JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

Validation of CT calibrations in proton therapy using water-based materials

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miro molecular imaging, radiotherapy & oncology

INTRODUCTION

To fully take advantage of proton therapy, an accurate map of stopping power ratios (SPRs) must be inferred from the patient's CT scan. However, conversion from CT to SPR is a major source of range uncertainty. For this reason the calibration needs careful validation before its clinical use. In the literature, it's often proposed to use animal tissues for this purpose[1] (proton radiography,...), for their similarity with human tissues. We propose here to use liquid organic mixtures with known properties instead, for their following advantages:

- A better tracking of potential issues thanks to the known properties (density, composition) of validation materials
- The isolation of the calibration issue in the validation process: no problems related to CT resolution, CT artefacts, alignment,...
- A facilitated validation procedure thanks to the natural homogeneity of the liquid mixtures: eased measurement setup and eased post-processing with no simulation needed.

AIM

To facilitate and possibly improve the validation of CT calibration using water-based mixtures instead of animal tissues.

METHOD

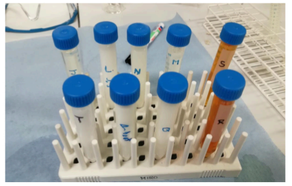
A CT scanner was calibrated for the open-source Monte Carlo dose engine MCsquare[2] using the stoichiometric calibration[3]. The material assignment, necessary for Monte Carlo simulations, was performed in three different ways:

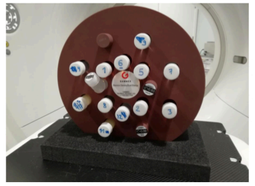
- Reproducing the conversion scheme from the RayStation TPS[4];
- Using the stoichiometric method for Monte Carlo algorithms[5];
- Applying a continuous version of the aforementioned stoichiometric calibration, directly interpolating materials instead of using pre-defined materials classes.

Twelve liquid organic mixtures were made (40-50g each), mimicking 9 soft tissues and 3 bones. Base products such as water, fatty acids, glucose, amino acids, alcohol or calcium compounds were used. Reference tissues were mimicked in terms of:

- Density
- Elemental composition / Mean excitation energy (I-value)
- Water weight fraction.

The obtained mixtures were placed in the CT scanner inside a Gammex[6] phantom and a mean HU was extracted for each sample.
Finally, SPR obtained theoretically (using known sample properties) and by the CT scan and its calibration were compared, as well as elemental compositions for soft tissues.





RESULTS

Regarding **produced mixtures**, the following is to be noted:

- Fatty and soft tissues were mimicked within ± 5 p.p. regarding elemental composition and within ± 0.025 g/cm^3 regarding mass density;
- For bones, such an accuracy was impossible due to their low water content, the weak solubility of calcium compounds and the incompatibility of calcium and carbon compounds. Low density bones were thus mimicked in terms of density and calcium weight mainly, leading to important discrepancies in oxygen and carbon fractions.

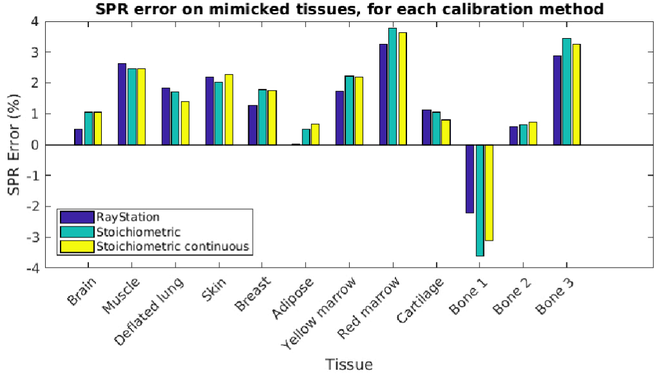
Regarding the **SPR**, the following observations can be made:

- Relative SPR errors were respectively 1.31±1.49%, 1.42±1.88% and 1.42±1.73% for the RayStation, the stoichiometric and the continuous stoichiometric methods;
- Generally speaking, the RayStation method performs slightly worse in soft tissues but better in bones and fatty tissues;
- The SPR is almost always overestimated by the 3 CT calibrations in this experiment.

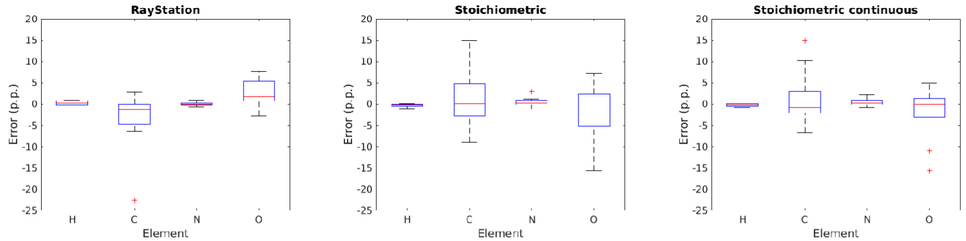
Regarding the **elemental composition**, we see that:

- The continuous stoichiometric method allows for a small reduction of the error, mainly for carbon and oxygen;
- The RayStation method leads to slightly more bias than both stoichiometric methods.
- Distinguishing between carbon and oxygen seems to be the main challenge of calibration methods.

Right:
Relative SPR error for each calibration method, on each produced sample.



Below:
Distribution of the error on elemental composition of soft tissues predicted by each calibration method, for hydrogen, carbon, nitrogen and oxygen weights.



CONCLUSIONS

- Three different calibration schemes were validated using liquid organic materials.
- The proposed validation materials allow verifying not only SPR accuracy, but also properties such as mass density or elemental composition.
- The homogeneity of these materials would result in eased measurement setup and post-processing.
- All calibrations performed similarly regarding SPR accuracy, with a slight advantage for the RayStation method.
- The continuous stoichiometric method allowed for a slight error reduction on the elemental composition compared to the classical stoichiometric method.
- A limitation of this study is the quite high uncertainty on the exact materials properties, due to the small produced quantities.
- A next step will be to produce larger quantities of these materials in order to directly measure their SPR in a proton beam and reduce the uncertainty on density and composition.
- These materials could also, in the future, replace the plastic materials used for *calibration*.

REFERENCES

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ACKNOWLEDGEMENTS

Marie Cohilis is supported by the Télévie grant from the Belgian "Fond National pour la Recherche Scientifique" (Grant No. 7652619F). Kevin Souris is funded by the Walloon Region (MECATECH/BIOWIN, Grant No. 8090), in collaboration with IBA s.a.
John A. Lee is a Senior Research Associate with the Belgian fund of scientific research (F.R.S.-FNRS).

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