Modeling of human body tissue compositions for Monte Carlo algorithm of Proton therapy dose computation with a Single Energy CT Calibration Curve

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2020 JULY 12–16 VIRTUAL JOINT AAPM COMP MEETING

Introduction

Proton dose computation with most planning systems rely on single energy computed tomography (CT) images in which the relative proton stopping-power ratio, mass density and relative electron density are derived from CT Hounsfield units (HU). Using a Monte Carlo dose calculation algorithm in proton treatment planning system, a CT HU of each pixel in patient CT image is assigned to mass density, in order to compute the proton stopping power ratio. The accuracy of proton dose computation in Monte Carlo algorithm relies on conversion from HU to mass density.

AIM

The aim of this study is to investigate the potential improvement in determining mass density using single energy CT (SECT) to reduce the uncertainty in predicting the proton range in patients.

Materials and Methods

The Stoichiometric method is used to model the CT HU of human body tissue compositions. In our calibration procedure, elemental compositions and densities of 34 "standard" human body tissues were taken from ICRU report 44. The CTHUs of Gammex Model 1467 were measured using a CT scanner, Siemens Somatom Definition AS. The following equation was used to model the treatment planning CT scanner by calculating scanner specific parameters:

$$HU = \rho_e \left(K^{ph}\tilde{Z}^{3.62} + K^{coh}\tilde{Z}^{1.86} + K^{KN}\right) * 1000 \qquad (1)$$

Where K^{ph}, K^{coh}, K^{KN} are the CT scanner specific parameters related to the photoelectric effect, coherent scattering, and Compton interactions.

Since low-density (lung) tissues, soft tissues and high-density (bone) tissues have showed different uncertainties through the calibration procedure, we estimated their uncertainties individually.

Also , using the empirical calibration method, the CT calibration curve has been generated by the measured CTHU of tissue substitute. By the interpolation method, the inherent uncertainties in the stoichiometric CT calibration curve have been compared to the ones derived from the empirical calibration approach using Gammex tissue-substitute.

Results

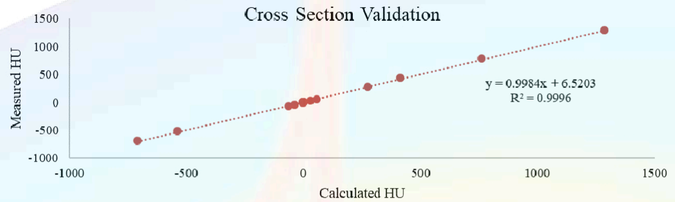

FIG 1. The calculated CTHUs of tissue substitute based on the scanner specific parameters, versus their measured values of a 120 kVp beam. The measured data are average of three scans with standard deviation between 0.29 to 1.30.

After the modeling validation, the stoichiometric calibration curve has been generated using the calculated CT HU of human body tissues.

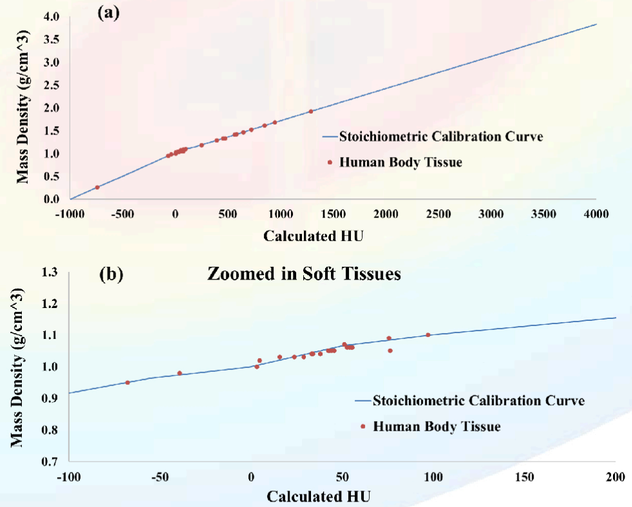

FIG 2. (a) The Conversion of CT Hounsfield Units (HU) to Mass density determined by the stoichiometric calibration. (b) On the below, zoomed in the soft tissue region, there is a fitting ambiguity between HU and mass density values.

Discussion

The inherent uncertainties in the stoichiometric CT calibration curve compared to the ones derived from the empirical calibration approach. The inherent uncertainty (rms error) in soft tissues using the empirical calibration method was estimated 1.31%, while the inherent uncertainty using the stoichiometric method estimated 48%. The total inherent uncertainty using the stoichiometric method for lung, soft and bone tissues was reduced by a factor of ~1.5.

Conclusion

The CT HU-to-Mass density look-up table for Monte Carlo dose calculation in a treatment planning system is derived from the CT HU-to-Mass density stoichiometric calibration curve. The inherent uncertainty resulting from the stoichiometric method has been reduced to 1.0%. Our results demonstrate that a more accurate prediction of mass density can be achieved by the stoichiometric calibration curve for the Monte Carlo dose calculation algorithm in the treatment planning system.

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