Proton Energy Spectrum-based Linear Energy Transfer Measurement

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INTRODUCTION

Proton relative biological effect (RBE) increases as the proton linear energy transfer (LET). Currently, a fixed RBE of 1.1 is used in clinic but it has been proposed to include LET in treatment planning. The value of LET is either calculated by Monte Carlo (MC) simulation or measured via some surrogates. In the latter case, MC is needed to calibrate the relationship between the surrogate and LET. We propose a novel method to measure LET that need not be calibrated by MC.

AIM

To provide an independent and accurate measurement of linear energy transfer for proton radiotherapy.

METHOD

To count energy loss to electrons from all the protons at the measurement voxel of interest, a collimator with an open at the voxel was placed in front of a multilayer ion chamber (MLIC), which recorded the proton integral depth dose (IDD). A novel algorithm was developed to extract the proton energy spectrum from the acquired IDD. According to the physics definition, track- and dose-averaged LETs were calculated from the energy spectra at the entrance and exit of the voxel. This method was also applied to IDDs acquired by a Bragg peak ion chamber (BPIC) during proton beam commissioning.

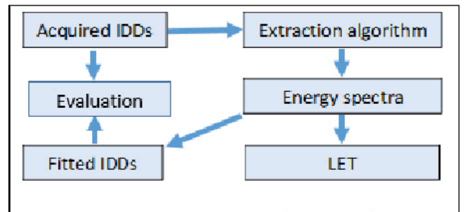

Fig. 1. Proton LET measurement schematic.

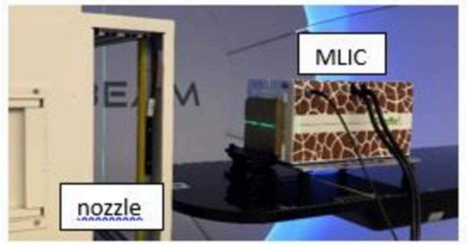

Fig. 2. Setup of acquiring IDDs with a collimator in front of a Giraffe MLIC.

RESULTS

LET increased slowly in the IDD's plateau and rapidly after the Bragg peak. For the IDD of a 160 MeV pencil beam scanned by BPIC, the track- and dose-averaged LETs (in unit of keV/μm) were 0.6 and 1.1 respectively at the water surface, and 8.7 and 14.3 respectively at depth 18.2 cm (the Bragg peak was at depth 17.3 cm) where the IDD was about 5% of the peak. For the same energy pencil beam but whose IDD was acquired by MLIC with the collimator, we obtained similar LET except that right behind the collimator. The dose-averaged LET in MC is erroneously step-size dependent, but in our method is independent.

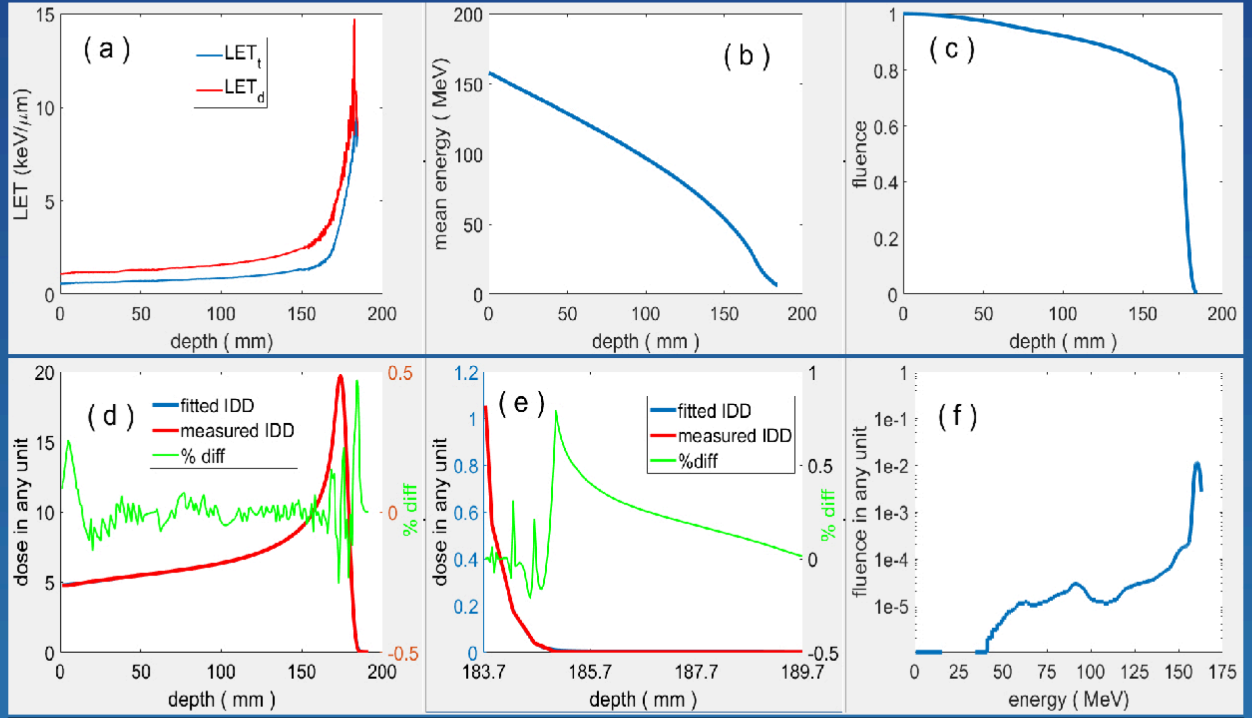

Fig. 3. Results from our proton energy spectrum–based LET measurement for a cyclotron-generated 160-MeV pencil beam. (a) Track-averaged LET_t and dose-averaged LET_d; (b) mean energy; (c) total fluence of the pencil beam at the depth in water; the measured and fitted IDDs of the pencil beam at the entrance (d) and at a depth of 18.37 cm (e); and (f) the energy spectrum of the pencil beam at the entrance. The LETs became unstable at depth > 18.4 cm due to IDD measurement uncertainty. Step size (slice thickness) was 1 mm at depth ≤ 15 cm, and 0.1 mm otherwise.

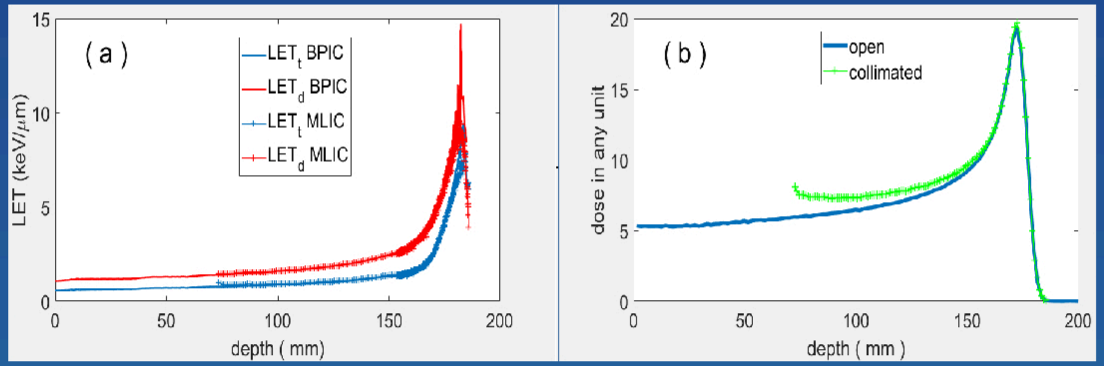

Fig. 4. (a) The measured LETs with our method from (b) the IDD acquired by a multilayer IC with a copper collimator at 7 cm solid water. For a comparison, the IDD of the same pencil beam (160 MeV) scanned by a Bragg peak IC and the LET from Fig. 1 are displayed. The difference between the IDDs is due to additional low energy protons traversing the collimator. Collimators with even higher stopping power materials than copper and specifically designed collimator open structure can help remove the additional low energy protons. These additional low energy protons increased LET_t and LET_d 28% and 4% respectively at depth 7 cm. The LETs from the multilayer IC became unstable at depth > 18.3 cm due to the IDD measurement uncertainty. Monitor units about 3 cGy were delivered for the IDD. The same step size (slice thickness) strategy as in Fig. 3 was used.

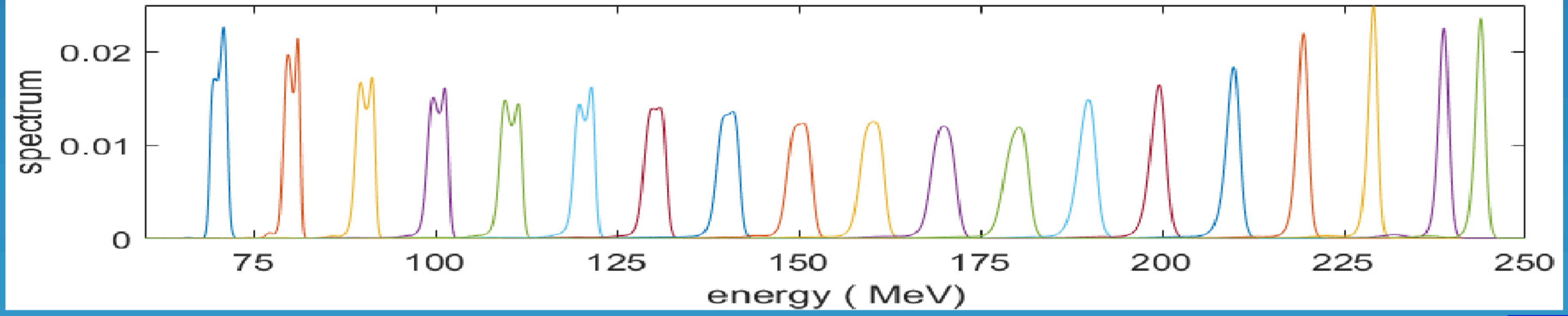

Fig. 5. Energy spectra of 19 pencil beams in air at the beam isocenter of our cyclotron. Each spectrum is normalized.

CONCLUSIONS

Our method provides an independent measurement of proton LET. Our algorithm of extracting the energy spectrum is high accurate and efficient. The collimator for the acquisition of IDDs introduced some low energy components. We will improve the acquisition by designing new collimators.

CONTACT INFORMATION

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