Development and Validation of In-House Automatic VMAT Planning for Single Fraction and 5-Fraction Partial Breast Irradiation

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ABSTRACT

Purpose: To describe the development and validation of in-house automatic planning for VMAT partial breast irradiation (PBI) in either 1 or 5 fractions.

Methods: The Treatment Planning Automation System (TPAS) is an in-house platform that enables VMAT plans to be produced in Eclipse with automatic priority adjustments and iterative re-optimization if planning goals are not met. For this study, TPAS protocols were developed for 26 Gy in 5 fractions and 13 Gy in 1 fraction VMAT PBI using planning goals from the upcoming SHIFT-PB phase II clinical trial (ClinicalTrials.gov ID NCT06885671). Forty-nine clinical 5-fraction plans were replanned with TPAS for both 5 and 1 fraction treatments and compared via PTV and OAR planning goals, 95% and 50% conformity indices (CI), PTV homogeneity index (HI), and monitor units (MU). Time from TPAS plan submission to completion and number of iterative optimizations per plan were recorded.

Results: All TPAS plans achieved all planning goals for PTVs, lungs, heart, and uninvolved ipsilateral breast. Compared to manually planned 5-fraction plans, TPAS 5-fraction plans had significantly lower median heart V1.5Gy and V3Gy ($p<0.001$ for both), contralateral breast D0.035cc ($p<0.001$), 95% and 50% CI ($p<0.001$ for both) but higher median HI ($p=0.004$) and MU ($p<0.001$). 40 of 49 5-fraction and 36 of 49 1-fraction TPAS plans completed in a single optimization. The remainder underwent automated priority adjustments and iterative re-optimization, with a median (range) number of optimizations of 2 (2-9) for both 5 and 1-fraction plans. The median (range) time from TPAS plan submission to completion was 9.0 min (7.0-24.3 min) for 5-fraction and 8.7 min (6.3-20.8 min) for 1-fraction plans.

Conclusion: In-house automation of VMAT PBI with TPAS for 5 or 1 fraction plans is feasible, efficient, and may reduce dose to OARs compared to manual planning.

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INTRODUCTION

This study is the first demonstration of fully automated planning for 1 or 5 fraction VMAT partial breast irradiation (PBI) within the widely used Eclipse treatment planning environment, using in-house open-source software.

The Treatment Planning Automation System (TPAS) is a vital component of the **Northern Plan Automation Services (NoPAUSE) project**[1] (see poster TU-310-BRP-40). TPAS enables VMAT plans to be produced within Eclipse in as little as one click. TPAS determines initial optimization objectives from an Eclipse clinical protocol and/or RapidPlan model, and automates the creation of optimization structures, field arc geometries, and the optimization and calculation of VMAT plans. TPAS also supports automatic priority adjustments and iterative re-optimization if dosimetric goals are not met. The TPAS architecture is outlined in Figure 1, and the TPAS web dashboard is shown in Figure 2.

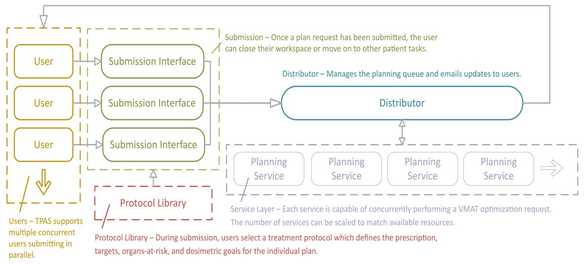

Figure 1. TPAS Architecture

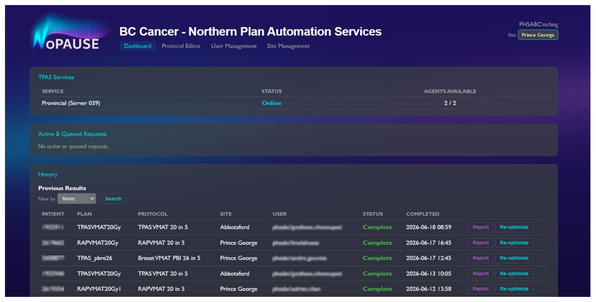

Figure 2. TPAS Web Dashboard

Herein, the utility of TPAS is demonstrated via application to VMAT PBI for 1 or 5 fractions for the recently opened SHIFT-PB phase II clinical trial (ClinicalTrials.gov ID NCT06885671). TPAS protocols were designed to minimize contralateral breast D0.035cc without violating planning constraints (Figure 3) for PTV, lungs and heart, which were derived from the Fast-Forward trial[2], APBI-IMRT-Florence trial[3], BC Cancer Vancouver VMAT PBI clinical practice, and (for single fraction) trial committee consensus opinion after biological effective dose conversion from 5 to 1 fractions.

SHIFT-PB PLANNING CONSTRAINTS
Acceptable values indicated in brackets where applicable

Mandatory OAR Constraints				
OAR	Fractions			
	5		1	
Ipsilateral lung	V10 Gy	≤ 20%	V5 Gy	≤ 20%
Heart	V7 Gy	≤ 5%	V4 Gy	≤ 5%
	V3 Gy	≤ 10%	V2 Gy	≤ 10%
	V1.5 Gy	≤ 30%	V1 Gy	≤ 30%
Contralateral lung	V5 Gy	≤ 10%	V3 Gy	≤ 10%
Ipsilateral breast-PTV	V50%	≤ 50 [60]%	V50%	50 [60]%
Target Planning Goals (both arms)				
PTV_eval	V95%		≥ 98 [95]%	
	V105%		≤ 5 [10]%	
Body	D0.035 cc		≤ 107 [110]%	
Non-Mandatory OAR Constraints (both arms)				
Contralateral breast	D0.035 cc		≤ 1 [2] Gy	

Figure 3. SHIFT-PB planning constraints

METHODS AND MATERIALS

TPAS PBI Eclipse clinical protocols were configured with a combination of high priority "constraint" objectives and low priority "ALARA" objectives (mean dose → 0) for the OARs with mandatory constraints, and an initial high priority on the contralateral breast max dose objective (0 %vol → 0 dose) (Figure 4).

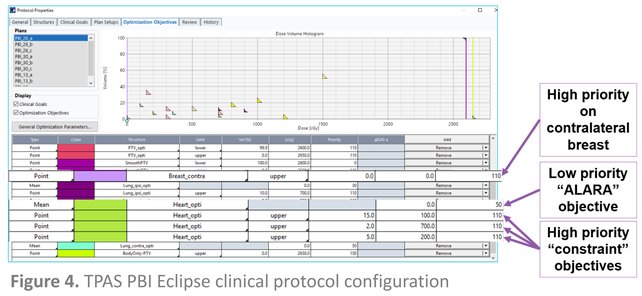

Figure 4. TPAS PBI Eclipse clinical protocol configuration

After each optimization, mandatory planning constraints were checked and any failing constraints had the corresponding objective's priority increased by a factor of 1.3, up to a maximum priority of 180. After 5 iterations, if any mandatory constraints were still failing, then (1) the priority on the contralateral breast objective was reduced by 50%, (2) all objectives and priorities were reset, and (3) the iterative optimization process was repeated. If after 5 more iterations any mandatory constraints were still failing, the priority on the contralateral breast objective was further reduced by 50% and the process repeated a final time, for a maximum of 15 total optimizations (Figure 5).

Figure 5. TPAS PBI iteration logic

Forty-nine clinical 5-fraction plans were replanned with TPAS for both 5 and 1 fraction treatments. Plans were compared via Wilcoxon sign-rank test using PTV and OAR planning constraints (Figure 3), 95% and 50% conformity indices (CI), PTV homogeneity index (HI), and monitor units (MU). Time from TPAS plan submission to completion and number of iterative optimizations per plan were recorded.

RESULTS

All TPAS plans achieved all planning constraints for PTVs, lungs, heart, and uninvolved ipsilateral breast. Compared to manually planned 5-fraction plans, TPAS 5-fraction plans had significantly lower median PTV V95% ($p<0.001$, Figure 6a) and V105% ($p = 0.018$, Figure 6b), heart V3Gy and V1.5Gy ($p<0.001$ for both, Figure 6g and 6h), contralateral breast D0.035cc ($p<0.001$, Figure 6i), 95% and 50% conformity index ($p<0.001$ for both) and higher median homogeneity index ($p=0.004$) and MU ($p<0.001$). Body D0.035cc, ipsilateral lung V10Gy, contralateral lung V5Gy, heart V7Gy, and uninvolved ipsilateral breast V50% were not significantly different (Figure 6c, 6d, 6e, 6f and 6j).

RESULTS

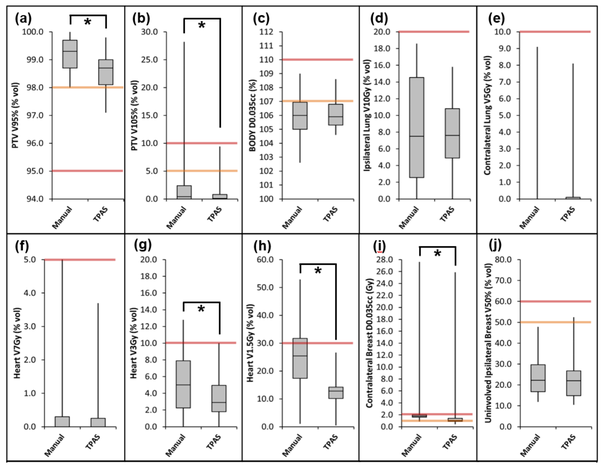

Figure 6. Box plots for 5-fraction manual vs. TPAS plans for (a) PTV V95%, (b) PTV V105%, (c) Body D0.035cc, (d) ipsilateral lung V10Gy, (e) contralateral lung V5Gy, Heart (f) V7Gy, (g) V3Gy and (h) V1.5Gy, (i) contralateral breast D0.035cc, and (j) uninvolved ipsilateral breast V50%. Orange and red lines are preferred and acceptable values, respectively. *=$p<0.05$.

40 of 49 5-fraction and 36 of 49 1-fraction TPAS plans completed in a single optimization (Figure 7). The remainder underwent automated priority adjustments and iterative re-optimization (as per Figure 5), with a median (range) number of optimizations of 2 (2-9) for both 5 and 1-fraction plans (Figure 7).

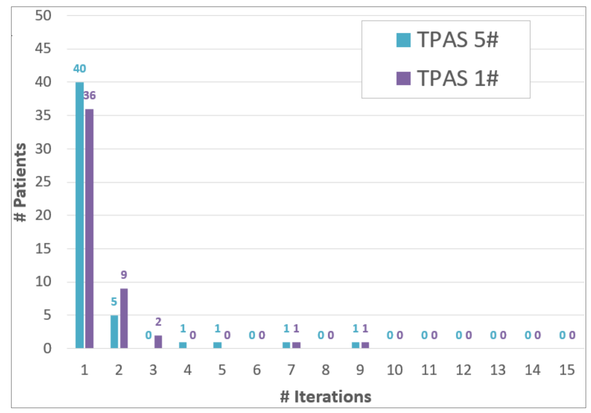

Figure 7. Number of iterations required for 5 and 1 fraction TPAS plans

The median (range) time from TPAS submission to completion was 9.0 min (7.0-24.3 min) for 5-fraction and 8.7 min (6.3-20.8 min) for 1-fraction plans.

CONCLUSIONS

In-house automation of VMAT PBI with TPAS for 5 or 1 fraction plans is feasible, efficient, and may reduce dose to OARs compared to manual VMAT planning.

The SHIFT-PB trial is open and accruing, and the first single fraction PBI patient has already been successfully planned with TPAS and treated at BC Cancer Prince George. We have implemented TPAS for VMAT PBI as a radiation oncologist (RO) initiated workflow with TPAS submission and RO plan approval in a single encounter, providing substantial efficiency gains vs. manual planning workflows.

REFERENCES

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