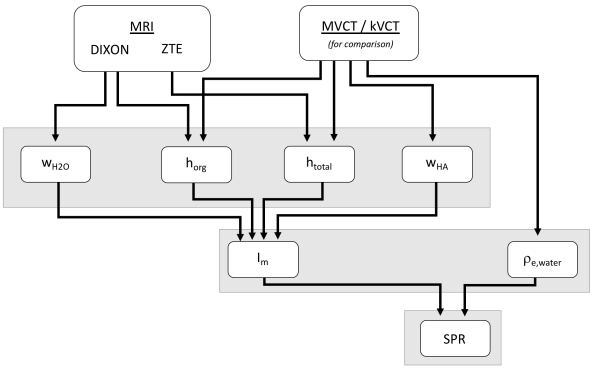
Methodology for high-accuracy calculation of SPR using multimodal imaging

Jessica Scholey, Dharshan Chandramohan, Tarun Naren, William Liu, Peder Larson, Atchar Sudhyadhom

Introduction: Proton therapy is becoming an increasingly popular cancer treatment modality due to the proton's physical advantage in that it deposits the majority of its energy at the distal end of its track where the tumor is located. Proton range in material is determined from the stopping power ratio (SPR), with errors in computing SPR from kVCT precluding the ability to utilize protons to their full potential. If achievable, using magnetic resonance imaging (MRI) to calculate SPR would provide numerous advantages. The goal of this work is to evaluate a multimodal imaging framework for determining SPR using synthetic tissues fabricated to emulate human biological tissues.

Materials and Methods: Synthetic tissues were created to mimic skin, muscle, adipose, and spongiosa bone. SPR was calculated using the Bethe Bloch equation from values of $\rho_{e,water}$ (relative electron density) and I_m (mean ionization potential) determined for each tissue. The UC method of calculating I_m is outlined by Sudyhadhom[1] whereby I_m is computed at the voxel level (**equation 1**) using the Bragg Additivity rule of elemental composition assuming human biological tissue is composed of water (H_2O), organic (org) material, and mineralized (hydroxyapatite; HA) material,

$$\ln I_{voxel} = \left(\sum_i \frac{w_i Z_i}{A_i} \ln I_i\right) \Big/ \left(\sum_i \frac{w_i Z_i}{A_i}\right) = \frac{\left(\frac{w_{H_2O} Z_{H_2O}}{A_{H_2O}} \ln(I_{H_2O})\right) + \left(\sum_{org} \frac{w_{org} Z_{org}}{A_{org}} \ln(I_{org})\right) + \left(\frac{w_{HA} Z_{HA}}{A_{HA}} \ln(I_{HA})\right)}{\sum_{total} \frac{w_{total} Z_{total}}{A_{total}}} \quad \textbf{(1)}$$



where for component i, w_i is the fraction by weight, Z_i atomic number, and A_i atomic mass. All variables above can be determined a priori, leaving w_{H2O}, w_{org}, w_{HA}, and h (hydrogen density by mass; used in calculating w_{org} and the denominator of equation 1) to be extracted from two MRI pulse sequences (DIXON fat-water separation and zero echo time, or ZTE) and CT as outlined in **figure 1**.

Figure 1: multimodal imaging framework for determining SPR using MRI and CT

Results: I_m and SPR results using the UC imaging method versus calculations from first principles are shown in **table 1**. The reported UC imaging method values use relative electron density from MVCT and physical density and w_{HA} from kVCT.

	I_m (eV)		SPR	
	UC Imaging Method	**Calculation**	**UC Imaging Method**	**Calculation**
Skin	77.3 ± 1.4	74.7	1.05 ± 0.01	1.06
Muscle	75.4 ± 0.7	74.1	1.03 ± 0.01	1.04
Adipose	65.9 ± 1.9	68.5	0.95 ± 0.01	0.95
Spongiosa	68.7 ± 1.0	74.5	1.04 ± 0.01	1.04

Table 1: I_m and SPR values for UC Imaging Method versus ground truth calculations.

Conclusion: The UC method using multimodal imaging is able to achieve high accuracy in computing SPR with average percent errors of 1.1, 1.0, 0.3, and 0.7% for synthetic skin, muscle, adipose, and bone, respectively.

References

Sudhyadhom A. Determination of mean ionization potential using magnetic resonance imaging for the reduction of proton beam range uncertainties: theory and application. *Phys Med Bio*. **62** (2017) 8521-35.