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Dosimetric Evaluation of Conventional Multileaf Collimator Based Intensity Modulated Radiotherapy Delivery Techniques; A Treatment Planning Study

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Abstract

The purpose of the study was to analyze the effects of the number of intensity levels on treatment planning outcome of static IMRT method with dynamic IMRT method and also to investigate the integral dose to non-target tissues in both the methods. The IMRT planning was carried out using Eclipse treatment planning system with millennium 120 multileaf collimator (Varian Clinac- 2100 DHX). Five cases each of head and neck, cervix and esophagus cancer were selected for this study. For each case, planning was carried out using both delivery methods. Further for the static IMRT, different numbers of intensity levels ranging from 5 to 20 were studied. The optimization values were kept common for both the techniques and only the leaf motion calculation was varied. The parameters associated with the Dose volume histograms were examined for a more quantitative comparison. The integral doses (0.5 Gy to 30 Gy) of Non-target tissues were also calculated for both techniques. Analyses were performed using a t test to determine difference in any of the parameters examined. For three sites studied, there were no significant changes observed between static IMRT (above 10 intensity levels) and dynamic IMRT method. However there were significant differences observed with 5 intensity level static IMRT plans compared to dynamic IMRT plans. There were no significant changes observed in normal tissue dose values between static IMRT plans and dynamic IMRT plans. The total number of monitor unit was more for dynamic IMRT plans compared to static IMRT plans for all three sites. The integral doses from 0.5 Gy to 30 Gy were analyzed and no significant changes were observed between static IMRT and dynamic IMRT plans.

Keywords: MLC based IMRT; Static IMRT; Dynamic IMRT; IMRT integral dose

Abbreviations: MLC: Multileaf Collimator; PTV: Planning Target Volume; OAR: Organ at Risk; NTT: Non-Target Tissues; IMRT: Intensity Modulated Radiotherapy; DVH: Dose Volume Histogram

Introduction

Intensity modulated radiation therapy refers to a radiation therapy technique in which nonuniform fluence is delivered to the patient from any given position of the treatment beam to optimize the composite dose distribution. There are many ways to deliver a desired fluence map. The most common delivery technique is based on computer controlled multileaf collimators. Depending on the relationship between MLC leaf movements and radiation dose delivery, the delivery can generally be divided into step-and-shoot delivery (static IMRT) and sliding window delivery (dynamic IMRT). The former is the simplest computer controlled delivery scheme of the fixed-gantry IMRT, in which MLC leaf movements and dose deliveries are done at different instances. Static IMRT leaf sequence file consists of alternatives of dose-only and motion only instances. Dynamic delivery differs from a step and shoot mode in that leaf movement and dose delivery are realized simultaneously [1]. The simultaneous delivery of dose and leaf movement makes the dynamic mode become more advantageous than static mode, since the delivered intensity profile almost matches the fluence created by treatment planning system (TPS). But in the static mode delivery, alternatively, the fluence created by TPS is converted into discrete intensity levels. The transfer from the TPS fluence to discrete one leads to some deprivation in dose distribution. Obviously, the degree of deprivation of the static IMRT mode depends mainly on the number of intensity levels used in the treatment planning process. The static IMRT with increased intensity levels is nearly comparable with dynamic IMRT provided the increased intensity levels makes large number of beam segments with relatively short beam on time [2,3].

In previous study by Chui et al. [4], comparisons were made among dynamic IMRT and static IMRT with different number of intensity levels and different spatial resolutions for three disease sites (nasopharynx, prostate, breast) with three cases for each site. The comparisons were made in terms of target coverage, organ at risk sparing, total monitor units and beam on time. They concluded that 5-10 intensity level static IMRT plan produced results comparable to that from a dynamic IMRT plan. In static IMRT plan, the target coverage was improved by increasing the number of intensity levels and OARs were better protected with finer spatial resolutions.

Additionally, since dynamic IMRT delivery depends on simultaneous MLC movement and radiation dose delivery, the MUs delivered to patient is quite more than static IMRT delivery where leaf movement and dose delivery are done at different instances. For this reason, it is obvious to anticipate the difference in integral dose delivered to NTT between both the techniques. Chui et al. [4] have shown that static IMRT requires 20% fewer MUs compared to dynamic IMRT techniques. Alaei et al. [5] concluded that dynamic IMRT requires 15% more MUs than static IMRT delivery techniques.

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The more MU delivered in dynamic IMRT raised the concern that, particularly patients with less aggressive malignancies may potentially increase the incidence of secondary malignancies.

Jothybasu et al. [6] evaluated the impact of static and dynamic IMRT delivery techniques on total integral dose to the healthy normal tissue surrounding the tumor-bearing area and to the volume receiving doses<5 Gy in 10 patients with carcinoma nasopharynx. They concluded that dynamic IMRT slightly increased the integral dose to normal healthy tissues when compared to static IMRT delivery. However, no significant difference was found in the low-dose volume with all the techniques.

The purpose of our work was to evaluate the effects of number of intensity levels on treatment planning outcome of static IMRT technique with dynamic IMRT technique on the basis of PTV, OAR and NTT dose for head and neck, cervix and esophagus cancer cases. Since the dynamic IMRT delivery requires more MUs to deliver same prescribed dose compared to static IMRT, the volume of normal tissue exposed to the low dose of radiation also expected to be increased in dynamic IMRT compared to static IMRT. In previous study by Jothybasu et al. [6] evaluated only the total integral dose and volume receiving <5 Gy (V_{5Gy}). Since the mean dose to NTT may not vary much between both the techniques, there won't be reasonable variations in total integral dose to NTT between static and dynamic IMRT. It is meaningful to investigate integral dose only in low dose regions of NTT. This is because to avoid any potential contributions from the high dose regions of PTV to NTT which is near to PTV. So we evaluated the integral dose to NTT in low to mid dose regions starting from 0.5 Gy to 30 Gy with increment of 1 Gy in both the delivery methods.

Materials and Methods

In this study, the IMRT treatment planning was carried out using Eclipse treatment planning system (Varian Medical Systems, Inc. ., Palo Alto CA) with millennium 120 multileaf collimator system (Varian Clinac 2100-DHX) having 0.5 cm projected leaf width at isocentre for central 40 pairs and 1.0 cm at isocentre for peripheral 10 pairs on both side. Five cases each of head and neck, cervix and esophagus cancer were randomly selected for this study. For head and neck and cervix treatment, 7 intensity-modulated fields of 6 MV photons were used. For esophagus cases 5 fields with 6 MV photons were used. The prescribed dose was 70 Gy in 35 fractions for head and neck cases, 56 Gy in 28 fractions for cervix cancer cases and 54 Gy in 30 fractions for esophagus cases. For each case, planning was carried out using both static IMRT and dynamic IMRT delivery methods. Further for the static method, different numbers of intensity levels ranging from 5, 10 and 20 were studied. The optimization values were kept common for both the techniques and only the leaf motion calculation was varied. The dose volume optimizer was used for optimization. The calculation algorithm used in this study was analytic anisotropic algorithm (AAA). All the plans were normalized to target mean dose. The plan accepting criteria was set at least 95% of prescribed dose should cover the target volume. Dose rate used for delivery was 300 MU/min. For the both methods, the spatial resolution used in this study was 2.5 mm. The dynamic IMRT plan values were kept as reference value and all static IMRT plans with 5, 10 and 20 intensity levels were compared against dynamic IMRT plan. The comparisons were made in terms of isodose distributions, dose volume histograms and total beam on-times (MUs). In addition, parameters associated with DVH like D_{max} (maximum dose), D_{min} (minimum dose), V_{95} (volume receives 95% of prescribed dose) and homogeneity index were also examined for a more quantitative comparison. For head neck cases, the OAR considered were spinal cord, brainstem, left and right parotids. Bladder, rectum, left and right femoral heads were considered as critical organs in cervix cancer patients. For esophagus cases, the risk organs considered were includes spinal cord, heart, left and right lungs. The OARs dose values were quantitatively examined using various DVH parameneters like D_{max}, D_{mean} (mean dose) and D_{50} (dose received by 50% of volume). The integral doses of low to mid dose regions (0.5 Gy to 30 Gy) of NTT were also calculated for both static IMRT and dynamic IMRT techniques. Non target tissues were created by subtracting target volume (PTV) from total body structure.

Isodose distribution were first compared visually on axial, sagittal and coronal slices for degree of conformity of the prescribed dose to the PTV, then for any inclusion of OAR within high dose regions. Specifically, we examined low to mid dose regions from 0.5 Gy to 30 Gy in our evaluation to account for the excess MU delivered in dynamic IMRT treatments compared to static IMRT treatments. Plan comparisons were made quantitatively by comparing DVH parameters and by computing and comparing relevant metrics for target coverage, target dose homogeneity within the target and critical organ sparing.

Homogeneity of dose within the target volume has been assessed by Sigma index ("S" index) as defined by the standard deviation of the normalized differential curve of PTV volume [7]

$$S-\text{index} = D_{SD} = \sqrt{\left[\sum (Di - D_{mean})^2 \times v_i / V\right]}$$

Where, D_{SD} represents the standard deviation of the dose, v_i is the i^{th} volume element receiving a dose of at least (D_i) and V is the total volume of PTV. D_{mean} is the mean dose of PTV. If the S index value is near to zero, then the PTV has superior dose homogeneity within the target.

The integral dose (ID) has been defined as the sum of the product of a given dose (Di) and the volume of tissue receiving that dose (Vi) and the density of that tissue volume (ρ_i), as represented by the equation [8]

$$ID = \sum_i Di \times Vi \times \rho i$$

Integral dose was calculated for NTT which was actually created by subtracting all targets from the body defined. The total ID which includes the volume of tissue receiving all dose levels and the ID of the regions of tissue receiving a maximum dose of interest, i. e 0.5 Gy to 30 Gy, were determined from the DVH data by using DVH differential function on the planning software such that bins of 1 cGy increments from 0 cGy to the corresponding volume of the given cGy level were tabulated and summed to yield ID at dose levels of 0.5 Gy, 1 Gy, 2Gy up to 30 Gy. As the mean dose of NTT is almost same in both static IMRT and dynamic IMRT plans and volume of NTT is same in all plans, the total integral dose calculated would be same irrespective of the planning technique. The discrepancies exist only in the low to mid dose regions. This prompted us to evaluate the integral dose only in the low to mid dose regions i.e 0.5 Gy to 30 Gy with 1 Gy dose increment. Integral dose was calculated and compared between dynamic and static IMRT plan with 5, 10 and 20 intensity plans in each dose increments of 1Gy using p values.

Monitor units were also compared between static IMRT plans with 5, 10 and 20 levels and dynamic IMRT plans. For monitor unit comparisons, all the plans were normalized to target mean dose and the dose rate set was 300 MU/min for delivery from Clinac-DHX Varian accelerator. Analyses were performed by using a paired two-tailed Student *t* test to determine if there was a significant difference in any

of the parameters examined. Differences were considered statistically significant at $p \leq 0.01$.

Results

Target coverage and normal tissue sparing

For the five head and neck patients studied, the overall results of the dynamic IMRT plans were not very different from that of the static IMRT plans with 10 and 20 intensity levels (Table 1). But there was significant differences observed with 5 intensity level static IMRT plan in terms of D_{max}, V_{95} and homogeneity index. Figure 1 shows the lack of dose distribution and target homogeneity in 5 level static IMRT plan (shown in circles) compared to dynamic IMRT plan.

The maximum target dose for the 5-level static IMRT plan was 109.48 % while that for the dynamic IMRT plan was 106.38%, a 2.91% difference and statistically significant (p=0.0003). However, the minimum target dose was differing only by 1.2% (84.72 % vs. 85.74%). There was significant difference observed in V_{95} between dynamic IMRT (98.2 %) and static IMRT 5 level plans (96.3%) about -1.96% (p = 0.005). But as the intensity levels increased to 10 and 20, the V_{95} values were increased to 97.4% and 97.7 % and the difference was only -0.81%, -0.43% respectively. Figure 2 shows the lack of dose coverage (V_{95}) in static IMRT 5 level plan compared to dynamic and static IMRT of 10 and 20 level plans.

Since the target coverage was affected in 5 level static IMRT plan, lack of dose homogeneity in the target was observed. The homogeneity index value for the 5 level static IMRT plan was 2.9 about 51.54% difference (p=0.0002) compared to dynamic IMRT plan (1.9). But no such difference was observed in target homogeneity values in 10 and 20 intensity level static IMRT plans compared to dynamic IMRT plan.

There were no significant changes observed in OAR dose values between dynamic IMRT plan and static IMRT plan with 5, 10 and 20 intensity levels (Table 2).

In case of spinal cord, the maximum dose for 5 level static IMRT plan was slightly higher than dynamic IMRT plan about 2.87 % but not statistically significant. The maximum dose for 10 and 20 level static IMRT plan was differs only by -0.029% and 0.17% compared to dynamic plan.

The mean dose and D_{50} were varied about 1.59% , 1.41%, 1.37% and -2.44% , -1.44% , -1.12% for 5, 10 and 20 intensity levels respectively compared to dynamic IMRT plan. Figure 3 shows comparison of DVH for brain stem between dynamic and static IMRT plans and it is clear that no much variation observed between dynamic and static IMRT plans.

The maximum dose to brain stem was varied about -0.344%, -0.50%, -0.84% for 5, 10 and 20 intensity levels respectively compared to dynamic IMRT plan. The mean dose and D_{50} of brain stem was differed only by -2.62%, -2.13%, -2.03% and -2.76%, -2.44% and -2.20% for 5, 10 and 20 intensity levels respectively compared to dynamic IMRT plan. There were no significant variations observed in the case of left parotid and right parotids. For the maximum dose to left parotid, static IMRT with 5 level plans was varied about 2.02% whereas 10 level and 20 level plans varied about -0.11%, -0.277% respectively. The mean dose and dose to D_{50} was not varied significantly in dynamic IMRT and static IMRT plans. In case of right parotid, the maximum dose was varied about 3.36%, 0.72% and 0.22% for 5, 10 and 20 intensity levels respectively.

For the five cervix patients studied, values of dynamic IMRT plans

PTV	Dynamic	Static 5 levels	Static 10 levels	Static 20 levels
D_{max}	106.4 ± 2.0	109.5 ± 2.2 (0.0003)*	107.2 ± 2.5 (0.042)	106.5 ± 2.1 (0.635)
D_{min}	84.7 ± 6.1	85.7 ± 3.5 (0.690)	85.8 ± 2.7 (0.625)	86.0 ± 3.1 (0.553)
V_{95}	98.2 ± 1.5	96.3 ± 2.0 (0.005)*	97.4 ± 1.2 (0.116)	97.7 ± 1.0 (0.124)
Homogeneity index	1.9 ± 0.7	2.9 ± 0.8 (0.0002)*	2.2 ± 0.6 (0.094)	2.0 ± 0.5 (0.429)

Values are mean (%) ± standard deviation, ( ) - p values, * - Statistically significant

Table 1: Target dose values for dynamic and static IMRT plans for head and neck cancers.

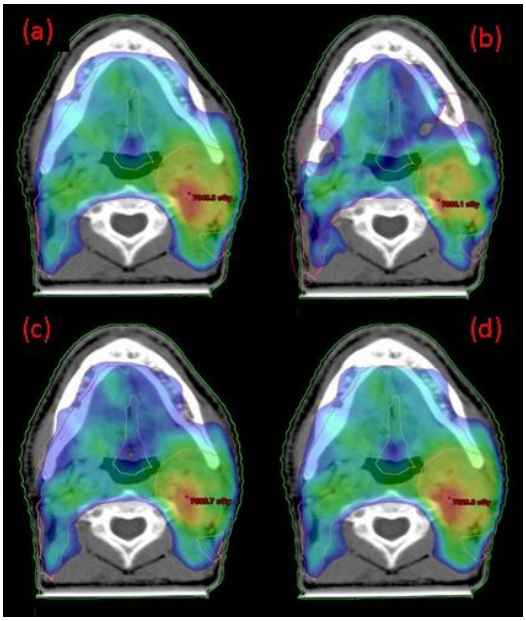

Figure 1: 95 % target dose distribution of (a) Dynamic IMRT, (b) Static 5 level, (c) Static 10 level, (d) Static 20 level plan. The circled areas in static IMRT 5 level plan shows degradation in dose distribution compared to dynamic IMRT.

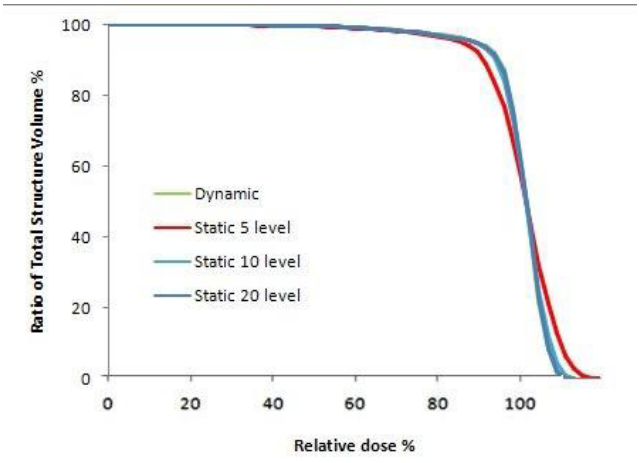

Figure 2: Comparison of cumulative dose volume histogram of PTV between dynamic and static IMRT plans.

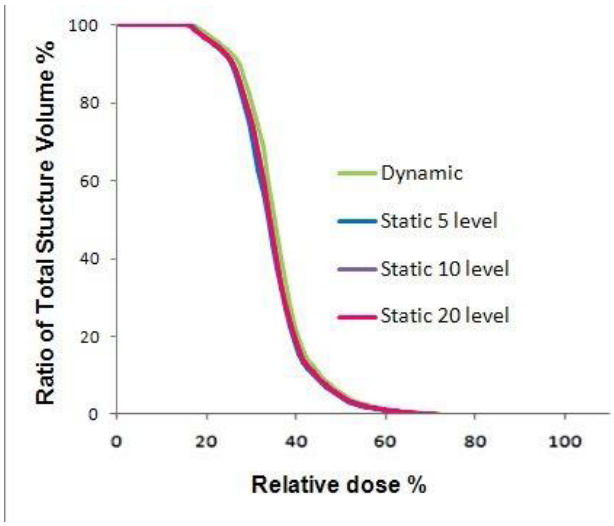

Figure 3: Comparison of cumulative dose volume histogram of brain stem between dynamic and static IMRT plans.

and static IMRT plans with 10 and 20 intensity levels were not varied significantly except for maximum dose in static IMRT of 10 level plans (Table 3).

But there was significant differences observed with 5 intensity level static plan with D_{max}, V_{95}, minimum dose and homogeneity index. The maximum target dose for the 5-level static IMRT was 108.92 % while that for the dynamic IMRT plan was 104.9%, a 3.83 % difference was observed (p=0.0006). The minimum target dose was differing by 1.93 % (90.22 % vs. 88.28 %). There was significant difference observed in V_{95} between dynamic IMRT (98%) and static IMRT 5 level plan (95.6%) about –2.41% (p=0.009). The homogeneity index was varied about 51.54%, 14.43%, 5.15% for static IMRT 5, 10, 20 levels plans compared with dynamic IMRT plan.

There were no significant changes observed in normal tissue dose values between dynamic IMRT plan and static IMRT plan with 5, 10 and 20 intensity levels (Table 4).

When compared to dynamic IMRT plan, the maximum dose varied about 2.67%, -0.41%, and 0.21% for bladder , 1.68% , 0.23% , 0.23% for rectum , -0.51% , 0.35%, 0.023% for left femoral head and -1.16% , 0.148%, -0.54% for right femoral head for static IMRT plans of 5, 10 and 20 intensity levels respectively. There were no significant variations observed in mean dose and D_{50} for critical organs analyzed in cervix cases.

For the five esophagus patients studied, as like above plans no significant variations observed between dynamic and static IMRT plan of 10 and 20 levels (Table 5).

But significant variations observed with 5 intensity level static IMRT plan with D_{max}, V_{95} and homogeneity index. The maximum target dose for the 5-level static IMRT was 110.14 % while that for the dynamic IMRT plan was 105.6 %, a 4.29 % (p=0.005) difference was observed. However, the minimum target dose was differing only by -2.53 % (90.06% vs. 87.78%). There was significant difference observed in V_{95} between dynamic IMRT and static IMRT 5 level plan about –4.61% (p=0.008). The homogeneity index was varied about 89.87%, 20.05%, 2.53% for static IMRT with 5, 10, 20 levels plans compared with dynamic IMRT plan.

There were no significant changes observed in normal tissue dose values between dynamic IMRT plan and static IMRT plan with 5, 10 and 20 intensity levels (Table 6). When compared to dynamic IMRT plan, the maximum dose varied about 3.60%, 0.07%, and -0.09% for spinal cord , 3.55% , 1.01% , 0.59% for heart , 2.61% , 0.393%, 0.15% for left lung and 3.56% , -0.29%, 0.38% for right lungs for static IMRT plans of 5, 10 and 20 intensity levels respectively. There were no significant variations observed in mean dose and D_{50} for normal structures analyzed in esophagus cases (Table 6).

Monitor unit comparison

In Table 7, the Monitor unit values for head and neck, cervix and esophagus cases were reported. As expected the dynamic IMRT plan delivers the more Monitor units compared to the static IMRT plan of 5, 10 and 20 intensity levels. In head and neck cases, the dynamic IMRT plan delivers 1062 (mean of 5 patients) MUs compared to 952 for 5 level static IMRT plan (-10.39% difference), 941 MU for 10 level static IMRT plan (-11.45%) and 923 MU for 20 level static IMRT plan (-12.95%). In cervix cases, the dynamic IMRT delivers 1218 MUs compared to 1070 (-12.15%), 1058 (-13.13%) and 1034 (-15.10%) for static IMRT

Normal Tissues		Dynamic	Static 5 levels	Static 10 levels	Static 20 levels
Spinal cord	D_{max}	68.8 ± 9.8	70.8 ± 8.6 (0.211)	68.8 ± 10.3 (0.711)	68.9 ± 10.1 (0.883)
	D_{mean}	52.6 ± 7.0	51.7 ± 6.8 (0.02)	51.8 ± 6.8 (0.02)	51.8 ± 6.8 (0.012)
	D_{50}	52.4 ±12.6	51.1 ± 12.1 (0.026)	51.7 ± 12.3 (0.016)	51.8 ± 12.4 (0.019)
Brain stem	D_{max}	75.5 ± 16	75.2 ± 16.9 (0.693)	75.1 ± 16.2 (0.294)	74.9 ± 16.2 (0.046)
	D_{mean}	41.2 ± 8.7	40.1 ± 8.0 (0.053)	40.3 ± 8.1 (0.042)	40.4 ± 8.1 (0.060)
	D_{50}	41.2 ±10.8	40.0 ± 9.9 (0.981)	40.2 ± 10.1 (0.047)	40.3 ±10 (0.080)
L parotid	D_{max}	100.8±2.6	102.9±5.3 (0.179)	100.7±3.6 (0.818)	100.6±2.6 (0.121)
	D_{mean}	66.4±13.5	65.0±13.5 (0.016)	65.3±14 (0.014)	65.3±13.8 (0.041)
	D_{50}	69.6±22.2	67.8±21.3 (0.019)	68.2±23.1 (0.022)	68.4±23.1 (0.032)
R parotid	D_{max}	96.4±8.6	99.6±9.4 (0.029)	97.1±8.9 (0.122)	96.6±8.5 (0.465)
	D_{mean}	64.2±12.3	63.5±13.3 (0.347)	63.6±12.7 (0.163)	63.5±12.5 (0.037)
	D_{50}	72.9±20.1	72.5±21.84 (0.684)	72.7±21.1 (0.742)	72.5±20.9 (0.383)

Values are mean (%) ± standard deviation, ( ) - p values, * - Statistically significant

Table 2: Normal tissue dose for dynamic and static IMRT plans for head and neck cancers.

PTV	Dynamic	Static 5 levels	Static 10 levels	Static 20 levels
D_{max}	104.9 ± 2.1	108.9 ± 1.5 (0.0006)*	106.1 ± 2.3 (0.001)*	104.9 ± 2.2 (0.854)
D_{min}	90.2 ± 3.4	88.5 ± 3.3 (0.007)*	89.7 ± 3.5 (0.074)	90 ± 3.4 (0.161)
V_{95}	98 ± 3.0	95.6 ± 3.9 (0.009)*	97.8 ± 3.0 (0.115)	97.9 ± 2.9 (0.192)
Homogeneity index	1.78 ± 0.19	2.76 ± 0.49 (0.0006)*	2.02 ± 0.85 (0.021)	1.82 ± 0.86 (0.373)

Values are mean (%) ± standard deviation, ( ) - p values, * - Statistically significant

Table 3: Target dose values for dynamic and static IMRT plans for cervix cancers.

Normal Tissues		Dynamic	Static 5 levels	Static 10 levels	Static 20 levels
Bladder	D_{max}	102.3 ±3.2	105.0 ± 4.3 (0.015)	102.7 ± 4.0 (0.426)	102.1 ± 3.2 (0.180)
	D_{mean}	70.1 ± 6.2	70.2 ± 6.4 (0.033)	70.4 ± 6.5 (0.060)	70.6 ± 6.4 (0.087)
	D_{50}	71.8 ±10.4	71.0 ± 10.3 (0.033)	71.4 ± 10.6 (0.037)	71.6 ± 10.4 (0.065)
Rectum	D_{max}	101.2 ± 3.5	102.9 ± 4.2 (0.019)	101.0 ± 3.4 (0.741)	101.0 ± 3.2 (0.591)
	D_{mean}	79.8 ± 17.5	79.7 ± 18.1 (0.871)	79.6 ± 17.7 (0.345)	79.6 ± 17.6 (0.374)
	D_{50}	80.9 ± 17.8	80.6 ± 18.2 (0.659)	80.5 ± 18.0 (0.177)	80.8 ± 18 (0.582)
L femoral head	D_{max}	84.9 ± 13.6	84.4 ± 14.1 (0.671)	85.2 ± 13.6 (0.356)	84.9 ± 13.7 (0.912)
	D_{mean}	42.3 ± 22.8	41.7 ± 23 (0.153)	42.2 ± 23.1 (0.374)	42.1 ± 23 (0.153)
	D_{50}	43.1 ± 24.1	42.5 ± 24.1 (0.326)	43 ± 24.4 (0.665)	42.8 ± 24.1 (0.195)
R femoral head	D_{max}	80.9 ± 16.5	80.0 ± 16.7 (0.070)	80.8 ± 17.1 (0.704)	80.5 ± 16.5 (0.088)
	D_{mean}	41.9 ± 24.2	40.8 ± 23.5 (0.025)	41.4 ± 23.8 (0.030)	41.2 ± 24 (0.031)
	D_{50}	40.6 ± 26.5	39.5 ± 26.5 (0.021)	40 ± 26.4 (0.037)	40.1 ± 26.8 (0.054)

Values are mean (%) ± standard deviation, ( ) - p values, * - Statistically significant

Table 4: Normal tissue dose values for dynamic and static IMRT plans for cervix cancers.

PTV	Dynamic	Static 5 levels	Static 10 levels	Static 20 levels
D_{max}	105.6 ± 1.3	110.1 ± 1.6 (0.005)*	106.0 ± 0.8 (0.089)	105.2 ± 1.07 (0.394)
D_{min}	90.1 ± 5.1	87.8 ± 4.5 (0.013)	90.0 ± 4.9 (0.918)	90.3 ± 5.2 (0.397)
V_{95}	99.5 ± 0.8	94.9 ± 2.5 (0.008)*	99.2 ± 0.8 (0.111)	99.50 ± 0.8 (0.755)
Homogeneity index	1.58 ± 0.19	3.0 ± 0.5 (0.002)*	1.9 ± 0.24 (0.029)	1.62 ± 0.17 (0.177)

Values are mean (%) ± standard deviation, ( ) - p values, * - Statistically significant

Table 5: Target dose values for dynamic and static IMRT plans for ca esophagus.

of 5, 10 and 20 levels respectively. Dynamic IMRT delivered 693 MUs compared to 598 of 5 level, 591 of 10 level and 589 of 20 level static IMRT plans respectively. As the number of intensity levels increased, the MU values are decreased gradually in static IMRT plans.

Integral dose to nontarget tissue

Evaluation of the integral dose to NTT showed that there was no increase in the ID of NTT in any dose levels from 0.5 Gy to 30 Gy with dynamic IMRT plan compared to static IMRT plans with 5, 10 and 20 intensity levels in all three treatment sites (Tables 8-10). This parameter was chosen so as to exclude any potential contributions and effects from the high dose regions, as might be the case if the ID of regions that received 0.5 Gy to 30Gy were examined. Importantly dynamic IMRT did not much increase the ID of normal tissue values in the dose regions of less than 5Gy compared to static IMRT plans. Figure 4 shows the DVH of NTT volume for dynamic and static IMRT plans. From the figure 4, it is clear that the NTT values was not significantly varied between dynamic and static IMRT plans in all dose levels from 0.5 Gy to 30 Gy.

Discussion

We evaluated dynamic IMRT and static IMRT treatments with 5, 10 and 20 intensity levels in terms of target coverage and homogeneity, dose to OAR and integral dose to NTT. Generally, from the results obtained in all three treatments sites: head and neck, cervix and esophagus, it is clear that dynamic IMRT is superior in target coverage and target homogeneity compared to static IMRT plans. This is may be due to the reason that the dynamic IMRT fluence is delivered as it is created by the treatment planning system; whereas, in the static IMRT delivery, the fluence created by the treatment planning system is converted into discrete intensity levels before the treatment. This conversion makes the static IMRT to lack in the desired dose distribution. Target coverage and homogeneity was significantly affected in static IMRT with 5 intensity level plans compared to dynamic IMRT plans, but static IMRT with 10 and 20 intensity level plans results were comparable to dynamic IMRT plans. This is for the reason that as the intensity level increased in static IMRT plans; the desired fluence created by TPS is delivered with less deficiency compared to 5 level static IMRT plans. So no much difference was observed between static IMRT plans with 10 and 20 intensity levels and dynamic IMRT plans.

Normal Tissues		Dynamic	Static 5 levels	Static 10 levels	Static 20 levels
Spinal cord	D_{max}	81.1 ± 8.3	84.0 ± 9.8 (0.069)	81.2 ± 8.2 (0.918)	81.0 ± 8.4 (0.773)
	D_{mean}	44.7 ± 4.8	44.8 ± 4.5 (0.280)	44.7 ± 4.7 (0.871)	44.6 ± 4.7 (0.298)
	D_{50}	51.9 ± 17.4	51.3 ± 16.6 (0.370)	52.1 ± 17.6 (0.324)	51.7 ± 17.5 (0.202)
Heart	D_{max}	101.3 ± 5.3	104.9 ± 4.5 (0.011)	102.4 ± 5.7 (0.028)	101.2 ±5.3 (0.541)
	D_{mean}	58.3 ± 10.4	58.0 ± 10.8 (0.419)	57.9 ± 10.6 (0.048)	57.9 ± 10.55 (0.045)
	D_{50}	56.9 ± 10.5	56.8 ± 11 (0.732)	56.7 ± 10.6 (0.065)	56.6 ± 10.8 (0.067)
L lung	D_{max}	101.7 ± 3.1	104.4 ± 2.3 (0.094)	102.1 ± 3.1 (0.365)	101.8 ± 3.14 (0.140)
	D_{mean}	39.9 ± 5.9	39.2 ± 6.1 (0.067)	39.5 ± 5.9 (0.019)	39.6 ± 5.9 (0.047)
	D_{50}	37.1 ± 7.2	36.5 ± 7.4 (0.021)	36.6 ± 7.2 (0.038)	36.7 ± 7.2 (0.011)
R lung	D_{max}	102.7 ± 0.8	106.4 ± 1.6 (0.014)	102.4 ± 5.7 (0.326)	103.1 ± 0.5 (0.136)
	D_{mean}	36.2 ± 4.2	35.7 ± 4.0 (0.071)	35.9 ± 4.2 (0.024)	35.4 ± 4.2 (0.041)
	D_{50}	31.1 ± 4.7	30.5 ± 4.7 (0.017)	30.9 ± 4.8 (0.303)	30.8 ± 4.8 (0.060)

Values are mean (%) ± standard deviation, ( ) - p values, * - Statistically significant

Table 6: Normal tissue dose values for dynamic and static IMRT plans for ca esophagus.

Sites	Dynamic	Static (5)	Static (10)	Static (20)
Head and Neck	1062	952 -10.35%	941 -11.39%	923 -13.08%
Cervix	1218	1070 -12.15%	1058 -13.13%	1034 -15.10%
Esophagus	693	598 -13.71%	591 -14.72%	589 -15.0%

All values (MU) are mean of 5 patients, percentage diff (%) calculated against dynamic plan

Table 7: Monitoring unit values for dynamic and static IMRT plans.

Dose Gy	Dynamic (J) ×10³	Static (5) (J) ×10³	*p*	Static (10) (J) ×10³	*p*	Static (20) (J) ×10³	*p*
0.5	1.3	1.3	0.35	1.2	0.89	1.2	0.43
1	3.4	3.3	0.29	3.3	0.48	3.3	0.23
2	4.9	4.8	0.20	4.8	0.31	4.8	0.16
3	5.9	5.8	0.20	5.8	0.30	5.8	0.15
4	6.9	6.8	0.19	6.8	0.31	6.8	0.14
5	7.7	7.6	0.17	7.6	0.26	7.6	0.11
6	8.5	8.4	0.14	8.4	0.23	8.4	0.10
7	9.2	9.1	0.12	9.1	0.22	9.1	0.13
8	10.1	9.9	0.11	10.0	0.25	10.0	0.14
9	10.8	10.8	0.19	10.8	0.13	10.8	0.05
10	11.7	11.6	0.18	11.6	0.10	11.6	0.07
11	12.4	12.4	0.18	12.4	0.14	12.4	0.09
12	13.2	13.2	0.17	13.2	0.20	13.2	0.09
13	14.1	14.0	0.22	14.0	0.31	14.0	0.13
14	14.9	14.8	0.18	14.8	0.27	14.8	0.12
15	15.8	15.7	0.27	15.7	0.29	15.7	0.12
16	16.7	16.6	0.28	16.6	0.41	16.6	0.15
17	17.7	17.6	0.18	17.6	0.34	17.6	0.15
18	18.7	18.6	0.32	18.6	0.30	18.6	0.13
19	19.7	19.7	0.34	19.6	0.22	19.6	0.11
20	20.9	20.7	0.23	20.7	0.12	20.7	0.07
21	22.0	21.8	0.19	21.8	0.07	21.8	0.05
22	23.1	22.9	0.14	22.9	0.02	22.9	0.03
23	24.2	24.0	0.09	24.0	0.01	24.0	0.01
24	25.3	25.1	0.03	25.1	0.02	25.1	0.01
25	26.4	26.3	0.01	26.2	0.05	26.2	0.01
26	27.6	27.5	0.17	27.4	0.09	27.4	0.03
27	28.9	28.8	0.33	28.7	0.13	28.7	0.07
28	30.3	30.2	0.33	30.1	0.15	30.1	0.07
29	31.7	31.6	0.37	31.5	0.26	31.5	0.09
30	33.2	33.1	0.41	33.1	0.45	33.0	0.10

p- p values, * - Statistically significant

Table 8: Integral dose to the non target tissues (Body_PTV) for head and neck cases.

In case of OAR doses, there were no much dissimilarity observed between dynamic IMRT and static IMRT plans with 5, 10 and 20 intensity levels. For some particular organs, dynamic IMRT yielded more doses than any static IMRT plan and sometimes static IMRT plans gave more doses to other OAR studied than dynamic IMRT plans. This inconsistent dose to OARs from both techniques planned was observed at all treatment sites in our planning. A study conducted by Chui et al. [4], explained that as the leaves are moving continuously in dynamic IMRT technique during which beam is on, there is possibility of radiation leakage through MLC leaves to OAR volumes; But static IMRT delivers with fewer MUs and stepped over the critical organs when beam is off, the dose to OARs is less than dynamic IMRT technique. But our study showed that there were no significant changes in doses to OARs in both techniques planned. The MLC we use has the 60 pairs in that central 40 pairs are 0.5 cm projected leaf width at isocentre and peripheral 20 pairs are 1 cm width at isocentre. Obviously the difference in MLC pattern could cause the variations in radiation leakage in dynamic IMRT delivery. The Monitor unit comparisons made in our study showed a maximum variation of -15 % and minimum variation of -10 % between static and dynamic IMRT techniques. Inspite of more monitor units delivered in dynamic IMRT method; there were no significant increment of the integral dose to NTT in dynamic IMRT technique compared to static IMRT

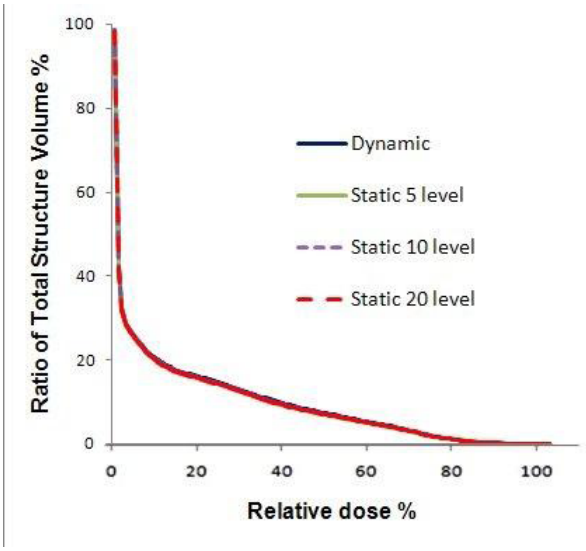

Figure 4: Comparison of cumulative dose volume histogram of NTT (Body_ PTV) between dynamic and static IMRT plans.

Dose Gy	Dynamic (J) x 10³	Static (5) (J) x 10³	*p*	Static (10) (J) x 10³	*p*	Static (20) (J) x 10³	*p*
0.5	3.3	3.3	0.08	3.3	0.21	3.2	0.55
1	6.7	6.7	0.14	6.7	0.15	6.7	0.28
2	8.8	8.8	0.36	8.8	0.25	8.8	0.23
3	10.4	10.5	0.40	10.5	0.38	10.4	0.41
4	12.3	12.4	0.35	12.3	0.52	12.2	0.27
5	14.7	14.9	0.21	14.8	0.24	14.7	0.45
6	17.7	18.0	0.20	17.6	0.77	17.7	0.32
7	20.8	21.2	0.23	20.7	0.80	20.9	0.46
8	23.9	24.2	0.28	23.8	0.66	24.0	0.70
9	26.8	27.0	0.37	26.6	0.30	26.7	0.78
10	29.4	29.5	0.58	29.2	0.22	29.3	0.40
11	32.0	31.9	0.70	31.6	0.24	31.7	0.24
12	34.4	34.2	0.24	34.0	0.24	34.1	0.17
13	36.9	36.7	0.09	36.4	0.26	36.5	0.16
14	39.5	39.3	0.07	39.0	0.30	39.1	0.15
15	42.4	42.2	0.06	41.9	0.32	42.0	0.16
16	45.6	45.4	0.08	45.2	0.36	45.2	0.17
17	49.2	49.0	0.46	48.7	0.42	48.8	0.19
18	53.1	53.2	0.78	52.6	0.43	52.7	0.20
19	57.5	57.7	0.63	57.1	0.44	57.2	0.21
20	62.5	62.4	0.38	62.1	0.40	62.1	0.19
21	67.8	67.3	0.36	67.3	0.30	67.4	0.15
22	73.6	73.1	0.39	73.1	0.32	73.1	0.15
23	79.6	79.0	0.40	79.2	0.31	79.1	0.22
24	85.9	85.2	0.37	85.4	0.27	85.4	0.23
25	92.3	91.7	0.35	91.8	0.27	91.7	0.21
26	98.7	98.2	0.42	98.2	0.30	98.1	0.25
27	105.3	104.7	0.42	104.7	0.28	104.6	0.24
28	111.7	110.9	0.28	111.1	0.20	111.0	0.22
29	117.8	116.7	0.18	117.1	0.17	116.9	0.21
30	123.5	122.1	0.15	122.6	0.18	122.5	0.18

p- p values, * - Statistically significant

Table 9: Integral dose to the non target tissues (Body_PTV) for cervix cases.

method in the range of 0.5 Gy to 30 Gy. . Each dose increment from 0.5 Gy to 30 Gy was compared between dynamic and static methods and no such variations was observed (p> 0.01*)*. This could be due to the forward scattering of higher energy (6 MV) photons with minimal lateral scattering contributions.

Addionally, when the MLCs are positioned in beam eye view of target, collimator jaws comes closer to the MLCs in dynamic IMRT method. So radiation leakage other than open part of MLCs is reduced by collimator jaws which cover the remaining part of MLCs.

Dose Gy	Dynamic (J) x 10^3	Static (5) (J) x 10^3	*p*	Static (10) (J) x 10^3	*p*	Static (20) (J) x 10^3	*p*
0.5	1.6	1.6	0.18	1.6	0.18	1.6	0.50
1	4.5	4.6	0.17	4.5	0.22	4.5	0.54
2	6.8	6.9	0.28	6.8	0.35	6.7	0.45
3	8.5	8.6	0.31	8.5	0.44	8.4	0.36
4	10.4	10.5	0.15	10.4	0.38	10.3	0.41
5	12.9	13.1	0.07	13.0	0.22	12.8	0.47
6	16.2	16.5	0.08	16.3	0.13	16.1	0.54
7	20.3	20.6	0.05	20.4	0.06	20.2	0.65
8	24.6	24.8	0.09	24.7	0.29	24.5	0.63
9	28.6	28.8	0.36	28.7	0.57	28.4	0.47
10	32.2	32.2	0.83	32.2	0.87	31.9	0.35
11	35.5	35.4	0.61	35.3	0.49	35.1	0.28
12	38.6	38.4	0.52	38.4	0.33	38.2	0.25
13	41.9	41.6	0.45	41.7	0.36	41.1	0.24
14	45.3	44.9	0.32	45.1	0.29	44.8	0.22
15	49.1	48.6	0.24	48.9	0.42	48.6	0.23
16	53.5	53.1	0.18	53.3	0.48	53.0	0.23
17	58.8	59.0	0.61	58.4	0.19	58.3	0.26
18	64.7	64.6	0.27	64.6	0.59	64.3	0.29
19	70.7	70.2	0.19	70.5	0.41	70.2	0.26
20	76.8	76.4	0.26	76.7	0.43	76.3	0.27
21	83.4	82.9	0.17	83.4	0.92	83.0	0.35
22	90.4	89.6	0.11	90.5	0.89	90.1	0.42
23	97.7	96.8	0.04	97.7	0.87	97.3	0.38
24	104.9	104.4	0.19	104.8	0.59	104.6	0.38
25	112.3	111.7	0.06	112.0	0.52	111.9	0.41
26	119.5	118.8	0.20	119.3	0.63	119.1	0.34
27	126.2	125.3	0.14	126.1	0.77	125.7	0.36
28	132.7	131.7	0.01	132.4	0.50	132.1	0.32
29	138.8	137.5	0.03	138.3	0.30	138.0	0.20
30	144.3	142.8	0.12	143.7	0.24	143.5	0.19

Table 10: Integral dose to the non target tissues (Body_PTV) for esophagus cases.

From the overall results, static IMRT plan with above 10 intensity level gives comparable results with dynamic IMRT plan. Though static IMRT with 5 level plans significantly affects target coverage and homogeneity, it may be used to plan where there is no stringent optimization needed; Ex PTV and OAR are located away from each other. So deprivation in conversion from TPS fluence and delivery fluence (discrete steps) may not play significant role in dose distributions of 5 level plans. Regardless of more MUs delivered in dynamic IMRT, the integral dose to NTT was not increased significantly compared to static IMRT. Hence hesitation about more MUs in dynamic IMRT delivery may be avoided as it is taken care by deliver system itself.

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