Fully Automated, Feedback-Driven VMAT Planning in Elekta Monaco for Localized Prostate Cancer

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ST GEORGE'S CANCER CARE CENTRE

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ABSTRACT

Purpose:
VMAT planning for prostate cancer in Elekta Monaco can be slow and variable due to differences in planner experience. Existing automation tools often depend on external prediction models or provide limited optimization support. We developed a fully automated workflow that operates entirely within Monaco and dynamically adjusts optimization objectives in response to real-time DVH feedback, aiming to deliver consistent, clinically acceptable plans without manual input.

Methods:
Fifty consecutive patients treated with 60 Gy in 20 fractions were retrospectively analysed. For each case, an automated VMAT plan was generated using a scripted pipeline that launched planning from a standardized template and iteratively modified isoconstraints and optimization parameters during Phase 1 and Phase 2. Automated plans were compared with clinically delivered manual plans using Wilcoxon signed rank tests. Metrics included target coverage, conformity, OAR sparing, MU, and modulation complexity. Ten randomly selected plans (20%) underwent ArcCHECK QA using 3%/2 mm gamma criteria.

Results:
All automated plans met institutional clinical constraints. Target coverage matched manual plans with no significant difference. Automated plans demonstrated slightly improved conformity and consistent reductions in low and mid-dose rectum metrics while maintaining similar high-dose values. For example, rectum V24Gy decreased by 9.76% ($p < 0.001$) and V32Gy by 5.85% ($p < 0.001$). Bladder results were mixed but clinically acceptable. MU and complexity scores increased modestly, but all QA tests passed with ≥99.8% gamma agreement, indicating no loss of deliverability. Average automated planning time was 38.7 minutes, substantially faster than typical manual workflows.

Conclusion:
A fully autonomous, feedback-driven Monaco workflow can consistently generate prostate VMAT plans that match or improve manual plan quality, reduce planning time, and minimize interplanner variability. This demonstrates a practical path toward routine, TPS-integrated automated planning.

INTRODUCTION

- Prostate VMAT planning improves conformity and OAR sparing but remains **time-intensive** and **planner-dependent**
- Existing automation methods:
  - Knowledge-based planning (KBP)
  - Template-based scripting
  - External/cloud optimization
    → Often **decouple decision-making from the TPS optimizer**
- Monaco provides:
  - Biological cost functions
  - Multi-criteria optimization (MCO)
  - **Limited but emerging scripting API access**
- **Gap**: Lack of validated, end-to-end, TPS-native automated planning workflows for Monaco

OBJECTIVE

Develop and validate a **deterministic, TPS-native automated planning algorithm (APA)** that:

- Interrogates **optimizer state variables** (isoeffects, cost weights, DVHs)
- Applies **rule-based control of optimization**
- Reproduces expert planning behaviour **without external models**

METHODS AND MATERIALS

Cohort
n = 50 prostate patients
60 Gy / 20 fx, single-arc VMAT
Retrospective paired comparison (manual vs automated)

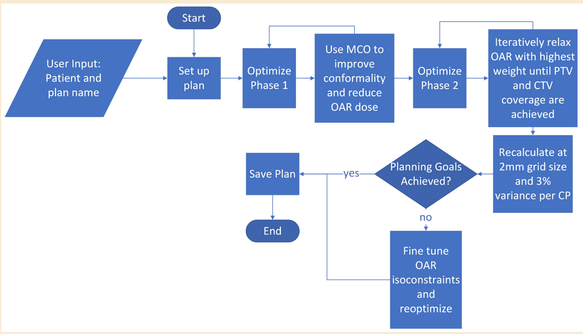

Figure 1: Simplified APA Flowchart

Algorithm Design

Core innovation: closed-loop optimization control within Monaco (Figure 1)

MCO-driven refinement in Monaco's Phase 1:

- Sequential activation of MCO
- Post-optimization interrogation of:
  - Isoeffect values
  - DVH statistics
- Rule-based update: $IC = f(IE)$

Constraint relaxation loop in Monaco's Phase 2:

- Rank cost functions by **effective weight**
- Identify dominant OAR constraint
- Apply selective relaxation:
  - Patient QO: ×1.8
  - OARs: ×1.08
- Iterate until coverage criteria satisfied

Evaluation

Dosimetry
Target coverage (PTV, CTV) OAR sparing (rectum, bladder)
Complexity
Monitor Units (MU), Modulation Complexity Score (MCS)
Statistics
Wilcoxon signed-rank, BH multiple testing correction
Deliverability
ArcCHECK QA (3%/2 mm)

RESULTS

Planning Efficiency
Automated planning time: 38.7 ± 14.7 min per case
Manual planning: ~2 hours (institutional estimate)

Median Dose Metrics for Automated and Manual Plans

Structure	Dose	Median (Auto)	IQR (Auto)	Median (Manual)	IQR (Manual)	Median Δ (Auto-Manual)	Adjusted p-value
CTV	D2%	63.05 Gy	0.18 Gy	62.94 Gy	0.56 Gy	0.101 Gy	0.323
PTV	V60Gy	99.9 %	0.36 %	98.98 %	1.28 %	0.682 %	<0.001
	V57Gy	98.23 %	0.65 %	98.35 %	0.77 %	-0.275 %	0.116
Rectum	V60Gy	0.35 %	0.29 %	0.36 %	0.38 %	-0.040 %	0.901
	V56Gy	6.52 %	3.25 %	6.61 %	3.55 %	-0.085 %	0.676
	V52Gy	11.37 %	5.11 %	11.32 %	5.25 %	-0.164 %	0.376
	V48Gy	14.74 %	6.87 %	14.96 %	6.01 %	-0.515 %	0.143
	V40Gy	20.01 %	8.69 %	22.03 %	8.58 %	-1.602 %	0.003
	V32Gy	26.13 %	11.83 %	31.97 %	10.39 %	-4.279 %	<0.001
	V24Gy	37.5 %	13.78 %	47.26 %	13.99 %	-8.187 %	<0.001
	Dmean	19.37 Gy	2.14 Gy	19.88 Gy	1.89 Gy	-0.485 Gy	<0.001
Bladder	V60Gy	2.61 %	1.31 %	0.82 %	1.03 %	1.326 %	<0.001
	V48Gy	10.4 %	6.38 %	14.12 %	6.17 %	-4.070 %	<0.001
	V40Gy	14.59 %	8.08 %	19.03 %	7.89 %	-2.909 %	<0.001
Femur L/R	V40Gy	0 %	0 %	0 %	0 %	0 %	-

Table 1: Median and IQR for each dose metric across the 50 automated plans, and median differences relative to the manual plans with corresponding adjusted p-values. For OARs, a negative number indicates improved sparing, and for targets a positive number indicates improved coverage.

Dosimetric Comparison
Automated plans achieved:

- significant reductions for rectum V40 Gy (−1.6%), V32 Gy (−4.3%), V24 Gy (−8.2%), and mean dose (−0.49 Gy).
- reductions for bladder V48 Gy (−4.1%) and V40 Gy (−2.9%), but a small increase in V60 Gy (+1.3%).

All 50 automated plans met clinical acceptance criteria for target coverage and OAR constraints, with 92% achieving optimal goals.

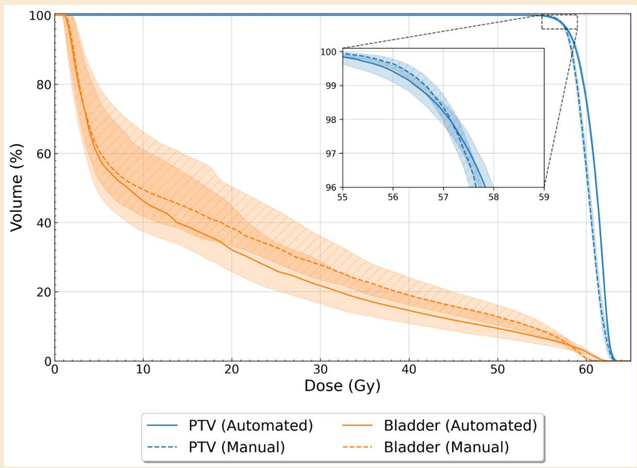

Figure 2: Median PTV and Bladder DVHs for the automated plan (solid line) and the manual plan (dotted line). The solid and cross-hatched shaded regions represent the interquartile range (IQR) of the DVHs for the automated plans and clinical plans respectively.

Deliverability
Excellent QA results: Gamma pass ≥ 99.8%
No clinical delivery concerns

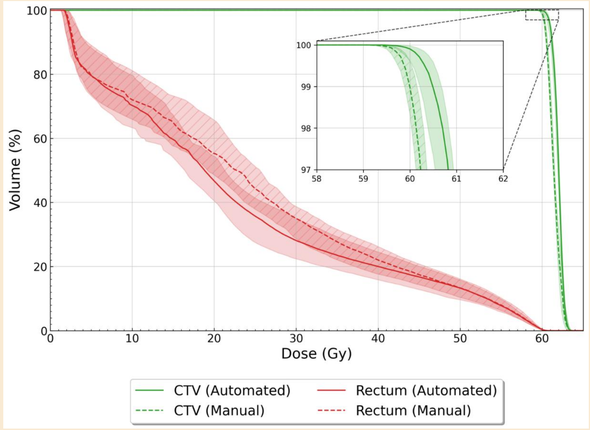

Figure 3: Median CTV and Rectum DVHs for the automated plan (solid lines) and the clinical plan (dotted lines). The solid and cross-hatched shaded regions represent the inter-quartile range (IQR) of the DVHs for the automated plans and clinical plans respectively.

Plan Complexity
MU: slightly higher for automated plans
(582.7 ± 38.2 vs 553.9 ± 51.3, $p < 0.001$)
MCS: slightly lower (more modulation)
(0.642 vs 0.672, $p < 0.001$)

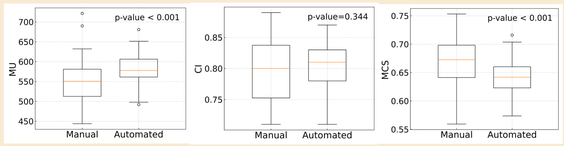

Figure 4: Box plots of the distribution of (a) Monitor Units (MU), (b) Conformity Index (CI), and (c) Modulation Complexity Score (MCS) across the manual and automated plans, with associated p-values. Automated plans demonstrated a statistically significant increase in MU and a decrease in MCS, and no statistically significant differences in CI.

DISCUSSION

Demonstrates feasibility of **TPS-embedded adaptive optimization control**

Compared to KBP: No dependence on training datasets

Compared to templates: Fully **patient-specific adaptation**

Increased modulation reflects: **Systematic constraint prioritization**

TPS-resident implementation preserves:

- Transparency
- Modifiability

CONCLUSIONS

First validated **feedback-driven, Monaco-native automation.**

Achieves:
Non-inferior dosimetry
Improved consistency
Reduced planning time

Supports broader adoption of **closed-loop optimization strategies in TPS environments.**

This approach offers a practical pathway for routine clinical automation in Elekta Monaco without external models or cloud systems.

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