 adipose	0.947	0.928	6.16	66.5	0.942
BR-12 breast	0.981	0.959	6.82	68.0	0.970
CT solid water	1.017	0.987	7.53	70.2	0.995
BRN-SR2 brain	1.051	1.046	6.06	63.6	1.067
LV1 liver	1.104	1.075	7.49	69.5	1.085
IB inner bone	1.144	1.103	9.45	74.5	1.104
B200 bone mineral	1.153	1.104	10.15	80.3	1.095
CB2-30% CaCO2	1.333	1.278	10.60	80.7	1.267
CB2-50% CaCO2	1.556	1.466	12.26	93.1	1.428
SB3 cortical bone	1.823	1.693	13.38	105.6	1.626

3. Results

Table II reports the measured CT# as well as the errors compared to the reference of the DECT derived quantities for the syngo.via and Hudobivnik

TABLE II

Mean CT# at 80 kVp and 140 kVp for the calibration phantom along with the mean relative error $\Delta X = (X_{\text{measured}} - X_{\text{reference}})/X_{\text{reference}} \times 100\%$ of DECT derived quantities for the syngo.via method (M1) and Hudobivnik method (M2). The mean of the absolute value of insert errors is additionally reported, excluding the lung inserts from the calculation for both M1 and M2, since M1 does not calculate Z_{eff} for CT# ≤ -500 HU (due to the low signal to noise ratio of lung tissues).

Insert	CT#$_{80}$	CT#$_{140}$	$\Delta\rho_e$[%]		ΔZ_{eff}[%]		ΔRSP [%]	
	(HU)	(HU)	M1	M2	M1	M2	M1	M2
LN-300 lung	−753.9	−754.8	—	3.0	—	1.9	—	−2.3
LN-450 lung	−577.1	−582.7	—	−2.7	—	−0.3	—	−2.6
AP6 adipose	−127.2	−100.0	0.6	−0.3	−2.3	1.2	−0.1	−1.1
BR-12 breast	−69.5	−58.3	0.8	0.2	−2.6	1.4	0.8	0.1
CT solid water	4.9	−8.6	0.7	0.5	−3.6	0.1	1.4	1.2
BRN-SR2 brain	−10.3	15.3	0.8	0.2	−7.3	−3.4	0.8	0.2
LV1 liver	93.1	81	0.7	0.3	−4.2	0.6	1.5	1.0
IB inner bone	349	219.1	0.5	0.7	−5.8	−4.6	0.4	0.8
B200 bone mineral	365.6	236.4	−1.3	−0.8	1.5	3.1	−2.3	−1.7
CB2-30% CaCO2	689.5	483.6	−0.7	−0.4	−0.9	0.0	−0.8	−0.5
CB2-50% CaCO2	1284.9	873.7	−1.0	−0.4	0.5	0.0	−1.1	−0.2
SB3 cortical bone	1968.6	1321.2	−0.5	0.4	0.6	−0.1	−0.6	0.6
Mean error	—	—	0.8	0.4	2.9	1.5	1.0	0.7

methods (referred to as M1 and M2, respectively) for the Gammex phantom inserts. The mean of the absolute value of insert RSP errors were 1.0% and 0.7% for M1 and M2, respectively. For intermediate quantities ρ_e and Z_{eff}, M1 had mean errors of 0.8% and 2.9% respectively, while for M2 ρ_e and Z_{eff}, had lower mean errors of 0.4% and 1.5%.

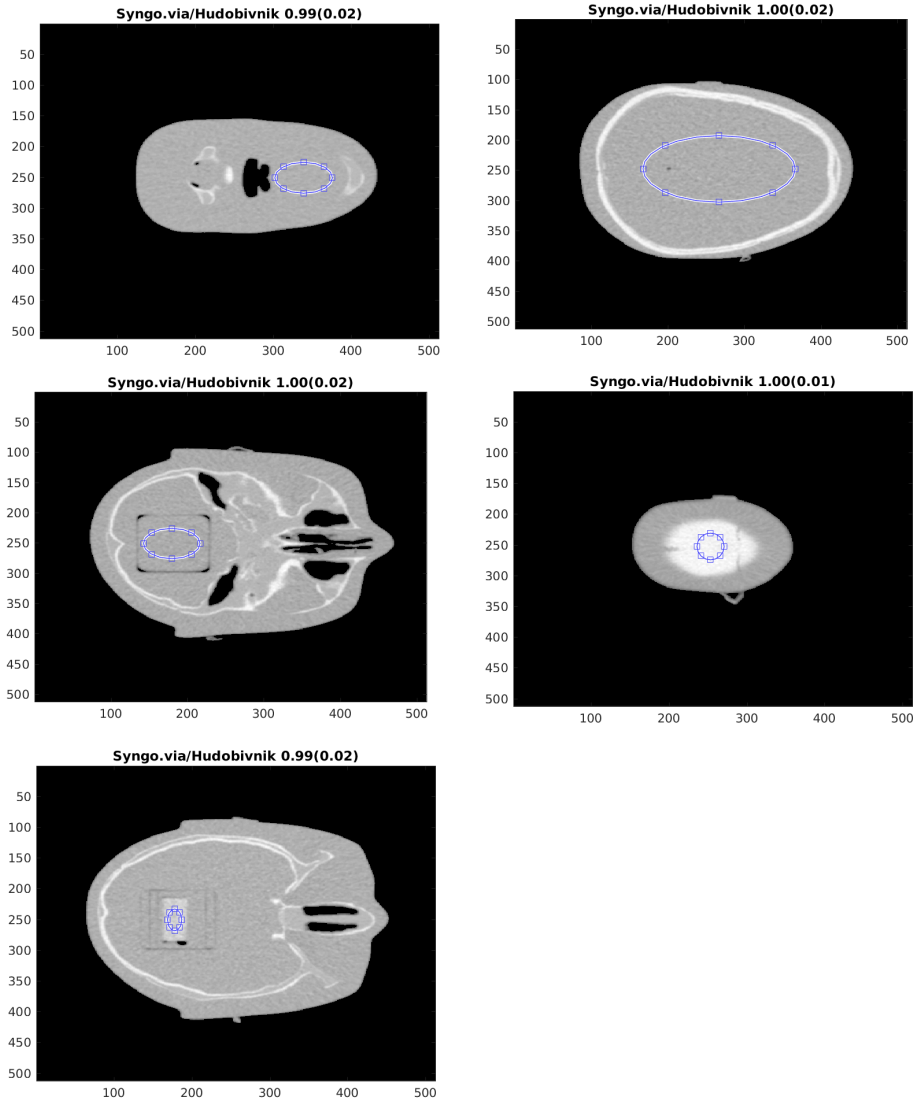

Fig. 1. RSP slices for the pediatric head phantom with ROIs used to calculate the mean value and standard deviation (in brackets) of the ratio of RSP from the syngo.via and Hudobivnik methods.

Figure 1 shows RSP for different slices of the pediatric head phantom where we observed that the RSP predictions from the two methods agreed within 1%. Due to the heterogeneous nature of the pediatric head phantom, it was not possible to compare the ROI RSP values to reference values, and only the comparison of M1 and M2 is reported here.

4. Discussion and conclusion

The generally higher errors for the syngo.via method are attributed to the fact that the scanner software calibration is valid for a wide range of DECT protocols and phantom diameters scanned at 80 and 140 kVp, while the Hudobivnik method was calibrated specifically for this phantom and scan parameters. In general, the RSP accuracy of both methods is at the level which is desired for PT ($\approx 1\%$). We can thus conclude that both methods are acceptable for PT dose calculations, and that the added convenience of using the clinically available syngo.via is warranted.

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