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Technical note

Analysis of a volumetric-modulated arc therapy (VMAT) single phase prostate template as a class solution

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ABSTRACT

Aim: To assess a class solution template for volumetric-modulated arc therapy (VMAT) for prostate cancer using plan analysis software.

Background: VMAT is a development of intensity-modulated radiotherapy (IMRT) with potential advantages for the delivery of radiotherapy (RT) in prostate cancer. Class solutions are increasingly used for facilitating RT planning. Plan analysis software provides an objective tool for evaluating class solutions.

Materials and methods: The class solution for VMAT was based on the current static field IMRT template. The plans of 77 prostate cancer patients were evaluated using a set of in-house plan quality metrics (scores) (PlanIQ^{TM}, Sun Nuclear Corporation). The metrics compared the class solution for VMAT planning with the IMRT template and the delivered clinical plan (CP). Eight metrics were associated with target coverage and ten with organs-at-risk (OAR). Individual metrics were summed and the combined scores were subjected to non-parametric analysis. The low-dose wash for both static IMRT and VMAT plans were evaluated using 40 Gy and 25 Gy isodose volumes.

Results: VMAT plans were of equal or better quality than the IMRT template and CP for target coverage (combined score) and OAR combined score. The 40 Gy isodose volume was marginally higher with VMAT than IMRT (4.9%) but lower than CP (−6.6%)($P = 0.0074$). The 25 Gy volume was significantly lower with VMAT than both IMRT (−32.7%) and CP (−34.4%)($P < 0.00001$).

Conclusions: Automated VMAT planning for prostate cancer is feasible and the plans are equal to or better than the current IMRT class solution and the delivered clinical plan.

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1. Background

Prostate cancer is the fourth most common cancer and the second most commonly diagnosed cancer in men worldwide (GLOBOCAN 2012).[1] Among the treatment options, external beam radiotherapy (RT) is widely used for tumour control. Three dimensional radiotherapy[2] has been replaced by dynamic techniques such as intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT). Intensity-modulated radiotherapy is a well-established technique that delivers a radiation beam either by modulating the beam using continuously moving multi-leaf collimator (MLC) leaves or by dividing the radiation beam into different segments of various shapes.[3] Volumetric-modulated arc therapy is a development of IMRT that offers potential advantages in the delivery of the radiation beam for various tumour sites including the prostate.[4,5] In VMAT, the gantry rotational speed, treatment aperture shape and dose rate are varied.[6] Advantages for VMAT over IMRT include shorter delivery time and smaller monitor units (MU).[3]

The main objective of RT is to deliver the maximum radiation dose to the tumour target, while minimising radiation to the surrounding normal tissues. In the case of the prostate, considerable margins are generally applied for the generation of the planning target volume (PTV) since the internal motion of the prostate is large (up to 1.2 cm and 1.5 cm for intrafractional and interfractional motions, respectively).[7] Large PTV margins, which can increase the PTV by 30–40%,[8] generally cause overlapping between the target volumes and the adjacent organs at risk (OARs). A major source of concern with VMAT is the possible increase in low dose radiation to surrounding normal tissues, which could increase the risk of complications like rectal bleeding as well as secondary malignancies.[4,9] However, some dosimetric planning studies have demonstrated comparable or higher sparing to organs-at-risk (OAR) with VMAT, compared to IMRT, especially using dual arc techniques.[10–12]

Automated treatment planning has improved plan quality and planning efficiency for several tumour sites, including for the prostate.[13–15] Recently we described the development of a class solution for prostate IMRT using the Monaco planning system (Elekta-CMS Software, MO, USA).[13,16] With the view that VMAT may be the preferred IMRT method for the treatment of prostate cancer,[3,17,18] recent effort by our clinical team has been directed towards the development and analysis of a VMAT planning template as an alternative to the existing static field IMRT class solution. The present study describes the application of plan analysis software to the VMAT template to objectively compare the plans with the existing IMRT template and the patients' delivered clinical plan (CP). Attention was also directed at measuring the effect of the low-dose wash with the VMAT template.

1.1. Patient cohort

Seventy-seven prostate cancer patients previously treated with single-phase IMRT during 2014 and early 2015 were chosen for this retrospective study. Patients were simulated with the same computed tomography (CT) scanning protocol and treated with 81 Gy in 45 fractions as described previously.[13] The work met the criteria for a Quality Improvement project according to NSW Health Ethics Guidelines and did not require formal ethical review (HREC reference number QA160).

1.2. Class solution for prostate VMAT

The development of a class solution (template) for prostate IMRT has previously been described.[13,16] In that study,[13] the R5 template was recognised as the template which provided the highest quality plans on the majority of clinical cases when used with a simple batch optimisation. In the present study, the IMRT R5 template was used as the basis for the development of a VMAT template for prostate cancer. Using a stepwise, quality improvement process and reference to evidence-based guidelines, three provisional VMAT templates based on 10 patients were developed. These templates were batch optimised – with no further manual planner adjustments – and run on the patient cohort in Monaco V5.0. The VMAT template that provided the highest quality plans across the 77 test cases was template number 5 (T5). The T5 template used a 360-degree, bi-directional, 6 MV VMAT arc. The T5 template was selected for comparison with the current IMRT template R5 and the "as treated" clinical plans.

The clinical plans were created using a standard departmental protocol, but although the end goal was clear, there was no consistent planning method for meeting planning and OAR constraints. Plans were created by approximately 20 different planners across three separate geographic sites. No standard normalisation was used in clinical plans, only planner and doctor discretion once protocol planning constraints had been met. The clinical plans were delivered via IMRT with DMLC using 6 MV and 7 fixed gantry angles; the gantry angles used were 150, 100, 60, 0, 300, 260 and 210 degrees.

All template and clinical plans were calculated using a Monte Carlo photon algorithm in the Monaco planning system. A 0.3 cm grid spacing was used for all plans.

1.3. Plan assessments

The quality metrics analysis tool (PlanIQ™, Sun Nuclear Corporation, Melbourne, FL, USA) previously developed by the workgroup was used for plan assessments.[13] The metrics and the dose constraints from the local clinical protocol are summarised in Table 1. Domains covered included target coverage (eight metrics), OARs (ten metrics), and three indicators that had a lesser weighting which were indicators of overall plan quality. Quality criteria such as homogeneity index and conformation number were included as part of the target coverage. For statistical analysis, individual metrics were combined into total scores for target coverage, OAR constraints and an overall score.

Concerns regarding the low dose wash in VMAT plans led to additional analysis on a subset of 20 cases. In the absence of clinical guidelines, the 40 Gy and 25 Gy isodose lines were selected empirically. By measuring the volumes covered by these isodose levels from the current clinical IMRT template, the preferred VMAT template and the clinically delivered plans, the effects of VMAT on low dose bath were objectively measured.

Table 1 – Plan quality metrics and assigned scores for assessing prostate plan quality.

Structure	Metric	Maximum		Middle range		Minimum	
		Score	Criteria	Score	Criteria	Score	Criteria
CTV	% covered by TD	20	100–99.5%	19.9–0.1	99.6–99%	0	<98.9%
PTV	% covered by TD	20	100–95%	19.9–0.1	94.9–90%	0	<89.9%
	% covered by 95%TD	10	100–99%	9.9–0.1	98.9–98	0	<97.9%
	% covered by 107%TD	10	<1%	9.9–0.1	1.1–2%	0	>2%
	% covered by 105%TD	10	0%			0	>15%
	Mean dose	5	81–83 Gy	2.9–0.1	84.6 –85.6 Gy	0	>85.6 Gy
	Homogeneity Index	5	0.02			0	>0.15
	Conformation Number	5	1	4.9–4 3.9–0	0.9–0.7 0.69–0.51	0	<0.5
	Volume (cc) covered by TD outside PTV	10	8–10 cc	7.9–0	10.1–20 cc	0	>20 cc
Rectum	Volume (cc) covered by 102.5%TD	0	<2 cc	0.1 to −5	2–3 cc	−5	>3 cc
	% covered by 40 Gy	10	<35%	8–10 7.9–0.1	35.1–40% 40.1–45%	0	>45%
	% covered by 65 Gy	10	<17%	9.9–0.1	17.1–21%	0	>21%
	% covered by 75 Gy	10	<10%	9.9–0.1	10.1–15%	0	>15%
	Coverage of 50%TD axial slice evaluation	0	Pass			−10	Fail
Bladder	% covered by 60 Gy	5	<35%	4.9–0.1	35.1–40%	0	>40%
	% covered by 40 Gy	5	<50%	4.9–0.1	50.1–60%	0	>60%
Penile bulb	% covered by 50 Gy	2	<95%	1.9–0.1	95.1–100%	0	>100%
Rt femoral head	% covered by 45 Gy	2	<2%	1.9–0.1	2–5%	0	>5%
Lt femoral head	% covered by 45 Gy	2	<2%	1.9–0.1	2–5%	0	>5%
Patient	Volume (cc) covered by 110%TD	0	<2 cc	−0.1 to −5	2–5 cc	−5	>5 cc
Global max location	Within CTV/PTV/elsewhere/rectum	5	CTV	3 0	PTV Elsewhere	−5	Rectum

Abbreviations: CTV, clinical target volume; PTV, planning target volume; TD, total dose (Gy).
Definitions: Homogeneity Index = [Dose covering 1% of PTV − Dose covering 99% of PTV] (Gy)/Prescribed dose (Gy). The prescribed dose was 81 Gy.
Conformation number = [PTV (cc) covered by specified dose (95% in Gy)]^2/[Total volume covered by 95% dose (Gy) × Total volume of PTV (cc)].

1.4. *Statistical analysis*

Statistical procedures were carried out using MedCalc v17.4 (Ostend, Belgium). The score function, total score and metrics were extracted from PlanIQ and tabulated in Microsoft Excel.

Differences between the data sets were assessed using the Friedman test, a non-parametric equivalent of repeated measures analysis of variance (RM-ANOVA). Where significant differences were noted between groups, pairwise comparisons of variables were carried out using Newman–Keuls test for normally distributed data and Conover's test[19] for non-parametric data. Proportions were compared using Fisher's exact test. A probability $P < 0.05$ (two-tailed) was considered statistically significant.

2. VMAT plan assessment

Total scores for target coverage, OAR constraints and the overall score are summarised in Table 2. Significant differences were evident between the clinical plan (CP), current IMRT template (R5) and VMAT template (T5). The combined target score for VMAT T5 was similar to R5 but significantly higher than CP ($P = 0.0498$). While the combined OAR score for VMAT T5 was similar to CP and R5, the combined OAR score for R5 was significantly different to CP ($P = 0.0051$). The overall scores were highest for the VMAT T5, followed by R5 and CP. These differences in the overall scores were highly significant ($P = 0.0003$).

The templates were also assessed by considering the *proportion* (number) of cases achieving overall scores similar or better than CP. "Similar" was defined as within 1 metric point of the score of CP; "better" was defined as >1 metric score of CP. The results are summarised in Table 3. More cases achieved an overall score better than CP when planned with VMAT T5 (51/77) than with R5 (33/77; $P = 0.0058$). On the other hand, a higher proportion of R5 cases achieved an overall score similar to CP than the VMAT T5 template ($P = 0.0371$). Comparing the templates, 10 cases (12.99%) planned with VMAT T5 achieved similar scores to R5; 48 (62.34%) achieved better scores than R5.

Plans with major violations which led to a "fail" increased from 10/77 (13.0%) to 11/77 (14.3%) ($P = 1.0$) when moving from R5 to the T5 template, a 1.3% increase in the fail rate. Six patients had major violations with both templates. This is with batch optimisation alone.

The low dose wash analysis is summarised in Table 4. The 40 Gy volume was slightly larger with the VMAT T5 template compared to the R5 template (average difference 17.5 cc; 4.9%), but smaller than CP (average difference −26.3 cc; −6.6%). These differences were statistically significant ($P = 0.0074$).

The 25 Gy volume was consistently smaller with VMAT T5 compared to both the R5 template (average −580.2 cc; −32.7%)

Table 2 – Comparison of VMAT template (T5) with the current IMRT template (R5) and the delivered clinical plan (CP) for prostate cancer (*n* = 77).

Plan quality metric	Clinical plan (CP)	IMRT template (R5)	VMAT template (T5)	*P*
Combined target score (max 75)	73.54 (24.5–75.2)	74.82 (32.5–75.0	74.84 (25.2–74.9)[a]	0.0498
Combined OAR score (max 46)	46.00 (23.4–46.0)	46.00 (11.3–46.0)[a]	46.00 (12.3–46.0)	0.0051
Overall score (max 146)	132.1 (77.8–144.1)	135.1 (68.6–143.9)[a]	138.9 (80.2–144.0)[a,b]	0.0003

Median (range).
[a] Compared to CP, $P < 0.05$.
[b] Compared to R5, $P < 0.05$.

Table 3 – Achieving the benchmark: the number of prostate cancer cases with overall scores similar or better than the delivered clinical plan (*n* = 77).

	VMAT T5 compared to CP	IMRT R5 compared to CP	VMAT T5 compared to R5
Similar	4 (5.19%)	13 (16.88%)	10 (12.99%)
Better	51 (66.23%)	33 (42.86%)	48 (62.34%)
Similar or better	55 (71.43%)	46 (59.74%)	58 (75.32%)

Comparisons with CP: similar = ±1 metric point on overall score; better = > 1 metric point on overall score.

Table 4 – Low dose wash analysis: comparison of VMAT template (T5) with the current IMRT template (R5) and the delivered clinical plan (CP) (*n* = 20).

Parameter	Clinical plan (CP)	IMRT template (R5)	VMAT template (T5)	*P*
40 Gy volume (cc)	366.4 (180.5–1054.1)	336.7 (182.4–643.7)[a]	345.2 (181.7–739.2)[a,b]	0.0074
25 Gy volume (cc)	1744 (732.6–3652)	1773 (720.2–3153)[a]	1096 (503.5–2745)[a,b]	<0.00001

Median (range).
[a] Compared to CP, $P < 0.05$.
[b] Compared to R5, $P < 0.05$.

and CP (−624.5 cc; −34.4%). These differences were highly significant ($P < 0.00001$).

3. Discussion

In this study, we assessed a class solution template for VMAT in a cohort of 77 prostate cancer patients using plan analysis software. In general, the VMAT template T5 scored as well as, or better than, the static field IMRT template R5 and actual CP. The concerns with the low dose wash with the VMAT template were also not realised: a slight increase in the 40 Gy volume was more than offset by a decrease in the 25 Gy volume with respect to both R5 and CP. Indeed, it appears that any VMAT template based directly off an acceptable static field IMRT template will by default reduce the low dose wash in pelvic treatment. Additional cost function refinements and optimisation may potentially produce even lower dose wash levels; however, this comes at the cost of increased interactive and iterative manual planning time. Additional planning iterations would also likely produce increased beam modulation, and therefore higher MU plans. Further improvements to the T5 template are anticipated as more data is gathered, but the initial transition to VMAT appears to facilitate reduced low dose wash without additional planning effort.

Our study is in line with earlier dosimetric studies which demonstrated a comparable or higher sparing to OARs with VMAT in comparison with the prostate IMRT plans, especially by dual-arc technique that can obtain a superior conformity and homogeneity compared with single-arc plans.[3,10,11,20–23] In a single-institution review of 90 cases, VMAT implementation produced comparable or slightly better target coverage and normal tissue sparing, compared to IMRT, with a faster treatment time.[3] On the other hand, tri-Co-60 IMRT with magnetic resonance image guided RT delivered smaller doses to bladder and rectum than those of VMAT, while maintaining target coverage.[9] The margins employed in this study may have had a bearing on the dose delivery: "The primary and boost planning target volumes (PTVs) of the tri-Co-60 IMRT were generated with 3 mm margins from the primary clinical target volume (CTV, prostate + seminal vesicle) and a boost CTV (prostate), respectively. VMAT had a primary planning target volume (primary CTV + 1 cm or 2 cm margins) and a boost PTV (boost CTV + 0.7 cm margins), respectively."[9] Recently, Buschmann et al. reported that automated VMAT planning for whole-pelvic prostate RT was feasible; automated plans exhibited improved organ sparing (bladder and rectum) and were dosimetrically superior to manually optimised plans.[14] All automated plans were clinically acceptable.

In the present study, 77% of R5 plans and 75.7% of T5 plans were clinically acceptable without further intervention. This high proportion of clinically acceptable plans being created with no manual adjustment means staff time can be better spent on high value complex planning. The use of a single template-based planning solution also means higher consistency in final plan dosimetry.

Further analysis of low dose bath and conformity can be investigated by the PlanIQ workgroup to determine suitable

metric values that can be incorporated in future analysis. At this point there is no universal standard on how this should be done.

4. Conclusions

Automated VMAT planning for prostate cancer is feasible and the plans are equal to or better than the actual delivered clinical plan and current IMRT class solution at our institution. The T5 VMAT template may be used clinically as the default starting point for all intact single-phase prostate patients.

Conflict of interest

None declared.

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None declared.

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