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Out-of-field photon dosimetry study between 3-D conformal and intensity modulated radiation therapy in the management of prostate cancer

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► ***Original article***

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ABSTRACT

Background: The present work aims to study the out-of-field photon calculation accuracy of a commercial treatment planning system (TPS), Oncentra, for three-dimensional conformal radiotherapy (3D-CRT) and intensity modulated radiation therapy (IMRT) treatment techniques from Elekta Synergy medical linear accelerator. ***Materials and Methods***: Accuracy of individual out-of-field dose components was studied by defining a square field of 10 x 10 cm^2 in our TPS and it is verified by using ionization chamber and TLDs (Thermoluminescent dosimeter) at 5 cm depth. Using 3D-CRT and IMRT techniques Ca (carcinoma) prostate treatment plans were created using 6 MV photon beam and calculated in Oncentra Masterplan v4.3 planning systems for out-of-field and further compared the same with TLD measurements. ***Results***: Individual components study shows the poor out-of-field calculations in TPS, with respect to that obtained from TLD measurements. Underestimation increases from 10 % to 80 % as a contribution from various components while moving far from field edge. Complex IMRT plans resemble this underestimation of TPS calculations in greater extend. ***Conclusion***: This study quantifies the poor accuracy for out-of-field dose calculations in TPS. No significant difference in 3D-CRT and IMRT plans is found at near field edge. While, as distance from field edge increases, underestimation of TPS in IMRT plan is higher. 10 % – 60 % difference in out-of-field dose was found as distance move from 2 cm to 7.5 cm far from field edge between TPS estimations and the measurements.

Keywords: *TPS, TLD, out-of-field dose, 3D-CRT, IMRT.*

INTRODUCTION

Radiation therapy was effectively used for more than half of cancers as treatment. Usually, megavoltage ionizing radiations are applied to destroy cancerous cells. All treatments are optimized to give minimum possible dose to healthy tissues, while the dose to the tumor cells should be maximum and uniform. Radiation that contributes to the out-of-field normal tissues is important to analyze the risk of stochastic effects [1, 2], and the severity of deterministic effect [3].

The importance of out-of-field dose to estimate secondary probabilities especially in pediatric cases are widely dependent on the treatment planning system (TPS) based estimations [4, 5]. Treatment planning systems are modeling the treatment fields to deliver adequate dose to planning target volumes (PTV). Many planning algorithms are developed for accurate dose predication in field dosimetry, while out-of-field dose predictions are poor [6-8]. Less optimization is applied in out-of-field dose modeling in many commercial TPS.

Secondary cancer estimation studies from out-of-field dose calculations from commercial TPS underestimate the values. Recent studies have estimated out-of-field dose photon dosimetry in real clinical cases. Individual components contributing to out-of-field dosimetry are collimator scatter, leakage radiation and patient scatter (phantom scatter). Patient scatter is the main dose contributor near the field edge, while leakage radiation becomes the major contributor at large distances from the field edge [9, 10].

Modern techniques in radiation therapy involve multi leaf collimators for better dose conformity. Greater number of monitor units (beam on time) is used in IMRT. This can increase leakage radiations contributions to out-of-field dose [11]. Moreover the radiation therapy planning systems are not well commissioned for out-of-field dose calculations. Recently IMRT becomes more standard mode of treatment compared to 3D-CRTs in the management of prostate cancer [15, 16].

Despite of these reports, out-of-field dosimetry is not well studied in real clinical cases. Contributions from individual components study is scare. Therefore, the objective of this study was to quantify the variations in out-of-field dosimetry in clinical cases and studied the individual components contributions from Oncentra Masterplan v4.3 commercial treatment planning systems. All individual contributions towards the out-of-field dose are separately considered and analyzed systematically. 3D-CRT and IMRT plans were generated for studies on clinical cases.

MATERIALA AND METHODS

Treatment planning

All the irradiations are performed using 6MV photon beams form ELEKTA Synergy platform medical linear accelerator (ELEKTA, England) equipped with 120-leaf multi leaf collimators (MLC). To study all possibilities of out-of-field dosimetry, we considered the point dose contribution from any depth in out-of-field is the combination of leakage radiation, collimator scatter and phantom scatters. As shown in figure 1, Oncentra calculated the out-of-field individual components for 10 × 10 cm^2 field size in PMMA (poly Methyl Meta Acrylic) slats at a depth of 5 cm. By directing the beam out of the phantom, we calculated the combination of leakage and collimator scatter (L+S). In the same beam direction, but completely closing the MLC and diaphragms, Oncentra calculated the contribution from leakage alone (L). While directing the beam to phantom gives the total contributions from all three possible components (T). Then the individual components are calculated based on the following equation:

Total out-of-field dose (T) = Leakage (L) + Scatter (S) + Phantom (P)

Four field 3D-conformal (3D-CRT), five and seven field intensity modulated radiation treatment (IMRT) plans were generated, for 10 patients (during the period of September 2012 – September 2013) following the approval of research and ethics committee approvals for this study (AJ hospital-Karnataka and Nanvathi hospital-Mumbai-India). Ca prostate were selected as prevalence to the cases seen in the department. All plans are optimized using collapsed cone convolution algorithm available in Oncentra Masterplan v4.3 for better conformity in target regions [12]. The average student's t-test value found to be 0.02 (0.001 < p

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< 0.07) for all patients.

Out-of-field doses in different points corresponding to critical organs in each plan were identified and dose from treatment planning system is calculated in 3D-CRT and IMRT cases, separately. Due to the lack of an anthropogenic phantom, elliptical IMRT phantom was used to represent the pelvic sections in our study. Beam orientations in all plans are shown in figure 2.

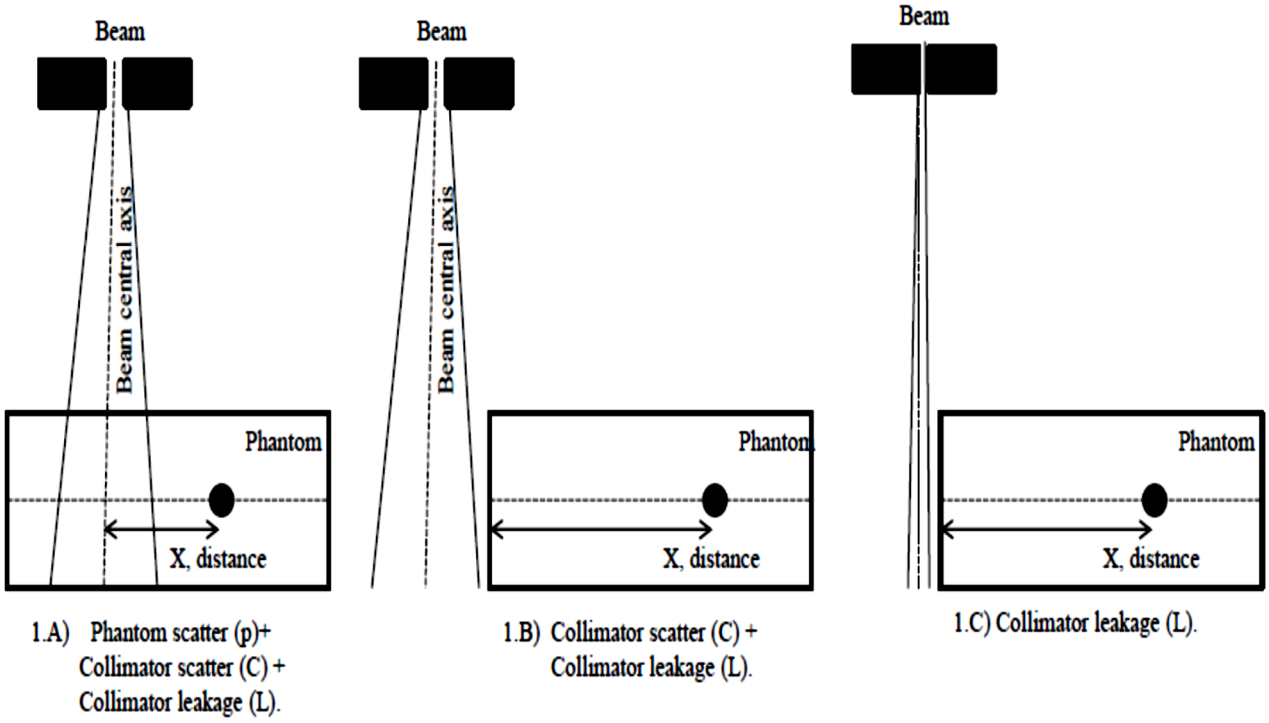

Figure 1. Configuration for individual component measurements for out-of-field dose.

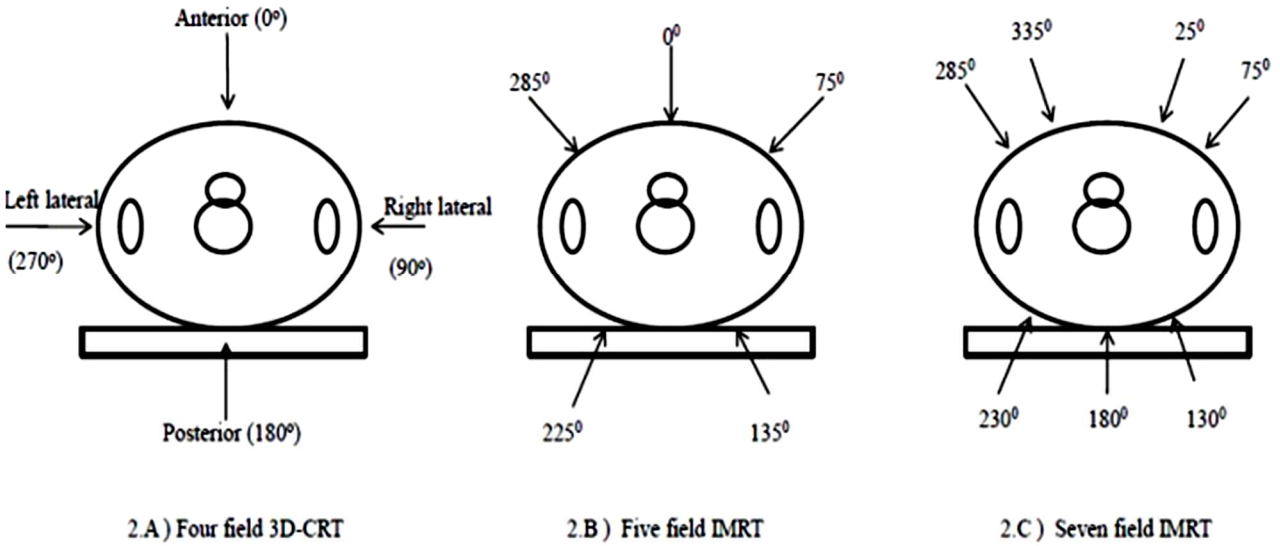

Figure 2. Beam orientation in elliptical IMRT phantom.

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Phantom and TLD measurements

PMMA solid phantom (Wellhofer, Uppsala, Sweden) made water equivalent elliptical plastic phantom is used in our study for phantom measurements. Indigenously build TLD holder, 1 cm thick of PMMA plate, is used to place TLD discs in desired places. Figure 3 shows the TLD holder plate. Our LINAC had been pre-calibrated with Farmer ionization chamber (0.6 cm^3 PTW 30001) and associated PTW Freiburg electrometer (PTW 10008), using TRS 398 D_w protocol [13].

$CaSO_4$: Dy (Dysprosium Doped Calcium *Sulphate*) TLD, of dimensions 7 = 7 = 4.^{3} mm^3, is used for out-of-field and organ dose measurements. Tissue equivalence characteristic of detector, linearity of response within the energy range of interest, small size and its wide availability justify its choice among other possible detectors [14]. The dosimeters were read in a Harshaw Bicron 3500 automatic TLD reader (Solon, Ohio, USA). They were annealed before each exposure for 1 h at 400°C and 20 h at 80°C. TLDs were placed in various out-of-field locations as described above for ionization measurements. Organ dose measurements are taken by placing TLD in anatomical points of interest. Two TLD discs were inserted into the predrilled holes in the holder plates, which were averaged to obtain the measurement of that location. TLDs are calibrated using 6MV photon beam in the same linear accelerator (ELEKTA Synergy, England), with that employed for all dosimetric measurements presented in this study. 2Gy prescribed at 5 cm depth of 10 × 10 cm^2 radiation fields is used for the calibration at SSD (Source to Surface Distance) 100 cm. Two TLD discs are kept for background measurements from the same batch of discs and the background signal was subtracted from final TLD readings. Accuracy of individual out-of-field dose components for open field is studied using TLD measurements, comparing the TPS calculated as shown in figure 4. ROOT v5-34 [17] software was used to plot these values after dependent Student's t-test for statistical acceptance ($p < 0.07$). Percentage of error in different components contribution is tabulated in table 1. TPS calculated and TLD measurements are compared and shown in table 2-4 for different anatomical locations, organs-at-risk for 2Gy per fraction prescription.

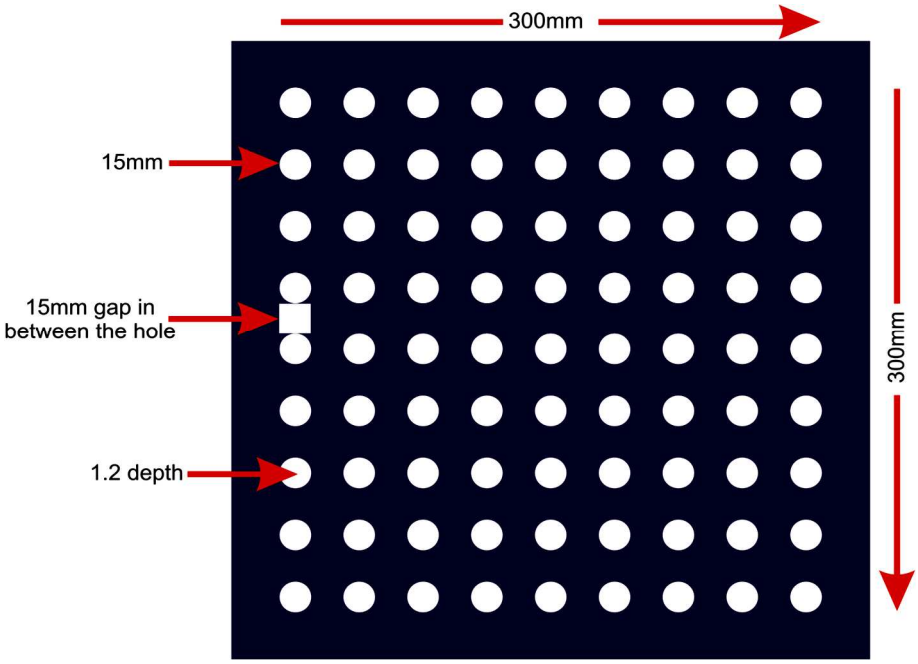

Figure 3. Custom build TLD holder plate made out of PMMA.

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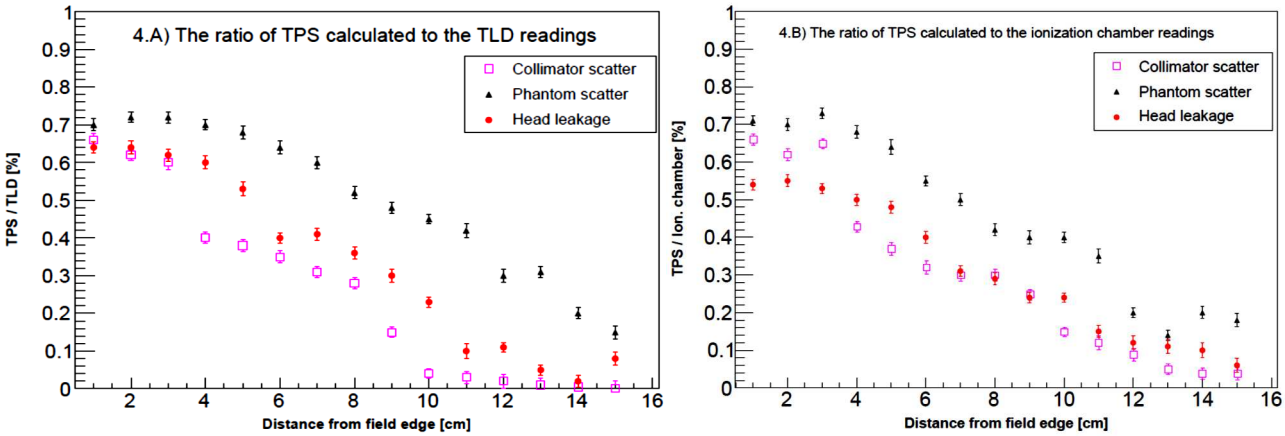

Figure 4. Different components contribution for out-of-field dose for an open field of 10 x 10 cm^2 at 5 cm depth.

Table 1. Percentage variations of out-of-field doses from 6MV due to phantom scattering, collimator scattering and head leakage of 10 x 10 cm^2 open field at 5 cm depth.

Distance (cm)	Individual components (%)			Total (%)
	Phantom scatter	Collimator scatter	Head leakage	
0 – 5	3 – 12	6 – 17	5 – 8	5 – 20
5 – 10	13 – 38	18 – 29	9 – 12	21 – 43
10 – 23	39 – 62	30 – 38	13 – 18	43 – 65

Table 2. Mean TLD measured (D_{TLD}) and mean TPS-calculated (D_{TPS}) doses for organs at risk in 3D-CRT Ca prostate treatment per fraction (2Gy). All readings with standard error (SD) are shown.

Organs at interest (Mean distance from field edge, cm)	D_{TLD} (Gy) Mean ± SD	D_{TPS} (Gy) Mean ± SD	D_{TLD}/ D_{TPS} Mean ± SD
Bladder (2.6)	1.85±0.52	1.74±0.26	1.063±0.43
Rectum (2.5)	1.45±0.47	1.32±0.32	1.098±0.29
Right Femoral Head (7.3)	1.07±0.51	0.94±0.46	1.138±0.58
Left Femoral Head (7.3)	1.09±0.36	0.94±0.41	1.159±0.47

Table 3. Mean TLD measured (D_{TLD}) and mean TPS-calculated (D_{TPS}) doses for organs at risk in 5 field IMRT Ca prostate treatment per fraction (2Gy). All readings with standard error (SD) are shown.

Organs at interest (Mean distance from field edge, cm)	D_{TLD} (Gy) Mean ± SD	D_{TPS} (Gy) Mean ± SD	D_{TLD}/ D_{TPS} Mean ± SD
Bladder (2.6)	1.36±0.45	1.29±0.28	1.054±0.26
Rectum (2.5)	1.62±0.48	1.54±0.41	1.052±0.3
Right Femoral Head (7.3)	0.80±0.41	0.69±0.31	1.159±0.35
Left Femoral Head (7.3)	0.81±0.36	0.68±0.27	1.191±0.29

Table 4. Mean TLD measured (D_{TLD}) and mean TPS-calculated (D_{TPS}) doses for organs at risk in 7 field IMRT Ca prostate treatment per fraction (2Gy). All readings with standard error (SD) are shown.

Organs at interest (Mean distance from field edge, cm)	D_{TLD} (Gy) Mean ± SD	D_{TPS} (Gy) Mean ± SD	D_{TLD}/ D_{TPS} Mean ± SD
Bladder (2.6)	1.22±0.58	1.16±0.37	1.051±0.32
Rectum (2.5)	1.44±0.67	1.37±0.43	1.051±0.47
Right Femoral Head (7.3)	0.72±0.26	0.62±0.19	1.161±0.24
Left Femoral Head (7.3)	0.72±0.34	0.61±0.22	1.180±0.28

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RESULT

The study of the individual components contribution normalized to the TPS calculated is shown in figure 4. The ratio of TPS calculated to the TLD measured and the ratio of TPS calculated to the ionization chamber readings are shown in figure 4(a) and figure 4 (b) respectively. Due to high statistical variations in individual component values the field distance after 2 cm from the field edge is considered to plot above diagrams. The components value is the average of the readings from two opposite sides (the gantry side and the target side) in the case of ionization measured and TPS calculations. While the target side readings are taken for TLD measurements, due to the expense for a large quantity.

Table 1 gives the percentage of errors in individual components estimation from TPS and TLD measurements. As distance from field edge increases overall underestimation increases from 5 % to 65 % at a distance of 23 cm. Phantom scatter component was in good agreement in near field edge (~5cm). An increase of 50 % underestimation is observed for a distance of 10 cm far from the field edge. Collimator scatter was underestimated by TPS in near field (15%) and increases as the distance increases (38%). Head leakage was underestimated by TPS consistently up to 5 cm by 5 %, while increases rapidly to 18% at far distance. 5 cm depth of the measurement will attenuate the low energy head leakage components to greater extend. All components are poorly modeled by the TPS in out-of-field.

Table 2–4 lists the mean TPS calculated and TLD measured (2 to 5 TLDs are placed) doses in all different treatment modes used in the study. IMRT plans underestimate out-of-field dose more than 3D-CRT plan. T2BN0M0 stage Ca prostate plan with PSA level 6.68ng/mL and Gleason score 8 is used in the study. Critical organs of interest in out-of-field are bladder, together with rectum and femoral heads.

The figure 4 A and 4B shows that near the edge of the treatment field (within 10cm of the field edge), the TPS severely underestimates the contribution from individual scatter components. Head leakage and phantom scatter components are consistently underestimated (by approximately 30 %) up to 10 cm from the field edge. TPS calculated head leakage and collimator scatter dropped below 10 %. Head leakage and collimator scatter are the dominant source of out-of-field dose at large distances from the field edge.

DISCUSSION

Our measurement data showed that the TPS calculated out-of-field doses are underestimated [23, 24]. A measurement using TLD and ionization chamber proves this conclusion in our study, taking the individual contribution of scatters separately. In an extensive review on the out-of-field dosimtery, numerous authors have measured out-of-field doses in several phantom designs, including water tanks and similar simple geometrical phantoms, and anthropomorphic phantoms [21,23,25,26], few are really considered the individual scatter contributions separately. To pinpoint the weakness of TPS for out-of-field dosimetry, we taken to account the error in dose calculation associated with each individual component of dose.

The TPS accuracy is worsened to 20 % underestimation as the distance of the organ of interest from the field edge increased (femoral heads) [16]. Still, even notice the 5 % substantial dose underestimation by TPS, for organs located close to the field (e.g. bladder and rectum). 5field and 7 field IMRT plans have slight difference (< 3 %) in femoral head location out-of-field dose, while the uncertainty associated with individual TLD readings was ≤ 4% [27]. Likewise, higher number of fields can affect more on out-of-field uncertainty and higher dosage. Inhomogeneity corrections for bladder and femoral head must be counted before actual underestimation.

Poor accuracy of out-of-field dose calculations in treatment planning system will be more severe in complex IMRT plans than that shown for open field [6]. This explains the dose difference in different locations seen in clinical cases. Underestimation of all components equally contributes to a higher inaccuracy in all

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treatment plans and critical organ dose calculations in out-of-fields. The severity of these underestimations increased for increasing distances from the field edge, as mentioned in previous studies [8-10, 24]. An interesting implication of these TPS inadequacies is that despite the different out-of-field dose distributions associated with new treatment techniques, such as volumetric-modulated arc therapy (VMAT) and radiation therapy with flattening filter-free (FFF) beams, the out-of-field accuracy of the TPS should not be expected to be different from that of IMRT because the same fundamental limitations in the TPS exist [28].

In this study, we have taken consider conformal and IMRT treatment modes for Ca prostate management. Under estimation of out-of-field dose from TPS calculations was the same in both modes of treatments as discussed in the recent studies [18, 19]. In IMRT treatments a difference of 5 % more inaccuracy was noticed in this study compared to 3D-CRT. Small field IMRT was widely used for the management of prostate cancer, the complete understanding of out-of-field dosimetry is essential [20]. We have provided direct evidence on importance of out-of-field dosimetry for clinics using common methods for prostate cancer managements in radiation therapy.

We studied only 6 MV photons, it would be also be interesting to quantity the error associated with TPS-calculated out-of-field doses for IMRT treatment with other photon energies as well. Higher photon energies should be associated with more leakage radiation and less patient scatter [21, 24]. Further studies are needed to investigate the accuracy for higher energy photons, which is beyond the scope of the current study.

Secondary cancer risk estimation studies and other dosimetric evaluation based on TPS out-of-field measurements severely affect the outcome. Care must be taken to evaluate the out-of-field dosimetry studies based on TPS values, without experimental validation using commonly available dosimeters, like ionization chambers or TLD measurements in any clinical situations. Our study emphases these points, which matches the previous studies as well [21, 22].

CONCLUSION

Out-of-field dose calculation accuracy is found very poor in the treatment planning system. Oncentra treatment planning system underestimates the out-of field by an average of 50%. Underestimation of-out-field dose increases to 65% with respect to TPS results, as distance from field edge increases to 7.5 cm. Individual component of out-of-field dose measurements shows that collimator scatter and leakage are higher at dmax (depth of maximum dose), while phantom scatter increases at further distances. We found that 3D-CRT and IMRT differ very little on out-of-field dose. Moreover, we found that IMRT out-of-field dose measurements are less accurate (5%) than those performed by standard 3DCRT techniques.

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