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Original Article

Step-and-Shoot versus Compensator-based IMRT: Calculation and Comparison of Integral Dose in Non-tumoral and Target Organs in Prostate Cancer

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Abstract

Introduction
Intensity-Modulated Radiotherapy (IMRT) is becoming an increasingly routine treatment method. IMRT can be delivered by use of conventional Multileaf Collimators (MLCs) and/or physical compensators. One of the most important factors in selecting an appropriate IMRT technique is integral dose. Integral dose is equal to the mean energy deposited in the total irradiated volume of the patient. The aim of the present study was to calculate and compare the integral dose in normal and target organs in two different procedures of IMRT: Step-and-Shoot (SAS) and compensator-based IMRT.

Materials and Methods
In this comparative study, five patients with prostate cancer were selected. Module Integrated Radiotherapy System was applied, using three energy ranges. In both treatment planning methods, the integral dose dramatically decreased by increasing energy.

Results
Comparison of two treatment methods showed that on average, the integral dose of body in SAS radiation therapy was about 1.62% lower than that reported in compensator-based IMRT. In planning target volume, rectum, bladder, and left and right femoral heads, the integral doses for SAS method were 1.01%, 1.02%, 1.11%, 1.47%, and 1.40% lower than compensator-based IMRT, respectively.

Conclusion
Considering the treatment conditions, the definition of dose volume constraints for healthy tissues, and the equal volume of organs in both treatment methods, SAS radiation therapy by providing a lower integral dose seems to be more advantageous and efficient for prostate cancer treatment, compared to compensator-based IMRT.

Keywords: Integral Dose; Step and Shoot Radiation Therapy; Compensator-based Intensity Modulated Radiation Therapy; Dose Volume Constraints; Dose Volume Histogram

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1. Introduction

Over the past decade, Intensity-Modulated Radiation Therapy (IMRT), which was first introduced in the 1990s, has become widely available across the world. IMRT has become an increasingly routine treatment for brain, head and neck, colorectal, and prostate cancers. In prostate and colorectal cancers, studies suggest that IMRT may offer patients reduced gastrointestinal toxicity, compared to conventional radiotherapy. Thus, IMRT is known as an advanced, almost unerring external beam radiation therapy, which can offer a solution to problems in radiotherapy[1]. The intensity of radiation beam is modulated by selective contouring of several beam pathways, delivered from different angles to maximize target radiation doses, while minimizing irradiation to healthy structures along any given beam pathway. Treatment planning in this method is sophisticated and relies on three-dimensional (3D) imaging techniques (CT or MRI) and computer dosi-metric algorithms to calculate the best series of beam direction for irradiating tumors with irregular structures and precise dose distribution[1].

This method delivers higher integrated radiation doses to tumors than can be safely achieved by conventional external beam radiotherapy. Commonly, CT scans between radiation sessions grant the recalibration of sculpted irradiation as the target volume decreases and tumor contour changes with treatment. Compared with other radiation techniques, IMRT allows more precise irradiation of concave tumors, including those enveloping non-tumoral tissues[1].

Based on the assumption that 3D imaging modalities have sufficiently high qualities, IMRT should accommodate the precise delivery of dose distribution along complex tumor contours and attenuate the need for therapeutic margins. Although IMRT requires longer treatment sessions and exposes more healthy tissues to low-dose radiation, compared to other modalities, it should facilitate the safe delivery of escalated irradiation to tumors, better local tumor control, and ultimately lead to longer patient survival with reduced damage to healthy organs.

In comparison with 3D conformal radiation therapy, IMRT has several advantages. IMRT conforms the prescribed dose to complex-shaped target volumes, while sparing the adjacent critical structures without compromising the target coverage [1]. Moreover, IMRT can enhance the fluence at target margins and compensate for the beam penumbra without extending the portal boundaries [1].

IMRT can be delivered by using conventional Multileaf Collimators (MLCs), binary MLCs, and/or physical compensators. Today, the most common techniques use MLCs for delivering IMRT treatments on linear accelerators [2]. One clear advantage of MLC-based IMRT technique is the automation of treatment delivery [3]. In the static approach, also known as Step-and-Shoot (SAS), MLCs remain static during irradiation and move to reshape the beam, while there is no exposure to radiation [4]. On the other hand, in SAS mode, the system alternates between delivering radiation with a static MLC pattern and moving to the next pattern without irradiating [5].

Also, compensators have been used in radiotherapy for decades to produce simple forms of intensity modulation [3]. Over the past decade, compensator techniques have been applied for delivering IMRT treatments, designed by dose optimization algorithms [6, 7]. Conventional compensators are modeled to attenuate the open-field photon fluence so that the transmitted fluence map is as designed by the dose optimization algorithm [8].

The static nature of compensator-based intensity-modulated therapy simplifies the treatment delivery, dose computation, and the quality assurance procedure [3]. Another advantage of compensator-based IMRT is that it can lead to continuously varying intensity modulation, whereas intensity modulation by

MLC-based technique is discrete, at least in one direction [3].

Integral dose (ID) is the volume integral of the dose deposited in a patient and is equal to the mean dose times the volume irradiated to any dose [9]. This parameter does not have any direct effects on treatment planning like other factors (i.e., the prescribed dose), although it plays an overriding role in selecting the approved plan among others. The purpose of this study was to compare the ID and also dose distribution for two different IMRT techniques (SAS and compensator-based IMRT), based on dose volume histogram (DVH) analysis of target and critical organs.

2. Materials and Methods

2.1. Target definition

At the beginning of the study, CT scan images (DICOM format) were obtained from five prostate cancer patients in supine position. Then, DICOM images were transferred to the Module Integrated Radiotherapy System (M.I.R.S version 5.0.00), which uses scatter integration algorithm to calculate the dose distribution.

Clinical Target Volume (CTV) was defined as the prostate gland and seminal vesicles. For both treatment planning techniques, i.e., SAS and compensator-based IMRT, Planning Target Volume (PTV) was delineated by adding 10 mm of 3D margin around CTV and 8mm in the posterior region towards the rectum. The rectum, bladder, and right and left femoral heads were considered as the Organs at Risk (OAR). Target and OAR delineation for both techniques were similar; therefore, all volumes were equal for two treatment planning methods.

2.2. Planning details and dose prescriptions

Clinical linear accelerator (Elekta, Precise Model, United Kingdom), which produces photons with three ranges of energy (6, 10, and 18 MV) and integrates 80 pairs of MLCs, was used for SAS and compensator-based IMRT. Moreover, a lead compensator was used for the modulation procedure. Therapeutic fields for the two studied techniques were the same in terms of direction, angle, and number. Also, for all therapeutic fields, the collimator angles were defined as zero. Table 1 shows the directions of the fields**.**

The prescribed dose for both IMRT planning techniques was considered to be 80 Gy. Dose per fraction was also considered to be 2 Gy for each session. The imposed Dose Volume Constraints (DVCs) for both IMRT techniques are shown in Table 2.

Five radiation fields were used to achieve the minimum criteria of 98% of PTV with 95% of the prescribed dose. DVH of PTV and normal tissues were utilized to evaluate the quality of the plan. Both plans were normalized to the isocenter point, which was placed in the center of PTV and received 95% of the prescribed dose.

2.3. ID calculation

ID is the total energy absorbed by the body and is computed based on the average organ density, average organ dose, and organ volume, as defined in equation 1:

$ID = D.\rho.V$ *(Gy.Kg)* [10] *(1)*

where D is the average organ dose, ρ denotes the average organ density, and V stands for the organ volume [11]. In this study, ID was calculated by equation 2:

*ID= Average Dose * Volume (Gy.CC)* [1] *(2)*

Table 1: Characterization of radiation fields

Field name	Field 1	Field 2	Field 3	Filed 4	Field 5
Degree	0	90	150	210	270

Table 2: DVCs for PTV and OAR

Structures	DVC (cGy)
PTV	Max dose =8160
	Min dose =7840
Rectum	D60≤4560
	D30≤7360
	D5≤7744
Bladder	D50≤5680
	D20≤6800
	D5≤8000
Right femoral head	D50≤5680
Left femoral head	D50≤5680

2.4. SAS technique

In this procedure, after the irradiation of each segment, the collimators move to the correct positions for the next segment and will continue until the total modulation is achieved [11]. This method is known colloquially as ‘‘step-and-shoot’’, otherwise known as multiple static field (MSF) or segmented MLC (SMLC) [11].

Advantages of this method include the feasibility of portal verification of intensity pattern, easy clinical interpretation, simple resuming of the interrupted treatment, a relatively simple accelerator control system, and possibility of forward and inverse planning. The disadvantage of this method is that the total number of required monitor units is often much higher than that of corresponding non-intensity modulated treatments [3]. As a result, treatment delivery time is often considerably extended. In fact, there are concerns regarding the radiation contamination of prolonged beam [12]. The current study was performed, using 11 segments for each field.

2.5. Compensator-based IMRT

Compensator is a beam modifying device. Compensation allows for variations in depth due to the surface shape and in some cases, variations in effective depth between the surface and target planes due to the presence of inhomogeneties. Commonly, the materials, which are used as compensators, are light metals such as aluminum.

In compensator-based IMRT, the radiation therapist needs to enter the treatment room and exchange the customized compensators between treatment fields. Also, preparation of compensators is labor-intensive; these are in fact the limitations of compensator-based IMRT. In this study, lead was applied as the compensator for the modulation of photon beams. Figure 1 shows a sample of compensator shape, achieved by the treatment planning system.

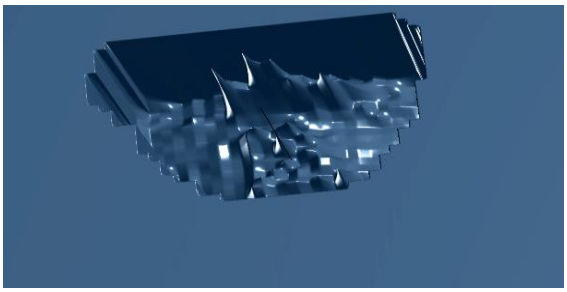


Figure 1. The shape of compensator for field A

3. Results

The volume, average dose, and ID of body, PTV, bladder, rectum, and right and left femoral heads are summarized in Tables 3, 4, 5, and 6.

Body was considered as the whole volume of CT scan images for each case. According to Table 4**,** ID of body for compensator-based IMRT was about 1.62% higher than SAS technique, on average. Considering the equal volume of body in two methods (Table 3) and also regarding to the ID equation, it is clear that the average dose plays an important role in the amount of ID. Figures 2 and 3 show the trend line of ID and average dose in the body with regard to energy.

Table 3. The volume of PTV and OARs in both techniques

	The Volume of OARs					The volume of PTV in SAS and compensator –based IMRT
	Body (CC)	Rectum (CC)	Bladder (CC)	Right femoral head (CC)	Left femoral head (CC)	PTV (CC)
Patient 1	19.533	0.089	0.169	0.169	0.17	0.462
Patient 2	15.75	0.074	0.083	0.191	0.189	0.455
Patient 3	15.66	0.188	0.165	0.172	0.17	0.57
Patient 4	14.857	0.128	0.111	0.175	0.164	0.4
Patient 5	16.398	0.172	0.105	0.146	0.144	0.353

Table 4. The average dose and ID for body and PTV in five patients

	Compensator				SAS			
	Body		PTV		Body		PTV	
Energy	D avr (Gy)	ID (CC.Gy)	D avr (Gy)	ID (CC.Gy)	D avr (Gy)	ID (CC.Gy)	D avr (Gy)	ID (CC.Gy)
6MV	15.72	306.99	81.57	35.01	8.74	170.80	79.63	34.18
10MV	14.05	274.48	81.22	34.86	8.58	167.67	79.82	34.26
18MV	13.51	263.91	81.18	34.85	8.43	164.65	79.79	34.25

Table 5: The average of dose and ID of OARs for compensator-based IMRT

	Bladder		Rectum		Right femoral head		Left femoral head	
Energy	D_{avr} (Gy)	ID (CC.Gy)	D_{avr} (Gy)	ID (CC.Gy)	D_{avr} (Gy)	ID (CC.Gy)	D_{avr} (Gy)	ID (CC.Gy)
6MV	52.01	8.79	59.28	5.28	37.70	6.41	33.41	5.80
10MV	50.44	8.52	59.04	5.25	36.87	6.27	32.61	5.66
18MV	49.88	8.42	59.04	5.25	36.88	6.27	32.57	5.65

Table 6: The average of dose and ID of OARs for SAS

	Bladder		Rectum		Right femoral head		Left femoral head	
Energy	D_{avr} (Gy)	ID (CC.Gy)	D_{avr} (Gy)	ID (CC.Gy)	D_{avr} (Gy)	ID (CC.Gy)	D_{avr} (Gy)	ID (CC.Gy)
6MV	45.79	7.73	57.87	5.15	25.76	4.38	21.73	3.77
10MV	45.51	7.69	57.85	5.15	26.50	4.51	22.12	3.84
18MV	44.84	7.57	57.62	5.13	27.14	4.62	23.11	4.01

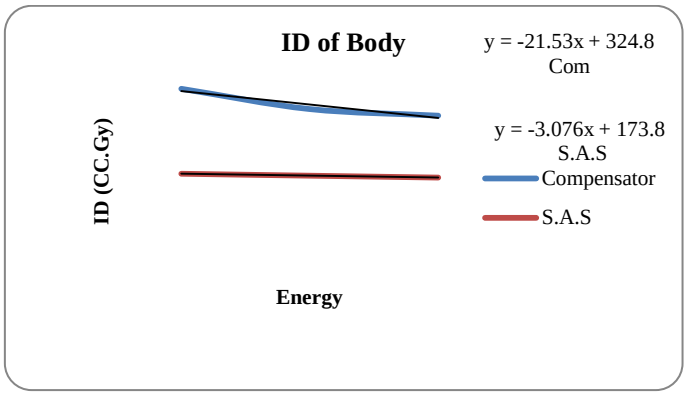


Figure 2. The ID of body

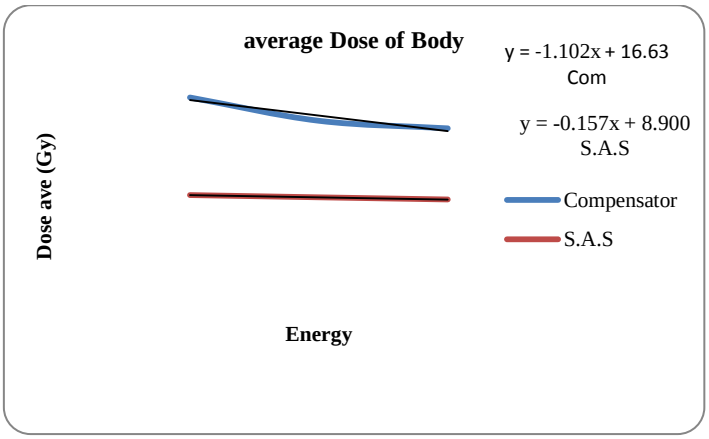


Figure 3. The average dose of the body

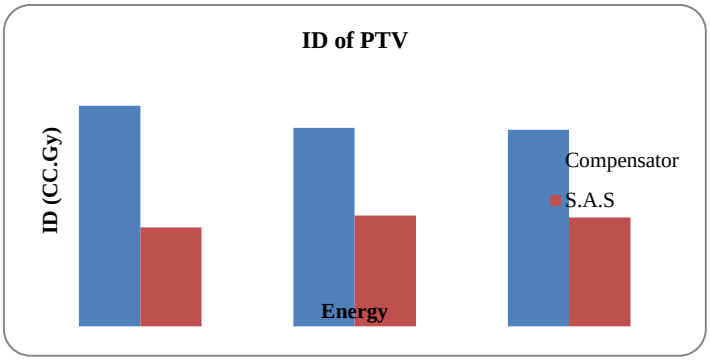
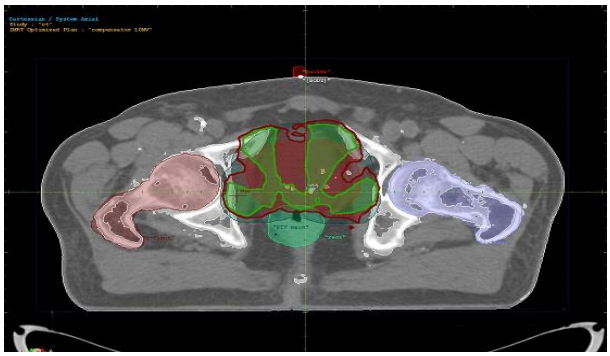


Figure 4. ID of PTV for both IMRT techniques

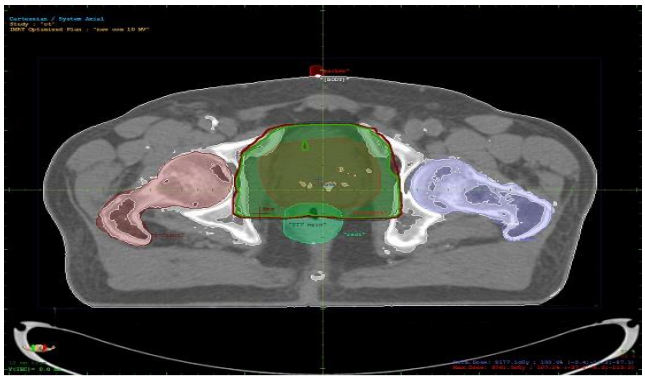
Based on the results in Table 4, For PTV, the mean value of ID for compensator-based IMRT was about 1.01% higher than SAS technique, on average. Therefore, in this region, the ID was approximatley the same for the studied techniques, as shown in Figure 4.

Tables 5 and 6 indicate the average dose and ID of OARs.

For the rectum, the mean value of ID for SAS technique was about 1.02% lower than the modulated method. In bladder, the mean value of ID for compensator-based technique was about 1.11% greater than SAS. On average, in right and left femoral heads, the IDs for compensator-based IMRT were about 1.40% and 1.47% greater than SAS technique, respectively. Dose distributions in axial sections are shown in Figures 5a and 5b for 10 MV photon beams. These axial sections show 98% and 95% of the prescribed isodoses in both techniques.



(a)



(b)

Figure 5. The axial section of dose distribution for compensator-based IMRT (a) and SAS IMRT (b)

4. Discussion

According to the obtained data, both IMRT techniques led to the same outcomes in PTV dose distribution (Tables 4, 5 and 6). Both plans were assessed using 95% of the prescribed dose and 98% of the target volume (Figures 5a and 5b).

The irradiated time in SAS IMRT technique, which is greater than compensator-based IMRT (due to the number of subfields for each field), leads to a longer treatment duration. On the other hand, relying on equal conditions for each treatment plan, such as the same prescribed dose and similar volumes for PTVs and OARs in both IMRT techniques, the logical expectation is to obtain higher values for the cumulative dose for SAS IMRT in comparison with the modulated IMRT.

However, ID or total cumulative dose to normal tissues is higher in compensator-based IMRT, compared to SAS method due to the higher production of scatter and backscatter particles, which are generated by the interaction between photons and lead compensator. Compared to compensator-based IMRT of prostate, SAS provided better ID values. This leads to the sparing of healthy organs and delayed consequent effects.

In general, IMRT for prostate is improved for high efficiency to conform the dose to the concave target volume, while sparing the organs at risk. The integral dose of compensator-based IMRT is approximately equal to SAS method for normal tissues (Tables 5 and 6). The equality of ID in OARs emanates from the equality in the average dose during optimization. Totally, high ID leads to secondary malignancies and can be among the major concerns of patients with a low risk for systemic relapse, who are likely to live for many years after the diagnosis of prostate cancer.

5. Conclusion

There was little difference between SAS and compensator-based IMRT for three ranges of energy (6, 10, and 18 MV photon beams) in the ID to the rectum, bladder, right femoral head, and left femoral head. The insignificant difference in ID in these organs originated from the identical average dose in both treatment planning methods. The differences in the average dose arose from scatter and backscatter particles and electron contamination. In the modulation procedure, considering the continuous form of the compensator, the scatter moved up and these which caused an increase in backscatter particles, the average dose, and subsequently the ID.

Both treatments had good results in prostate cancer treatment. However, according to our results, SAS IMRT led to better treatment outcomes regarding the ID.

References

1. 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 Apr-Jun;34(2):66-72.
2. Intensity Modulated Radiation Therapy Collaborative Working Group. *Intensity-modulated radiotherapy: current status and issues of interest*. Int J Radiat Oncol Biol Phys. 2001Nov;51(4):880–914.
3. Chang SX, Cullip T J, Deschesne K M, Miller E P, Rosenman J G. *Compensators: An alternative IMRT delivery technique*. Journal of Applied Clinical Medical Physics. 2004 summer;5(3):15-36.
4. Luan S, Wang C, Chen D Z, S. Hu X. *A new MLC segmentation algorithm/software for step-and-shoot IMRT delivery*. Medical Physics. 2004 April;31(4), 695-707.
5. Ezzell GA, Chungbin S. *The overshoot phenomenon in step-and-shoot IMRT delivery*. Med. Phys. 2001 summer;2(3):138-48.
6. Meyer J, Mills JA, Haas OC, Parvin EM, Burnham KJ. *Some limitations in the practical delivery of intensity modulated radiation therapy.* Br J Radiol. 2000 Aug;73(872):854-63.
7. Chang SX, Cullip TJ, Deschesne KM. *Intensity modulation delivery techniques: "Step & shoot"* MLC auto-sequence versus the use of a modulator. Med Phys 2000 May;27(5):948-59.
8. Laub WU, Bakai A, Nüsslin F. *Intensity modulated irradiation of a thorax phantom: Comparisons betweenmeasurements, Monte Carlo calculations, and pencil beam calculations*. Phys Med Biol. 2001 Jun;46(6):1695-706.
9. Aoyama H, Westerly DC, Mackie TR, Olivera GH, Bentzen SM, Patel RR et al. *Integral Radiation Dose To Normal Structures With Conformal External Beam Radiation*. Int J Radiat Oncol Biol Phys. 2006 Mar 1;64(3):962-7.
10. Shi C, Peñagarícano J, Papanikolaou N. *Comparison of IMRT treatments plan between linac and helical tomotherapy based on integral dose and inhomogeneity index*. Med Dosim. 2008 Autumn;33(3):215-21.
11. Williams PC. *IMRT: delivery techniques and quality assurance*. Br J Radiol. 2003 Nov;76(911):766-76.
12. Rawlinson JA, Islam MK, Galbraith DM. Dose to radiation therapists from activation at high-energy accelerators used for conventional and intensity-modulated radiation therapy. Med Phys. 2002 Apr;29(4):598-608.