Proton Dose Calculation with Dual Energy CT Using Scripting

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INTRODUCTION

Dual Energy CT (DECT) uses two separate x-ray photon scans to better analyze material composition. The implementation of DECT can help further reduce the range uncertainty in proton therapy. The DECT calculation of stopping power ratios (SPR) is more accurate than SECT. Since commercial treatment planning systems do not support DECT based SPR calculation. The use of the Eclipse API permits DECT calculation to be implemented in safe way for comparison with SECT calculation

AIM

The aim of this experiment is for implementation, commissioning and validation of a dual energy CT (DECT) Varian Eclipse (application programming interface) API script for calculation of stopping power ratios (SPRs) and proton dose.

METHOD

- The Gammex and CIRS phantoms were scanned using DECT with sequential scans at 140 kVp and 80 kVp
  - Only the Gammex Phantom was used for calculations but both phantoms were scanned due to minimum thickness for DECT image reconstruction
- The Zeff and Rho_e images were extracted using Siemens software and imported into the Eclipse
- SPR of Gammex Plug's were calculated using the formula below:
  - For low density tissue Siemens Zeff values are not reliable and proton stopping power ratio is set to the SECT value

$$PSP_{DECT} = \begin{cases} PSP_{SECT} & ; 0 \le Z_{eff} < 0.5 \\ (1.1114 - 0.0148\, Z_{eff})\, \rho_e & ; 0.5 \le Z_{eff} < 8.5 \\ 0.9905\, \rho_e & ; 8.5 \le Z_{eff} < 10 \\ (1.1117 - 0.0116\, Z_{eff})\, \rho_e & ; Z_{eff} \ge 10 \end{cases}$$

- Calculated SPR were measured against DECT script SPR readouts (Fig. 1 for phantom results)
- Overwrite certain CT numbers in specific structures such as
  - Image artifacts, air pockets, couch structures
- Clinical examples of DECT API Script:
  - Examples include H&N and pelvis (liver) cases
- Workflow of planning on clinical examples:
  - Optimize with SECT (Mixed energy DECT) Image → DECT API script calculates DECT SPR from Zeff and Rho_e (Fig 2) and forward calculates plan on DECT SPR for final dose distribution (Fig. 3B and 4B).

RESULTS

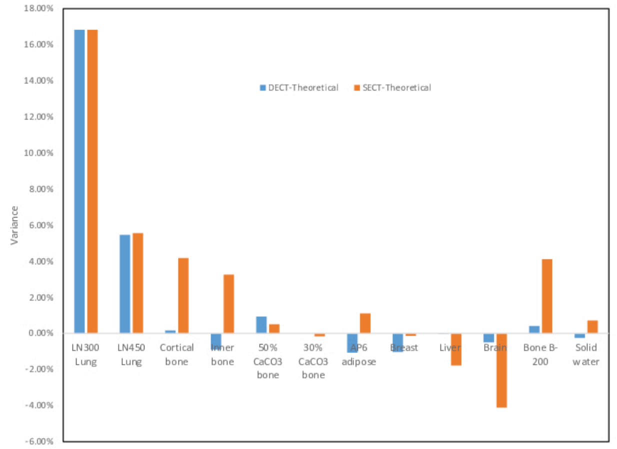

Figure 1: Comparison between percentages difference between DECT, SECT SPR with theoretical SPR

Validation:
The accuracy of the theoretical SPR is dependent on the accuracy of the material composition and density data supplied by the vendor. It can be seen that DECT SPR have less than 1% variance from the ground truth for most of the plugs as seen in Fig 1 except for the lung LN 300 and LN450 and 30% CaCO3 bone. For SECT SPR, the variance from ground truth values can be up to 4% even if the lung plugs were excluded. Based on the comparison of the Gammex phantom SPR, it can be concluded the DECT SPR is more accurate than SECT. There is no systematic upwards or downwards shift in SPR between SECT and DECT as different materials can show either positive or negative variance from the ground truth. This means that differences in SPR across different tissue types can slightly cancel out each other when a proton beam passes through heterogeneous issue (eg adipose, muscle and bone).

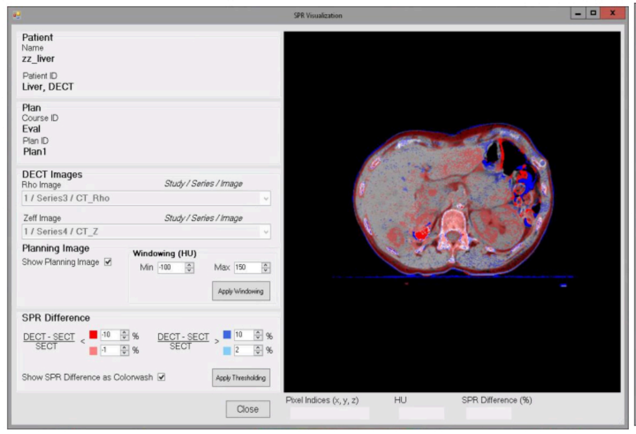

Figure 2A: DECT API script calculated SPR differences for liver. The SECT SPR for lipiodol is overestimated by more than 20% compared to DECT

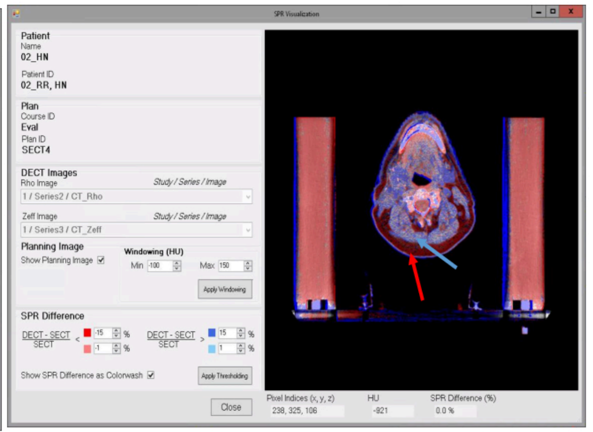

Figure 2B: SPR differences H&N. Fat tissue (adipose) shows lower DECT SPR (red arrow) while muscle shows higher DECT SPR (blue arrow).

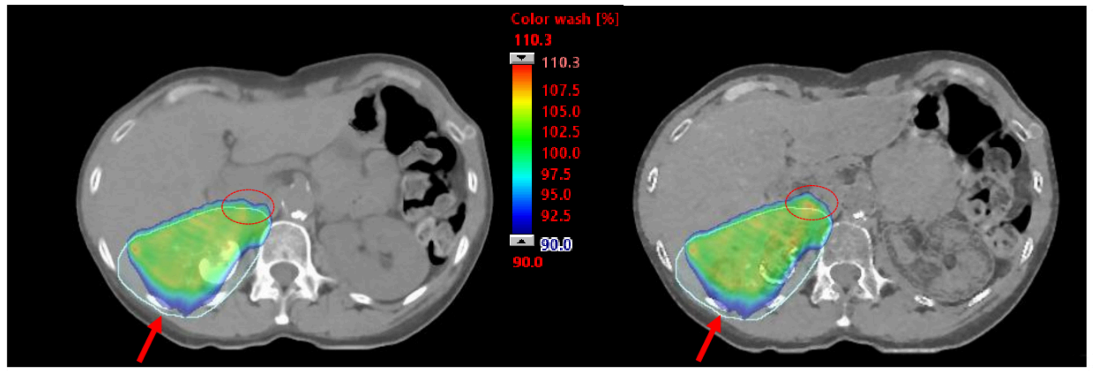

Figure 3A: SECT optimized, RPO field dose

Figure 3B: Forward calculation: DECT API script final dose. Over-ranging in RPO field is due to incorrect SPR in lipiodol

Liver:
A robustly optimized SFO SECT proton plan was created using one lateral and one posterior oblique field to cover CTV 7500 with robustness parameters of 3mm isocenter shift and 3.5% range uncertainty. Lipiodol is visible within the CTV and by turning on only the posterior oblique field (Fig. 3A) , it can be seen that the DECT API script calculated dose demonstrates over-ranging of up to 4mm (Fig. 3B) .

Head and neck:
A robustly optimized MFO SECT proton plan was created using two posterior oblique fields and one anterior field to cover CTV 5400, CTV 6000, CTV 6300 with robustness parameters of 3mm isocenter shift and 3.5% range uncertainty. Since plan robustness evaluation is not available on the DECT API script, only nominal dose distributions can be compared between the SECT and DECT plans.
Comparison was made with the PTV for the targets in place of CTV as well as the OAR doses between the SECT and DECT plans. The dose distribution is shown in Fig 4 with small decreases seen in the mean and maximum doses of the OARS in the DECT API script calculated dose.

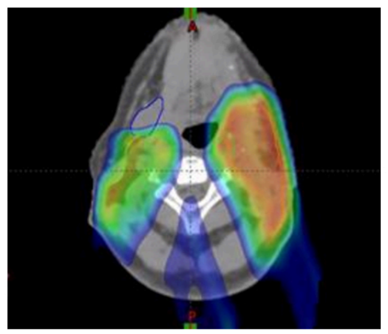

Figure 4A: SECT optimized nominal HN dose

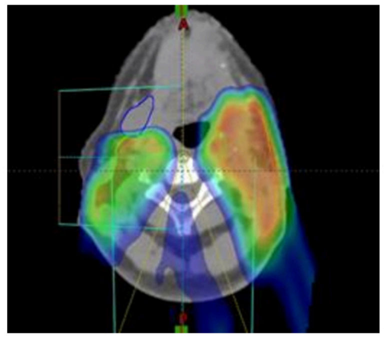

Figure 4B: Forward calculation: DECT API script final dose.

CONCLUSIONS

The Eclipse DECT API is a streamlined tool for generating the SPRs values based on the DECT images allowing for direct comparison of SECT based dose calculation. The comparison of the SPRs generated by this tool and the theoretical calculations and measured values show good agreement for most tissue equivalent material. Clinical examples show that the DECT script can be used to optimize treatment plans and reduce the range uncertainty further Through the use of the API script, clinical implementation of DECT can be performed in a convenient way that can lead to widespread adoption.

REFERENCES

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