Stoichiometric curve validation through biologic tissue measurements: end-to-end range uncertainty determination

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Objectives

The aim of this work is to derive a quantitative value of overall range uncertainty after establishing a material composition vs Hounsfield Units (HU) calibration curve. In addition to measuring individual tissue samples, we present a distal fall-off measurement technique that can provide a number for overall range uncertainty.

Introduction

- Robustness based optimization has become standard practice in spot scanning proton therapy. This approach accounts for delivery uncertainties by simulating perturbation scenarios.
- The values used to account for setup uncertainties are site-dependent, e.g. 2-3 mm for brain lesions and 5 mm for thoracic targets.
- Range uncertainty is produced by the inherent limitation of using Hounsfield units to represent material composition. In order to establish a relationship between CT numbers and patient tissue properties every treatment planning software requires a calibration curve.
- The stoichiometric method implies a complex analytical methodology, which contributes to dose computation uncertainty. The recommended value used for range uncertainty is 3.5 %[1].
- Generating a CT calibration curve is only a component of the process and a comprehensive validation must also be performed. The validation must ensure that biologic tissue can be accurately simulated by the TPS.
- This work describes a methodology that can be followed to validate the CT calibration curve for clinical proton dose calculations.

Methods

Following the well-established stoichiometric method, a mass-density vs HU curve was generated for our CT scanner. The curve was then validated with two different methodologies: a) relative stopping power (RSP) measurements of fresh tissue samples[2] and b) dose fall-off quantification of a uniform SOBP in a non-uniform mixture of biologic tissue.

1. **Relative stopping power (RSP) measurements of fresh tissue samples**
   For RSP determination, the individual tissue samples were placed in containers of known thickness, and a multi-layer ionization chamber (MLIC) was used to measure the Bragg-peak pull-back.

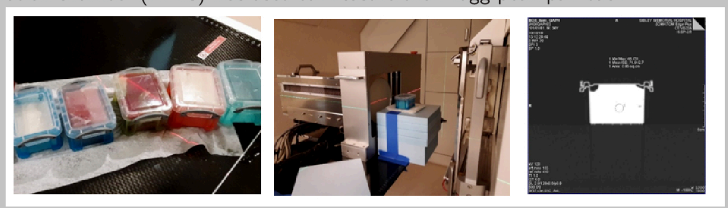

Figure 1: Fresh tissue samples and measurement setup using a Multi-Layer Ionization chamber. The individual samples consisted of: lamb brain, lamb kidney, pork loin, beef round, suet, pork fat and pork liver.

2. **SOBP distal fall-off quantification in unprepared tissue**
   For the SOBP distal fall-off quantification, the unprepared animal tissue was placed in a container on top of slabs of solid water, and a 2D array was used as measuring device. A plan was created in Raystation using an arbitrary target that enabled the measurement of the distal fall-off of the SOBP. The plan was computed using Raystation 9A Monte Carlo engine. 2000 cGy of RBE dose (Physical dose*1.1) in 10 fractions were prescribed to the center of the SOBP.

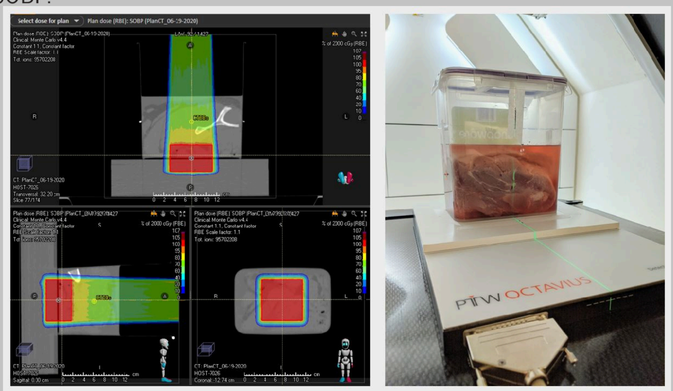

Figure 2: Biologic phantom for range uncertainty determination. The sample includes a mixture of pork fat, bone and muscle. A 2D Ionization chamber array was used as measurement instrument.

2D planar dose measurements were performed at 11 different depths, with 1 mm spacing. Four points were selected in the square field to evaluate proton range in non-homogeneous media.

Results

1. **Relative stopping power (RSP) measurements of fresh tissue samples**

The RSP values reported in figure 3 were derived using the following formula:

$$RSP^{sample}_{meas} = \frac{R_{80,empty} - R_{80,sample}}{R_{80,empty} - R_{80,water}} \qquad (1)$$

where $R_{80,empty}$ is the measured proton range for the empty box $R_{80,sample}$ is the range measurement for the tissue filled box and $R_{80,water}$ is the range measurement for the water filled box.

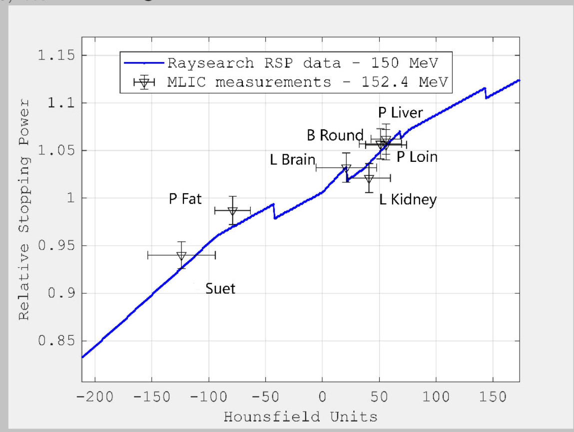

Figure 3: RSP MLIC measurements compared to RSP data computed from our TPS calibration curve

The differences between measured and calculated RSP showed values between 0.66 % and 1.46 %.

2. **SOBP distal fall-off quantification in unprepared tissue**
   The measured and planned distal fall-off of the SOBP in Figure 4 show differences of 0.5-2 mm. Considering a path length of 144.0 mm, 2.0 mm yields a range uncertainty of 1.38 % which is well within the standard planning criteria of 3.5 %.

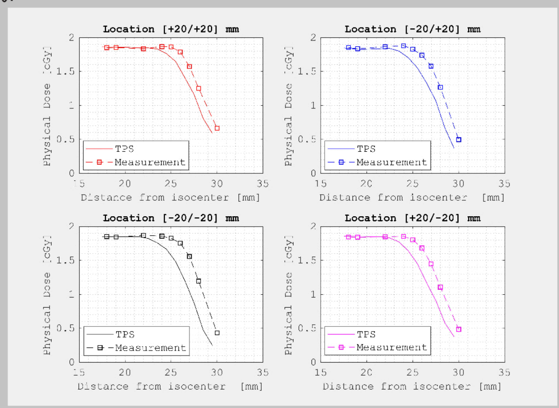

Figure 4: Distal fall-off comparison

Conclusion

- The numbers obtained during the distal fall-off measurement are in agreement with the results provided by IROC (spine phantom test). The combination of the test designed by Taasti et al. (2017) and the distal fall-off measurement provide a comprehensive end-to-end review of the commissioning of a CT scanner.

References

[1] Yang, Ming, et al. "Comprehensive analysis of proton range uncertainties related to patient stopping-power-ratio estimation using the stoichiometric calibration." *Physics in Medicine & Biology* 57.13 (2012): 4095.

[2] Taasti, Vicki T., et al. "Validation of proton stopping power ratio estimation based on dual energy CT using fresh tissue samples." *Physics in Medicine & Biology* 63.1 (2017): 015012.

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