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Original research article

Treatment planning evaluation of sliding window and multiple static segments technique in intensity modulated radiotherapy

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ABSTRACT

Background: The demand of improved dose conformity of the tumor has been increased in radiation therapy with the advent of recent imaging facilities and efficient computer technologies.

Aim: We compared the intensity modulated radiotherapy (IMRT) plans delivered with the sliding window (SW IMRT) and step and shoot (SS IMRT) techniques.

Materials and methods: Thirteen patients were planned on 15 MV X-ray for five, seven, nine and thirteen beams direction making the dose constraints analogous. Eclipse treatment planning system with Helios inverse planning software, and Linear Accelerator Varian 2100 C/D with 120 multileaf collimators (MLCs) were used. Gamma analysis was applied to the data acquired with the MapCheck 2^{TM} for different beam directions plan in the sliding window and step and shoot technique to meet the 95% pass criteria at 3%/3 mm. The plans were scrutinized using D_{mean}, D_{max}, D1%, D95%, dose uniformity index (UI), dose conformity index (CI), dose homogeneity index (HI) and monitor units (MUs).

Results: Our data show comparable coverage of the planning target volume (PTV) for both the sliding window and step and shoot techniques. The volume of PTV receiving the prescription dose was 99.8 ± 0.05% and the volume of PTV receiving the maximum dose was 107.6 ± 2.5% in both techniques. Bladder and rectum maximum mean doses for the sliding window and step and shoot plans were 38.1 ± 2.6% and 42.9 ± 10.7%. Homogeneity index (HI) for both techniques was 0.12 ± 0.02 and 0.13 ± 0.02, uniformity index (UI) was 1.07 ± 0.02 and 108 ± 0.01 and conformity index at 98% isodose (CI 98%) was 0.96 ± 0.005 and 0.96 ± 0.005 for the sliding window and step and shoot techniques, respectively, and MUs were 10 ± 12% lower in the step and shoot compared to the sliding window technique.

Conclusion: All these factors indicate that coverage for PTV was nearly identical but dose to organs-at-risk (OARs) was lower in the step and shoot technique.

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1. Background

The advent of inverse planning systems and methods for delivering nonuniform radiation intensities have ushered in the epoch of the intensity-modulated radiation therapy (IMRT), representing the state of the art in the treatment of many cancers.[1] IMRT modulates the beam to create a conformal dose distribution around the target, while minimizing dose to the surrounding normal tissues, and enables tumor dose escalation. IMRT plans also improve the conformity and homogeneity indices.[2] Both the static, also known as (step and shoot), and dynamic (sliding window) methods of IMRT dose delivery have been developed.

IMRT can be delivered using a conventional MLC, binary MLC or a physical compensator. Among the three, a conventional MLC is the most commonly used. IMRT delivery using a conventional MLC involves either a segmental MLC (SMLC)-based or dynamic MLC (DMLC)-based approach. Although the former involves the delivery of radiation when MLC leaves are stationary, in the latter case MLC leaves move as the radiation is delivered. The main advantage of using a DMLC is that the continuous leaf motion enables the delivered intensity to closely match with the optimal fluence calculated by the inverse treatment planning (ITP) algorithm, accurately preserving both the spatial and intensity resolutions. On the other hand, an SMLC approach resembles a conventional multi-segmented treatment and requires approximating the intensity profile into discrete intensity levels, resulting in a lower resolution.[3]

Numerous comparisons between the different delivery methods have been undertaken utilizing dose volume histogram (DVH) parameters to determine the superiority of any particular technique.[4,5] The SS IMRT may be convenient to verify and is technically less demanding than an SW treatment. A SW IMRT-based delivery requires more monitor units (MU) than the SS method, as the beam is kept on throughout the delivery of radiation.[6] The leakage radiation from collimator leaves and scattered radiation are also different for the two delivery techniques. A difference in integral dose delivered to the surrounding tissues or the volume receiving low dose is thus expected between the two methods due to the difference in the required MU to deliver the same prescription dose.

Slosarek et al. have shown that SW IMRT is independent of the beam rate but these differences are minor.[7] Kry et al. have shown that depending on the treatment energy, IMRT using step and shoot requires 3.5–4.9% times more monitor units than the conventional treatment.[8] These figures are likely to increase with the use of dynamic IMRT. Chui et al. have shown that a SW IMRT requires 20% more MUs as compared to static IMRT.[9] Alaei et al. have shown that SS required on average 15% fewer MUs than a SW with 15% longer treatment time than an SS IMRT treatment.[10] This can lead to an increase in the low-dose volume as well as the risk of radiation-induced malignancies. The issue of integral dose or the total cumulative dose received by tissues is clinically relevant because of the anticipated higher risk of second malignancies associated with a higher integral dose.[11,12]

The main objective of this study is to evaluate the effect of the two IMRT delivery techniques, SW and SS IMRT, using the Eclipse treatment planning system for PTV and healthy normal tissue surrounding the tumor-bearing area.

2. Materials and methods

The Eclipse radiation treatment planning system (RTPS) (Eclipse, Varian 6.5, build 7.1.59, Varian Associates, Palo Alto, CA) with the pencil beam convolution algorithm and Helios inverse planning software was used for optimization and isodose distribution for all IMRT treatment plans in this study. A Varian 2100 C/D (Varian Medical System, Palo Alto, CA) with 120 leaf millennium MLC was used to deliver the treatments. Absolute dose measurements were performed with a cylindrical ionization chamber N30001 (PTW Freiburg, Germany). In our clinic, the calibrated output is adjusted to be 1 cGy = MU to water with a field size of 10 cm × 10 cm and source to surface distance (SSD) of 100 cm with the detector at the depth of the maximum dose according to TG-51 protocol.[13] Thirteen patients were planned on 15 MV X-ray for five, seven, nine and thirteen beams direction making the dose constraints similar.

The MapCHECK 2™ (Model 1177, Sun Nuclear, Melbourne, FL) was used for verification of both the static and dynamic IMRT technique due to their ease of use and immediate readout of results. Gamma analysis was employed to test the acceptability of the delivered plan with a 95% pass criteria at ±3%/±3 mm criterion (Fig. 1).[14]

Prostate patients were chosen which were treated to 50 Gy in 25 fractions of 2 Gy in 7 weeks in conventional 3 DCRT. The boost was given by IMRT in 2 Gy of 8 fractions. CT images of 5 mm thickness at different transverse sections away from the mid plane were taken to create a 3D image.

Partial rectum and partial bladder were created by subtracting the bladder and rectum from PTV using a Boolean operator. All plans with SW and SS techniques of IMRT were generated on the same CT data set with identical structures. The five field IMRT plan was generated for each patient for SW and SS techniques with gantry angles of 135°, 75°, 0°, 285°, and 225°. The seven field IMRT plan for SW and SS techniques had gantry angles of 180°, 105°, 60°, 30°, 330°, 300°, and 255°. The nine field IMRT plan for SW and SS techniques had gantry angles starting with 0° and ended at 320° every 40°. The thirteen field IMRT plan for SW and SS techniques had gantry angles of 160°, 130°, 110°, 80°, 60°, 40°, 0°, 320°, 300°, 280°, 250°, 230°, and 200°.[15] Constraints were applied to obtain possible minimum doses to critical organs without compromising the PTV coverage of at least 95% dose to 95% of PTV volume.

This work was also projected to furnished Monitor units, DVH comparisons among several fields and exercised DVH to calculate D_{mean}, D_{max}, $D_{1\%}$, $D_{95\%}$, dose uniformity index (UI), dose conformity index (CI) and dose homogeneity index (HI) for dose coverage of planning target volume (PTV) and D_{mean}, D_{max}, $D_{15\%}$, $D_{25\%}$, $D_{35\%}$, $D_{50\%}$ volume of the organ at risk were analyzed for the critical organ sparing.

To assess the target coverage and normal tissue sparing the following factors were used.

1. The uniformity index was defined as:

$$UI = \frac{D_5}{D_{95}}$$

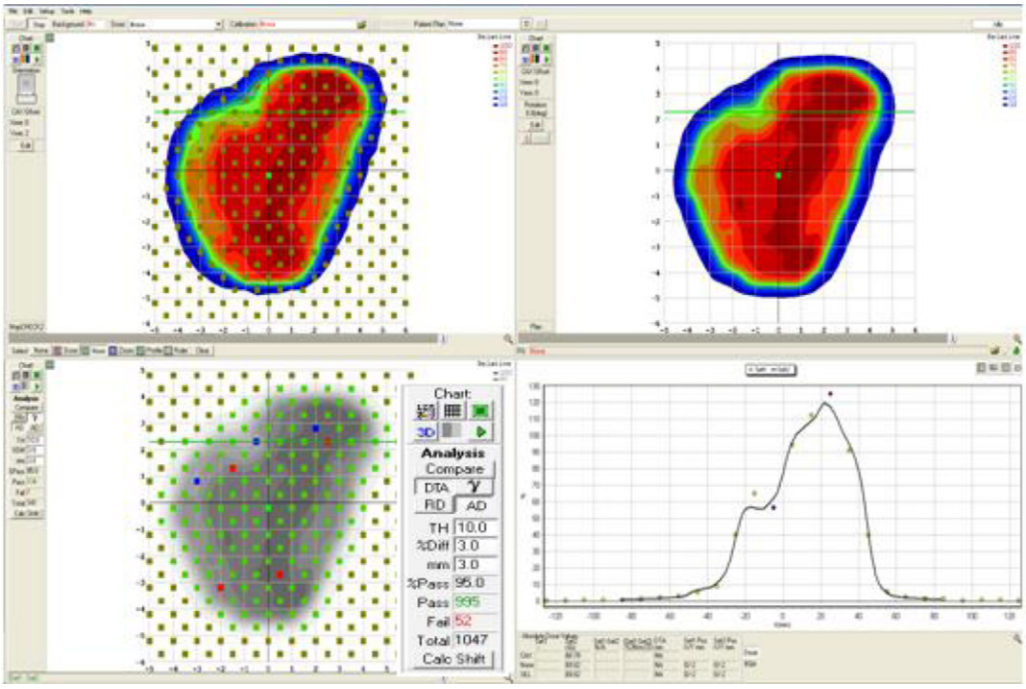

Fig. 1 – MapCHECK 2™ gamma analysis used for both prostate IMRT techniques.

where D_5 and D_{95} are the minimum doses delivered to 5% and 95%, respectively, of the PTV.[16]

2. The homogeneity index was defined as:

$$\mathrm{HI} = \frac{D_{1\%} - D_{99\%}}{\text{prescription} \cdot \text{dose}}$$

where $D_{1\%}$ and $D_{99\%}$ are the doses delivered to 1% and 99% volume, respectively, of the PTV.[17,18]

3. The conformity index was calculated by the formula:

$$\mathrm{CI} = \frac{\text{ref. isodose} \cdot \text{volume}}{\text{target} \cdot \text{volume}}$$

The 95% isodose volume was taken as reference volume of the PTV.[19,20]

In addition, the mean and maximum doses to PTV, percentage of target volume receiving at least 95% of the prescribed dose $D_{95\%}$ and the dose to 1% of target volume $D_{1\%}$ were calculated to asses a target coverage.

4. Sparing of organ at risk was evaluated by comparing maximum and mean doses between the two delivery methods. Doses at 15%, 25%, 35% and 50% volume were calculated for organs at risk (OARs) receiving a dose higher than the tolerance limit and compared. The values of the above parameters (UI, HI, CI) for thirteen cases planned by the SW and SS techniques of IMRT for different field orientations were compared. Statistical analysis was performed on DVH with a two tailed paired *t*-test. A *p*-value of <0.05 was considered statistically significant.

3. Results

The PTV DVHs for the SW IMRT and SS IMRT for 5-field, 7-field, 9-field and 13-field are shown in Fig. 2. The dosimetric

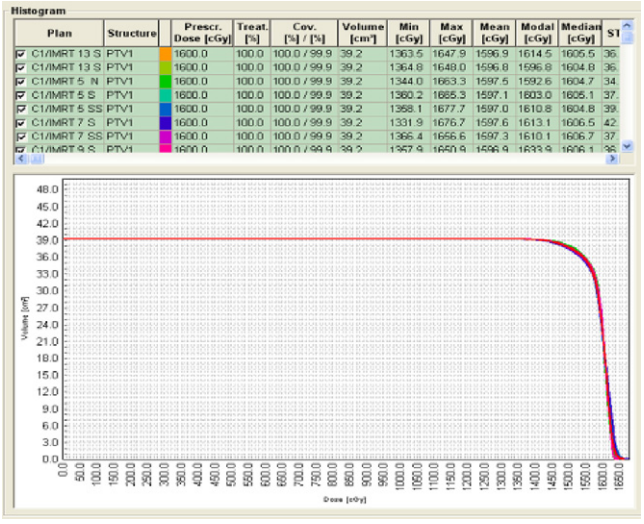

Fig. 2 – Comparison of DVH curves of PTV for all fields using SS IMRT and SW IMRT.

results of the PTV were almost similar for the SS and SW IMRT techniques.

The mean doses to PTV and comparison of the dose coverage with the SW and SS treatment plans is given in Table 1. These results illustrate that mean doses to PTV are identical for both techniques. Fig. 2 also demonstrates that the coverage of the PTV is similar but the result in Table 1 indicates that the uniformity index and homogeneity index and $D_{95\%}$ are different ($p < 0.05$). All other parameters are not significantly different ($p > 0.05$) (Table 2).

DVH of partial bladder and partial rectum of the representative patient using both delivery methods for 5-field, 7-field,

Table 1 – Comparison of dosimetric parameters for irradiation of PTV using both techniques.

PTV	5F SW	5F SS	7F SW	7F SS	9F SW	9F SS	13F SW	13F SS	t-Value	Prob.
D_{mean}	99.78 ± 0.05	99.78 ± 0.05	99.78 ± 0.05	99.78 ± 0.05	99.78 ± 0.05	99.78 ± 0.05	99.78 ± 0.05	99.78 ± 0.05	0.00NS	1.00
D_{max}	107.08 ± 2.5	107.55 ± 2.3	106.05 ± 3.6	106.62 ± 3.5	105.20 ± 1.6	106.00 ± 1.4	106.15 ± 2.4	105.57 ± 2	0.98NS	0.329
$D_{1\%}$	104.27 ± 1.8	104.8 ± 1.3	103.37 ± 1.6	103.96 ± 1.4	103.44 ± 1.2	103.93 ± 0.9	103.20 ± 1.5	103.06 ± 1.2	−1.24NS	0.216
$D_{95\%}$	95.40 ± 0.9	95.11 ± 1	95.88 ± 0.9	95.33 ± 0.8	95.95 ± 0.9	95.43 ± 0.8	95.93 ± 1.2	95.74 ± 0.7	2.15	0.034
UI	107 ± 0.02	108 ± 0.01	1.05 ± 0.01	1.07 ± 0.01	1.05 ± 0.01	1.06 ± 0.01	1.06 ± 0.01	1.06 ± 0.01	−2.01	0.047
HI	0.12 ± 0.03	0.13 ± 0.02	0.13 ± 0.02	012 ± 0.01	0.10 ± 0.01	0.12 ± 0.01	0.11 ± 0.01	0.12 ± 0.01	−2.05	0.043
CI	0.95 ± 0.01	0.95 ± 0.009	0.96 ± 0.01	0.95 ± 0.009	0.96 ± 0.009	0.95 ± 0.009	0.96 ± 0.01	0.96 ± 0.005	1.72NS	0.089

D_{mean}, mean dose, D_{max}, maximum dose, $D_{1\%}$, dose to 1% of target volume; $D_{95\%}$, dose to 95% of target volume; UI, uniformity index; CI, conformity index; HI, homogeneity index; NS, non significant.

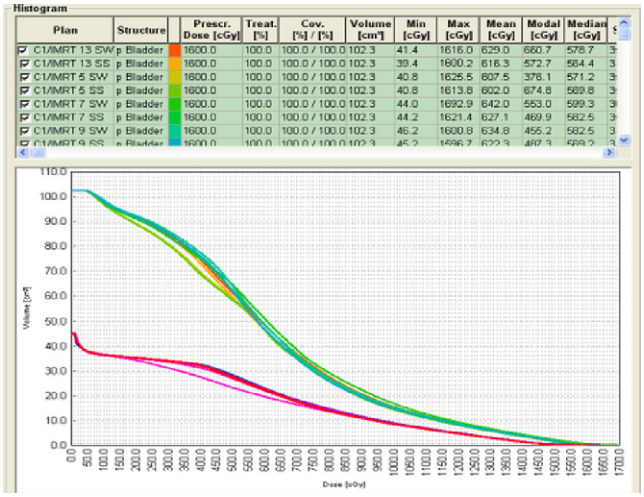

Fig. 3 – Comparison of OAR DVH for all fields using SS IMRT and SW IMRT.

9-field and 13-field are shown in Fig. 3. The data of thirteen patients indicates that the mean and maximum doses of the partial bladder and partial rectum are lower in the SS technique as compared to SW and it was measured that 2–5% maximum doses of the organ at risk is reduced in the step and shoot technique.

The doses to OAR for 5-field, 7-field, 9-field and 13-field plans are shown in Fig. 4 which demonstrates that mean dose, maximum dose, $D_{15\%}$, $D_{25\%}$, $D_{35\%}$, and $D_{50\%}$ for different number of fields with appropriate angle selection verify that SS IMRT delivers better results for sparing OARs than SW IMRT.

The average MU per day for each plan over the 13 patients is shown in Fig. 5. For all patient plans in this study, the SS IMRT methods had fewer MUs than the SW IMRT method.

4. Discussion

These data indicate that SW IMRT and SS IMRT plans demonstrate comparable PTV coverage. Conformity Index has been used to appraise the clinical verification of better treatment but it has no significant results in all beam directions. Better conformity may help to deliver higher doses to PTV without delivering additional doses to adjacent normal tissue. The value of 1 for CI is considered for an ideal plan.[20] The greater uniformity index indicates higher heterogeneity and smaller homogeneity index means more homogeneous dose distribution to the PTV.[15,18] The average homogeneity and uniformity indices for the SW IMRT yield better values as compared to the SS IMRT. *t*-Value of different parameters describes the significance or non-significance of a treatment plan using both techniques. It was scrutinized that PTV results were significant for HI, UI and $D_{95\%}$ and non significant for CI, D_{maen} and D_{max}.

With respect to OAR, the SS IMRT is able to sustain lower mean doses and maximum doses in contrast with the SW IMRT. This dose reduction in critical organs without compromising the dose in target volume could lead to additional clinical advantages.

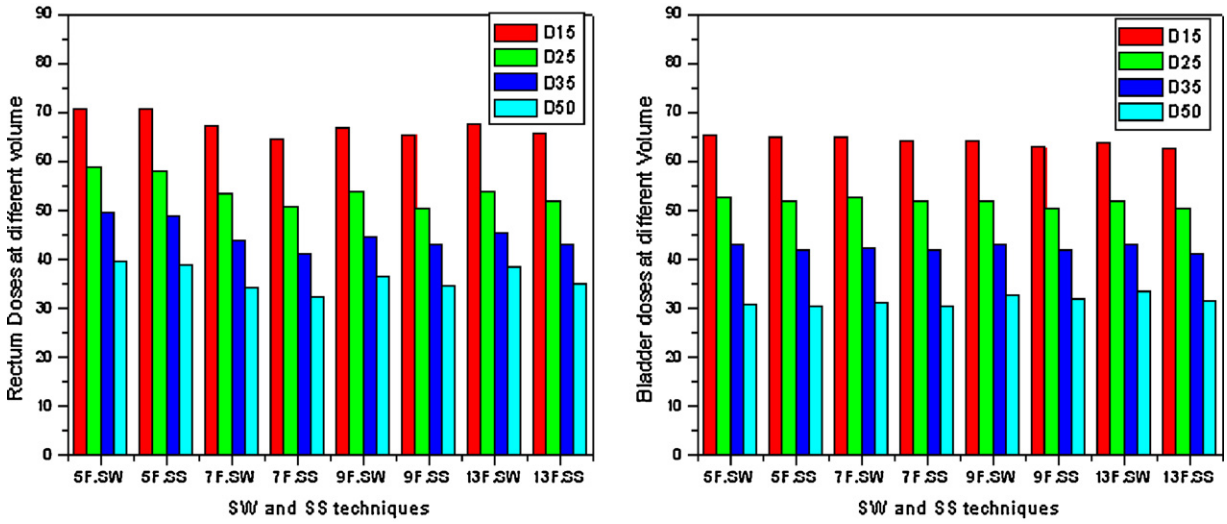

Fig. 4 – Comparison of both techniques for different volume of partial bladder and partial rectum.

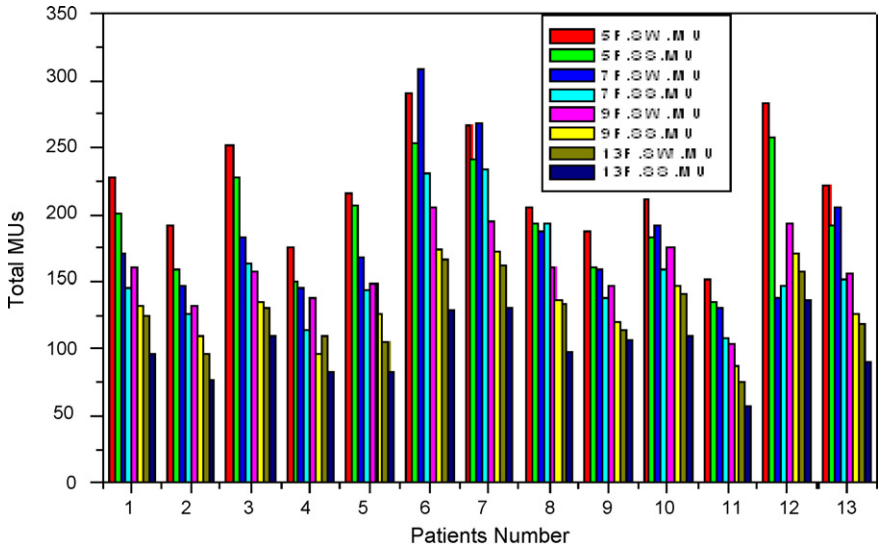

Fig. 5 – Average MU assessment of individual patient for different field with SW IMRT and SS IMRT.

Table 2 – Comparison of mean dose distribution in the organ at risk (OARs) for both techniques.

OAR	Mean dose ± SD (%)							
	SF SW	5F SS	7F SW	7F SS	9F SW	9F SS	13 FSW	13F SS
Partial rectum								
D_{mean}	42.92 ± 10.7	42.44 ± 9.1	37.61 ± 8.1	36.91 ± 7.6	40.60 ± 7.3	38.9 ± 6.6	41.63 ± 7.4	39.54 ± 6.7
D_{max}	98.66 ± 8.6	97.60 ± 2	98.51 ± 3.4	96.6 ± 4.7	100.09 ± 3.1	98.43 ± 2.8	99.45 ± 3	98.81 ± 3.5
$D_{15\%}$	70.92 ± 8.7	70.76 ± 8.8	67.38 ± 7.2	64.53 ± 6	66.92 ± 5.5	65.38 ± 5.4	67.69 ± 5.6	65.69 ± 5.3
$D_{25\%}$	58.92 ± 11.5	58.26 ± 10.9	53.38 ± 7.7	50.69 ± 6.5	53.92 ± 4.5	50.42 ± 9.7	54.07 ± 5.4	51.84 ± 4.8
$D_{35\%}$	49.84 ± 12.8	49 ± 11.7	43.76 ± 7.4	41.11 ± 6.9	44.80 ± 5.4	43.26 ± 5.3	45.46 ± 5.9	43.03 ± 5.5
$D_{50\%}$	39.84 ± 12.8	38.92 ± 11.2	34.19 ± 7.4	32.30 ± 7.6	36.69 ± 7	37.65 ± 6.1	38.57 ± 8.8	35.23 ± 7.3
Partial bladder								
D_{mean}	36.36 ± 2.2	35.57 ± 2.1	36.90 ± 2.9	36.77 ± 2.6	37.98 ± 2.4	37 ± 2.3	38.11 ± 2.6	36.73 ± 2.4
D_{max}	100.87 ± 3.1	99.3 ± 3.6	100.34 ± 3.1	99.46 ± 2.3	100.29 ± 2.6	99.66 ± 3.4	101.38 ± 3	100.62 ± 2.7
$D_{15\%}$	65.46 ± 10	64.92 ± 9.6	65.07 ± 9.8	64.46 ± 9.7	64.46 ± 8.9	62.92 ± 8.6	63.76 ± 9.2	62.84 ± 9
$D_{25\%}$	52.76 ± 9.5	52.15 ± 9.3	52.61 ± 9.7	52.07 ± 9.4	51.84 ± 7.9	50.30 ± 8	52.03 ± 8.7	50.38 ± 8.6
$D_{35\%}$	43 ± 9.5	42.07 ± 9.3	42.38 ± 9.9	42 ± 9.7	43.23 ± 7.8	42.07 ± 7.9	43.07 ± 9.1	41.38 ± 8.7
$D_{50\%}$	31 ± 9.5	30.61 ± 9.4	31.11 ± 11.9	30.46 ± 11.7	32.46 ± 9.4	31.92 ± 8.9	33.61 ± 10.5	31.5 ± 10.2

The number of monitor units delivered for each plan was smaller in the SS IMRT as compared to the SW IMRT. This can be attributed to the lower number of MUs required and also due to the change of field shapes in the SS IMRT when the beam is kept off. In the SW IMRT the beam is continuously switched on, which increases the dose to the OARs due to transmission and leakage through the leaves. Moreover, a SW IMRT delivery cannot completely shield any area, but rather sweeps the area with minimal gap at a maximum speed possible.

5. Conclusion

This study shows that SW and SS IMRT have identical results related to the PTV coverage. PTV has significant result in homogeneity index, uniformity index and $D_{95\%}$ and non significant results for CI, D_{mean}, D_{max}. SS IMRT needs less MUs for delivery of treatment as compared to the SW. The dose to OAR or healthy tissue is considerably lower in the SS IMRT than SW IMRT. We conclude that while choosing the IMRT delivery technique the concern about OARs volume received low doses in SS IMRT using Eclipse TPS.

Conflict of interest

The authors have no conflict of interest.

Financial disclosure

None declared.

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