AbstractID: 10141 Title: Intensity Modulated Proton Planning for Ocular Tumor using Human Anatomy Dose Algorithm and Preliminary Comparison with IMRT Planning

I Purpose:

The need for high dose accuracy has long been an issue since the complexity of human body and the complex treatment planning. Even considering its low speed and high cost, Monte Carlo is firmly established as a necessary tool to provide basic and benchmarking data for clinical faster and simplified methods, both for patient dose calculations and for treatment machine characterization.

In this work, we aim to build a general and accurate dose calculation algorithm based on human anatomy-based model for providing benchmarking data for therapeutic photons and compare the dose simulated by Monte Carlo to standard photon IMRT planning using Pinnacle3® TPS. The Monte Carlo code we used in this work is MCNPX[1], developed by Los Alamos National Laboratory and exclusively benchmarked against measurements for over sixty years history. The human anatomy-based model was adapted from the Visible Human Project of National Library in Medicine. NLM created a set of complete, anatomically detailed, three-dimensional representations of the normal male and female human bodies, combing with the transverse CT images of representative male and female cadavers. The model we used in this study was a male who was sectioned at one millimeter intervals. The sectioned images were digitalized to voxel-based volume arrays for generating computational models that represent the human anatomy.

II Method and Materials:

Monte Carlo dose calculation algorithm for external protons

The Energy deposit per mass[2] is calculated using the equation (I):

$$H_t = \frac{\rho_a}{m}\int dE\int dt\int dV\int d\Omega\sigma_t(E)H(E)\psi(\vec{r},\Omega,E,t) \cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(I)}$$

Where

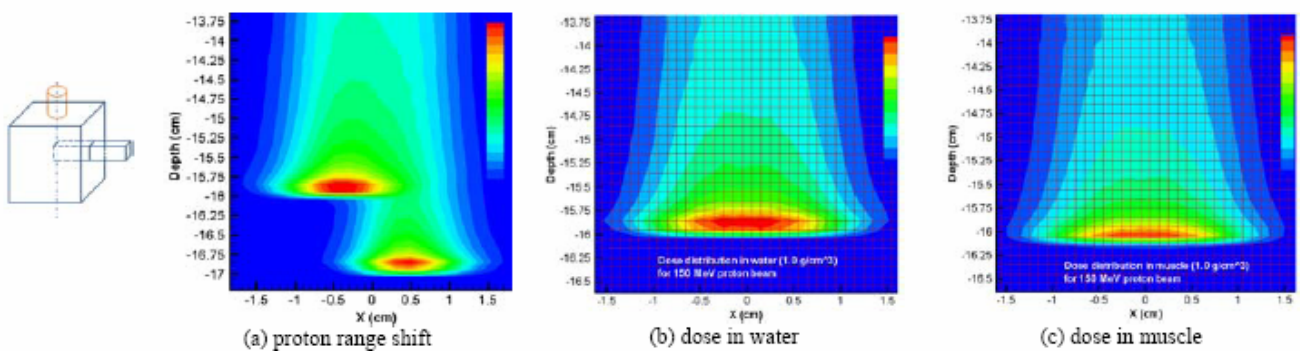
H_t = total energy deposition in a cell (MeV/g); ρ_a = atom density (atoms/barn-cm); m = cell mass (g); $\sigma_t(E)$ = microscopic total cross section (barns); $H(E)$ = heating number (MeV/collision); $\vec{r},\hat{\Omega},E,t$ = particle position vector (cm), direction vector, energy (MeV), and time (sh; 1sh = 10-8 s) respectively

Proton Range-energy Monte Carlo Simulation and Benchmark

The proton energy ranges from 40.0 MeV to 250.0 MeV at intervals of 10.0 MeV for this study. A central segment along the beam axis (X=0) was used for the percentage depth dose and depth range analysis. Two widely used range-energy tables, from International Commission on Radiological Units and Measurements (ICRU) Report 49 and from Data Nuclear Data Tables (DNDT), were used for comparison of the simulated range-energy data to the measurements.

Proton depth dose in phantom-based Heterogeneity

Tissue inhomogeneity corrections in proton therapy include two factors: tissue density correction and tissue composition correction. Two simplified scenario were used to demonstrate the inhomogeneity using 150 MeV proton beam: (a) water phantom with a density bar insert, (b) two materials with the same density but different composition. In case A, a density bar (0.5 g/cm^2) was inserted at a depth of 2 cm with its head at the beam central axis. Figure 1(a) shows the proton range shift. In Case B, water (H 11.1%, O 88.8%) and muscle (H 10.2%, C 14.3%, N 3.4%, O 71.0%, P 0.2%, S 0.3% K 0.4%) were used. Figure 1(b) and Figure 1(c) show the dose distribution in water and muscle, respectively.

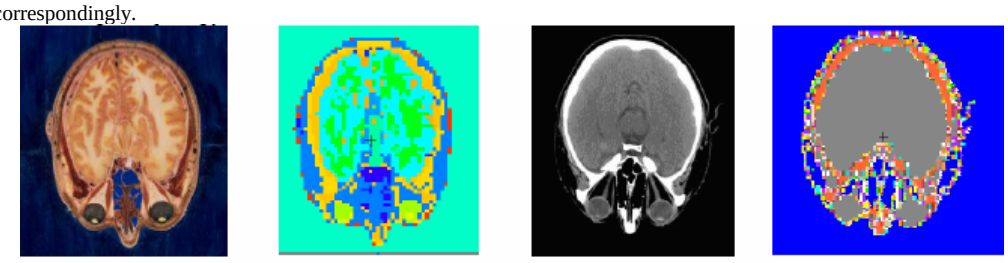


(a) proton range shift (b) dose in water (c) dose in muscle

Figure 1: Tissue inhomogeneity for proton beam

Human Anatomy-based Model development

The human anatomy-based model was adopted from the VHP sectioned images which contains high resolution with pixel size of 0.33 x 0.33 mm. Xu *et al* reconstructed a body model, called Visible Photographic Man (VIP-man)[3], based on the VHP images in 2000 for multi-particle Monte Carlo calculations and radiation dosimetry. The VIP model was built with 4 x 4 x 4 mm voxel resolution totaling to over 6 million voxels for describing the whole body. The original color photographs from the VHP data set had been identified and segmented to 1,400 anatomical structures (Spitzer and Whitlcok 1998, Xu 2000). Each voxel was assigned physical properties, including density and isotopic composition. Therefore, the image-based whole-body adult male model was constructed from the color photographs of the Visible Human Project. Figure 2(a) and Figure 2(b) shows an axial slice of the VPH, which original size is 4096x2700x24 bit raw data, and the corresponding slice generated by MCNPX, respectively. Figure 2(c) and Figure 2(d) show the axial view of the CT and the MCNPX reconstruction of the patient used in this study. We developed an in-house pre-clinic dosimety software package, called Human Anatomy-based Monte Carlo dose (HAMD) to analyze the huge dose dataset based on Monte Carlo simulation and superposition the dose to the CT image correspondingly.



(a) Axial - VHP (b) Axial - VHP MCNPX (c) Axial - Patient CT (d) Axial - Patient CT MCNPX

Figure 2: NLM human body and patient cross sections

III Results:

Figure 3(a) and Figure 3(b) show the beam set up for the treatment scenarios using IMRT and IMPT to treat ocular cancer, respectively. The energies for both treatment modalities were optimized to give conformal dose to the tumor volume while minimizing dose to healthy surrounding tissues. Both modalities utilized a minimum number of treatment beams at various angles to optimize dose to the tumor and minimize dose to healthy tissues. In IMPT, the proton beam energy ranges from 37.5 MeV to 77.5 MeV using Gaussian distribution.

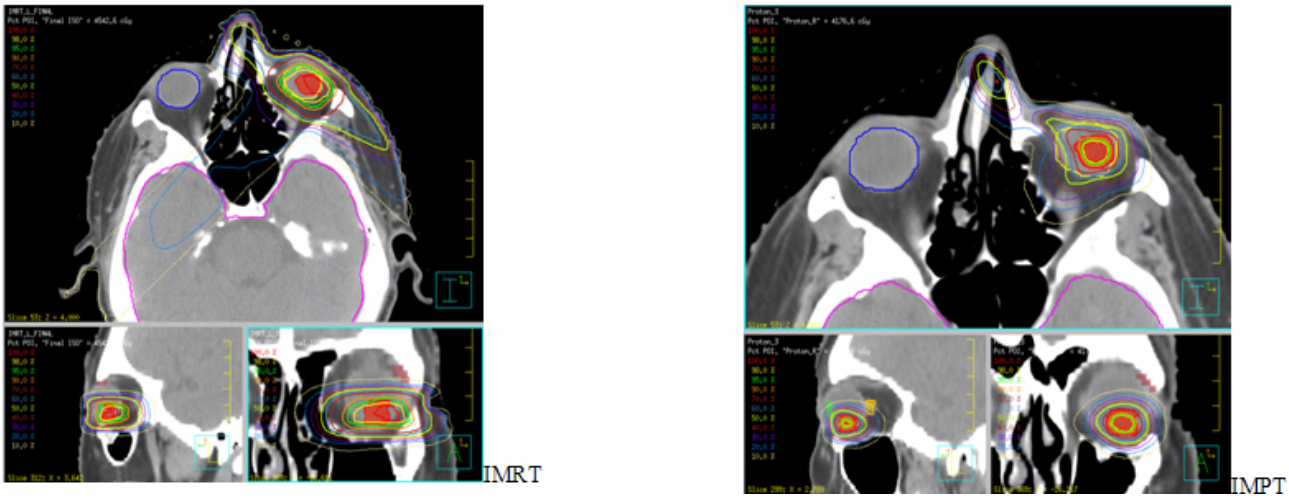
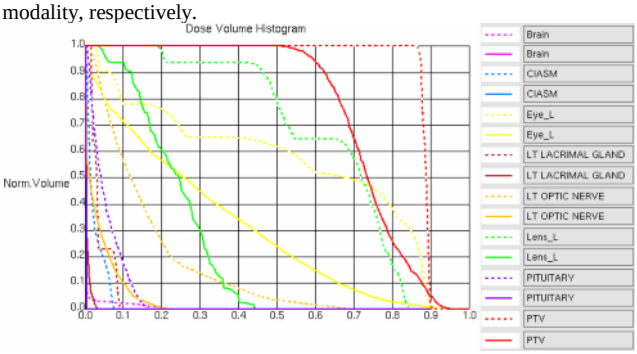


Figure 3: Treatment plans illustrating isodose lines and angle of beam orientation

Figure 4(a) and Figure 4(b) show the dose volume histogram and the minimum, maximum, and average dose value in cGy obtained for each treatment modality, respectively.



(a) IMRT vs. IMPT DVH comparison

	IMRT			IMPT		
	Min (cGy)	Max (cGy)	Average (cGy)	Min (cGy)	Max (cGy)	Average (cGy)
Brian	0.00	1090.10	26.50	0.00	0.60	0.00
Ciasm	16.00	378.90	120.00	0.00	0.00	0.00
Eye	106.00	4582.10	2770.50	2.80	4834.30	1524.50
Lacrimal Gland	82.00	466.20	193.10	0.80	176.90	20.40
Optic Nerve	48.70	3489.50	794.10	0.00	1078.00	162.30
Lens	961.30	4295.80	3300.10	191.10	2252.80	1192.10
Pituitary Gland	27.50	838.80	272.10	0.00	0.00	0.00
PTV	4392.20	4582.10	4508.10	2521.70	4834.30	3762.80

(b) IMRT vs. IMPT Dose value comparison

Figure 4: Comparison of the dose volume histograms. Proton (Solid) vs. IMRT (Dashed)

The ocular tumor was well covered by 95% in IMRT and 70% isodose in IMPT. Comparing the IMRT and IMPT, the mean dose was 4508 cGy and 3762 cGy-Eq for PTV, 2770 cGy and 1524 cGy-Eq for the eye, 3300 cGy and 1192 cGy-Eq for lens, 794 cGy and 162 cGy-Eq for optic nerve, 193 cGy and 20 cGy-Eq for lacrimal, 26 cGy and 0.0 cGy-Eq for brain, 120 cGy and 0.0 cGy-Eq for chiasm, 272 cGy and 0.00 cGy-Eq for pituitary and, respectively. The HAMD performed extremely impressive in heterogeneity regions for proton beam. Proton beam therapy resulted in less average dose to all ROI.

Conclusion:

We have recently made breakthroughs in dose calculation for therapeutic proton beams in radiation therapy (RT) based on human anatomy model and Monte Carlo simulation. The in-house developed dose algorithm HAMD performs very well in organ dose calculation. The HAMD needs further validation by using additional human anatomy-based models and more specified proton source configuration. The long-term and board objective is to provide an extreme accurate dose calculation algorithm and offer basic benchmarking data for clinically simplified CT-based dose calculation.

Reference

[1]H. Zaidi1 and X. G. Xu Computational Anthropomorphic Models of the Human Anatomy: The Path to Realistic Monte Carlo Modeling in Radiological Sciences, Annu. Rev. Biomed. Eng. 2007. 9:471–500

[2]X. G. Xu, T. C. Chao, and A. Bozkurt,"VIP-Man: an image-based whole-body adult male model constructed from color photographs of the Visible Human Project for multi-particle Monte Carlo calculations," Health Phys **78** (5), 476-486 (2000).

[3]J. F. Janni, “Proton range-energy tables, 1 keV - 10 GeV,” At. Data Nuclear Data Tables **27**, 147, 1982