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CASE STUDY

Comparison of Oncentra® Brachy IPSA and graphical optimisation techniques: a case study of HDR brachytherapy head and neck and prostate plans

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Abstract

There are a number of different dwell positions and time optimisation options available in the Oncentra® Brachy (Elekta Brachytherapy Solutions, Veenendaal, The Netherlands) brachytherapy treatment planning system. The purpose of this case study was to compare graphical (GRO) and inverse planning by simulated annealing (IPSA) optimisation techniques for interstitial head and neck (HN) and prostate plans considering dosimetry, modelled radiobiology outcome and planning time. Four retrospective brachytherapy patients were chosen for this study, two recurrent HN and two prostatic boosts. Manual GRO and IPSA plans were generated for each patient. Plans were compared using dose–volume histograms (DVH) and dose coverage metrics including; conformity index (CI), homogeneity index (HI) and conformity number (CN). Logit and relative seriality models were used to calculate tumour control probability (TCP) and normal tissue complication probability (NTCP). Approximate planning time was also recorded. There was no significant difference between GRO and IPSA in terms of dose metrics with mean CI of 1.30 and 1.57 ($P > 0.05$) respectively. IPSA achieved an average HN TCP of 0.32 versus 0.12 for GRO while for prostate there was no significant difference. Mean GRO planning times were greater than 75 min while average IPSA planning times were less than 10 min. Planning times for IPSA were greatly reduced compared to GRO and plans were dosimetrically similar. For this reason, IPSA makes for a useful planning tool in HN and prostate brachytherapy.

Introduction

The goal of brachytherapy is to deliver a high dose of radiation to the target while minimising the dose to the surrounding normal tissues.[1]

Prostate brachytherapy has been proposed as an alternative method to external beam radiotherapy as either a boost or monotherapy.[2] There have been a number of single institution studies investigating the use of brachytherapy as a boost for intermediate risk prostate cancer with favourable results. The two most prominent trials to look at the benefit of brachytherapy boost for prostate cancer were the phase II RTOG0321[2] and the phase III Mt Vernon trial.[3] The Mt Vernon trial concluded that the brachytherapy boost group had a significant improvement in relapse-free survival compared to the external beam alone group with a 31% reduction in recurrence ($P < 0.01$).

Brachytherapy in HN cancer has three clinical uses; (1) primary treatment for small T1 and T2 squamous cell carcinomas, (2) used in conjunction with external beam radiotherapy and (3) retreatment of either recurrence or

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new primary. For the purpose of this work, we will only focus on retreatment of recurrence using brachytherapy.[1] HDR Brachytherapy following the Paris rules is often used in combination with debulking surgery for recurrent HN cancer. The catheters are placed during surgery with a robust well vascularised skin flap in an attempt to avoid complications such as fistula, haemorrhage or wound breakdown.

There are a number of different dwell position and time optimisation techniques available in the Oncentra® Brachy (Elekta Brachytherapy Solutions, Veenendaal, The Netherlands) treatment planning system. Geometrical optimisation assumes that the dwell positions represent the target volume. Geometrical optimisation only determines a relation between the dwell times, that is, prescription and normalisation must be completed separately. Dose-point optimisation optimises the dose to user-defined points. Graphical optimisation is an interactive method of optimisation where the user may manually manipulate the dose distribution using the mouse select and move isodose lines.

Inverse planning by simulated annealing (IPSA) is the inverse algorithm available in Oncentra® Brachy, it was designed to work with any kind of brachytherapy and can produce plans in a matter of seconds.[4] IPSA starts by first describing the clinician's requests using dose constraints. The dose (D_i) calculated to a point i is converted into a penalty value W_i (the cost function) through the following relation.

$$W_i = \begin{cases} m^{\min}|D_i - D^{\min}| & \text{if} \quad D_i < D^{\min} \\ m^{\max}|D_i - D^{\max}| & \text{if} \quad D_i > D^{\max} \\ 0 & \text{if} \quad D^{\min} \le D_i \le D^{\max} \end{cases}, \quad (1)$$

where, $D_{\min}$ and $D_{\max}$ represent the lower and upper range of acceptable doses. Looking at the above relation, one can see that if the dose is within the specified range the penalty is zero. If the dose to point i is above or below the specified range, the penalty increases at rates of $M_{\min}$ and $M_{\max}$.

The purpose of this case study is to compare graphical and IPSA optimisation techniques for interstitial head and neck (HN) and prostate plans considering dosimetry, radiobiology and planning time.

Materials and Methods

Patients

Ethics approval was granted by the local human research ethics executive committee for this radiotherapy quality improvement study and all patient data was de-identified. Four patients who had undergone HDR brachytherapy previously were retrospectively chosen for this study, two recurrent HN cancer patients from our local institution and two demonstration prostate patients provided by the manufacturer as our institution does not currently provide prostate HDR brachytherapy. The HN patients had previously received external beam IMRT for advanced stage squamous cell carcinoma (SCC) of the floor of mouth (HN_01) and tongue (HN_02). The HN catheters were placed intra-operatively concurrently with excision of recurrent disease.

Planning

All patients were contoured and planned in the Oncentra® Brachy treatment planning system on CT

Table 1. IPSA class solution for generating HDR prostate plans.[5]

	Minimum surface		Maximum surface		Minimum volume		Maximum volume	
Structure	Weight	Dose (cGy)	Dose (cGy)	Weight	Weight	Dose (cGy)	Dose (cGy)	Weight
Prostate	100	950	1425	30	100	950	1425	20
Urethra	50	950	950	75	50	950	950	75
Bladder	0	0	475	40	0	0	475	40
Rectum	0	0	475	30	0	0	0	0

IPSA, inverse planning by simulated annealing; HDR, high dose rate.

Table 2. IPSA class solution for generating interstitial HDR head and neck plans.

	Minimum surface		Maximum surface		Minimum volume		Maximum volume	
Structure	Weight	Dose (Gy)	Dose (Gy)	Weight	Weight	Dose (Gy)	Dose (Gy)	Weight
CTV	100	3	4.5	20	100	3	4.5	20

IPSA, inverse planning by simulated annealing; HDR, high dose rate; CTV, clinical target volume.

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Table 3. Definition of dosimetric indices used to assess target volumes.

Parameter	Definition	Optimal value
Conformity index (CI)	$\frac{PIV}{PTV}$	1
Conformity number (CN)	$\frac{PTV90}{PTV} \times \frac{PTV90}{PIV}$	1
Homogeneity index (HI)	$\frac{D2 - D98}{D50}$	0

PIV, prescription isodose volume; PTV90, volume of PTV receiving at least 90% of prescription dose; D2, D98 and D50 dose received by 2%, 98% and 50% of the PTV, respectively.

datasets with 2–3 mm slices. For the prostate patients, 19 Gy was prescribed to be delivered in two fractions to the clinical target volume (CTV). The brachytherapy planning target volume (PTV) was identical to the CTV. Dose constraints from the RTOG 0321 trial were employed during the planning process,[2] whereby the goal was to deliver the prescription dose to at least 90% of the PTV, while reducing the dose to surrounding normal tissues. Normal tissue constraints consisted of ensuring the volume of bladder and rectum receiving 75% of the prescription dose was less than 1 cm^3 (V75 < 1 cc) and the volume of urethra receiving 125% of the prescription dose was less than 1 cm^3 (V125 < 1 cc). GRO involved optimising using point-based optimisation to the surface of the target and then manually adjusting the dose distribution to meet the clinical goals. The IPSA planning technique employed a class solution from UCSF[5] as a starting point (Table 1) with allowances for adjusting the optimisation objectives to meet clinical goals. All plan optimisation was performed by a senior brachytherapy planner with 5 years experience, although as our institution does not provide a prostate HDR service prostate planning experience was limited.

The HN patients were prescribed 24 Gy to be delivered in eight fractions twice daily over 4 days. The planning goals included making sure the prescription dose was delivered to at least 90% of the CTV, while ensuring the V200 was less than 20%. Planning with GRO involved first optimising using point-based optimisation to the surface of the target and then manually adjusting the dose distribution to meet the clinical goals. The IPSA planning technique employed a class solution developed locally (Table 2) with allowances for adjusting the optimisation objectives to meet clinical goals.

Analysis

A number of dosimetric indices were calculated to assess the conformality and homogeneity to the target volumes[6–9] these are listed in Table 3. A number of dose-volume metrics were also calculated for the targets; V100, V150 and V200 and normal tissues; V75 and V125.

Table 5. Approximate planning times for each patient and optimisation technique.

	Planning time (min)	
Patient	GRO	IPSA
Prostate_01	>90	<10
Prostate_02	>90	<10
HN_01 (floor of mouth)	~60	<5
HN_02 (tongue)	~60	<5

IPSA, inverse planning by simulated annealing; GRO, graphical optimisation.

Table 4. Parameter values used for the relative seriality[11] and the TCPlogit[12] models used in this study.

	Default values				
Parameters	Rectum	Bladder	Urethra	Prostate	CTV (Head and neck)
α/β	5.4 Gy	7.5 Gy	7.5 Gy	2.6 Gy	10
s	0.75	1.3	1	–	–
γ_{50}	10.64	14.5	14.5	0.74	3.25
D_{50}	80 Gy for severe proctitis/necrosis/ stenosis/fistula	80 Gy for symptomatic bladder contracture and volume loss	68 Gy for clinical stricture/perforation	38.39 Gy for T0-T4	67.23 for T4

α/β, tissue parameter as described in the linear quadratic model; s, seriality parameter; γ_{50}, the slope of the dose response curve; D_{50}, the dose for 50% control or complication; CTV, clinical target volume.

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Before radiobiology metrics could be calculated DVH files were converted into standard effective doses in 2 Gy fractions (eq. 2).

$$\mathrm{SED} = \frac{D\left(1 + (D/n)\Big/(\alpha/\beta)\right)}{\left(1 + X/(\alpha/\beta)\right)}, \qquad (2)$$

where, D is the dose matrix for a given structure, X is the standard dose per fraction (2 Gy in this instance), n is the number of fractions and (α/β) is a tissue parameter as described in the linear quadratic model. Tumor control probability (TCP) based on the logit model and normal tissue complication probability (NTCP) based on the relative seriality model were also calculated for the targets and normal structures, respectively,[10] using equations (3) and (4).

$$\mathrm{TCP}_{\mathrm{logit}} = \prod \left[\frac{1}{1 + \left(\frac{D_{50}}{D_i}\right)^{4\gamma_{50}}} \right]^{v_i}, \qquad (3)$$

where D_{50} is the dose for 50% control or complication, γ_{50} is the slope of the dose–response curve, v_i is the normalised volume for voxel or dose bin being considered and D_i is the dose to the voxel or dose bin being considered.

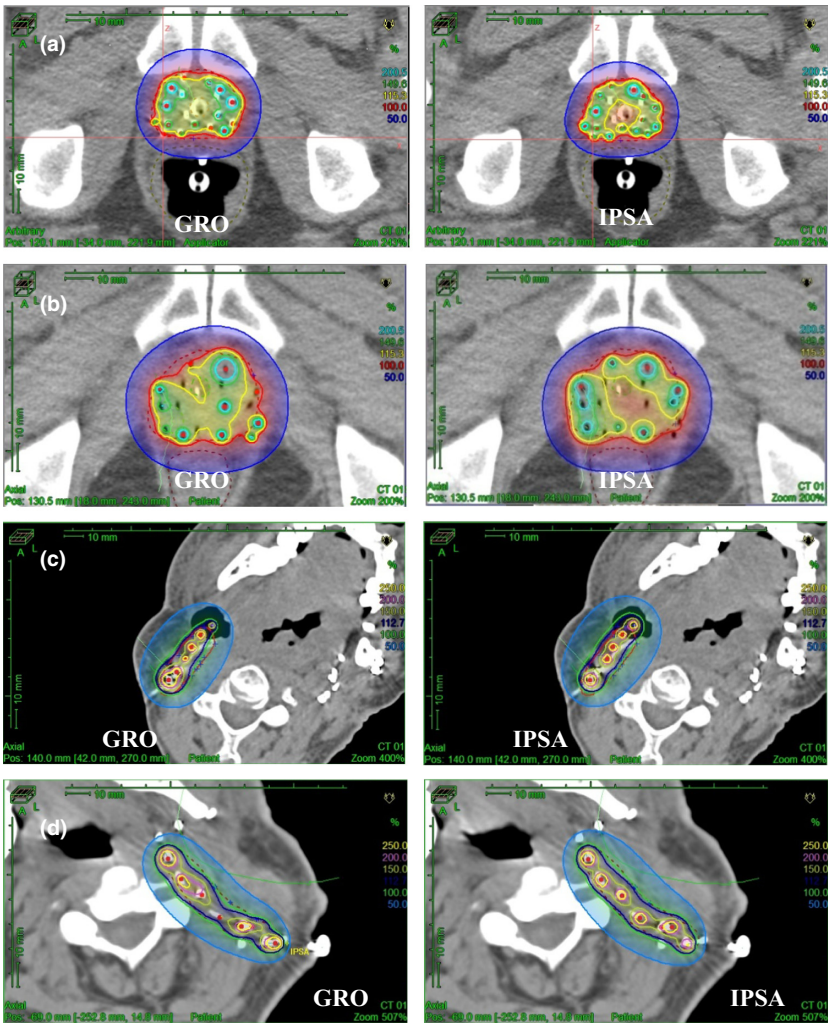

Figure 1. Side by side screen shots of dose distributions optimised, using GRO (left column) and IPSA (right column). (a) Prostate_01, (b) Prostate_02, (c) HN_01 and (d) HN_02. IPSA, inverse planning by simulated annealing; GRO, graphical optimisation; HN_01, head and neck, floor of mouth; HN_02, head and neck, tongue.

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$$\mathrm{NTCP}rs = \left(1 - \prod[1 - P((D_i)^s)]^{v_i}\right)^{1/s}$$
$$P_{M=0} = 1 - (1 - P_{\mathrm{FSU}})^N \quad , \qquad (4)$$
$$P(D_i) = \left(\frac{1}{2}\right)^{\exp\left[\gamma_{50}\left(1 - D_i/D_{50}\right)\right]}$$

where s is the seriality parameter and N is the number of functional subunits and the other parameters are as described above. The values for parameters used in the above models can be found in Table 4.

Planning time was quantified by recording the starting and finishing times of each planning session. These times are only approximate as the planning was conducted over multiple planning sessions.

Results

Approximate planning times can be seen in Table 5, which represents the time taken from when all contouring has been completed to having an acceptable plan.

Screen captures of the dose distributions for each patient and planning technique are displayed in Figure 1. What is obvious from these images is that the dose distributions are very similar with IPSA providing slightly better coverage in some areas. For the prostate cases, it can be seen that the UCSF urethral sparing class solution provides a 'tunnel' of low dose through which the urethra passes.

Tables 6 and 7 contain dosimetric and radiobiological results for the planning comparisons. For most metrics, the plans were not significantly different.

For the prostate patients, TCP differences were less than 5% with the GRO plans slightly higher. This is likely due to the GRO plans having larger V150 and V200 values. There were no significant differences between optimisation techniques for the bladder and rectum. The NTCP metrics for the parallel organs were zero or very close to zero as they received a relatively low does to small volume. The brachytherapy in this study was intended as a boost to external beam treatment and if those doses were included, the NTCP would have been higher. The external beam doses were not included as the aim of the study was to assess brachytherapy optimisation techniques. The urethra results were interesting, in that for each patient there was one optimisation technique that had 100% chance of complication. This was in both cases due to the DVH having a very long high dose tail. For prostate_01 this was 63.0 Gy and for prostate_02 it was 75.8 Gy although both plans met the RTOG 0321 dose assessment criteria see Figure 2.

Table 6. Calculated dose, volume and radiobiological metrics for GRO and IPSA optimised prostate HDR plans.

Patient	Structure	Volume (cm^3)	Plan	D_{min} (Gy)	D_{max} (Gy)	V75	V100	V125	V150	V200	iso90	SED TCPlogit	SED NTCPrs	CI	CN	HI
Pros_1	Prostate	44.75	GRO	13.110	75.810	–	94.802	–	30.149	11.998	98.613	0.873	–	1.31	0.75	2.32
			IPSA	12.635	75.810	–	93.744	–	28.257	12.029	98.185	0.856	–	1.44	0.68	2.39
	Bladder	89.96	GRO	0.665	17.765	0.484	–	–	–	–	–	–	0.000	–	–	–
			IPSA	0.665	16.055	0.130	–	–	–	–	–	–	0.000	–	–	–
	Rectum	50.37	GRO	1.710	20.995	1.913	–	–	–	–	–	–	0.000	–	–	–
			IPSA	1.710	17.765	1.602	–	–	–	–	–	–	0.000	–	–	–
	Urethra	1.28	GRO	17.385	62.985	–	–	20.831	–	–	–	–	1.000	–	–	–
			IPSA	15.675	29.450	–	–	1.700	–	–	–	–	0.000	–	–	–
Pros_2	Prostate	39.15	GRO	9.880	75.810	–	91.946	–	35.965	13.438	96.981	0.870	–	1.23	0.77	2.27
			IPSA	12.255	75.810	–	92.296	–	21.842	9.185	97.326	0.844	–	1.32	0.72	2.48
	Bladder	82.93	GRO	0.570	16.530	0.036	–	–	–	–	–	–	0.000	–	–	–
			IPSA	0.570	17.385	0.031	–	–	–	–	–	–	0.000	–	–	–
	Rectum	111.55	GRO	0.665	15.390	0.079	–	–	–	–	–	–	0.000	–	–	–
			IPSA	0.665	13.775	0.000	–	–	–	–	–	–	0.000	–	–	–
	Urethra	4.05	GRO	2.090	37.905	–	–	20.707	–	–	–	–	0.164	–	–	–
			IPSA	2.280	75.810	–	–	2.780	–	–	–	–	1.000	–	–	–

Prost, prostate; IPSA, inverse planning by simulated annealing; GRO, graphical optimisation; Vx %, volume receiving x% dose; iso90, the volume covered by the 90% isodose line; SED TCPlogit, tumour control probability; SED NTCPrs, normal tissue complication probability; CI, conformity index; CN, conformity number; HI, homogeneity index.

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Table 7. Calculated dose, volume and radiobiological metrics for GRO and IPSA optimised head and neck HDR plans.

Patient	Structure	Volume (cm^3)	Plan	D_{min} (Gy)	D_{max} (Gy)	V100	V150	V200	iso95	SED_TCPlogit	CI	CN	HI
HN_1	CTV	42.46	GRO	11.520	95.760	87.102	42.563	19.660	91.006	0.153	1.423	0.624	2.246
			IPSA	13.080	95.760	92.679	45.415	19.279	96.148	0.261	1.571	0.616	2.101
HN_2	CTV	12.41	GRO	9.960	95.760	83.975	40.106	19.657	87.787	0.093	1.229	0.688	2.408
			IPSA	14.760	95.760	96.868	47.678	19.696	98.522	0.378	1.926	0.528	2.026

HN, head and neck; IPSA, inverse planning by simulated annealing; GRO, graphical optimisation; CTV, clinical target volume; Vx %, volume receiving x% dose; iso90, the volume covered by the 90% isodose line; SED TCPlogit, tumour control probability; SED NTCPrs, normal tissue complication probability; CI, conformity index; CN, conformity number; HI, homogeneity index.

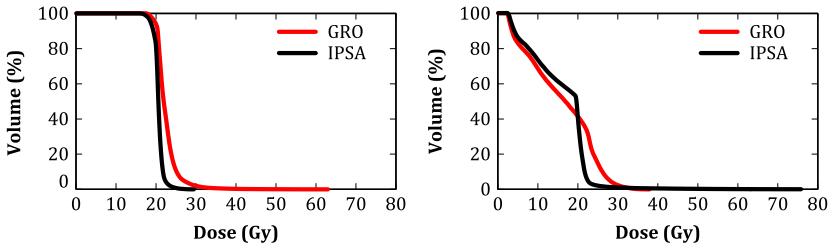

Figure 2. Comparison of urethra DVH for prostate_01 (left) and prostate_02 (right). IPSA, inverse planning by simulated annealing; GRO, graphical optimisation

There were also no significant differences in dosimetry between GRO and IPSA for the HN patients, although the IPSA plan had better coverage with an average V100 of 94.8%, while the average GRO V100 was 85.5%.

Discussion

This case study compared GRO and IPSA optimisation techniques available in the Oncentra® Brachy treatment planning system. Four patients were assessed, two HN and two prostate using dosimetry and radiobiological metrics. To our knowledge, this is first study comparing IPSA and GRO for HN patients. Treatment planning times were compared for the two groups. Due to the small patient numbers in the study, there were no statistically significant differences between the two groups in terms of dosimetry and radiobiology although planning for IPSA were approximately 1/10 of that required for GRO.

Similar studies have been published for prostate brachytherapy. While the NTCP values were very low for the bladder and rectum and they are similar to those calculated by Takam et al.[11] Takam et al. calculated the average rectal NTCP values of 0.5 ± 0.4% for HDR brachytherapy using the same model and parameters. The average urethral NTCP calculated in this study for all plans was 54 ± 53% while Takam et al. found 11.2 ± 3.9% for HD monotherapy delivered in four fractions of 9.5 Gy. What this highlights is the importance of the high-dose tail for a relatively serial organ like the urethra.

Dinkla et al.[13] reported a comparison of optimisation techniques for HDR/PDR (pulsed dose rate) prostate brachytherapy treatment planning. Similar to the current study, all optimisation methods were comparable in terms of DVH parameters. Mean planning time for IPSA was 4.3 ± 1.3 min compared to 7.6 ± 2.5 for GRO. The differences in planning times between the current study and those reported by Dinkla et al. may be due to different number of catheters (Dinkla et al.: median = 14, current study = 16 and 18), implant geometry and/or planner experience.

While the dosimetric differences were statistically insignificant, the planning times were greatly reduced for IPSA. Planning times for IPSA were roughly 1/10 that required for GRO to reach a similar dosimetrically acceptable plan. For this reason, IPSA makes for a useful planning tool in HN and prostate brachytherapy.

Conflict of Interest

The authors declare no conflict of interest.

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