

Impact of different IMRT techniques to improve conformity and normal tissue sparing in upper esophageal cancer

Amin E Amin¹, Mohamed Kelaney¹, Samah K Elshamndy², Osiris W Guirguis³

¹Department of Radiotherapy & Nuclear Medicine, El-Demerdash Hospital, Faculty of Medicine, Ain Shams University, Cairo, Egypt

²Department of Radiotherapy and Nuclear Medicine, Faculty of Medicine, Suhag University, Suhag, Egypt

³Department of Biophysics, Faculty of Science, Cairo University, Giza, Egypt

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Abstract

Purpose: Intensity modulated radiotherapy (IMRT) for cervical esophageal cancer is challenging. Although IMRT techniques using inverse planning algorithms are facilitating the treatment planning process, the irradiation dose to the normal tissues can be a critical issue. This study was performed to investigate the effect of beam numbers and their directions and local optimization (1) dose conformity and homogeneity to the planning target volume (PTV) and (2) dose to the organ at risks (OARs). **Methods:** Four upper esophageal cancer cases were randomly selected for this treatment planning study. Eight IMRT plans were for each case with the same dose-volume constraints but with different beam numbers and arrangements. Local optimization using regular structures drawn automatically around the PTV with margins from 0.5-1.5 cm was performed. IMRT plans were evaluated with respect to isodose distributions, dose-volume histograms (DVHs) parameters, homogeneity index (HI), and conformity index (CI). The statistical comparison between the types of plans was done using the One Way ANOVA test. **Results:** results showed that IMRT using three or five beams was not sufficient to obtain good dose optimization. The seven field plans showed the best coverage for the PTV with tolerable doses for the OARs, and the beam orientation was very critical. Increasing beams (Bs) number from 7 to 13 did not show significant differences in the PTV coverage, while the mean lung dose was increased. The PTV coverage were 95.1, 95.1, 98.1, 97.3, 97.3, 97.3, 97.0, and 97.0% for 3Bs, 5Bs, 7Bs, 9Bs, 13Bs, 7Bs(30), 7Bs(60) (beam angles were changed from 0° to 30° and 60°), and 7Bs(R) (seven IMRT plans with ring), respectively. The mean heart dose did not exceed 0.36 Gy with $p < 0.05$. For lung doses, the best plan was the one with 9Bs which reduced lung volume doses V_{20Gy} (%) and V_{30Gy} (%), and reduced mean lung dose from 5.4 to 4.5 Gy with $p < 0.05$ for 7Bs(R) plans. IMRT improved the homogeneity indices ($p > 0.05$), yet conformity was better with 9Bs and 7Bs(R) IMRT plans with $p < 0.05$. **Conclusion:** Seven equispaced coplanar intensity-modulated beams with an addition of a ring structure can produce desirable dose distributions to the PTV. Moreover, dose-volume of exposed normal lung can be reduced with 9Bs and 7Bs(R) IMRT plans.

Keywords: Intensity Modulated Radiotherapy; Esophageal Cancer; Local Optimization; Planning Target Volume; Organ at Risks

Introduction

Organ preservation is a common treatment goal for carcinoma of the cervical esophagus.^{1, 2, 3} Technical challenges including rapid change in patient contour and dose-limiting adjacent critical structures present difficulty in achieving uniform target (tumor) coverage.^{4, 5} Despite these challenges, radiotherapy is the primary treatment modality for carcinoma of the cervical esophagus. Innovative technologies in radiation delivery such as intensity-modulated radiotherapy (IMRT) offer the potential for improved tumor coverage, while reducing the dose delivered to the surrounding normal tissues.⁶ IMRT has shown to be superior to 3-dimensional conformal radiation therapy (3DCRT) with respect to dose conformity in multiple sites including, but not limited to the larynx, nasopharynx, lung, and prostate.⁷ Multiple planning studies have shown IMRT superiority in the treatment of

various head and neck sites as well as lower esophageal tumors.^{8, 9} These planning studies have used to develop techniques that will produce the best dosimetric results when applied to a group of patients with a specific tumor location.¹⁰ Consequently, IMRT has become the standard of care for various cancers of the head and neck.¹¹ No consensus has been reached as to the optimal radiation technique and target volume delineation for treating cervical esophageal cancer. The cervical and upper thoracic esophageal regions are characterized by variation of body thickness, the distance of esophagus to the body surface, and the closeness of the target to the spinal cord, which represents a unique challenge with respect to the tumor coverage and adjacent critical structure. A number of additional limitations and potential concerns regarding IMRT are relevant to cervical esophageal cancer.

Corresponding author: Osiris W Guirguis; Department of Biophysics, Faculty of Science, Cairo University, Giza, Egypt.

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Some of these limitations are dose per fraction, organ motion, and target delineation. It is a challenge to limit the dose to the spinal cord while keeping the dose uniformity in the target volume in the IMRT plans. In addition, the quality of the IMRT plan also depends greatly upon the planner's experiences, and many trials and errors are required to match the constraints. The ideal number of beams in an IMRT plan has not been decided. Generally, a larger number of beams would a greater flexibility to achieve a desired dose distribution. However, the more the number of beams used, the more the effort is required for planning, quality assurance, dosimetric verification, and treatment. Practically, it is desirable to reduce the number of beams to as few as possible without compromising the quality of the treatment.¹²

A number of studies have assessed whether IMRT is suitable or effective for treating esophageal cancer, partly because of the concern that IMRT may increase the radiation at low doses to large volumes of normal lung tissue, which could be detrimental to radiosensitive structures. Only few reports have been published so far on the use of IMRT for esophageal cancer.^{9,13} In two earlier studies,^{9,10} 9 beams (9Bs) IMRT plans were equivalent in comparison with 3DCRT plans regarding planning target volume (PTV), dose homogeneity and mean lung dose (MLD). However, the 4Bs IMRT plans with the same beam orientation as the 3DCRT plans increased the PTV dose homogeneity and reduced the mean lung dose. A more recent report from Wu *et al.*¹³ found that IMRT could be an effective tool to reduce volume of lung irradiated above 25 Gy for mid-thoracic esophageal cancers. Apparently, more extensive studies are needed to explore the potential gains of IMRT with respect to dosimetric improvements before embarking on a clinical trial.

In the present work, a pilot study was carried out investigating the feasibility of using different IMRT plans for cases of upper esophageal cancer, which typically involves irradiation of normal lung tissue, spinal cord, and heart. We determined whether the best IMRT plan could reduce dose delivered to the normal lung and improve the target conformity. Eight types of IMRT beam arrangements were made to assess the optimal beam angles. Furthermore, authors intend to establish IMRT treatment strategies for esophagus cancers, and the results from this study could be useful for designing future clinical trials.

Methods and Materials

In the present study, four upper esophageal cancer cases were randomly selected. All of the patients had tumors involving the upper and cervical esophagus. Through treatment simulation session, computed tomography (CT) images of the entire thorax were obtained using 3 mm slice spacing, including the entire lung, spinal cord, and heart. Images were obtained with the patients in the supine position. Pa-

tients were immobilized using with thermoplastic sheets thermoplastic material.

The planning target volume (PTV) and organs at risk (OARs) were delineated by a radiation oncologist on the CT slices using contouring option in the XiO (version 4.7) treatment planning system (TPS). The aperture based inverse planning (or direct aperture inverse planning "DAO") with standard superposition algorithm was used for dose calculations. For each patient, two different treatment volumes are defined: clinical tumor volume (CTV) esophagus (gross tumor volume (GTV) + margin). The margins are expanded based on the institutional protocol for IMRT, i.e., 1 cm along the transverse direction, 1 cm along the cranial caudal direction, 1 cm anteriorly, and 0.5 cm posteriorly.

The PTV is given by the sum of CTV and margin. The margin was 4 cm proximal/distal and 1 cm radial. Eight treatment plans with different beams number (Bs): 3Bs, 5Bs, 7Bs, 9Bs, 13Bs, 7Bs(30°), 7Bs(60°) and 7Bs(R), were generated for each case. The effect of beam directions and local optimization were studied with the 7Bs plans, and the beam angles were changed from 0° to 30° and 60°, as well as, three rings were drawn around the PTV with margins 0.5, 1, and 1.5 cm, respectively, as automatic margins from the PTV [7Bs, 7Bs(30°), 7Bs(60°) and 7Bs(R)]. **Table 1** and **Figure 1** summarize the number of beams and gantry angles for each plan category. The target dose was 50.4 Gy delivered in 28 fractions. The IMRT plans were generated using equispaced beams (6 MV photon energy from Elekta Precise linear accelerator).

The treatment planning parameters used to ensure coverage of the PTV are presented in **Table 2** to calculate the conformity index (CI). A structure called 'normal tissue' was created to include all of the tissues enclosed by the external contour (patient skin) minus the expanded PTV. The planning objectives for this structure were generally prioritized in the following order: PTV, lung, spinal cord, heart, and rings. The full inverse planning process of the IMRT plans for the 7Bs was carried out 25 times, during which the priority, ranking order and treatment planning dose constraints for each organ were adjusted to obtain plans with results congruent with the planning goals. The treatment-planning software uses a superposition based inverse planning algorithm to generate optimal beam modulation satisfying the physicist specified dose objectives and constraints. The goal of optimization was to minimize the overall cost of objective function (i.e., the function of the difference between the desired and calculated doses for the target and all specified critical organs). After the inverse planning, the leaf motion required for the accelerator is generated for each IMRT plan by using the sliding-window technique.¹⁴ The final dose distribution in each plan was normalized to 95% coverage of the PTV receiving the prescribed dose (50.4 Gy in 28 fractions).

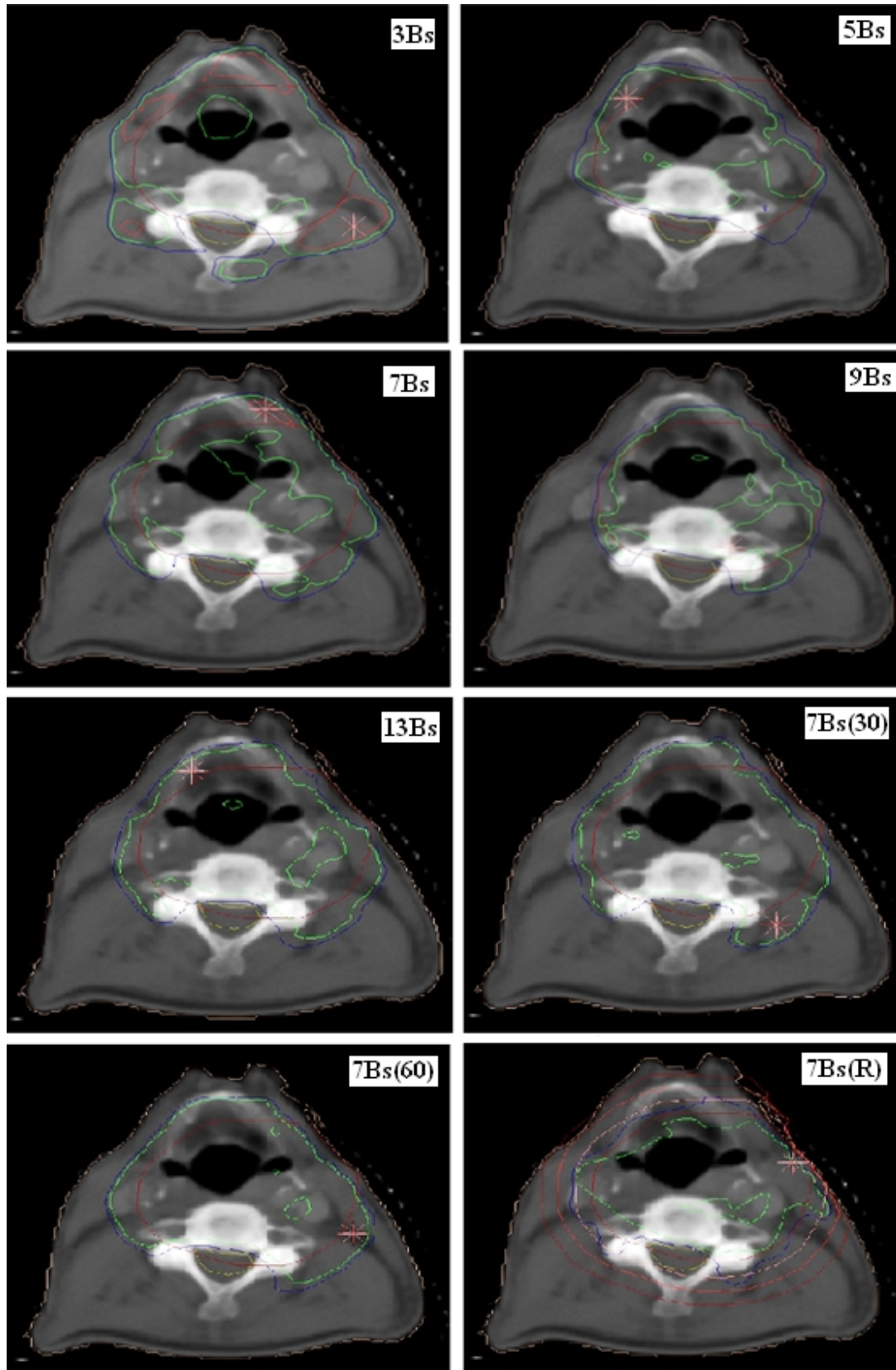


FIG. 1: IMRT isodose distributions in 3Bs, 5Bs, 7Bs, 9Bs, 13Bs, 7Bs(30), 7Bs(60) and 7Bs(R) plans in one of upper esophageal cancer. Red, green and dark blue lines represent 110, 100, and 95% isodose distributions, respectively.

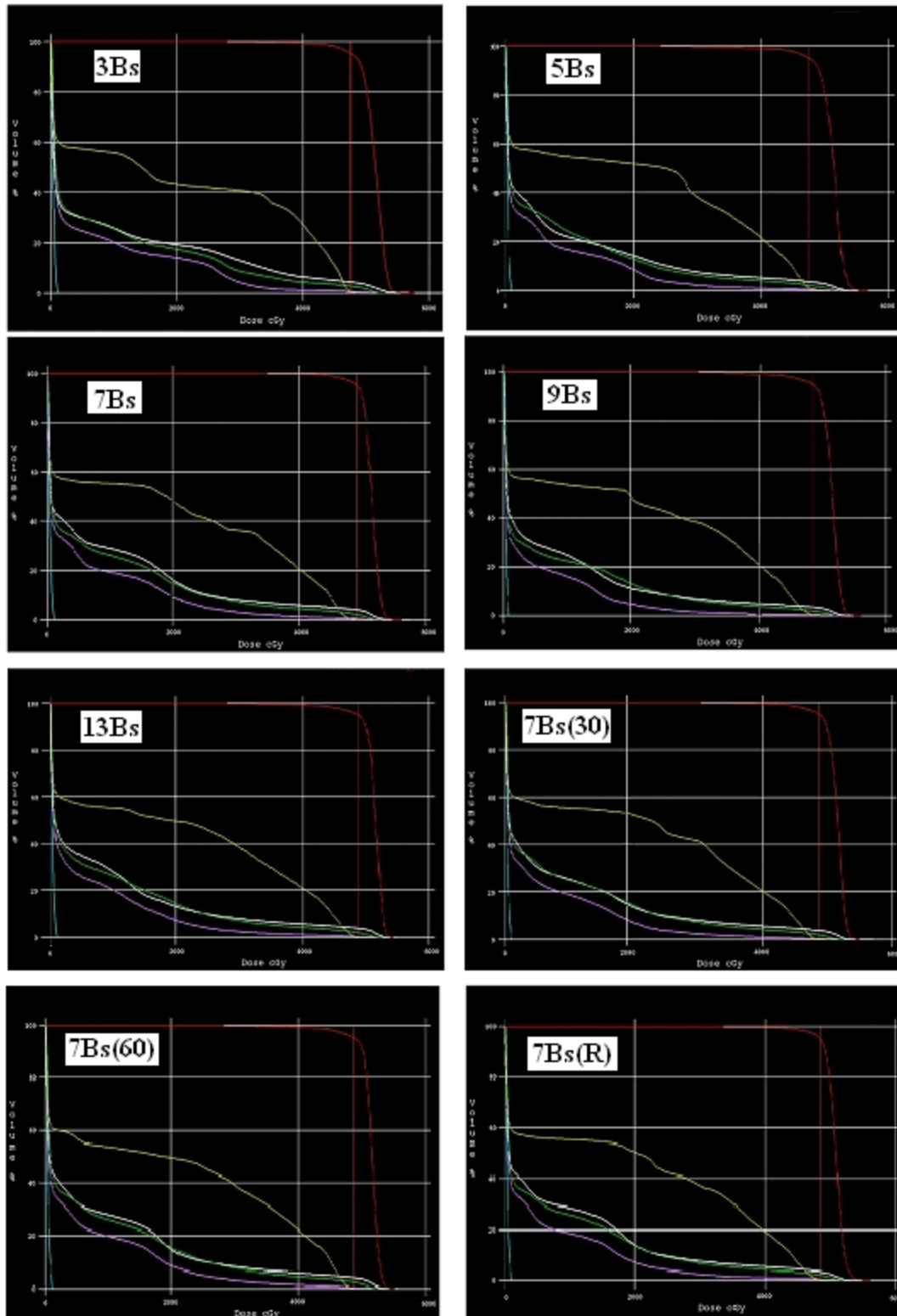


FIG. 2: IMRT Dose volume histogram (DVH) in 3Bs, 5Bs, 7Bs, 9Bs, 13Bs, 7Bs(30), 7Bs(60) and 7Bs(R), plans in one case of upper esophageal cancer. PVT (red curve), spinal cord (yellow curve), left lung (green curve), right lung (violet curve), heart (blue curve) and total volume (white curve).

TABLE 1: Summarizes the number of beams and gantry angles for each plan category.

Number of beams	Gantry angles
3Bs	0°, 120°, 240°
5Bs	0°, 72°, 144°, 216°, 288°
7Bs	0°, 52°, 103°, 154°, 206°, 257°, 308°
9Bs	0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, 320°
13Bs	0°, 28°, 55°, 83°, 111°, 139°, 167°, 195°, 223°, 251°, 279°, 307°, 335°
7Bs(30)	30°, 82°, 134°, 186°, 238°, 290°, 342°
7Bs(60)	60°, 112°, 164°, 216°, 268°, 320°, 372°
7Bs(R)	0°, 52°, 103°, 154°, 206°, 257°, 308°

TABLE 2: IMRT dose constraints to upper esophageal cancer.

Structure	Type	Rank	Objective	Dose (Gy)	Volume (%)	Weight	Power
PTV	Target	1	Maximum	53	0	300	2.8
			Minimum	51	100	300	2.6
Spinal cord	OAR	2	Maximum	35	0	100	2.3
Heart	OAR	3	Dose volume	38	25	100	2.0
Right lung	OAR	4	Dose volume	35	5	100	2.0
			Dose volume	8	15	100	2.0
			Dose volume	6	30	100	2.0
Left lung	OAR	5	Dose volume	35	5	100	2.0
			Dose volume	8	15	100	2.0
			Dose volume	6	30	100	2.0
R1	OAR	6	Maximum	50	0	100	2.0
R2	OAR	7	Maximum	41	0	100	2.0
R3	OAR	8	Maximum	35	0	100	2.0

The plans are evaluated and compared to each other according to the following values:

- Isodose distribution
- Dose volume histogram (DVH)
- Homogeneity index (HI) of PTV
 $HI = (D_{2\%} - D_{98\%}) / D_{50\%}$, where $D_{2\%}$, $D_{98\%}$ and $D_{50\%}$ correspond to the dose delivered to 2, 98 and 50% of the PTV, respectively. HI greater than 0 indicates that there is a high dose difference inside the PTV, thus, a greater degree of dose heterogeneity in the PTV. HI of zero represents the ideal plan.
- Conformity index (CI) of PTV
 $CI = (V_{98\%} / PTV_{98\%})$, where $V_{98\%}$ is the volume enclosed by the 98% of prescribed dose. Ideal CI value is 1. CI greater than 1 indicates that the volume of 98% isodose line is greater than the PTV_{98%} and so greater health tissue irradiation.
- The PTV_{95%}
- Lung Dose
- Maximum dose to spinal cord
- Mean heart dose
- Number of monitor units (MUs), number of segments, and total fraction

Results and Discussion

The present study addressed whether different IMRT techniques for esophageal cancer can be used to achieve higher

PTV coverage and reduce dose to the OAR, especially the volume of lung irradiated at low doses of 5 to 30 Gy. This goal was achieved with all types of IMRT plans reducing V_{30 Gy}(%) and MLD.

PTV isodose distributions

In **Figure 1**, the isodose levels of 50.4 Gy are shown and the isodose lines are displayed on an absolute dose scale. The isodose distributions on axial images for different IMRT plans at the isocenter of PTV for one of the four cases were obtained. Treatment plans were produced using equispaced non-opposed coplanar beams starting with a direct anterior beam, and the adding ring structure provided the optimal IMRT dose distribution. The effect of the ring on the high dose outside the PTV was studied for the seven-field plans.

By looking at the isodose lines, the plans with three and five beams (i.e., 3Bs and 5Bs) showed larger high-dose regions outside the PTV as well as more normal tissues irradiation. Some areas near the skin received high dose. The results showed that increasing number of beams lead to decrease in high dose regions outside the PTV and increase of the conformity of the prescribed dose to the PTV. Also, the use of ring for dose optimization in 7Bs plan increased the conformity compared to the 9 and 13 Bs plans.

DVH

The DVH has become a critical tool to evaluate complex 3D absorbed dose distributions. **Figure 2** shows the DVH for different IMRT plans for the PTV and OARs for one case of upper esophageal cancer. The mean dose to the PTV for the four cases of upper esophageal cancer and the standard deviation (SD) are listed in **Table 3**. Three beams plan is presented to show the influence of the number of intensity modulated beams. For 7Bs and 7Bs(R), the mean doses to the PTV were 98.1 and 97.1%, respectively. The DVHs were similar to other IMRT plans, and the indices did not show any obvious difference as the beam number increased to nine and thirteen. The beam direction for 7Bs plans did not improve the PTV coverage.

HI of PTV

HI of mean PTV were 0.14 ± 0.01 and 0.14 ± 0.03 for 7Bs and 7Bs(R), respectively, with $p > 0.05$ which represented the best homogenous plans (**Table 3**). Dose homogeneity HI of 3Bs and 5Bs were inferior with slight differences between other plans. **Figure 3** shows the relation between the number

of beams and HI for different IMRT plans in the PTV for the cases of the upper esophageal cancer.

CI of PTV

The CI results showed that three and five equispaced coplanar intensity modulated beams (3Bs and 5Bs) did not meet the requirement of dose conformity, and this may have been due to the fact that the beams number and their directions were not sufficient for dose optimization. The conformity was improved as the number of intensity modulated beams increased, but the improvement was marginal when the number of beams was above five. As expected, high dose conformity of the target volumes in IMRT plans was generally improved by using ring to 7Bs when compared to 9Bs and 13Bs. **Figure 4** shows the relationship between number of beams and CI for different IMRT plans in the PTV for cases of the upper esophageal cancer.

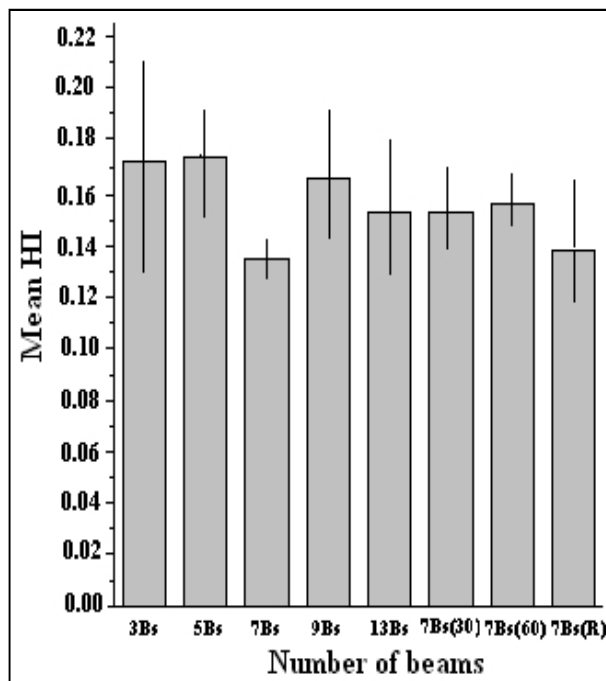


FIG. 3: The relationship between the number of beams and mean HI.

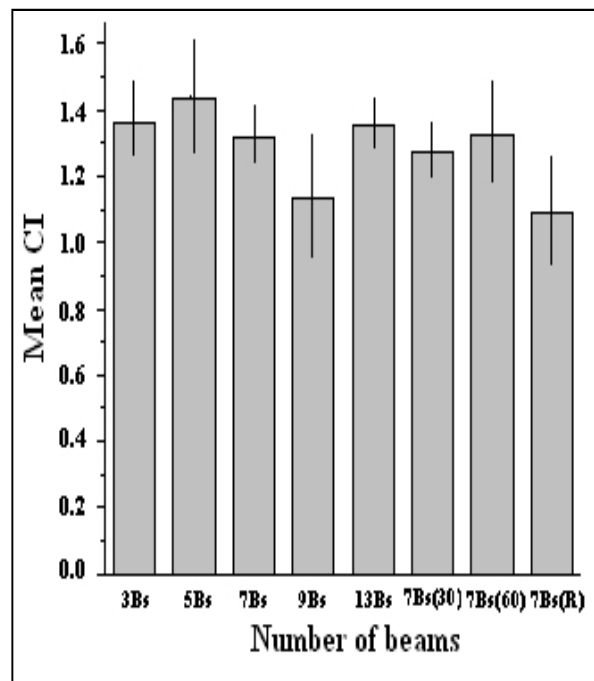


FIG. 4: The relationship between the number of beams and mean CI.

TABLE 3: The mean results for different IMRT plans of the upper esophageal cancer patients (mean \pm SD).

Structure and Parameters	3Bs	5Bs	7Bs	9Bs	13Bs	7Bs(30)	7Bs(60)	7Bs(R)	P-value
PTV									
D ₂ % (Gy) \pm SD	53.80 \pm 0.94	55.05 \pm 0.70	53.66 \pm 0.74	53.43 \pm 0.70	53.06 \pm 0.82	53.48 \pm 0.48	53.3 \pm 0.92	53.34 \pm 0.90	0.067
D ₅₀ % (Gy) \pm SD	51.46 \pm 0.54	51.40 \pm 0.53	51.57 \pm 0.34	51.51 \pm 0.37	51.43 \pm 0.36	51.67 \pm 0.55	51.47 \pm 0.41	50.97 \pm 0.79	0.699
D ₉₈ % (Gy) \pm SD	44.92 \pm 1.06	46.08 \pm 0.92	46.69 \pm 0.86	44.85 \pm 0.64	45.19 \pm 0.65	45.59 \pm 0.82	45.25 \pm 0.61	46.29 \pm 0.79	0.027
PTV _{95%} (Gy) \pm SD	95.10 \pm 0.66	95.10 \pm 0.61	98.10 \pm 0.60	97.30 \pm 0.54	97.30 \pm 0.62	97.30 \pm 0.63	97.00 \pm 0.63	97.00 \pm 0.55	0.011
Mean HI\pmSD									
Mean CI \pm SD	0.17 \pm 0.04	0.17 \pm 0.02	0.14 \pm 0.01	0.17 \pm 0.03	0.15 \pm 0.03	0.15 \pm 0.02	0.16 \pm 0.01	0.14 \pm 0.03	0.440
	1.36 \pm 0.12	1.43 \pm 0.17	1.32 \pm 0.10	1.13 \pm 0.21	1.35 \pm 0.08	1.27.00 \pm 0.10	1.32 \pm 0.18	1.09 \pm 0.14	0.036
Lung									
MLD (Gy)	6.11 \pm 0.51	5.74 \pm 0.60	5.69 \pm 0.52	4.45 \pm 0.45	5.47 \pm 0.45	5.4 \pm 0.42	5.78 \pm 0.59	5.39 \pm 0.40	0.006
V ₅ Gy(%)	26.00 \pm 2.24	25.80 \pm 2.46	27.00 \pm 2.45	21.90 \pm 2.25	27.40 \pm 2.66	26.50 \pm 2.78	27.5 \pm 2.23	26.20 \pm 2.39	0.077
V ₁₀ Gy(%)	21.51 \pm 2.92	20.42 \pm 2.09	21.10 \pm 2.62	17.71 \pm 2.14	21.83 \pm 1.00	20.60 \pm 2.11	21.51 \pm 1.23	20.77 \pm 1.85	0.198
V ₂₀ Gy(%)	14.35 \pm 1.95	11.89 \pm 2.36	10.31 \pm 1.96	7.21 \pm 1.88	9.23 \pm 1.91	9.28 \pm 2.65	10.4 \pm 2.74	8.92 \pm 1.70	0.004
V ₃₀ Gy(%)	5.06 \pm 0.80	5.02 \pm 0.83	3.77 \pm 0.96	2.45 \pm 0.85	3.32 \pm 0.91	3.46 \pm 0.88	3.87 \pm 0.84	3.19 \pm 0.84	0.003
Spinal cord									
Max dose (Gy)	46.89 \pm 0.65	48.98 \pm 0.74	46.49 \pm 0.81	47.04 \pm 0.73	47.15 \pm 0.62	47.28 \pm 0.56	46.97 \pm 0.78	46.51 \pm 0.54	0.001
Heart									
Mean heart dose (Gy)	0.36 \pm 0.04	0.36 \pm 0.04	0.34 \pm 0.03	0.25 \pm 0.04	0.34 \pm 0.03	0.33 \pm 0.03	0.36 \pm 0.04	0.34 \pm 0.04	0.005

The PTV_{95%}

The PTV as defined by ICRU report 50 is used to select appropriate beam sizes and beam arrangements. Clinically, a plan is normally acceptable if the 95% isodose surface covers the 100% of PTV volume. In the present work, the plan was considered acceptable if PTV_{100%} covered with 95% of the prescribed dose. The targets dose coverage in all plans was more than 95% except in 3Bs and 5Bs plans. It was possible to reduce the number of intensity modulated beams (IMBs) required to produce this benefit from 13Bs to 7Bs beams without the loss of target coverage or dose homogeneity. It has been shown that the optimization by reducing the number of IMBs from 13Bs to 7Bs had no adverse effect on the PTV coverage (**Table 3**). Statistically, significant differences in mean PTV dose are noted between the different techniques. **Figure 5** shows the relationship between number of beams and PTV_{95%} coverage for different IMRT plans of mean PTV of cases of the upper esophageal cancer.

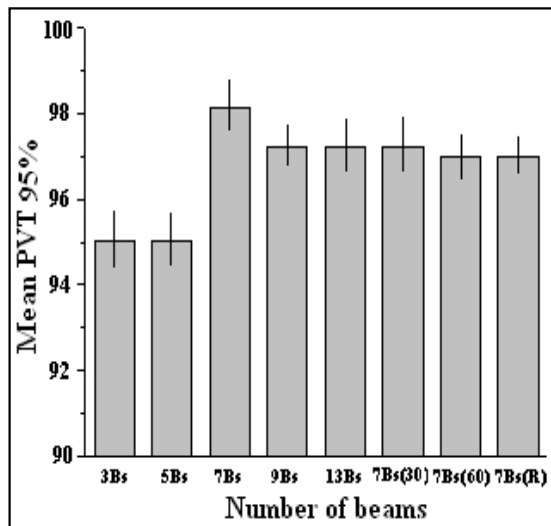


FIG. 5: The relationship between the number of beams and mean PTV_{95%}.

OARs "dose optimization"**Lung doses**

The effects of beam numbers and rings on dose optimization for lung were studied. The nine non-opposed equispaced coplanar intensity modulated beams presented the best treatment plan. Among four cases of the upper esophageal cancer, the mean V_{5Gy} (%) for the 9Bs was 21.93% with $p > 0.05$. The comparison for all plans with mean V_{5Gy} (%) and its significant values are presented in **Table 3**. **Figure 6** shows the relationship between the number of beams and V_{5Gy} (%) for the different IMRT plans. As expected, IMRT plan with more beams (13Bs) had a greater potential for dose sculpting than those with fewer beams (9Bs). However, because beams have to enter patient through more directions, the volume of normal tissue exposed to low doses is increased. This is

agreed with the previous study by Chandra *et al.*¹⁶ The volume of normal tissue exposed to low doses is also affected by leakage of the dynamic multi-leaf collimator.

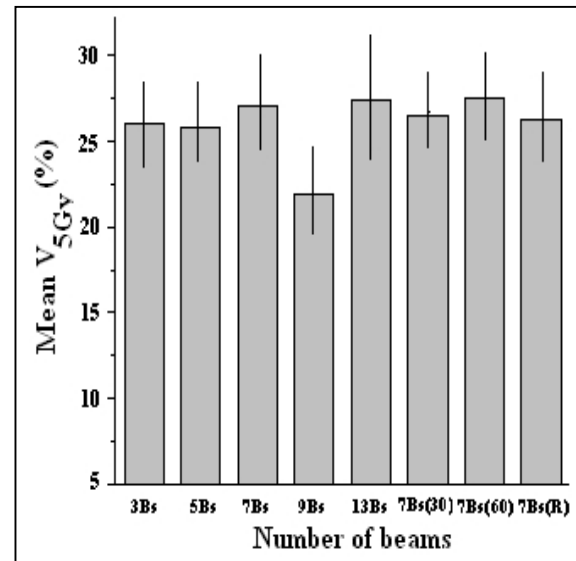


FIG. 6: The relationship between the number of beams and mean V_{5Gy} (%).

For V_{10Gy} (%), the results showed that nine beams (9Bs) plan was also sufficient to give the lowest doses for lung than other plans with $p > 0.05$. The comparison for all plans with mean V_{10Gy} (%) and its significant value are presented in **Table 3**. **Figure 7** shows the relationship between the number of beams and mean of V_{10Gy} (%) for different IMRT plans in the total lungs for the cases of the upper esophageal cancer.

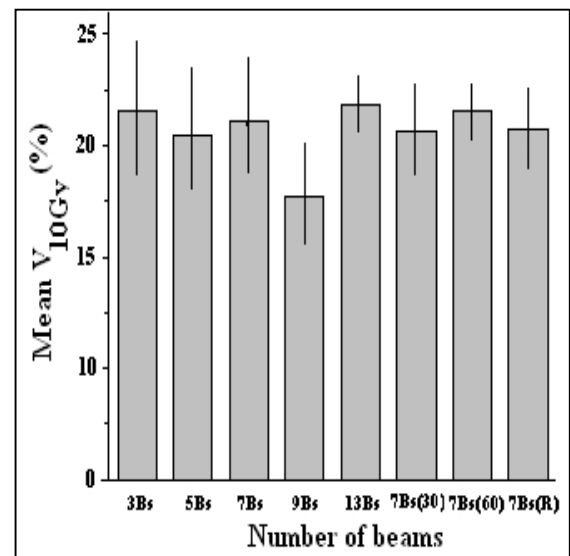


FIG. 7: The relationship between the number of beams and mean V_{10Gy} (%).

V_{20Gy} (%) was reduced in the 9Bs IMRT plan among the four cases. The mean V_{20Gy} (%) for the 9Bs and 13Bs IMRT plans was 7.21 and 9.23%, respectively, with $p < 0.05$, which represented statistical significance. The comparison among all plans for mean V_{20Gy} (%) and significant values are presented in **Table 3**. **Figure 8** shows the relationship between the number of beams and mean of V_{20Gy} (%) for different IMRT plans in the total lungs for the cases of the upper esophageal cancer.

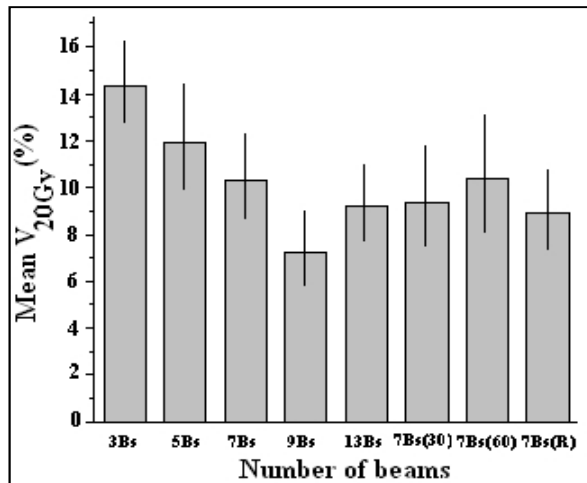


FIG. 8: The relationship between the number of beams and mean V_{20Gy} (%).

V_{30Gy} (%) was reduced in the 9Bs IMRT plan than 13Bs among four cases. The mean V_{30Gy} (%) for the 9Bs and 13Bs IMRT plans was 2.45 and 3.32%, respectively, with $p < 0.05$, which represented statistical significance. The comparison among all plans for mean V_{30Gy} (%) and significant values are presented in **Table 3**. **Figure 9** shows the relationship between the number of beams and mean of V_{30Gy} (%) for different IMRT plans in the total lungs for the cases of the upper esophageal cancer.

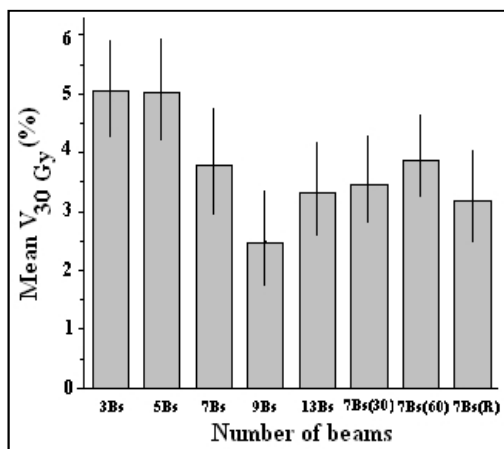


FIG. 9: The relationship between number of beams and mean V_{30Gy} (%).

Figure 10 shows the relationship between the number of beams and the MLD for different IMRT plans in the total lungs for four cases. The obtained results were in agreement with the previous work of Chandra *et al.*¹⁵ but not in agreement with that of the results obtained by Nutting *et al.*^{9,15} since they found that no benefit of 9Bs over the 3DCRT. Such discrepancy may come from variation in the inverse planning algorithms, treatment planning procedures, and patient selection.

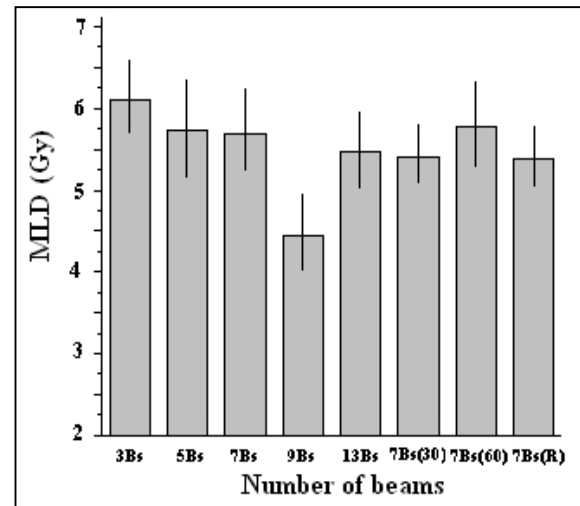


FIG. 10: The relationship between the number of beams and MLD.

The results showed that 9Bs IMRT plans significantly reduced V_{5Gy} (%), V_{10Gy} (%), V_{20Gy} (%), V_{30Gy} (%), and MLD for the lung (**Table 3**). The degree of reduction on irradiated lung volume varied from one patient to another patient. For lung dose optimization, the 9Bs plan provided the best dosimetric results.

Dose to spinal cord

The dosimetric effects of different IMRT plans on the spinal cord are explored. The results showed that all of the plans had a maximum spinal cord dose of about 47 ± 0.4 Gy except for 5Bs IMRT plan where the maximum dose to spinal cord was 49 Gy with $p < 0.05$, which was a statistically significant between the different IMRT plans on evaluation of the assigned endpoints for this structure. The comparison for all plans with maximum dose to spinal cord and its significant values are presented in **Table 3**. All doses were obtained at 0.2% of spinal cord volume. For cervical and upper esophageal, the beam number and orientation have big influence on maximum dose of spinal cord. Because of the small volume of spinal cord for each CT slice in comparison with the target volume, spinal cord dose optimization did not affect the PTV optimization, and this can be achieved if the distance between the spinal cord and the PTV is more than 0.5 cm as in the patient cases of this study. **Figure 11** shows the relationship between the number of beams and maximum dose to

spinal cord for different IMRT plans for the cases of the upper esophageal cancer.

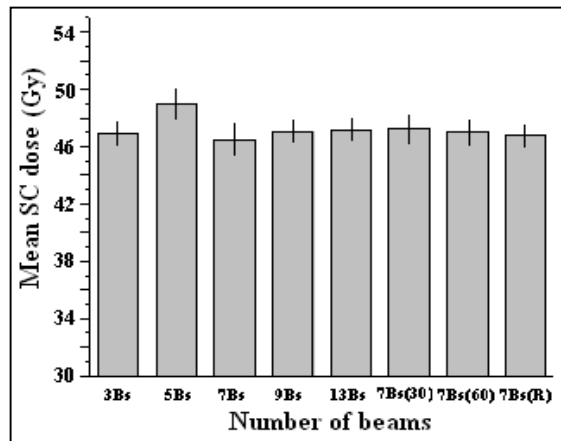


FIG. 11: The relationship between the number of beams and mean spinal cord dose.

Mean heart dose

The dosimetric effects of different IMRT plans on the mean heart dose were investigated. The results showed $p < 0.05$ which indicated a statistically significant between different IMRT plans on evaluation of the assigned endpoints for this structure. For all IMRT plans, the mean heart dose did not exceed 0.36 Gy because a small heart volume is involved in cervical esophagus region. The comparison for all plans with mean heart dose and significant values are presented in **Table 3**. **Figure 12** shows the relationship between number of beams and mean heart dose for different IMRT plans of the cases of the upper esophageal cancer.

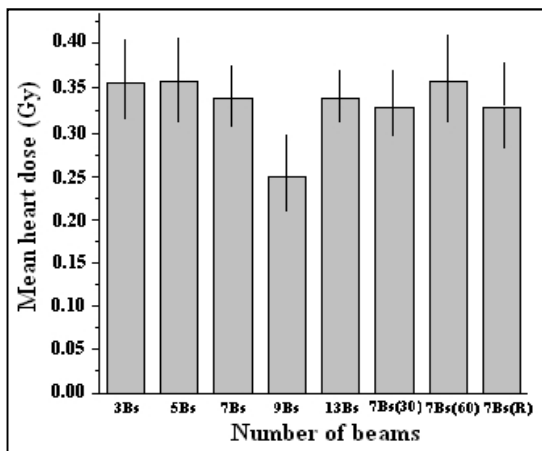


FIG. 12: The relationship between the number of beams and mean heart dose.

Number of MUs and segments

The main drawbacks of IMRT despite its efficiency in dose conformity to tumor are increased treatment delivery time and MUs. The increased treatment time will increase the patients' discomfort. Also, the increased MUs may lead to relatively larger low-dose volume of OARs and normal tissues, and this may lead to side effects such as radiation pneumonitis as well as inducing secondary cancer.

In the present work, the seven IMRT plans with ring [7Bs(R)] showed good homogeneity and conformity, and the treatment time was comparable among other plans. Decreasing the number of segments leads to reduction in the treatment time, which made the treatment course simpler and efficient. The reduced treatment time may come at the cost of delivering small doses of radiation to a larger volume of healthy tissue.

It can shorten overall treatment time, which was preferable for treating tumors with rapid repopulation. One must consider the radiobiological consequences of different fraction sizes for the gross disease, regions of microscopic spread, and electively treated lymph nodes. The number of segments decreased by using 7Bs(R) IMRT plans can decrease in the number of MUs, thus shorting the treatment time. **Table 4** shows the beam arrangement of IMRT plans for four cases with cervical and upper thoracic esophageal cancer, number of segments, number of MUs, total fraction and treatment time per fraction.

Dose calculation accuracy

The radiotherapy treatment for esophageal cancer is challenging by several ways: firstly, the large tumor volume and long tumor extension may lead to delivery of high doses to different OARs; and secondly, the tissue heterogeneity demands more accurate dose calculation algorithm to computer dose in treatment plans. The accurate dose estimations in the presence of large tumor tissue heterogeneity are typically performed by using superposition algorithm. The superposition algorithm takes into account lateral scattering and applies tissue heterogeneity corrections.^{17, 18, 19} Moreover, the choice of the treatment planning systems is very important in radiotherapy dose calculation, especially in the presence of treatment planning complexity such as irregular shaped tumors and tumor heterogeneities.^{20, 21}

TABLE 4: Different plans parameters for cervical and upper thoracic esophageal cancer cases.

Number of beams	Number of segments	Number of MUs per fraction	Total fraction	Total MUs	Treatment Time per fraction
3Bs	41	464.37	28	13002.26	4.50
5Bs	64	463.33	28	12973.36	6.50
7Bs	93	517.00	28	14475.95	8.72
9Bs	126	649.74	28	18192.62	11.16
13Bs	191	650.79	28	18222.15	15.16
7Bs(30)	103	616.79	28	17270.07	9.05
7Bs(60)	98	498.38	28	13954.53	8.66
7Bs(R)	87	463.86	28	12988.12	8.54

Conclusion

The preliminary findings from this study showed that if the planning objectives are not set aggressively or appropriately considering completing goals, the treatment planning system will not honor various dose-volume constraints by default. In general, for XiO TPS version 4.7, the dose prescription should be more restricted than the desired dose prescribed to the PTV and normal tissue, i.e., if the PTV desired dose is 50.4 Gy, the minimum dose should be at least 51 Gy in dose optimization window of TPS. For the OARs, if the desired maximum dose to the spinal cord is 45 Gy, the maximum dose prescription in optimization window should be less than or equal to 35 Gy. For dose conformity, the local optimization using rings are very important. Dose-volume of exposed normal lung can be reduced with 9Bs and 7Bs(R) IMRT plans, although the best conformity is achieved by 7Bs(R) IMRT plan.

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Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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