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Automated Planning Dose Optimization Methods for Prostate SBRT to Generate Synthetic Dose Data for Training a Plan Optimization Deep Learning Neural Network

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PURPOSE / OBJECTIVES

This study aims to quantify the plan quality of a Knowledge-Based Planning (KBP) model using a dosimetric scorecard.

The goal is to generate large amounts of high-quality, quantified dosimetric data that can be used to train a deep learning-based dose optimization tool. By iteratively improving plans using the scorecard, the model seeks to provide an efficient and consistent method for prostate SBRT planning that meets clinical trial criteria and supports future advancements in dose optimization.

MATERIAL & METHODS

KBP Model Development: The KBP model was developed using 41 prostate SBRT cases, with 22 from the ARTIA trial (with rectal spacers) and 19 from an external institution (without rectal spacers). The cases were iteratively replanned using a comprehensive dosimetric scorecard, ensuring high plan quality through optimization of dose objectives and priorities. The KBP Model was then trained on the replanned cases.

Dosimetric Scorecard: A 32-metric dosimetric scorecard was created with input from physicians. The scorecard quantified clinical intent through metrics such as Dose at Volume and Volume at Dose, assigned using piecewise linear scoring functions. The total plan quality score was out of 216 points. This scorecard was used both to improve the training set cases and to tune the automatic optimization objectives of the KBP model.

Validation: The KBP model was validated on 10 independent cases using both VMAT and IMRT beam arrangements. Each case was scored using the dosimetric scorecard, allowing direct comparison between the KBP-generated plans and the original clinical plans. The validation covered various clinical scenarios, ensuring flexibility and robustness in both target coverage and organ-at-risk (OAR) sparing.

RESULTS

Dosimetric Score Improvement: The average score for validation cases improved, significantly increasing from the clinical baseline of 166.2/216 to 194.0/216 ($p<0.0015$). This improvement reflects enhanced plan quality across both VMAT and IMRT techniques.
Validation Case Performance: For VMAT plans, the average score was 194.00/216, while IMRT plans averaged 187.49/216, both of which outperformed the original clinical plans.
Target Coverage and OAR Sparing: The KBP model consistently produced plans with >99% PTV-U coverage (V@36.25Gy) and reduced rectal dose (Rectum D@50%), showing a good balance between target coverage and organ-at-risk sparing.
Flexibility and Adaptability: The model demonstrated the flexibility to adapt to different clinical scenarios, including urethral sparing and varied fractionation schemes. The ability to scale dose levels for specific clinical intents without compromising plan quality underscores the versatility of the KBP model.

Figure 1: Pie chart illustrating distribution of scorecard point weighting for each OAR and PTV

Clinical Relevance Comparison Results (Out of 216 Points)

Case #	Clinical Ethos (9 Field IMRT)	RapidPlan Halcyon (6 Arc VMAT)	RapidPlan Halcyon (19 Field IMRT)	RapidPlan TrueBeam M120 (3 Arc VMAT)	RapidPlan TrueBeam HDMLC (3 Arc VMAT)
23	154.21	194.83	186.24	186.64	195.16
24	160.77	190.89	182.04	189.39	195.23
25	177.27	202.56	196.68	200.32	203.61
26	168.7	189.65	182.79	186.77	192.46
27	170.12	192.07	189.72	182.86	194.35
Mean	166.21	194.00	187.49	189.20	196.16

Table 1: The results of scores for each different plan made on our validation set.

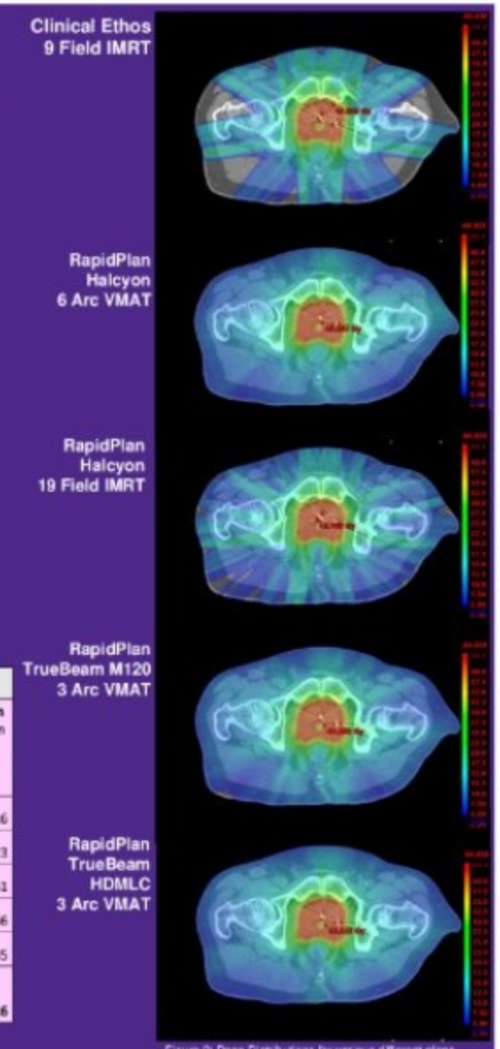

Figure 2: Dose Distributions for various different plans produced with the presented rapid plan model

RESULTS

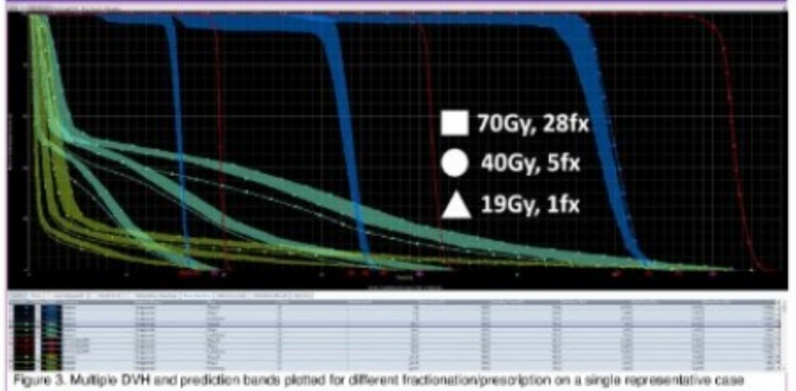

Figure 3. Multiple DVH and prediction bands plotted for different fractionation/prescription on a single representative case

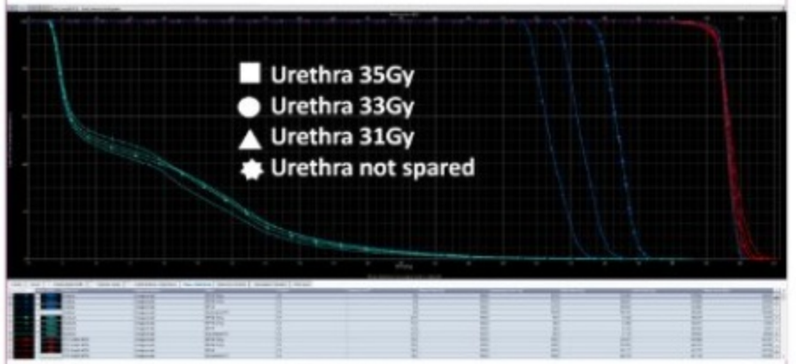

Figure 4. Example of changing target dose for PTV + Urethra

SUMMARY / CONCLUSION

The KBP model, trained on only 24 cases and guided by the dosimetric scorecard, consistently generates superior treatment plans compared to clinical baselines. Additionally, it has demonstrated flexibility for adapting to different planning criteria and is suitable for creating large volumes of dosimetric data necessary for training deep learning models. Future work will focus on using the dosimetric scorecard directly in optimization algorithms and employing the KBP model to support neural network training for dose optimization engines. Ultimately, the goal is to develop an autoplanning tool capable of understanding dosimetric tradeoffs while maintaining flexibility across different clinical protocols.