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ORIGINAL ARTICLE **CME**

Comparison of RapidArc and Static Gantry Intensity-modulated Radiotherapy for Nasopharyngeal Carcinoma

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ABSTRACT

Objective: *RapidArc (Varian Medical Systems, Palo Alto, CA) is a new volumetric-modulated arc radiotherapy technique with continuous modulation of gantry speed, dose rate, and multileaf collimator shape. Taking advantages of dose painting capabilities along with rotational delivery, RapidArc has shown promise in the treatment of a wide range of tumours, including intracranial, head and neck, prostate, and endometrial cancers. However, supportive data on RapidArc therapy for nasopharyngeal carcinoma are scanty. In this study, comparison of the quality of a treatment plan and efficiency of radiation delivery by RapidArc and intensity-modulated radiotherapy for nasopharyngeal carcinoma was evaluated.*

Methods: *Datasets of 3 nasopharyngeal carcinoma patients were used to design both RapidArc and intensity-modulated radiotherapy plans. Results were analysed in terms of dose distribution and dose-volume histograms.*

Results: *For all patients, RapidArc plans provided a comparable homogeneity index and adequate organs-at-risk sparing relative to intensity-modulated radiotherapy plans. In terms of target dose conformity, the conformity index favoured intensity-modulated radiotherapy, especially for higher dose targets using a simultaneous integrated boost approach.*

Conclusion: *Taken together, our preliminary experience in dose optimisation with RapidArc for radiation treatment of nasopharyngeal carcinoma was able to deliver reasonable treatment plans. Development of a sophisticated planning system with a quick optimisation algorithm and adjustable level of modulation appears crucial to take full advantage of RapidArc technology. With the ever-increasing complexity of RapidArc treatment planning and delivery, further parallel efforts in optimising quality assurance are warranted.*

Key Words: *Nasopharyngeal neoplasms; Radiotherapy dosage; Radiotherapy planning, computer-assisted; Radiotherapy, intensity-modulated; Tomography, X-ray computed*

中文摘要

快速旋轉強度調控放射治療及靜態機架強度調控放射治療對鼻咽癌的比較研究

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目的：快速旋轉強度調控放射治療 (RapidArc) 是一種新容量式的調控旋轉放射治療技術，在旋轉的過程中不斷對機架速度、放射劑率及葉式準直儀作出調控。通過轉圈及調控放射劑率，快速旋轉強度調控放射治療已被認為是對醫治多種癌症頗有療效的一項技術，包括顱內、頭頸、前列腺及子宮內膜的腫瘤。然而，快速旋轉強度調控放射治療技術在鼻咽癌治療方面的數據並不足夠。在本研究中，我們比較了快速旋轉強度調控放射治療及強度調控放射治療對鼻咽癌的治療計劃及放射效果。

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方法：把三名鼻咽癌患者的數據用作設計快速旋轉強度調控放射治療計劃及強度調控放射治療計劃，利用放射劑量分佈及劑量體積直方圖來分析結果。

結果：對於三位患者，快速旋轉強度調控放射治療提供了與強度調控放射治療相約的劑量均勻指數及對危及器官的劑量有足夠的減緩。目標劑量適形方面，強度調控放射治療的適形指數較佳，尤其是在同步加量的高量區下。

結論：我們的初步經驗顯示快速旋轉強度調控放射治療有助為鼻咽癌提供合理的治療設計。要發揮快速旋轉強度調控放射治療的最佳效果，需要發展一套有快速優化算法及可調節調控水平的完善系統。隨著快速旋轉強度調控放射治療技術的複雜性不斷提高，優化質量保證也需同步進行。

INTRODUCTION

Nasopharyngeal carcinoma (NPC) is endemic in Southern China and part of Southeast Asia, being one of the top 10 cancers in the Hong Kong Chinese population. Unlike other head and neck cancers where radical surgery is feasible, radiotherapy remains the cornerstone of treatment for non-metastatic NPC. Over the past decade, intensity-modulated radiotherapy (IMRT) has become a reality, allowing safe delivery of the desired dose to targets of irregular shapes with maximal sparing of the surrounding structures. Renowned for its dose-sculpting ability, IMRT has gradually evolved as the new standard of care for NPC.[1-3] Several studies demonstrated remarkable local control of more than 90% in NPC with IMRT, even among patients with advanced T3-4 diseases.[4-6]

RapidArc (RA) [Varian Medical Systems, Palo Alto, CA, US] is a new volumetric-modulated arc radiotherapy technique with continuous modulation of gantry speed, dose rate and multileaf collimator shape.[7,8] By means of a progressive sampling algorithm, the optimisation begins with a coarse gantry sample and then, as the optimisation progresses, the arc resolution is gradually improved.[9] It can provide 2 key benefits, including great reduction in optimisation time and circumvention of highly restrictive leaf motion constraints (early in the optimisation process).[10]

Taking advantages of dose painting capabilities along with rotational delivery, RA has shown promise in the treatment of a wide range of tumours, including intracranial, head and neck, prostate, and endometrial cancers.[11-18] Without compromising target coverage, a marked improvement in organ-at-risk (OAR) sparing has been reported when shifting from IMRT to RA.[16-18] However, supportive data on RA for NPC are scanty. In this study, comparison of the quality of a treatment plan and efficiency of radiation delivery by RA and IMRT for NPC was evaluated.

METHODS

Three NPC patients including 2 with early-stage and one with recurrent cancer treated with radiotherpay alone were selected for the study. Patients with a smaller tumour volume in the nasopharynx without neck lymph node metastasis were selected to explore the feasibility of replacing IMRT with this new technique using a cautious approach to accumulate initial experience in our institution. Patient characteristics are summarised in Table 1. Each patient was immobilised in a supine position with a thermoplastic shell. Intravenous contrast-enhanced computed tomography (CT) simulation was performed at 3-mm intervals from the vertex to 5 cm below the sternoclavicular notch with a 16-slice Brilliance Big Bore CT (Philips Medical Systems, Cleveland, OH, US). For contouring, images from diagnostic magnetic resonance imaging (MRI) obtained for staging were fused with the CT images.

Table 1. Patient characteristics and target volumes.

	Patient 1	Patient 2	Patient 3
Staging	T2N0M0	T1N0M0	rT4N0M0
Sex	M	M	M
Age (years)	65	83	60
Target volumes (cm^3)	PTVnp72 = 51.2 PTVnp66 = 188.5 PTVnp60 = 284.8 PTVn60 = 118.3	PTVnp68 = 15.8 PTVnp62 = 31.2 PTVnp56 = 100.9 PTVn56 = 123.4	PTVnp66 = 17.7 PTVnp60 = 70.9
No. of fractions	33	31	30

Abbreviations: PTVnp = nasopharyngeal planning target volume; PTVn = nodal planning target volume; PTVnp72 = 72 Gy to PTVnp; PTVnp68 = 68 Gy to PTVnp; PTVnp66 = 66 Gy to PTVnp; PTVnp62 = 62 Gy to PTVnp; PTVnp60 = 60 Gy to PTVnp; PTVnp56 = 56 Gy to PTVnp; PTVn60 = 60 Gy to PTVn; PTVn56 = 56 Gy to PTVn.

Contour Delineation

The target volumes as defined by the International Commission on Radiation Units and Measurements Reports 50 and 62 were delineated by the clinical oncologists. The gross tumour volume (GTV) included the primary nasopharyngeal tumour and involved lymph nodes as determined by radiological imaging, clinical, and endoscopic findings. Two clinical target volumes (CTV-1 and CTV-2) were then designed to represent high- and low-risk disease regions, respectively. In our institution, the high-risk CTV-1 was derived from the GTV, usually with 1-cm 3-dimensionl margins for both the primary tumour in the nasopharynx, and the metastatic lymph nodes in the neck (if present). All 3 patients in the current study presented without metastatic lymph nodes and no CTV-1 was contoured in the neck region. When clinically indicated, the margin was smaller (at around 0.5 cm) in the posterior direction for the primary nasopharyngeal tumour, to avoid excessively close proximity of the CTV-1 to the brain stem. Similarly, the margin for the primary tumour could be slightly larger (at around 1.5 cm) in the anterior direction to ensure a bigger safety margin for occult mucosal spread along the nasal fossa mucosa, which is not easily demonstrated by MRI. The CTV-2 was usually devised to provide an additional margin of safety for the CTV-1, taking into consideration the propensity of potential microscopic spread in relation to anatomical structures in the vicinity of the nasopharynx, and to cover potential lymphatic drainage in the neck region.

Regarding the 3 patients recruited for this study, none had clinically significant neck lymph nodes and hence only CTV-2 was contoured in the neck for patients 1 and 2. Prophylactic neck irradiation was not indicated in patient 3, who had no associated neck recurrence and thus no nodal CTV was contoured. The planning target volume (PTV) was created by placing a 3-mm margin around the CTV to compensate for setup errors and patient movement. In our institution, a standard dose-fractionation schedule of 66 Gy in 33 fractions was usually prescribed to the high-risk CTV (CTV-1) with 3-mm margins in both the nasopharynx (PTVnp66), and if applicable in the neck region (PTVn66). Whereas 60 Gy (in the same 33 fractions) was delivered to the low-risk CTV (CTV-2), with 3-mm margins in both regions (PTVnp60 and PTVn60). For optimal local tumour control, a simultaneous integrated boost (SIB) to the GTV of the primary tumour in the nasopharynx with 3-mm margins (PTVnp72) was employed with a higher fractional dose, in order to achieve 72 Gy in the same 33 fractions. When skin was not involved or at risk of tumour involvement, a 3-mm gap was created between the PTVs and skin, with a view to decreasing dermal toxicity for dose-volume histogram (DVH) evaluation, the OARs including the brainstem, spinal cord, optic nerves, optic chiasm, eyes, lens, temporal lobes, parotid glands, auditory structures, constrictor muscles, larynx and mandible were contoured on axial CT slices.

Treatment Planning

Both RA and IMRT plans were generated for 6 MV photons using an Eclipse treatment planning system (version 8.6) with an anisotropic analytic algorithm (Varian Medical Systems, Palo Alto, CA, US). Plans for RA were optimised by selecting a maximum dose rate of 600 monitor unit (MU)/min, and a fixed dose rate of 400 MU/min was selected for IMRT. For all RA plans, the collimator was set to 0° with a limited opening, which allowed finer modulations for each arc. The same dose requirements for PTV coverage and OAR sparing were set for all cases. The plans generated aimed to cover at least 95% of the PTV with the planned prescription dose, whilst keeping the maximal point dose below 115% of the prescribed dose at each dose level. For OARs, dose constraints were designed to limit the maximum dose so as not to exceed 54 Gy for the brainstem, optic nerves, optic chiasm, eyes, 45 Gy for the spinal cord, 70 Gy for the temporal lobes, and 6 Gy for the lens. The mean dose was not to exceed 50 Gy for auditory structures, and 45 Gy for the glottic larynx, and the median dose was not to exceed 30 Gy for the parotid glands.

In the present study, the 3 selected NPC cases covered a variety of tumour sizes, extension and complexity levels. Patient 1 with Stage II (T2N0M0) NPC was treated with 3 standard dose levels as described, which were delivered in 33 fractions: 72 Gy to PTVnp72 (GTVnp + 3 mm margins), 66 Gy to high-risk PTV (PTVnp66: CTV-1 of the primary tumour + 3 mm margins) and 60 Gy to low-risk PTV (PTVnp60: CTV-2 of the primary tumour + 3 mm margins), with fractional doses of 2.18 Gy, 2 Gy, and 1.82 Gy respectively. The low-risk PTV of the upper neck lymphatics (PTVn60: CTV-2 of the neck lymphatics, the only PTV for the node-negative neck) covered level II and upper level III lymphatics bilaterally; they also received 60 Gy in 33 fractions. The RA

plan was generated using 2 full arcs plus 1 partial arc covering 220° from 250° to 110° clockwise rotation. The sliding-window dynamic delivery IMRT plan was designed with 9 equally spaced coplanar beams. For patients 1 and 2, the lower neck was treated by separate anterior cervical field matching with both the IMRT and RA plans.

Similarly, patient 2 with Stage I (T1N0M0) NPC was also treated to cover 3 PTVs, each at a different prescription level. Taking into consideration of the patient's age (83 years) and prevailing medical co-morbidities, a total dose of 62 Gy (instead of 66 Gy) was prescribed to the high-risk PTV in 31 (instead of 33) fractions, while the GTV with a margin of 3 mm received 68 Gy (instead of 72 Gy) through SIB, and 56 Gy (instead of 60 Gy) was delivered to the low-risk PTV. As a result, fractional doses of 2.18 Gy, 2 Gy, and 1.82 Gy were administered to the respective PTVs, which were consistent with the institution's standard fractional dose levels. Similarly, the upper neck lymphatics received 56 Gy (instead of 60 Gy) in 31 fractions. For the RA plan, 2 full arcs and 1 partial arc covering 270° from 225° to 135° clockwise rotation were adopted. Using identical dose limits for targets and OARs, the IMRT plan was developed for sliding window dynamic delivery using 9 equally spaced coplanar beams.

Patient 3 with locally recurrent NPC (rT4N0M0) after radiotherapy posed a challenging clinical problem. Daily fractions of 2.2 Gy and 2 Gy were prescribed to the 2 PTVs with a total dose of 66 Gy and 60 Gy, respectively (in 30 fractions). The RA plan consisted of coplanar dual-arcs, each covering 270° while the sliding-window dynamic delivery IMRT plan utilised 7 equally spaced coplanar beams. No prophylactic neck irradiation was given to the patient who had no associated neck lymph node recurrence.

Data Analysis

The PTV dose coverage, OARs dose sparing, overall maximum dose, and number of MUs were compared. Cumulative DVHs for each PTV, OAR, and the 'healthy tissue' (defined as the volume of the body excluding all PTVs) were computed for analysis. Conformity of the prescription dose to the PTV was expressed by the conformity index (CI), which represented the volume of the body receiving more than 95% of the prescribed dose, divided by the volume of the PTV.[19,20] The homogeneity index (HI) of the PTV was defined as the ratio of D5% to D95% for the PTV, where D5% and D95% corresponded to the dose delivered to 5% and 95% of the PTV, respectively.[21] Values of CI and HI approaching 1 were generally regarded as favourable indications of the plan's quality.

Table 2. Conformity index (CI), homogeneity index (HI), planning target volume (PTV) coverage, and monitor unit (MU) data for all cases.

		Patient 1			Patient 2			Patient 3		
		IMRT	RA	Relative increase*	IMRT	RA	Relative increase	IMRT	RA	Relative increase
PTV of higher dose through SIB (PTVnp72 for patient 1, PTVnp68 for patient 2, PTVnp66 for patient 3)	CI	2.97	3.62	22%	2.11	3.97	88%	3.60	3.81	6%
	HI	1.04	1.04	0%	1.06	1.07	0%	1.07	1.06	-1%
	PTV_{95}	98.10	99.60	2%	99.42	99.88	0%	99.70	99.43	0%
PTV of prescribed dose (PTVnp66 for patient 1, PTVnp62 for patient 2, PTVnp60 for patient 3)	CI	2.25	2.32	3%	5.96	7.84	32%	1.40	1.43	2%
	HI	1.12	1.12	0%	1.14	1.15	1%	1.15	1.14	-1%
	PTV_{95}	98.70	99.60	1%	99.87	100.00	0%	98.70	98.75	0%
PTV of lower dose (PTVnp60 for patient 1, PTVnp56 for patient 2)	CI	1.55	1.44	-7%	1.72	1.55	-10%			
	HI	1.19	1.19	0%	1.25	1.24	-1%			
	PTV_{95}	99.30	99.50	0%	100.00	99.80	0%			
PTV covering neck lymphatics (PTVn60 for patient 1, PTVn56 for patient 2)	CI	1.55	1.44	-7%	1.72	1.55	-10%			
	HI	1.09	1.19	9%	1.09	1.11	2%			
	PTV_{95}	99.80	99.40	0%	99.98	100.00	0%			
MU		1388	1200	-14%	1204	1196	-1%	986	707	-28%

Abbreviations: IMRT = intensity-modulated radiotherapy; RA = RapidArc; PTVnp = nasopharyngeal planning target volume; PTVn = nodal planning target volume; PTVnp72 = 72 Gy to PTVnp; PTVnp68 = 68 Gy to PTVnp; PTVnp66 = 66 Gy to PTVnp; PTVnp62 = 62 Gy to PTVnp; PTVnp60 = 60 Gy to PTVnp; PTVnp56 = 56 Gy to PTVnp; PTVn60 = 60 Gy to PTVn; PTVn56 = 56 Gy to PTVn; PTV95 = volume of the PTV covered by the 95% isodose.

* Relative increase = (RA – IMRT) / IMRT x 100%.

RESULTS

The CI, HI, PTV coverage and MU data for all cases are summarised in Table 2. For patient 1, MUs were reduced by 14% in the RA plan in comparison with the IMRT plan. Except for PTVn60 which had a 9% higher HI for the RA plan, there were similar HIs for other PTVs with respect to the IMRT and RA plans. For the RA plan, the CI for PTVnp72 and PTVnp66 were 22% and 3% higher, respectively; whereas the CIs for PTVnp60 and PTVn60 were both 7% lower. Figure 1 shows the isodose distribution of various prescription dose levels in relationship to the corresponding PTVs in both the IMRT and RA plans for this patient. It was noticeable that in the IMRT plan, distribution of the higher prescription dose levels of 72Gy and 66Gy conformed slightly more tightly to the PTVs than the RA plan. With respect to all OARs, both the IMRT and RA plans were able to keep their doses below accepted limits (Table 3). In general, the RA plan improved the OAR's DVHs. In particular, the RA plan produced improved DVHs for constrictor muscles, the larynx, the eyes and optic nerves, and similar DVHs for both lenses, the optic chiasma, the spinal cord, the brainstem, the parotids, the temporal lobes, 'healthy tissue' as defined above, and worse DVHs for auditory structures.

For patient 2, both MUs and HIs were similar for IMRT and RA plans. As compared with the IMRT plan, the respective CIs for PTVnp68 and PTVnp62 were 88% and 32% higher for the RA plan but there

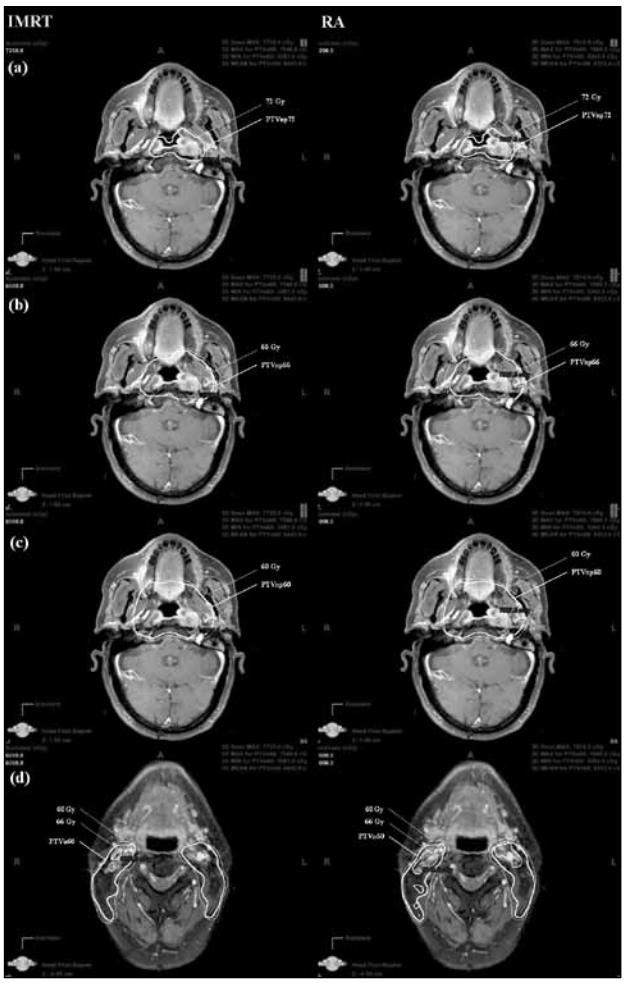

Figure 1. Comparison of isodose distribution between (left) intensity-modulated radiotherapy (IMRT) and (right) RapidArc (RA) plans of patient 1 for (a) PTVnp72, (b) PTVnp66, (c) PTVnp60, and (d) PTVn60.

Table 3. Organs at risk data for all cases.

	Patient 1			Patient 2			Patient 3		
	IMRT	RA	Relative increase*	IMRT	RA	Relative increase	IMRT	RA	Relative increase
Dmax (Lt lens) / Gy	2.85	3	5%	1.36	1.37	1%	1.02	0.97	-5%
Dmax (Rt lens) / Gy	2.96	3.03	2%	1.63	1.52	-7%	1.14	1.07	-6%
Dmax (Optic chiasmas) / Gy	54.25	52.81	-3%	12.35	11.35	-8%	2.49	2.42	-3%
Dmax (Lt eye and optic nerve) / Gy	15.9	12.23	-23%	2.95	2.83	-4%	5.36	5.38	0%
Dmax (Rt eye and optic nerve) / Gy	30.1	18.63	-38%	4.45	4.11	-8%	5.03	4.19	-17%
Dmax (Spinal cord) / Gy	41.9	42.77	2%	41.48	39.35	-5%	7.41	8.37	13%
Dmax (Brainstem) / Gy	53.9	53.27	-1%	49.67	44.14	-11%	11.26	10.69	-5%
Dmedian (Lt parotid gland) / Gy	53.4	48.93	-8%	30.5	29.81	-2%	5.5	9.26	68%
Dmedian (Rt parotid gland) / Gy	27.5	29.61	8%	28.31	30.51	8%	2.22	3.03	36%
Dmean (Lt auditory structure) / Gy	38.12	47.98	26%	42.42	39.84	-6%	49.81	43.43	-13%
Dmean (Rt auditory structure) / Gy	32.76	46	40%	40.56	42.65	5%	37.91	30.7	-19%
Dmean (Larynx) / Gy	8.63	7	-19%	33.31	30.66	-8%	0.41	0.41	0%
Dmean (Constrictor muscle) / Gy	6.15	3.96	-36%	28.96	24.02	-17%	0.23	0.22	0%
Dmax (Lt temporal lobe) / Gy	68.7	70.69	3%	64.76	68.04	5%	67.56	67.76	0%
Dmax (Rt temporal lobe) / Gy	69.8	71.74	3%	59.87	61.32	2%	63.87	60.4	-5%
Dmean (Healthy tissue) / Gy	15.75	15.2	-3%	9.49	8.79	-7%	3.55	3.33	-6%

Abbreviations: IMRT = intensity-modulated radiotherapy; RA = RapidArc.

* Relative increase = (RA – IMRT) / IMRT x 100%.

was a small 10% reverse advantage for PTVnp56 and PTVn56. All dose volume constraints for OARs were fulfilled in both the IMRT and RA plans.

For patient 3, the RA plan improved treatment delivery efficiency with a 28% reduction in MUs compared with the IMRT plan. With a similar HI to that for IMRT, the RA plan had a slightly higher CI for PTVnp66 and PTVnp60 at 6% and 2%, respectively. Even though both plans could maintain all OAR doses below tolerance, the IMRT plan offered better parotid sparing, resulting in 68% and 36% reductions in the median left and right parotid doses, respectively when compared to the RA plan. The DVH comparisons between the IMRT and RA plans of patient 3 for PTVs and both parotid glands are shown in Figure 2.

DISCUSSION

The feasibility of RA to serve as an alternative to IMRT for the treatment of early stage and relatively small locally recurrent NPC cases was demonstrated. Within the plan acceptance criteria, all the 3 RA plans provided comparable HIs and adequate OAR sparing relative to the 3 corresponding IMRT plans. In our preliminary early experience in employing RA for NPC, we had difficulty in sculpting complex dose distributions with steep dose gradients, which compromised the plan quality in comparison to IMRT planning. In terms of target dose conformity, the CIs favoured IMRT, especially for the PTVs receiving the highest prescription dose levels using the SIB approach in patients 1 and 2 (PTVnp68 and PTVnp72 respectively) [Figures 1a, 1b and Table 2]. The reduced conformity implied the need for a higher level of modulation in RA plans, especially in aligning the required doses to irregular targets such as the PTVs for SIB of the GTVs in our first 2 cases.

Problems with suboptimal dose distribution within the superficial volume of the PTVs were particularly obvious in the RA plans. Up to 10% lower CIs for nodal PTVs were noted in RA plans in comparison to the IMRT plans. As the collimator angle was set at 0°, there was no excessive hot spot with any D_{max} >115% of the prescribed dose at the matching junctions. However, the RA optimisation algorithm was likely to increase the dose in the buildup regions by creating intensity peaks, which could lead to undesirable hot spots elsewhere. As the price to pay for better target conformity, the HI for nodal PTVs inevitably increased in RA plans (Table 2). Special caution is needed in the presence of hot spots, which could result in unwarranted complications.[22] Like IMRT, if under-dosage of the PTV in the nearby skin was

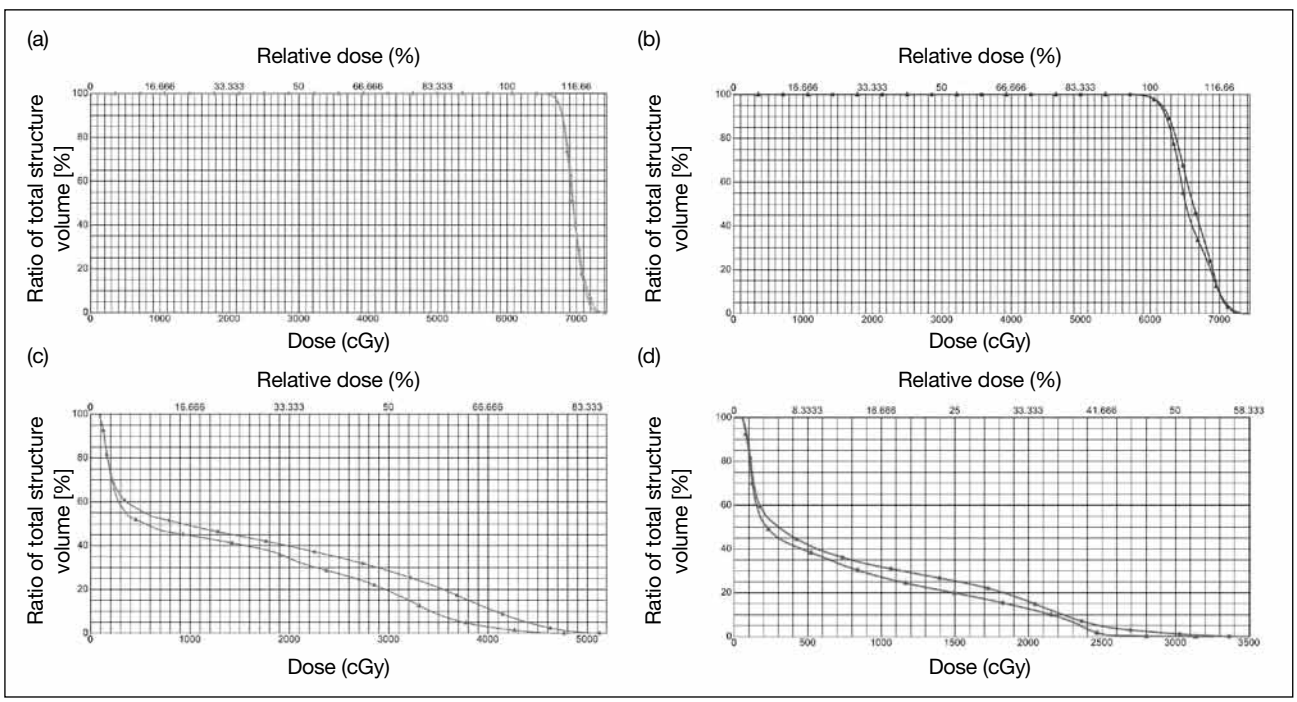

Figure 2. Comparison of dose-volume histogram curves between (—▲—) intensity-modulated radiotherapy and (—■—) RapidArc plans of patient 3 for (a) PTVnp66, (b) PTVnp60, (c) Lt parotid, and (d) Rt parotid.

unacceptable, use of a bolus for the build-up should be considered.

Salvage treatment for locoregional recurrence of NPC could pose particular dosimetric challenges, because recurrent lesions are frequently deep and the tighter dose limit to OARs after the prior primary course of radiotherapy treatment. Our initial clinical experience with RA for early NPC recurrence was encouraging. Both IMRT and RA plans had similar dosimetric quality, but RA allowed a reduction of 279 MUs in radiation delivery, translating into a saving of approximately 45 seconds in beam-on time. In comparison to IMRT, an additional 50 seconds could be saved using RA, by reducing time taken to reposition the gantry and to re-program the linear accelerator.[16] Treatment time reductions could play a decisive role in improving delivery efficiency and patient care achieved through image-guided positioning and plan adaptation.[14,15]

Though numerous studies have demonstrated a marked improvement in OAR sparing with RA, such benefit was not evident in our study.[16-18] With particular emphasis on plan quality, we did not apply a tight constraint on the number of MUs for RA optimisation. Both cases of early stage NPC in this report used over 1000 MUs in the RA plan. This was more than the average MU in other studies of head and neck treatment.[20,23] One possible reason may be the complexity of treatment, as contributed by the numerous OARs and their proximity to the treatment target. Our prescription scheme consisted of SIB targets with 3 dose levels in the nasopharynx as well as a separate dose level for the nodal region in the first 2 patients, which further increased the complexity of planning and dose delivery. Wolff et al[24] suggested that a larger MU in RA plans may be needed for high levels of modulation in complex treatment plans. An optimal range of MU for NPC RA is thus instructive as a guide to devising an efficient and acceptable treatment plan. Further efforts are needed to investigate the optimal range for this type of complex treatment.

Our experience indicated that pronounced reduction in OAR doses and MUs for RA plans could be achieved at the expense of PTV coverage. Strategies like adding another arc and increasing total optimisation time might be effective in improving the quality of RA plans for head and neck cancers.[10] Yet, a compromise between plan quality and planning time had to be made. In line with another study by Guckenberger et al,[25] we found that multiple-arc RA plans improved results compared with single-arc RA plans, but at the cost of increased delivery time. Vieillot et al[26] also demonstrated that double-modulated arc therapy resulted in superior target coverage than a single-arc plan. With the current planning algorithm of RA, there is a restriction on the total gantry angle of 1000° (about 2.8 full rotations) per plan. Adding further arcs was prohibited once the limit was reached. Based on our previous clinical experience, we chose to use 2 to 3 arcs for all head-and-neck cases, of which the setting is close to the upper gantry angle limit. In our study, compared with IMRT, the time required for RA treatment planning and dose calculation was nearly doubled (data not shown).

CONCLUSION

Taken together, our preliminary experience in dose optimisation with RA for radiation treatment of NPC was able to deliver reasonable treatment plans, although it is not as promising as with established IMRT that has been used for more than 8 years in our institution. Development of a sophisticated planning system with a quick optimisation algorithm and adjustable level of modulation will be crucial to take full advantages of RA technology. With the ever-increasing complexity of RA treatment planning and delivery, further parallel efforts in optimising quality assurance are equally warranted.

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