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Evaluation of DirectSPR-generated SPR Maps from different DECT protocols for Proton Therapy Dose Calculations Using Porcine Tissue

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Objectives

DirectSPR, a commercial product, enables direct generation of stopping power ratio (SPR) maps from dual-energy CT (DECT) for proton therapy applications. This study aims to evaluate the accuracy of SPR maps generated via DirectSPR using different DECT protocols for proton therapy dose calculations in the RayStation treatment planning system (TPS), employing actual porcine tissues in place of tissue surrogate phantoms.

Methods

The same set of porcine tissues samples was scanned on two Siemens CT scanners, SOMATOM go.Open Pro and SOMATOM Drive, with DECT protocols utilizing 80kV-140kV (80/Sn140) and 100kV-140kV (100/Sn140) energy combinations. Both scanners incorporated a dual-source dual-energy approach. DECT data were processed in syngo.via to generate CT images whose image value I is linearly correlated with SPR, namely SPR = I/1000 + 1. These images were subsequently imported to the TPS with this linear calibration curve applied. A 200.3 MeV proton beam was simulated to pass through the scanned porcine tissues. With a custom RayStation script calculating the integral depth dose (IDD) along the trajectory, water-equivalent thickness (WET) was computed and compared against measured WET values obtained via a multi-layer ionization chamber on the Hitachi Probeat-V Proton Beam Therapy System. For each tissue type, measurements were acquired at a minimum of three distinct points.

Results

All calculated WET values were within 2% of measured values, with the exception of one point in cortical bone, where discrepancies of +2.67% to +3.78% were observed, indicating a potential overestimation of SPR in high density bone by DirectSPR. For each tissue type excluding bone, the mean WET discrepancies were within 1.1%, consistent with previous findings. Overall, the mean WET differences (excluding bone) were +0.22% and +0.13% for 80/Sn140 and 100/Sn140 protocol respectively in SOMATOM go.Open Pro. The Wilcoxon signed rank test yielded a p-value of 0.03 (<0.05), suggesting a slightly better accuracy for 100/Sn140. Meanwhile in the case of SOMATOM Drive, both DECT protocols produced a mean WET difference (excluding bone) of +0.37%, with no statistically significant difference observed.

Conclusions

Optimization of the initial linear mapping between image value and SPR is advisable for enhancing DirectSPR accuracy in RayStation, particularly in regions containing cortical bone. DirectSPR demonstrates acceptable accuracy in soft tissues, with the 100/Sn140 protocol favored for its superior penetration depth and comparable accuracy to the 80/Sn140 protocol.

Figure 1.

Example of the CT-scanned porcine tissue (muscle).

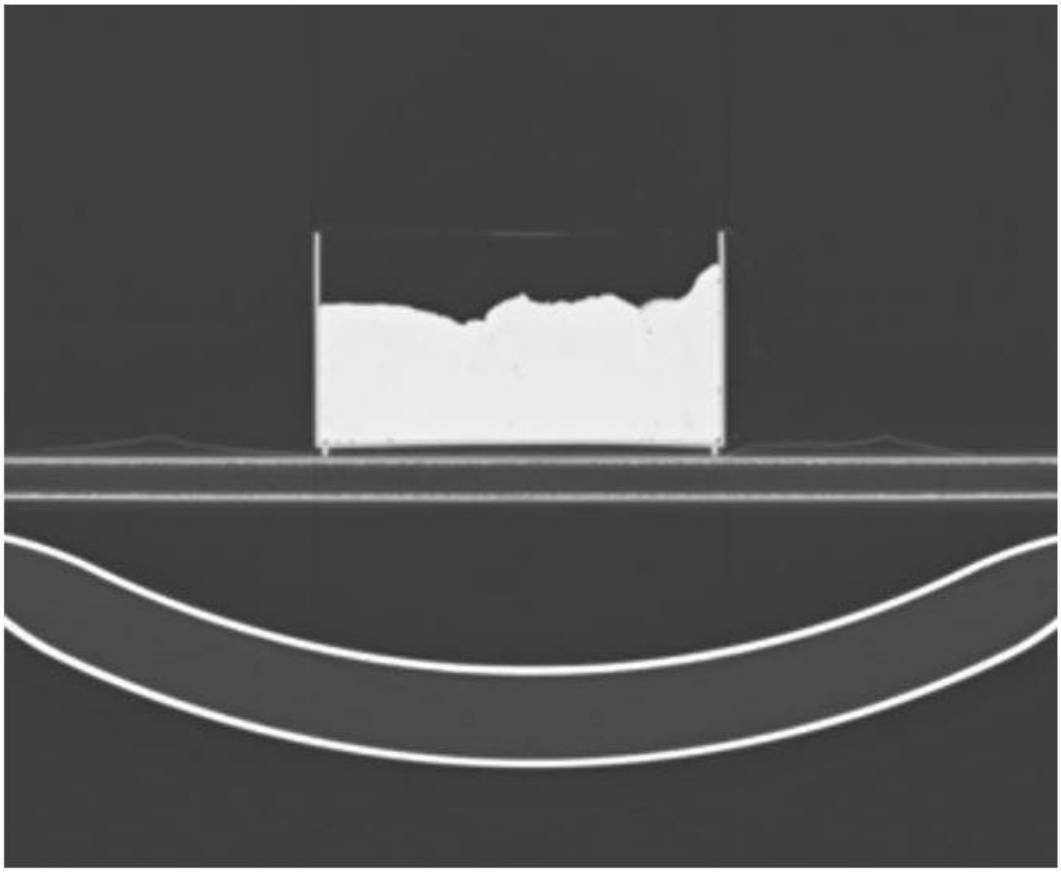

Table 1.

Porcine tissue WET %diff was calculated as [(Calculated WET/Measured WET-1]x100%. Mean WET %Diff was obtained by taking average of WET %diff among measurement points for each type of tissue. Range of WET %Diff indicated the smallest and largest WET %Diff for each individual tissue. Maximum deviation is highlighted in bold and italic.

(a) Top: Porcine tissues scanned in SOMATOM go.open Pro

(b) Bottom: Porcine tissues scanned in SOMATOM Drive

SOMATOM go.open Pro

Porcine Tissues	Dual Energy Scanning Protocol			
	80/Sn140	100/Sn140	80/Sn140	100/Sn140
	Mean WET %Diff		Range of WET %Diff	
Bone	1.14	1.26	(0.15 , ***2.67***)	(-0.03 , ***3.44***)
Ribs	0.63	0.54	(-0.28 , 1.7)	(-0.27 , 1.46)
Muscle	0.06	-0.03	(-0.05 , 0.19)	(-0.14 , 0.08)
Kidney	-0.32	-0.45	(-1.7 , 0.43)	(-1.83 , 0.27)
Brain	0.42	0.28	(0.17 , 0.56)	(0.05 , 0.41)
Liver	0.13	0.04	(0 , 0.28)	(-0.1 , 0.18)
Heart	0.05	-0.08	(-0.96 , 0.61)	(-1.08 , 0.42)
Adipose	0.55	0.63	(0.26 , 0.78)	(0.32 , 0.91)

SOMATOM Drive

Porcine Tissues	Dual Energy Scanning Protocol			
	80/Sn140	100/Sn140	80/Sn140	100/Sn140
	Mean WET %Diff		Range of WET %Diff	
Bone	1.87	1.82	(0.75 , ***3.69***)	(0.73 , ***3.78***)
Ribs	1.07	1.02	(0.1 , 1.67)	(0.11 , 1.63)
Muscle	0.07	0.03	(-0.06 , 0.23)	(-0.1 , 0.19)
Kidney	0.39	0.36	(-0.42 , 1.02)	(-0.42 , 0.98)
Brain	0.74	0.73	(0.51 , 0.87)	(0.5 , 0.88)
Liver	0.12	-0.03	(0.05 , 0.24)	(-0.16 , 0.11)
Heart	-0.26	-0.31	(-1.46 , 0.59)	(-1.48 , 0.62)
Adipose	0.43	0.82	(0.25 , 0.58)	(0.58 , 1.04)