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WP13 - D.3  Publication on evaluation and optimization treatment planning for protons

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Overview

The last deliverable in work package 13, before completing the PARTNER project, is meant to summarize my work in the form of a publication. The manuscript has been accepted for publication in the International Journal of Radiation Oncology, Biology, Physics, therefore below only abstract will be presented.

A retrospective treatment study, reported in the publication however, is not the last part of my work within the project. More about ongoing study dedicated to combined modality treatment can be found in the Milestone 4.

Title of the manuscript

Is there an advantage in designing adapted, patient specific PTV margins in scanned proton therapy for prostate cancer?

Summary

This retrospective study deals with the challenge of organ motion in scanned proton beam therapy. To evaluate its dosimetric impact on the target coverage and organ at risk sparing, nine prostate cancer patients underwent repeated imaging. Three different PTV approaches were investigated. Detail examination of the results indicated the advantages and disadvantages for each of the presented approaches and revealed the most robust margin strategy.

Purpose

Anatomic variations in the pelvic area can affect the delivered dose distribution in scanned proton beam therapy. The purpose of this planning study was to investigate the most robust margin strategy to account for inter-fractional motion in prostate cancer.

Material & Methods

Nine prostate cancer patients were arbitrarily selected. For each, one planning CT and 7 weekly CBCTs were acquired. CBCTs were registered to the planning CT and prostate, rectum, rectal wall, bladder and bladder wall were delineated on each data set. All structures defined on the CBCT were mapped on the planning CT. The following PTV approaches were investigated, where differences between the conventional margin approach (PTV_{10mm}), correction protocol based, reduced margin recipe (PTV_{Red}) and a patient specific adaptive approach were compared (PTV_{Hull}): a) PTV_{10mm} – extension of clinical target volume delineated on planning CT (called CTV_{ct}) by 10 mm uniform margin, b) PTV_{red} – CTV_{ct} extended by 5 mm
in LR, AP, 8 mm in IS direction and c) PTV\textsubscript{Hull} - created by summing contours of the CTV\textsubscript{ct}, and CTVs delineated on five CBCTs acquired during the first week, plus a margin of 3 mm in LR, IS and 5 mm in AP direction. For each patient three separate plans (PLAN\textsubscript{Red} - for PTV\textsubscript{Red}, PLAN\textsubscript{10mm} - for PTV\textsubscript{10mm} and PLAN\textsubscript{Hull} - for PTV\textsubscript{Hull}), calculated on the planning CT, were created, using a spot-scanning technique based on 2 lateral fields utilizing the treatment planning system XiO (ELEKTA, St. Louis, MO). The prescribed dose for the PTV was 78Gy. The plan was accepted when 95% of the prescribed dose was delivered to 95% of the PTV. Dose constraints for bladder and rectum were based on in-house prostate IMRT protocol. The dosimetric impact of organ motion on targets and OARs were assessed via DVH analysis using structures variations extracted from CT and CBCT information.

**Results**

Dosimetric comparison between 3 plans for all nine patients showed that each of the presented methods achieved excellent target coverage. Changes in the dose to 98% of the volume (D\textsubscript{98}), the median dose (D\textsubscript{median}) and D\textsubscript{2} were not substantial (the largest difference was 0.5 Gy). Differences were observed in V\textsubscript{98}, where PTV\textsubscript{Hull} and PTV\textsubscript{Red} were superior over the PTV\textsubscript{10mm} method. The PTV\textsubscript{Hull} approach seemed to be more robust to organ motion, V\textsubscript{98} for the CTVs was 99.7%, while for PTV\textsubscript{Red} plans and the PTV\textsubscript{10mm} plans V\textsubscript{98} was 98% and 96.1% (Fig.1).

The maximal dose for the bladder wall delineated on the planning CT was quite similar for PTV\textsubscript{Red} and PTV\textsubscript{10mm} based plans (78.8 Gy and 78.7 Gy). A slightly higher, but not significantly, value was obtained for PLAN\textsubscript{Hull} where D\textsubscript{max} was 79.6 Gy. For bladder wall contoured on weekly CBCTs the mean value for PLAN\textsubscript{Red} drops down to 78.2 Gy. Moreover, bladder wall sparing (CT structure) for the PTV\textsubscript{Red} based plans was the best, the 70 Gy resulted in 9.7 cm\textsuperscript{3} of the bladder wall volume, while for PLAN\textsubscript{10mm} and PLAN\textsubscript{Hull} it was 12.5 cm\textsuperscript{3} and 11.3 cm\textsuperscript{3}. V\textsubscript{30Gy} was 16.8 cm\textsuperscript{3}, 20.0 cm\textsuperscript{3} and 18.3 cm\textsuperscript{3} (for PLAN\textsubscript{Red}, PLAN\textsubscript{10mm} and PLAN\textsubscript{Hull} respectively). Motion of the bladder did not change the result, V\textsubscript{70Gy} for bladder wall information derived from CBCTs for PTV\textsubscript{Red} based plans were 3.1 cm\textsuperscript{3} lower compared to PTV\textsubscript{10mm} approach and 1.4 cm\textsuperscript{3} lower compared to PTV\textsubscript{Hull} approach, for the V\textsubscript{30Gy} it was respectively 3.6 cm\textsuperscript{3} and 1.9 cm\textsuperscript{3} lower. Although, in general doses to bladder wall were higher for the PLAN\textsubscript{Hull} and PLAN\textsubscript{10mm} compared to PLAN\textsubscript{Red}, only the differences between PLAN\textsubscript{10mm} vs PLAN\textsubscript{Red} were statistically significant.

The rectal wall sparing for the PTV\textsubscript{10mm} method was the worst. A significant difference was found between that method compared to others, the V\textsubscript{70Gy} was 3.9 cm\textsuperscript{3} higher than PTV\textsubscript{Red} and 2.4 cm\textsuperscript{3} than PTV\textsubscript{Hull} plans.
The $V_{30Gy}$ was on average 5.1 cm$^3$ and 3.1 cm$^3$ lower for PLAN$_{Red}$ and PLAN$_{Hull}$, respectively. Taking motion into account PTV$_{Red}$ and PTV$_{Hull}$ methods were also superior over PTV$_{10mm}$ method, mean CBCTs volume values were similar as for the structure contoured on the planning CT. The $D_{max}$ values for CT rectal wall were similar for each of the methods, as well as for CBCTs. Figure 2 represents dose volume histograms for the target and organs at risk and shows dosimetric impact of interfractional motion for two particular cases, where the prostate does not move much during the course of radiotherapy (left) and where the motion is significant (right).

Figure 1: Dose distribution for three PTV concepts in the case, where prostate moved the most, a) PLAN$_{10mm}$ created for PTV$_{10mm}$, b) PLAN$_{Red}$ Created for the PTV$_{Red}$, c) PLAN$_{Hull}$ Created for PTV$_{Hull}$; red contours- CTV on different treatment days derived from weekly CBCTs; thick yellow line- PTV$_{10mm}$; pink thick line- PTV$_{Red}$; thick white line- PTV$_{Hull}$; shaded light blue area- rectum.
Figure 2. Dose volume histograms for patient 1 (left) and patient 9 (right). a) DVHs for target volumes, b) DVHs for the bladder wall, c) DVHs for the rectal wall. Thick lines represent volumes delineated on the planning CT; color filled areas represent the dose range of particular volumes, which were derived from weekly CBCTs information (upper-right corner—the same DVH in a different scale).
Conclusions

All 3 described PTV approaches reached planning goals, but the PTV_{10mm} method was inferior in terms of organ sparing. PTV_{Red} approach was the best to spare bladder and rectal wall, but not significantly better compared to the PTV_{Hull} method. The PTV_{Hull} concept, based on organ motion information taken from repeated images, was the most insensitive to target motion. Therefore, when looking at organ sparing there is no difference between using PTV_{Red} or PTV_{Hull} method, however by choosing PTV_{Hull} a benefit of better coverage and target motion compensation can be gained. Moreover, it was shown that repeated imaging is useful to estimate interfractional motion and its impact on the dose distribution.