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Constructing and Validating a Knowledge-Based Planning Model for Lung SBRT in Eclipse

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ABSTRACT

Purpose
To develop and clinically validate a RapidPlan knowledge-based planning (KBP) model for lung stereotactic body radiotherapy (SBRT), aiming to improve plan quality, consistency, and efficiency in routine clinical practice.

Methods
A RapidPlan model was trained on 161 coplanar VMAT lung SBRT plans calculated using Acuros XB (2 mm grid; 6 MV FFF), covering multiple prescription regimens. Model Analytics was used to evaluate DVH prediction behavior and identify geometric and dosimetric outliers, leading to exclusion of four atypical plans. A priority-based optimization strategy combining a higher-priority internal target volume (ITV) objective with a lower-priority planning target volume (PTV) upper gEUD objective (a = 20) was implemented. Prospective validation was performed on 21 patients by comparing KBP-generated plans with clinically approved plans.

Results
Most plans met clinical criteria on first optimization, and the majority were equal to or improved compared to prior clinical plans. Global maximum dose was consistently contained within the ITV, demonstrating effective hotspot control. Remaining deviations were minor and were corrected with limited manual adjustment.

Conclusion
The RapidPlan model provides a reproducible and efficient framework for lung SBRT planning, supporting consistent plan quality and robust control of high-dose regions across a range of clinical scenarios.

INTRODUCTION

- Lung stereotactic body radiotherapy (SBRT) requires high dose conformity and steep dose gradients to achieve tumor control while sparing adjacent organs at risk.
- Treatment planning is often iterative and planner-dependent, leading to variability in plan quality and efficiency.
- Knowledge-based planning (KBP), including RapidPlan, leverages prior high-quality plans to predict achievable dose–volume histograms (DVHs) and guide optimization.
- While KBP has been widely adopted for several treatment sites, practical workflows for lung SBRT remain less well standardized.
- In this work, a RapidPlan model was developed and clinically implemented with a priority-based optimization strategy to improve consistency and spatial dose control.

METHODS AND MATERIALS

Model Development
•161 coplanar VMAT lung SBRT plans
•Dose calculation: Acuros XB, 2 mm grid, 6 MV FFF
•Prescription range: 30 Gy ×1 to 60 Gy ×8
Model Analytics
•Evaluation of:
- DVH prediction bands
- Sigma index (target homogeneity)
- Geometric and dosimetric outliers
- 4 atypical plans excluded

Optimization Strategy
•Explicit target priority hierarchy:
- ITV lower objective (higher priority)
- PTV upper gEUD (a = 20, lower priority)

•Gradient-oriented constraints:
- D2cm
- Ribs

•Manual NTO:
- Priority ≈ 145
- Start: 100%, End: 40%, Fall-off: 0.20

•Iterative tuning using 5 representative
Validation
•Prospective validation on 21 patients
•Comparison with clinically approved plans
•Recorded:
- First-pass acceptability
- Required manual adjustments

RESULTS

Model Performance
•Stable DVH prediction bands:
- ITV: mean 114%, SD = 1.12
- PTV: mean 108%, SD = 2.25

Clinical Acceptability
•52% acceptable on first optimization
•71% equal or better than prior clinical plans

Adjustment Efficiency
•Remaining deviations:
- Brachial plexus Dmax
- Spinal canal Dmax
- PTV undercoverage

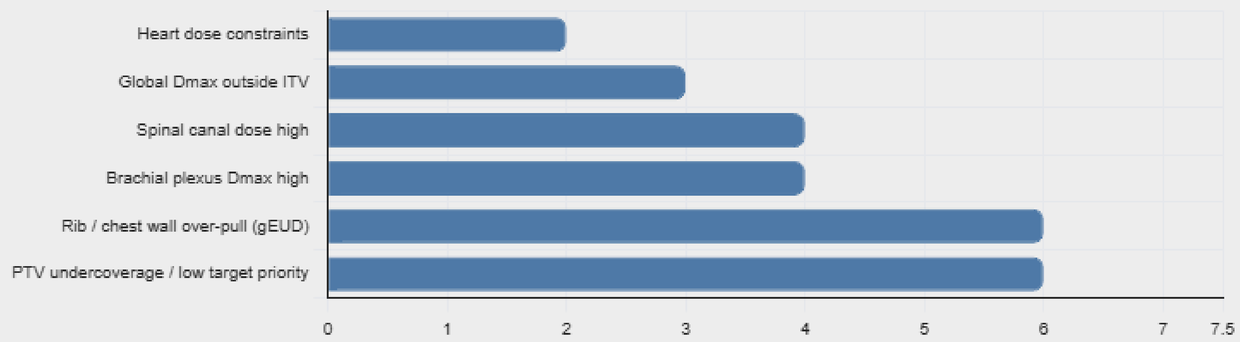
•Corrections completed in <10 minutes

Dose Control (KEY RESULT)
•High-dose regions consistently confined within the ITV
•Stable hotspot localization achieved
•Maintained without geometric cropping of ITV to PTV

Table 1. Common Validation Failure Modes and Typical Corrective Actions.

Failure Type	Typical Cause	Correction Strategy
PTV undercoverage	Target priority too low	Increase PTV objective priority
Rib / chest wall over-pull	Excessive pull from rib/chest wall objectives	Reduce rib/chest wall constraint influence
Spinal canal Dmax high	OAR proximity to target	Add or tighten spinal canal upper constraint
Brachial plexus Dmax high	OAR proximity or overlap	Add or tighten brachial plexus upper constraint
Global Dmax outside ITV	Imbalance between ITV and PTV objectives	Adjust ITV–PTV priority hierarchy
Heart dose constraint issue	Local anatomy / competing objectives	Add or strengthen heart-specific limit

Figure 1. Distribution of first-run RapidPlan validation failure modes in the 21-patient clinical validation cohort. The most frequent issues were PTV undercoverage and rib/chest wall over-pull, followed by brachial plexus and spinal canal dose excursions.



DISCUSSION

- The developed KBP model demonstrates that **institutional planning knowledge can be effectively encoded into a reusable framework**, reducing dependence on individual planner experience.
- The use of **priority-based optimization**, combined with a gEUD objective, provides a mechanism to influence the **spatial distribution of high dose**, rather than controlling isolated points.
- This approach enables improved control of **hotspot location and dose falloff**, which is particularly important in lung SBRT where steep gradients are required.
- Observed deviations from clinical criteria were **predictable and localized**, and could be resolved with minimal adjustments without modifying the underlying model.
- Overall, the model supports a more **efficient and consistent planning workflow**, while maintaining clinically acceptable plan quality.
- Figure 1 shows the distribution of first-run validation failure modes.

CONCLUSIONS

•A RapidPlan KBP model for lung SBRT was successfully developed and clinically validated.

•The model provides:
- •Consistent plan quality
- •Efficient optimization workflow
- •Reliable control of high-dose regions

- Priority-based optimization, combined with gEUD objectives, enables improved spatial dose control without additional geometric constraints.
- The approach is suitable for routine clinical implementation and supports standardization of lung SBRT planning.

REFERENCES

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