Using prompt gamma emission profiles to monitor day-to-day dosimetric changes in proton therapy

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Purpose/Objective:

Prompt gamma (PG) emission profiles can be used to determine the proton range in patients, but studies on the correlation between PG measurements and relevant dosimetric parameters are mostly lacking. The aim of this study was to investigate the feasibility of using PG emission profiles to monitor dosimetric changes in pencil beam scanning (PBS) proton therapy as a result of day-to-day variation in patient anatomy.

Materials/methods:

We included 11 prostate patients with a planning CT scan and 7–9 repeat CT scans (99 CT scans in total), illustrating daily variation in patient anatomy. For each patient, we had a PBS treatment plan with two lateral fields. We determined the real-time PG emission profiles on a cylindrical surface around the patient by simulating each plan on the planning CT and on the repeat CT scans of each patient using the Geant4-based TOPAS Monte Carlo code. The scored (i.e. detected) PGs were discriminated on the basis of energy (E≥1 MeV) and angle of incidence (87°≤θ≤93°) so as to select PGs perpendicular to the treatment beam. The treatment plans consisted of a mean of 1417 spots and the PGs were scored for each spot individually.

From the planned and simulated dose distributions, we determined the $V_{95\%}$ of the GTV and the D_{mean} and V_{60Gy} of the rectum. Next, the PG profiles that corresponded with the 5% most intense spots (i.e. with the highest number of protons) were selected. We fitted sigmoid functions to the falloff region of all selected PG emission profiles and used the 50% point of the sigmoid curve (X_{50}) as a measure for the falloff location (which is known to correlate strongly with the Bragg peak location of the corresponding spot). We used the distribution of the absolute differences between the X_{50} ($|\Delta X_{50}|$) of all selected spots simulated using the planning CT scan and the repeat CT scans for each patient as a measure of similarity between simulations. To evaluate the validity of using $|\Delta X_{50}|$, we determined Pearson correlation coefficients (r) between the mean and standard deviation (SD) of $|\Delta X_{50}|$ and dosimetric differences between simulations.

Results:

Figure 1 illustrates dosimetric differences due to anatomical changes. An increase in D_{mean} and V_{60Gy} of the rectum of up to 16.0 Gy and 13.6%-point, respectively, and a decrease in $V_{95\%}$ of the GTV of up to 20.7%-point, were observed. Measurable correlations were observed between the change in $V_{95\%}$ when simulating the treatment plan on the repeat CT scans and the mean $|\Delta X_{50}|$ ($|r|$≥0.51 for 6 out of 11 patients; mean $|r|$ of 0.56 (SD: 0.29)). In addition, the SD of $|\Delta X_{50}|$ appears to be a potential predictor for a change in D_{mean} of the rectum ($|r|$≥0.58 for 6 patients; mean $|r|$ of 0.46 (SD: 0.29)) (Figure 2). No significant predictor was found for V_{60Gy} due to the small mean difference between simulations.

Conclusion:

These promising results show, as a proof of principle, that PG emission profiles can be used to monitor daily dosimetric changes in proton therapy as a result of day-to-day anatomical variation.
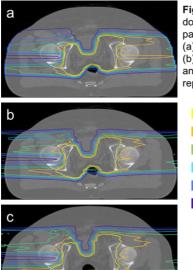

Figure 1: Illustration of dose distributions for patient 1: planned dose (a) and simulated dose (b) on the planning CT, and simulated dose on repeat CT 4 (c).
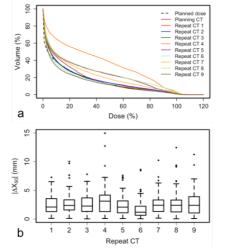
🟨	44.4 Gy
🟧	37.0 Gy
🟩	29.6 Gy
🟦	22.2 Gy
🟦	14.8 Gy
🟪	7.4 Gy

Figure 2: Dose volume histograms of the rectum for the planned dose and the simulated dose for all available CT scans of patient 1 (a) and the $|\Delta X_{50}|$ distribution for all repeat CT scans (b).