Treatment plan LET validation using measured integral depth dose for proton therapy

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PURPOSE:

- Biological effects associated with proton therapy, e.g. Linear energy transfer (LET) dependent relative biological effectiveness (RBE) dose in proton therapy have been of recent interest.
- LET is an important value to be validated especially for the concerned organs at risk (OARs) before treatment. However, it imposes a bottleneck in measuring LET due to very limited techniques available.
- Here we propose a new efficient method for patient-specific LET validation for the OARs in the proton treatment planning.

METHODS:

- The beam-specific depth of the concerned OAR in the patient was converted to a depth in a solid water phantom by matching the shapes of the treatment planning system (TPS) calculated LET distributions in the patient CT and phantom.
- The integral depth dose (IDD) at the determined depth in the phantom was acquired by a multilayer ionization chamber (IC).
- A collimator made up of 2 cm thick copper with a 1 cm diameter opening was placed in front of the IC to collect those protons of interest (Figure 1).
- The energy spectrum (ES) of the protons was extracted from the IDD, and the LET was calculated from the energy spectrum (Figure 2).
- A comparison of the measured and the TPS calculated dose averaged LET (LET_d) on the brainstem was done for 7 brain and 1 head-and-neck (HN) tumor patients.
- For all 8 patients, a total of 30 measurements were done in the ROIs within 7-15 cm depths.

- LET_d was calculated from the extracted ES and stopping power Sp(Ei).

$$LET_d = \int S_p^2(E)\, C(E)\, dE \Big/ \int S_p(E)\, C(E)\, dE \qquad (1)$$

Where,
C(E) is the extracted energy spectrum.
Sp(E) consists of the electronic and nuclear parts and was from the National Institute of Standards and Technology pSTAR program.

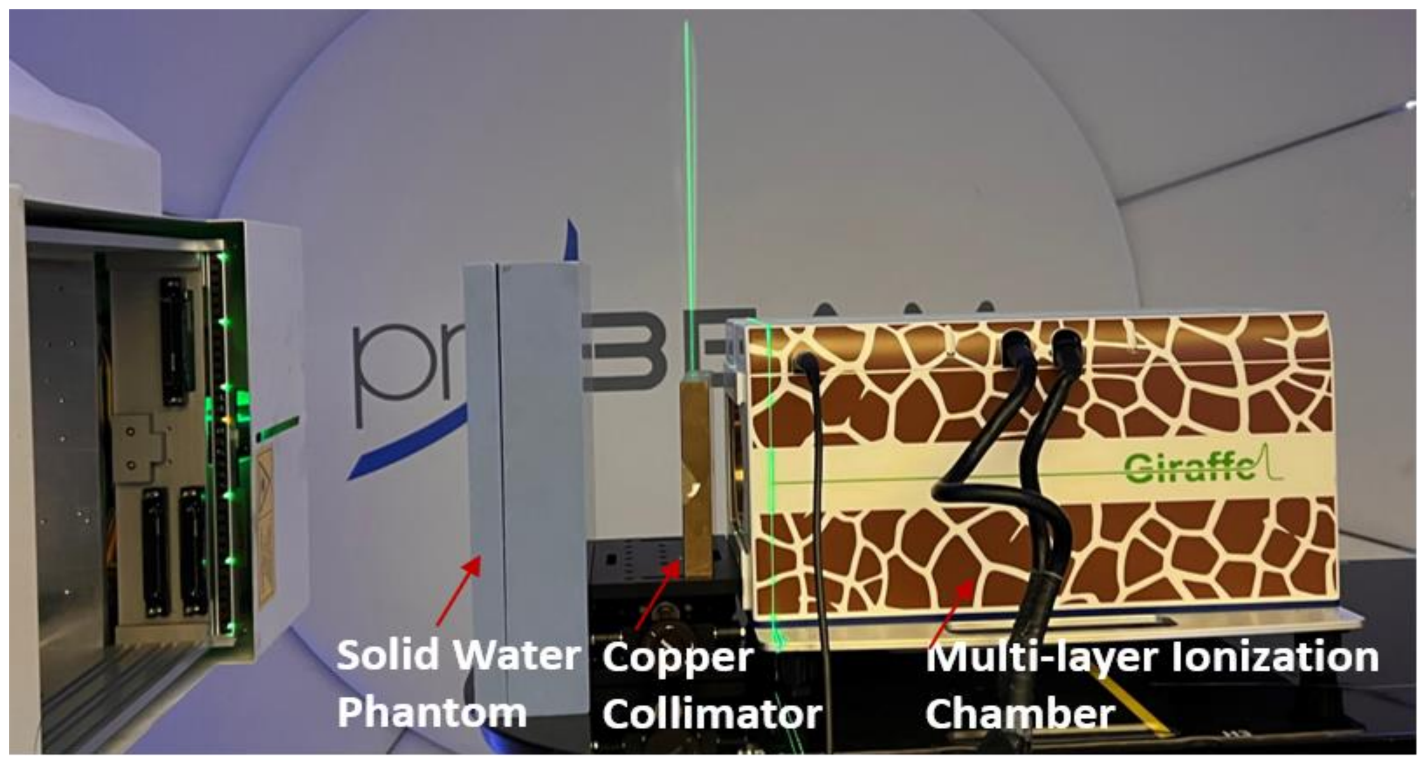

Figure 1. IDD Measurement Setup

RESULTS:

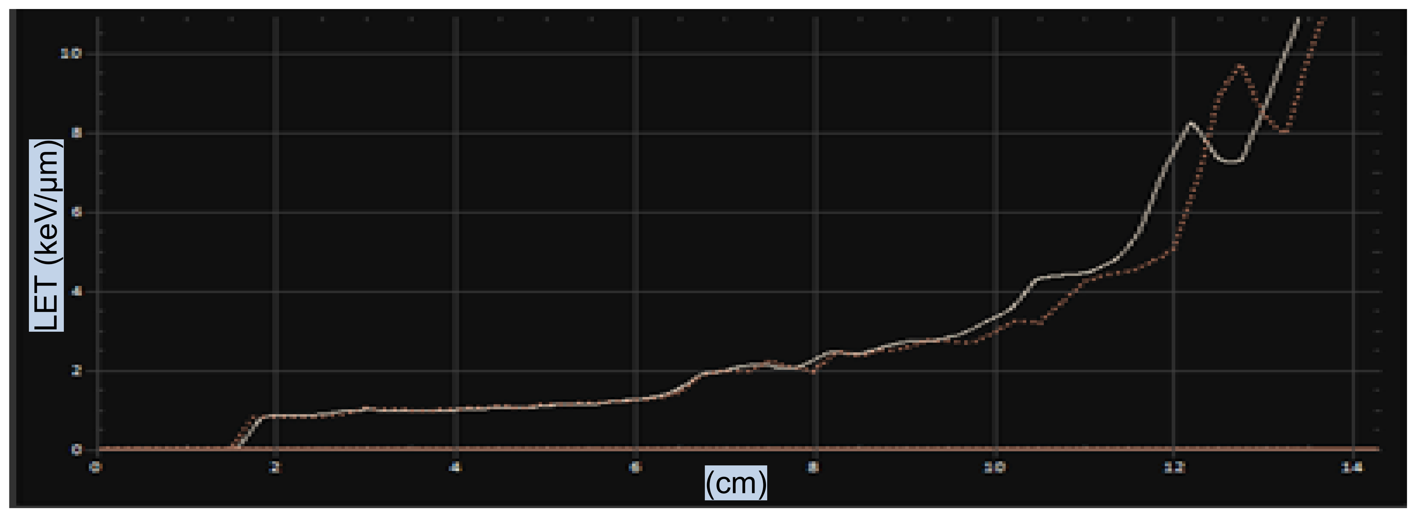

Figure 2. Displays how to determine the depth in solid water phantom for an OAR in the patient. Solid curve: LETd along the beam path in the treatment plan. Dotted curve: LETd along the beam path in the solid water phantom. The curves are matched at a depth < 7 cm because the muscle in this region has a similar density to that of the phantom. The curves are not matched at depth > 7 cm because the beam passes through bony structures, but the shapes of the curves are like each other. If the OAR is at depth 10 cm, then from the shapes, we determine the depth in the phantom as 10.5 cm.

- For all the 30 measurements, the LET_d ranged between 2.9 to 13.1 keV/µm, while the corresponding LET_d from the TPS ranged from 2.5 to 13.7 keV/µm.
- The differences between measurement and TPS were within -1 to +0.6 keV/µm. In 23 of 30 cases, the LET_d was higher for the measurement than that of the TPS.
- There was a strong correlation between the calculated and measured LET_d with R^2 of 0.974 (Figure 3).

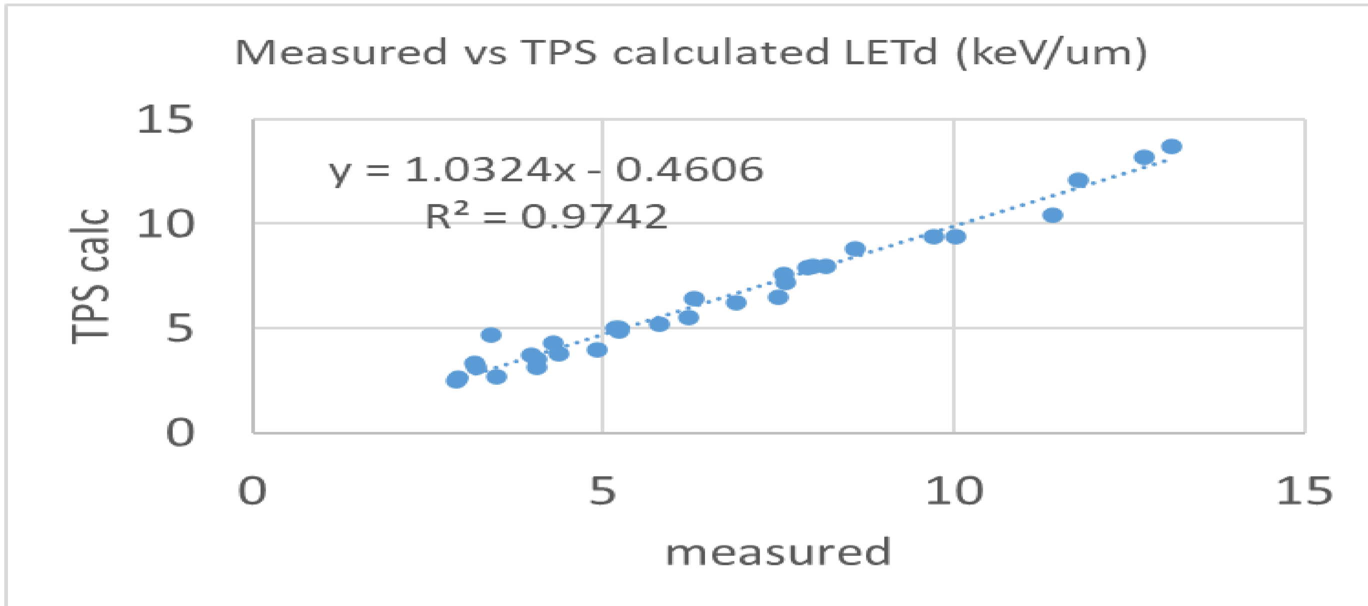

Figure 3. LET_d measured vs TPS calculated.

CONCLUSION:

- Our proposed method was used to successfully validate the treatment planning system calculated dose-averaged LET (LET_d).
- This may be a potential tool to QA the LET doses on the organs at risks during proton therapy.

REFERENCES:

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2. Wilkens JJ, Oelfke U. Analytical linear energy transfer calculations for proton therapy. **Med Phys.** 2003; 30: 806-815.