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Volumetric-Modulated Arc Therapy for Oropharyngeal Carcinoma: A Dosimetric and Delivery Efficiency Comparison with Static-Field IMRT

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Abstract

The purpose of this study is to evaluate the treatment plan adequacy and delivery efficiency among volumetric-modulated arc therapy (VMAT) with one or two arcs and the conventional static-field dynamic multileaf collimator (dMLC) intensity-modulated radiation therapy (IMRT) in patients undergoing oropharyngeal carcinoma. Fifteen patient cases were included in this investigation. Each of the cases was planned using step-and-shoot IMRT, VMAT with a single arc (Arc1) and VMAT with double arcs (Arc2). A two-dose level prescription for planning target volumes (PTVs) was delivered with 70 Gy/56 Gy in 30 fractions. Comparisons were performed of the dose-volume histograms (DVH) for PTVs, the DVH for organs at risk (OARs), the monitor units per fraction (MU/fx), and delivery time. IMRT and Arc2 achieved similar target coverage, but superior to Arc1. Apart from the oral cavity, Arc1 showed no advantage in sparing of OARs compared with IMRT, while Arc2 obtained equivalent or better sparing of OARs among the three techniques. VMAT reduced MU/fx and shortened delivery time remarkably compared with IMRT. Our results demonstrated that for oropharyngeal cases, Arc2 can achieve superior target coverage and normal tissue sparing, as well as a significant reduction in treatment time.

Keywords

volumetric-modulated arc therapy; VMAT; oropharyngeal carcinoma; intensity-modulated radiation therapy; IMRT; radiotherapy

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I. Introduction

Intensity-modulated radiation therapy (IMRT) has been demonstrated to be superior to three-dimensional conformal radiotherapy (3D-CRT) for head and neck cancer in terms of toxicity and quality of life. IMRT can improve critical structure sparing especially with regard to the parotids, together with good target coverage^[1,2]. However, drawbacks of the IMRT technique have also been reported, including the requirement of more machine monitor units (MU) and large volume of normal tissues exposed to low-dose irradiation, which in turn may increase the risk of secondary malignancies^[3]. In addition, the prolonged beam delivery time may worsen the accuracy of treatment due to increased intra-fractional patient motion^[4].

Volumetric modulated arc therapy (VMAT) has been introduced clinically as a useful treatment technique that can reduce treatment time while producing comparable or improved dose distribution compared to fixed-field IMRT by simultaneously varying dose rate, gantry rotation speed, and multileaf collimator shape. Faster treatment could have a clinical impact on patients in terms of comfort on couch and minimization of organ displacement. The clinical use of VMAT has been investigated for a number of disease sites, such as prostate, cervix, anal canal, lung, brain, and head-and-neck cancers^[5-9].

Head and neck is an ideal advanced benchmark for assessment of the conformal avoidance capabilities since the anatomical features of this disease site require highly sophisticated treatment techniques to ensure adequate treatment^[9]. In a busy radiotherapy clinic, however, different treatment techniques are generally pre-selected for particular disease sites based on the treatment requirements and the dosimetric quality and delivery efficiency of individual treatment techniques. This retrospective planning study compares static-field dMLC IMRT and VMAT treatments with one or two arcs for patients with oropharyngeal cancer. The results of this study will be useful to the clinical decision making in selecting these techniques for treating head and neck cancers based on their dosimetric efficacy and delivery efficiency.

II. Materials and Methods

A. Patient selection and doses

Fifteen patients with squamous cell carcinoma of the oropharynx were selected for this study (base of tongue: 2 T1N1M0, 1 T2N1M0, 4 T2N2M0, 1 T3N0M0, 1 T3N2M0; tonsil: 1 T1N2M0, 5 T2N2M0). They were treated with IMRT at Fox Chase Cancer Center (FCCC) between August 2010 and June 2011 on Trilogy and iX linear accelerators (Varian Medical Systems, Palo Alto, CA). Each patient underwent re-planning with the RapidArc technique (Varian Medical Systems, Palo Alto, CA) using the same dataset. The treatment objectives were the same.

A two-dose-level IMRT by means of a simultaneously integrated boost (SIB) approach was used for all patients; 56 Gy (CTV56) was prescribed to include the primary tumor (GTV), the nodes with macroscopic invasion and the regional nodes at risk^[10]; 70 Gy (CTV70) included only the primary tumor (GTV) and the nodes with macroscopic invasion. Each

CTV was expanded to its corresponding PTV with a 5-mm margin. All doses were given in 30 fractions over 6 weeks, one fraction per day and 5 fractions per week. Optimization constraints of PTVs and OARs based on RTOG 0022 are summarized in Table 1.

B. IMRT Planning

The static-field dMLC IMRT for these patients was planned using a nine-field step-and-shoot technique with approximately 12 to 15 MLC segments per beam. The optimization was performed by the Eclipse treatment planning system (version 9, Varian Medical Systems, Palo Alto, CA) with 6MV photon beams. The IMRT dose rate was set at 500 MU/min.

C. RapidArc Planning

Both a single-arc plan (Arc1) and a double-arc plan (Arc2) were created for each patient, optimized using Direct Aperture Optimization (DAO) of the Eclipse treatment planning system. Arc1, consisting of a single 360° rotation, was delivered counter clockwise. Arc2 was calculated with two arcs of 360°: The first counter clockwise from 179.9° to 181.1°, and the second clockwise from 181.1° to 179.9°. The maximum dose rate was selected as 600 MU/min.

D. Evaluation of plans and statistical analysis

Quantitative evaluation of plans was performed by means of standard dose-volume histogram (DVH). For PTV, the following data were analyzed: Dmax, Dmin (dose received by 2% and 98% of the target volume as the maximum and minimum doses), dose homogeneity index (HI), which is the difference between the dose covering 5% and 95% of the PTV, and dose conformity index (CI95%), which is the ratio of the 95%-isodose-volume and the volume of the PTV. For OARs, in addition to their Dmax and Dmin, the evaluation also included $V \times Gy$, which is the volume receiving at least $\times Gy$. In addition, monitor units and delivery time per fraction were also compared among groups.

Paired Wilcoxon sign rank test was applied in the data analysis. The threshold for statistical significance was $p < 0.05$.

III. Results

A. Target coverage

Dose distributions obtained with IMRT, VMAT-Arc1 and VMAT-Arc2 for a representative case are shown in Fig. 1. The mean volumes of the PTV70 and PTV56 were 237.9 and 761.9 cm³, respectively, for the 15 patients investigated. The mean DVHs for the two target volumes are shown in Fig. 2 and the mean PTV coverage, Dmax, Dmin, HI and CI are summarized in Table 2 for all the 15 patients. It is evident that Arc2 presented the least dose inhomogeneity in PTV70, followed by IMRT and Arc1 while there was a minimal difference in PTV56 among the three techniques (Fig. 2). A significant improvement in HI for PTV70 was also observed for Arc2 as compared to Arc1 and IMRT. There were no statistically significant differences in CI95% when the three techniques for the entire cohort were compared at both dose levels (Table 2).

B. Spinal Cord

All techniques met the dose objective of the spinal cord ($D_{\max} \leq 45$ Gy). It was clear from Fig.3-(a) that the Arc1 plans resulted in higher doses to the spinal cord in the high dose region, while Arc2 and IMRT were comparable.

C. Brain stem

The brain stem received less than the pre-set limiting dose of 54 Gy in all cases. The mean value of $D_{\max}$ was significantly lower in IMRT (46 Gy) as compared to Arc1 (49 Gy), as seen in Table 3. Beam angle selection played an important role in IMRT planning, as illustrated in Fig. 1. The Arc2 plans (48 Gy) were only slightly better than Arc1 plans.

D. Contralateral parotid

Fig.3-(c) reported the average DVH of the ontra-lateral parotid, from which we observed that IMRT plans achieved better sparing than Arc2, which in turn had superior sparing compared to Arc1. According to Table 3, the mean doses for IMRT, Arc1 and Arc2 were 20.0 ± 4.3 , 24.6 ± 5.5 and 22.1 ± 5.4 Gy, respectively. Likewise, the $D_{33\%}$, $D_{50\%}$ and $D_{66\%}$ for Arc1 were significantly greater than those attained in IMRT or Arc2 plans.

E. Mandible

Similarities in the high dose region among these three techniques for the mandible were seen in Table 3, although Arc1 showed a little lower quality in Fig. 3-(d).

F. Glottis larynx

All strategies met the dose objectives and showed no statistically significant difference for the glottis larynx.

G. Oral cavity

A significant difference between the IMRT and VMAT plans was observed in the maximum dose to the oral cavity. A shift of technique from IMRT to VMAT reduced the maximum dose by about 7 Gy as shown in Table 3.

H. Monitor units and delivery time

The mean values of MU per fraction were 1335.1 ± 281 for IMRT, 427 ± 67.8 for Arc1 and 523.5 ± 111.2 for Arc2, respectively (Table 4). Significant differences in MU per fraction were noted between any two techniques. This resulted in significantly longer delivery time for IMRT plans (mean beam-on time 836 seconds) than VMAT plans (mean beam-on time 245 seconds for Arc1 and 356 seconds for Arc2, respectively). Although the maximum rotation speed for a clinical accelerator is limited to $360^\circ/\text{min}$ Arc1 plans usually took longer beam-on time to deliver in order to achieve desired target dose conformity with proper beam apertures at various gantry angles. This is because of the limited MLC leaf speed that requires much lower dose rate in order for the leaves to move to desired locations. The effective dose rate was 105 MU/min for Arc1 and 88 MU/min for Arc2, respectively.

IV. Discussion

The dosimetric quality and treatment delivery characteristics have been evaluated by previous investigators^[5–9,12–18]. Intrinsically, VMAT uses more beam angles and therefore spreads the incident/exit beams more evenly in surrounding normal tissues leading to more uniform surface doses. By contrast, IMRT provides more intensity modulation in a few optimally selected beam angles that potentially result in better sparing of some critical structures due to their geometrical relationship to the target. Theoretically, a single arc VMAT plan is typically a result of an optimization process with about 60 gantry angles/MLC apertures that may not provide sufficient intensity modulation for some complex target/critical structure geometries. VMAT plans with multiple arcs employ more control points (equivalent to >120 MLC segments) than static IMRT (typically 50 to 120 MLC segments). This could result in higher degree of modulation and better plan quality, especially for a complex-shaped target volume. For prostate cancer, Sze et al.^[11] reported lower rectal doses with double arcs when compared to a single arc. In our institution, a systematic investigation of static field IMRT and single- and double-arc VMAT plans led to a clinical decision to allow for both IMRT (typically 7 to 9 fields) and VMAT with at least two arcs^[12]. Lin *et al* demonstrated that VMAT (with two arcs) was more suitable for centrally located targets while IMRT was more advantageous for large, irregular-shaped or peripheral targets although accurate treatment delivery could be achieved with both modalities^[18]. In a busy clinic with limited planning capabilities it would be impractical to perform comparisons of different treatment techniques (e.g., even between Arc1 and Arc2) for every patient. A systematic study on these treatment techniques for different disease sites can provide valuable information about the suitability of a treatment technique for a particular disease site. This investigation reports on a comparison of the VMAT technique with single or double arcs against IMRT for head and neck patients.

Our results showed that all head and neck plans were similar in terms of target coverage. The only statistically significant difference observed in this study was in favor of Arc2 plans on dose homogeneity for PTV70. Similar results were reported by previous investigators^[13,14]. Conversely, Stieler *et al* showed that single arc plans brought slight improvement in target coverage as compared to IMRT in some head and neck cases^[16,17]. For critical structures, however, our results showed that static-field IMRT outperformed VMAT in the doses to brain stem, spinal cord, contralateral parotid and glottis larynx, likely due to the optimal selection of beam angles. Arc2 produced the lowest doses to the mandible and oral cavity due to the combination of more beam angles and increased intensity modulation. The Arc1 plans, in comparison, were inferior to either IMRT or Arc2 in all dosimetric aspects. This observation was consistent with the findings of several other studies^[13,16]. In a multi-institutional study, dual arc was required over single arc to yield the most promising, clinically acceptable VMAT plans in the comparison with static field IMRT for head and neck cancer^[9]. The ipsilateral parotid sparing was not presented in our study because it was partly covered by PTV in some cases, and therefore it was very much case dependent for this structure. It should be noted that in all of these studies, the prescription dose, the target volume, the plan parameters, the treatment planning system and the treatment delivery systems varied from one institution to another, which may partially

explain the differences in plan quality with various treatment techniques among all of the investigations.

Prominent reductions in delivery time and MU per fraction have previously been observed when converting from IMRT to VMAT for head and neck cancer^[9,13,17]. For the cases investigated in this work, Arc1 plans required the shortest delivery time and least MU/fx, which were followed by Arc2 plans with a small increase in delivery time. The VMAT plans could shorten the delivery time by nearly 70% and reduce the MU by about 60% as compared to IMRT plans. Reduced treatment time is an important factor to patient comfort and treatment accuracy, especially in a complex image-guided radiation therapy (IGRT) procedure. Due to limitations on accelerator head leakage modeling and scatter dose calculation of currently available treatment planning systems, the normal tissue doses at low-dose regions could not be computed accurately. Therefore, we could not analyze the integral body dose reliably for IMRT and VMAT. The head leakage dose to the normal tissues may be estimated by the total MUs used to deliver a treatment plan, which suggested a slightly higher theoretical risk of radiation-induced second malignancies^[3] from IMRT compared to VMAT (Table 4). However, previous investigations also showed that the normal tissue integral doses for head and neck radiotherapy did not vary significantly despite the use of different treatment techniques because of the dominating effects of primary and scattering radiation^[19]. The treatment delivery accuracy was found to be adequate for both IMRT and VMAT techniques^[20]. During the initial implementation, it usually took more time to generate a VMAT plan than an IMRT plan due to increased beam angles and beam apertures^[13]. In this study, we did not collect the total time for IMRT/VMAT dose calculation and treatment optimization given the fact that our retrospective VMAT plans were generated 1–2 years after the IMRT plans, and that new dose algorithms and optimization techniques are continuously being developed. It is expected that the planning time will be further shortened in the future with increasing experience and improved computer hardware/software.

V. Conclusions

VMAT with two arcs have shown a slight improvement in target dose homogeneity and lower doses to the mandible and oral cavity while static-field IMRT outperformed VMAT in critical structure sparing (lower doses to brain stem, spinal cord, contralateral parotid and glottis larynx). In contrast, VMAT with a single arc was inferior to either IMRT or VMAT with two arcs in all dosimetric aspects. These results suggest that either static-field IMRT or VMAT with at least two arcs be used for the treatment of oropharyngeal carcinoma in a routine clinic. Because of the shorter delivery time and smaller number of MU, VMAT with two arcs offers potential advantages over IMRT. However, further investigations are required to verify whether the dosimetric and delivery advantages can be translated into benefits in clinical outcome.

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References

1. Nutting CM, Morden JP, Harrington KJ, et al. Parotid-sparing intensity modulated versus conventional radiotherapy in head and neck cancer (PARSPORT): a phase 3 multicentre randomised controlled trial. *Lancet Oncol.* 2011; 12(2):127–136. [PubMed: 21236730]
2. Gregoire V, De Neve W, Eisbruch A, Lee N, Van den Weyngaert D, Van Gestel D. Intensity-modulated radiation therapy for head and neck carcinoma. *Oncologist.* 2007; 12(5):555–564. [PubMed: 17522243]
3. Stathakis S, Roland T, Papanikolaou N, Li J, Ma C. A prediction study on radiation-induced second malignancies for IMRT treatment delivery. *Technol Cancer Res Treat.* 2009; 8(2):141–148. [PubMed: 19334795]
4. Hoogeman MS, Nuyttens JJ, Levendag PC, Heijmen BJ. Time dependence of intrafraction patient motion assessed by repeat stereoscopic imaging. *Int J Radiat Oncol Biol Phys.* 2008; 70(2):609–618. [PubMed: 17996389]
5. Palma D, Vollans E, James K, et al. Volumetric modulated arc therapy for delivery of prostate radiotherapy: comparison with intensity-modulated radiotherapy and three-dimensional conformal radiotherapy. *Int J Radiat Oncol Biol Phys.* 2008; 72(4):996–1001. [PubMed: 18455326]
6. Cozzi L, Dinshaw KA, Shrivastava SK, et al. A treatment planning study comparing volumetric arc modulation with RapidArc and fixed field IMRT for cervix uteri.
7. Clivio A, Fogliata A, Franzetti-Pellanda A, et al. Volumetric-modulated arc radiotherapy for carcinomas of the anal canal: A treatment planning comparison with fixed field IMRT. *Radiother Oncol.* 2009; 92(1):118–124. [PubMed: 19181409]
8. Verbakel WF, Senan S, Cuijpers JP, Slotman BJ, Lagerwaard FJ. Rapid delivery of stereotactic radiotherapy for peripheral lung tumors using volumetric intensity-modulated arcs. *Radiother Oncol.* 2009; 93(1):122–124. [PubMed: 19552979]
9. Holt A, Van Gestel D, Arends MP, et al. Multi-institutional comparison of volumetric modulated arc radiotherapy vs intensity-modulated radiation therapy for head and neck cancer: a planning study. *Radiation Oncol.* 2013; 8:26.
10. Gregoire V, Levendag P, Ang KK, et al. CT-based delineation of lymph node levels and related CTVs in the node-negative neck: DAHANCA, EORTC, GORTEC, NCIC, RTOG consensus guidelines. *Radiother Oncol.* 2003; 69(3):227–236. [PubMed: 14644481]
11. Sze HC, Lee MC, Hung WM, Yau TK, Lee AW. RapidArc radiotherapy planning for prostate cancer: Single-arc and double-arc techniques vs. intensity-modulated radiotherapy. *Med Dosim.* 2012; 37(1):87–91. [PubMed: 21925863]
12. Ma C-M, Lin MH, Dai XF, Koren S, Klayton T, Wang L, Li JS, Chen L, Price RA. Investigation of pulsed low dose rate radiotherapy using dynamic arc delivery techniques, *Phys. Med. Biol.* 57(2012):4613–4626.
13. Lee TF, Ting HM, Chao PJ, Fang FM. Dual Arc Volumetric-modulated Arc Radiotherapy (VMAT) of Nasopharyngeal Carcinomas: A Simultaneous Integrated Boost Treatment Plan Comparison with Intensity-modulated Radiotherapies and Single Arc VMAT. *Clin Oncol (R Coll Radiol).* 2011; 24(3):196–207. [PubMed: 21752615]
14. Tang G, Earl MA, Luan S, Wang C, Mohiuddin MM, Yu CX. Comparing radiation treatments using intensity-modulated beams, multiple arcs, and single arcs. *Int J Radiat Oncol Biol Phys.* 2010; 76(5):1554–1562. [PubMed: 20338482]
15. Stieler F, Wolff D, Schmid H, Welzel G, Wenz F, Lohr F. A comparison of several modulated radiotherapy techniques for head and neck cancer and dosimetric validation of VMAT. *Radiother Oncol.* 2011; 101(3):388–393. [PubMed: 21962821]
16. Guckenberger M, Richter A, Krieger T, Wilbert J, Baier K, Flentje M. Is a single arc sufficient in volumetric-modulated arc therapy (VMAT) for complex-shaped target volumes. *Radiother Oncol.* 2009; 93(2):259–265. [PubMed: 19748146]

17. Bertelsen A, Hansen CR, Johansen J, Brink C. Single Arc Volumetric Modulated Arc Therapy of head and neck cancer. *Radiother Oncol.* 2010; 95(2):142–148. [PubMed: 20188427]
18. Lin MH, Price RA, Li JS, Kang SW, Li J, Ma C-M. Investigation of pulsed IMRT and VMAT for re-irradiation treatments: dosimetric and delivery feasibilities. *Phys. Med. Biol.* 58(2013):8179–8196. [PubMed: 24200917]
19. Jothybasu KS, Bahl A, Subramani V, Rath GK, Sharma DN, Julka PK. Static versus dynamic intensity-modulated radiotherapy: Profile of integral dose in carcinoma of the nasopharynx. *J Med Phys.* 2009; 34(2):66–72. [PubMed: 20098539]
20. Li G, Zhang Y, Jiang X, Bai S, Peng G, Wu K, Jiang Q. Evaluation of the ArcCHECK QA system for IMRT and VMAT verification. *Phys. Medica.* 2013; 29:295–303.

- A thorough evaluation of plan adequacy and delivery efficiency for H&N IMRT and VMAT
- IMRT is generally better than VMAT with a single arc for head and neck RT
- IMRT and VMAT are similar if a minimum of 2 arcs are used for high-quality VMAT
- VMAT with 2 arcs produce high-quality plans with less MU and shorter delivery time

Fig. 1.
Dose distributions for a typical head and neck patient (isodose lines represent 70 Gy, 56 Gy, 35 Gy and 21 Gy, respectively).

Fig. 2.

Average DVHs for PTV70 and PTV56 over the 15 patients investigated. The dose is expressed as a percentage of the PTV70 prescription dose (70Gy).

Fig. 3.

Average DVHs for OARs over the 15 patients investigated. The dose is expressed as a percentage of the PTV70 prescription dose (70Gy).

Table 1

Dose-volume constraints used in the treatment planning process.

Planning priority		Dose-volume	Objective
PTV	PTV70	D95%	100%
		V110%	<20%
		V93%	>99%
	PTV56	D95%	100%
		V110%	<20%
		V93%	>99%
OAR	Brainstem	D0.1cc	<54GY
	Spinal cord	D0.1cc	<45GY
	Glottis Larynx	D2/3	<50GY
		Mean dose	<45GY
	Mandible	D0.1cc	<70GY
	Contralateral-parotid	Mean dose	<26GY
		D50%	<30GY
	Oral cavity	D0.1cc	<60GY

OAR, organ at risk.

Table 2

Summary of DVH analysis for the two PTVs.

PTV	Volume[cc]	IMRT	Arc1	Arc2	P<0.05
PTV70	237.9±116.5	Dmean(Gy)	72.7±0.6	72.3±0.6	NS
		Dmax(Gy)	77.8±1.4	78.4±2.3	e2,e3
		Dmin(Gy)	60.1±5.0	61.2±2.9	NS
		HI	7.1±1.1	7.9±2.3	e2,e3
		CI95%	1.48±0.3	1.57±0.32	NS
PTV56	761.9±370.1	Dmean(Gy)	51.6±2.2	52.0±2.1	NS
		Dmax(Gy)	62.3±2.2	62.6±1.7	e3
		Dmin(Gy)	30.0±4.3	30.0±3.7	NS
		HI	23.4±3.1	24.9±4.2	NS
		CI95%	1.46±0.39	1.48±0.33	NS

Paired Wilcoxon analysis: e1=IMRT vs. Arc1; e2=IMRT vs. Arc2; e3= Arc2 vs. Arc1

Table 3

Summary of DVH analysis for the OARs.

Organ	Dose-volume index	IMRT	Arc1	Arc2	P<0.05
Spinal cord	D0.1cc(Gy)	41.1±3.0	44.3±3.6	40±3.9	e1,e3
Brain stem	D0.1cc(Gy)	46.0±3.7	49.4±3.4	48.0±4.2	e1
Contralateral parotid	Mean(Gy)	20.0±4.3	24.6±5.5	22.1±5.4	e1
	D33%(Gy)	22.2±5.7	27.6±7.0	24.6±6.7	e1,e2
	D50%(Gy)	17.6±4.5	23.1±5.5	20±5.0	e1
	D66%(Gy)	14.4±4.1	19.8±5.0	17±4.0	e1
Mandible	D0.1cc(Gy)	73.4±6.8	73.1±6.3	72.9±4.4	NS
	V75Gy(cc)	0.25±0.38	0.46±0.8	0.04±0.05	NS
Glottis larynx	Mean(Gy)	29.6±12	32.6±12.2	31.3±11.1	NS
	D66%(Gy)	24.5±14.2	27.3±14.5	25.9±13.3	NS
Oral cavity	D0.1cc(Gy)	63.3±6.5	57.1±7.7	55.4±8.6	e1,e2

Paired Wilcoxon analysis: e1=IMRT vs. Arc1; e2=IMRT vs. Arc2; e3= Arc2 vs. Arc1

Table 4

Treatment delivery parameters by technique.

	IMRT	Arc1	Arc2	P<0.05
MU per fraction	1335.1±281	427±67.8	523.5±111.2	e1,e2,e3
Beam on time (second)	836.2±613.8	245±178.8	356±230.5	e1,e2,e3

Paired Wilcoxon analysis; e1=IMRT vs. Arc1; e2=IMRT vs. Arc2; e3= Arc2 vs. Arc1