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A knowledge-based quantitative approach to characterize treatment plan quality: application to prostate VMAT planning

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For optimal radiotherapy treatment plans (TPs), the anatomical variations among patients must be considered in the planning process. The identification of an optimal or sub-optimal plan for a given patient requires quantitative knowledge of what is dosimetrically achievable for that particular patient anatomy. Even when using inverse-planning methods, creating an optimal plan is still a complex task. Radiation therapy treatment planners set and adapt dose-volume objectives and constraints for the targets and organs at risk (OARs) repeatedly in a trial and error treatment planning process to optimize clinically acceptable plans. However, using unachievable constraints may lead to sub-optimal plans. As a result, plan quality varies among planners according to their level of experience. This unsatisfactory situation highlights the need for a quality control (QC) method to estimate the achievable OARs absorbed dose sparing. Such a QC algorithm should not entirely rely on personal judgment but should consider the geometric variations among patients.

In this work, a quantitative QC algorithm to characterize treatment plan quality is proposed. The tool is validated using Volumetric Modulated Arc Therapy (VMAT) plans for the treatment of prostate cancer. This tool helps to improve plan quality by estimating the achievable OAR sparing, based on the knowledge learned from prior plans. The knowledge base used in this work comprises 450 plans, consisting of 181 homogenous prostate plans and 269 simultaneous integrated boost (SIB) prostate plans. A knowledge-based algorithm was used to relate the absorbed doses of the OARs (rectum and bladder) and their proximity to the planning target volume (PTV). A metric ($M_{q,r}$ value) was defined to characterize the OAR sparing based on the weighted differences of the mean doses at binned distances to the PTV surface. The 90% probability ellipse of the normally distributed OARs $M_{q,r}$ values were considered to define a threshold above which the treatment plan is highly recommended to be re-optimized. Model validation was performed by computing dose-volume histograms (DVHs) for both rectum and bladder of the plans before and after re-optimization. Following re-optimization, 8/11 of the homogenous plans and 6/13 of the SIB plans outside the 90% probability ellipse gained better OARs sparing while achieving the same or better target coverage. Also, 3/4 of the homogenous TPs and 1/9 of the SIB TPs between 80% - 90% were improved. The decreased $M_{q,r}$ values of bladder and rectum after re-optimization of the plans in both groups (homogenous and SIB) show that better sparing of OARs was achieved. The quantitative and qualitative ($M_{q,r}$ and DVHs) comparison of plans before and after re-optimization shows the efficiency of this metric for evaluating the goodness between the compared plans.

The algorithm correctly identified sub-optimal plans which in a high percentage showed further OAR sparing after re-optimization. The algorithm was validated for the prostate but can be applied to other treatment sites. Adoption of such a method will advance the quality of current planning providing better treatment planning consistency in terms of OAR sparing.