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Evaluation of out of field dose and comparison of dose to healthy tissue between VMAT and IMRT plans.

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Abstract

Background: Purpose of this study was to evaluate out of field dose calculation accuracy against measured dose and comparing the dose to healthy tissue between VMAT and IMRT plans. Methods and materials: We created a plan with various field sizes to deliver 1Gy dose at 1.58cm in a homogeneous phantom. The calculated dose along the central axis at three depths 1.58cm, 5.0cm and 10.0cm was noted down. Calculated monitor unit was delivered and measured. Dose difference between calculated and measured was found. Ten patients with prostate cancer were selected to evaluate healthy tissue dose with VMAT and IMRT plans. Difference between VMAT and IMRT plans was compared statistically. Results: The deviation between calculated and measured was lesser than 1% within the field. From field edge to 5cm the maximum deviation was -36%, -28% and -15% at Dmax, 5cm and 10cm depths respectively among all points. For larger field size the percentage of error was larger. VMAT controlled the higher doses to healthy tissue within the treatment field along with low and intermediate doses to tissues out of the treatment field ($p<0.002$). Conclusion: Out of field dose calculation accuracy was reduced for larger field size. VMAT can control dose to healthy tissue volume and it can help to reduce secondary cancer risk.

Keywords: Intensity Modulated Radiation Therapy, out of field dose, secondary cancer, Volumetric Modulated Arc Therapy.

Introduction

Though technologies have improved in external radiotherapy for conformal delivery of prescribed dose to the tumor, healthy tissues are still unavoidably irradiated. Few studies reported that radiation is one of the clear risk factor for secondary cancers [1-2]. A secondary malignancy is a histological distinct cancer that develops after the first cancer. Radiotherapy patients are at greater risk of developing a solid cancer than the general population [3].

Risk of secondary malignancy changed based on the Age, Sex and dose distribution [4-9]. Secondary malignancy risk changes 1) according to different dose distributions like low and high dose; 2) irradiation of different locations like healthy tissue within the primary treatment volume, at field edge and peripheral volume [10,3].

Dose received healthy tissues are classified into two categories; 1) healthy tissues within the treatment volume and 2) healthy tissues outside of the treatment volume. Dose to the healthy tissues is considered as non-target dose. This non-target dose is classified into three categories based on the approximate dose level. (i) high

dose (more than 30Gy or 50% of the prescribed dose), (ii) intermediate dose (3- 30Gy or 5- 50% of the prescribed dose) and (iii) low dose (less than 3Gy or 5% of the prescribed dose) [10]. Low radiation outside the treatment volume can cause deleterious effects to the patient [11].

Diallo et al. [12] found that 66% of secondary cancers occurred at the periphery of the treatment volume (from the field edge to 5cm), 22% occurred beyond 5cm from the treatment field and 12% occurred within the treatment volume.

The increasing modulation to achieve the planning objectives requires a large number of monitor unit leading to an increase in the head leakage and subsequent increase in the peripheral dose [11]. Increasing number of fields results in irradiation of a larger volume of healthy tissues [13].

Dose distribution with different delivery techniques differs due to their degrees of freedom. The requirement for each technique is different such as the method of delivery, number of monitor unit and number of fields [4,13].

A good radiotherapy plan should not only deliver the intended dose to tumor and spare critical structures but should also avoid the irradiation of surrounding healthy tissues as much as possible. According to the Task Group (TG) -158 [10] recommendations, plan evaluation has to include documentation of healthy tissue received dose since radiation is one of the carcinogenic factors.

Besides, many studies reported that between 3.75 cm and 11cm from field edge the average difference between measured and calculated dose was 40% to 50% [10,14] and especially in the dose range of 5% to 0.1% the difference would be larger [10]. Few more studies also showed that out of field dose calculation accuracy of commercially available planning systems underestimate the dose, therefore the dose evaluation of organs for estimating the risk involvement becomes a challenging task.

For precise plan evaluation, the calculated out of field dose by treatment planning systems has to be validated against the measured values. Dose calculation accuracy would help for risk estimation as well as in many clinical situations such as treatment of pregnant patients or patients with implanted pacemakers [15]. Therefore, we intended to carry out this study to validate our Treatment Planning Systems (TPS) against measured dose as well as comparing the out of field healthy tissue dose between VMAT and IMRT plans.

Methods and materials

For the validation of dose calculation accuracy, plans were created in a homogeneous water phantom using Eclipse TPS (10.0.39). 1 Gy dose was prescribed to the reference point at the depth of 1.58cm (Dmax) along the central axis for 100cm SSD. With this similar condition, dose was calculated for various field sizes ranging from 5X5 cm2 to 40x40 cm2. Dose was calculated using Anisotropic Analytical Algorithm (AAA) algorithm with 2.5mm calculation grid size. The calculated dose at central axis within the treatment field was noted down and out of field dose along the primary axis at six points (1cm, 2cm, 3cm, 4cm 5cm and 6cm from field edge) was noted down.

Similarly, dose at 5cm depth and 10cm depth was also noted down (figure 1).

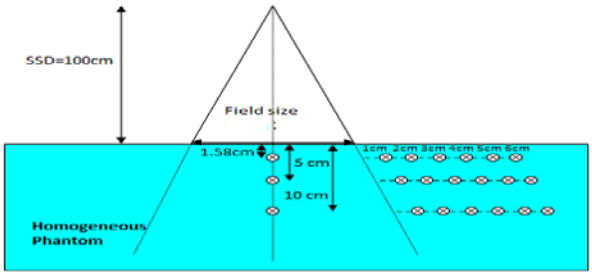

Figure 1. Dose measurements at various points in homogeneous phantom.

Dose measurements were carried out using 0.125cc thimble chamber in homogeneous water phantom (RFA). The TPS calculated monitor unit was delivered at SSD=100cm. Dose at three depths along the central axis and dose at various points along the primary axis at the three depths was measured (figure 1). Dose difference between TPS calculated and measured was found.

Ten patients with prostate cancer were studied. For this study purpose, two set of plans one with IMRT and another with VMAT were generated in the TPS. Both plans were optimized for 6MV photon with similar planning objectives. Dose was calculated using Anisotropic Analytical Algorithm (AAA) with 2.5mm calculation grid size. Plans were evaluated using various indices for Planning Target Volume (PTV) coverage and Sparing of Organs At Risk (OARs). In addition, various doses received healthy tissue volume within and out of treatment volume was also evaluated. The mean difference between IMRT and VMAT was analyzed using paired 't' and Wilcoxon signed rank test. $p<0.05$ was considered as statistical significant.

Results

Results showed that the maximum dose difference between TPS calculated and measured values at the center of the field was -0.64%,-0.65% and +0.71% at Dmax, 5cm and 10cm depths respectively (table 1).

	Dose at central axis within field			
Depth in water	**Field size (cm^2)**	**TPS (Gy)**	**Measured (Gy)**	**Difference (%)**
1.58 cm (Dmax)	5x5	100.00	99.50	0.50
	10x10	100.00	100.08	-0.08
	15x15	100.00	100.64	-0.64
	20x20	100.00	100.64	-0.64
	25x25	100.00	100.02	-0.02
	30x30	100.00	100.17	-0.17
	40x40	100.00	100.42	-0.42
5 cm	5x5	84.60	84.31	0.34
	10x10	86.70	86.56	0.16
	15x15	87.20	87.77	-0.65
	20x20	88.00	88.20	-0.23
	25x25	88.40	88.14	0.30
	30x30	88.60	88.32	0.31
	40x40	88.60	88.82	-0.25
10 cm	5x5	63.00	62.93	0.12
	10x10	67.10	67.03	0.10
	15x15	69.20	69.34	-0.21
	20x20	70.40	70.49	-0.12
	25x25	71.30	70.79	0.71
	30x30	71.80	71.29	0.71
	40x40	72.10	72.00	0.14

Table 1: Dose difference between TPS calculated and measured dose at central axis within field

Out of the field, the maximum dose difference among all points from field edge to 1cm and up to 6cm was -36%, -28% and -15% at Dmax, 5cm and 10cm depths respectively. Moreover, the absolute dose difference was -1.1cGy, -1.38cGy and -0.54cGy at Dmax, 5cm and 10cm depths respectively. The maximum difference was observed within 2cm and especially with larger field sizes. TPS calculated dose from 1cm to 6cm of the field edge was lesser than the measured values at all three depths (figures 2a,2b and 2c).

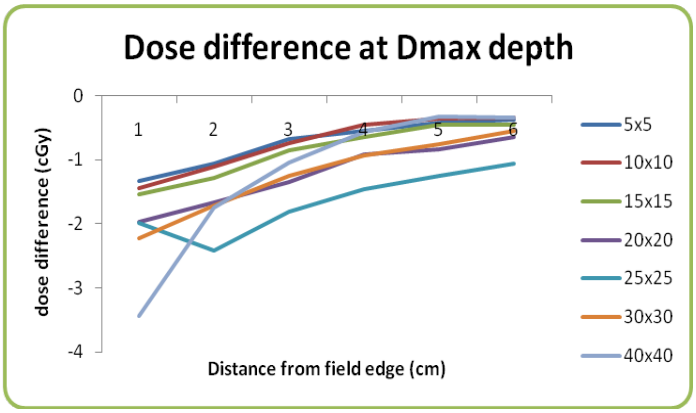

Figure 2 a.

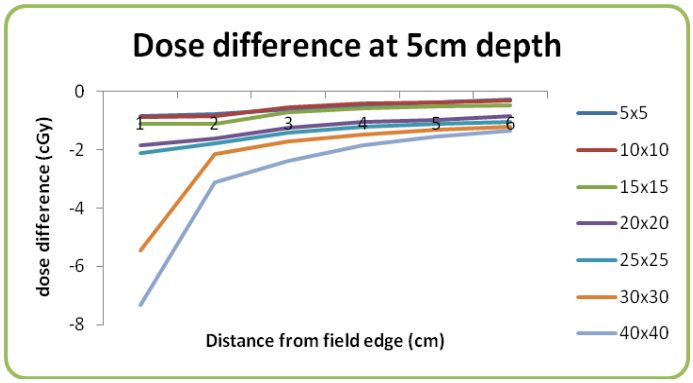

Figure 2 b.

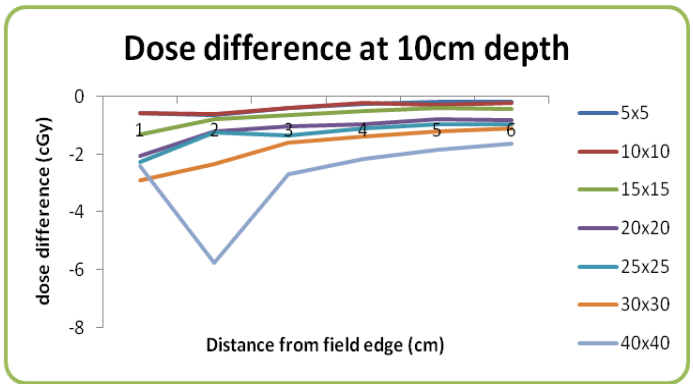

Figure 2 c.

Figure 2a,2b and 2c: Out of field dose difference between calculated and measured dose from field edge to 1cm and up to 6cm at three depths (Dmax, 5cm and 10 cm).

Both VMAT and IMRT plans achieved acceptable dose coverage and spared the OARs below the tolerance level. Moreover, low dose (5%) and intermediate dose (10%) were significantly ($p<0.05$) lesser with IMRT within the treatment field whereas VMAT reduced the low and intermediate dose to healthy tissue from field edge to 5cm significantly ($p<0.002$). VMAT also significantly reduced high dose (50%) to healthy tissue within the treatment field ($p<0.001$) (table 2 and 3).

Within treatment field			
Field region	**Dose received healthy tissue volume (%) Mean ± SD**		**p**
	VMAT	**IMRT**	
Low dose (5%)	94.32 ± 1.28	93.01 ± 5.73	0.018*
Intermediate dose (10%)	81.87 ± 4.72	76.53 ± 9.38	0.006*
High dose (50%)	5.88 ± 2.31	7.79 ± 2.89	<0.001$

Table 2: Dose to healthy tissue between VMAT and IMRT plans - within treatment field.

Out of treatment field			
Dose	**Dose received healthy Tissue volume (%) Mean ± SD**		**p**
	VMAT	**IMRT**	
Low dose (5%)	9.162 ± 2.93	12.810 ± 4.91	0.002$
Intermediate dose (10%)	1.438 ± 0.89	3.276 ± 1.92	0.001$

Table 3: Dose to healthy tissue between VMAT and IMRT plans – out of treatment field.

'*' - paired t test, '$' - Wilcoxon signed rank test, VMAT – Volumetric Modulated Arc Therapy, IMRT – Intensity Modulated Radiation Therapy, SD- Standard Deviation.

Discussion

AAPM TG-158 [10] reports recommended that dose to healthy tissue has to be evaluated and documented.

For risk estimation, the healthy tissue dose needs to be documented with different dose levels as well as different regions. Before the plan evaluation process, the dose calculation accuracy of the planning systems in different regions that are i) within the treatment field and ii) out of the treatment field has to be validated.

Majer M, et al [16] studied about out of field measurement and showed that the TPS underestimated the out of field doses with both IMRT and 3DCRT. Kaderka R, et al [17] observed a significant difference among the out of field doses at distances larger than 3 cm to the target. Huang et al [18]. reported that with this calculation errors, making a clinical decision would be unambiguous and especially in the case of pregnant patients and patients with implantable electronic devices. Moreover, they observed that dose underestimation by Pinnacle TPS was more than 30% within 4 cm and while approaching far from the field edge the error was 100% in their study. Our study also showed similar underestimated dose by TPS. However, the maximum difference was found with larger field sizes at all the depths. Though the configured beam profiles were measured below the 2% range, the TPS underestimated the dose within 6cm from the field edge. As the field size increases the penumbra also increases. Penumbral region plays an important role near the field edge especially within 3 cms. Moreover, this study also shows that dose underestimation increases with field size.

Followill et al [19] undertook a study of doses outside the treatment fields for IMRT and showed that for photons of 6-MV, 18-MV, and 25-MV the whole-body equivalent doses per cGy were 80 μSv, 6.5 μSv, and 10 μSv, respectively.

The dose increases with increasing scatter and leakage from the collimator head due to intensity modulation and are most noticeable farther from the treatment field. Near the field edge, the dose is dominated by patient scatter which is only dependent on the volume of target [20-21].

Higher dose (50%) to healthy tissue within the treatment field has to be reduced as much as possible. Dose to healthy tissue from field edge to 5cm has to be reduced to reduce the higher risk (66%) of secondary cancer [12].

Majer M, et al [16]. reported that IMRT increased the out of field (non-target) organ's dose than 3-Dimensional Conformal Radiotherapy (3DCRT) plan with a mechanical wedge. However, none of the studies addressed the high and low dose received healthy tissue volume. This study found that higher dose received healthy tissue volume was significantly lesser with VMAT than IMRT. Though IMRT showed significant reduction of low and intermediate dose within the treatment field, the involvement of secondary cancer risk is higher with 50% dose received healthy tissue volume [12]. Moreover, the low and intermediate dose to healthy tissue from field edge to 5cm (higher risk region) was significantly controlled with VMAT plan.

Though this was a comparison study, the documentation of the healthy tissue dose would help either in the selection of a plan or for making a clinical decision. Dose calculation accuracy has to improve with a suitable algorithm in order to account collimator scatter dose within and out of the treatment field and patient scatter dose within and out of treatment field.

TPS underestimates the out of field dose. Out of field dose calculation accuracy is reduced as the field size is increased. VMAT can control higher dose receives healthy tissue volume within the field as well as dose out of field dose in order to reduce secondary cancer risk.

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