Original

Evaluation of AAA and XVMC Algorithms for Dose Calculation in Lung Equivalent Heterogeneity in Photon Fields: A Comparison of Calculated Results with Measurements

Singh N.[1]*, Painuly N. K.[1], Chaudhari L. N.[2], Chairmadurai A.[3], Verma T.[1], Shrotiya D.[4], Bhatt C.P.[5]

[1]Department of Radiotherapy, King George Medical University, Lucknow, India
[2]M.S. Patel Cancer Center, Shree Krishna Hospital and Research Centre, Karamsad, Gujarat, India
[3]Department of Radiotherapy, Jaypee Hospital, Noida, Uttar Pradesh, India
[4]Department of Radiotherapy, J.K.Cancer Hospital, Kanpur, Uttar Pradesh, India
[5]Department of Radiation Oncology, Batra Hospital, New Delhi, India

ABSTRACT

Aims: The aims of the present work are (1) to evaluate dose calculation accuracy of two commonly used algorithms for 15 MV small photon fields in a medium encompassing heterogeneity and (2) to compare them with measured results obtained from gafchromic film EBT2.

Materials and Methods: Authors employed kailwood (Pinus Wallichiana) to mimic lung. Briefly, seven Kailwood plates, each measuring 25x25 cm^2 of varying thicknesses totaling 13 cm equivalent to the mean thickness of an adult human lung, were sandwiched between 5 cm tissue equivalent material from top and 10 cm below. Physical measurements were performed using Radiochromic film EBT2. The field sizes of 1x1, 2x2, 5x5 and 10x10 cm^2 were selected at 100 cm SSD. Simulations were performed using EGSnrc/DOSRZnrc Monte Carlo code. The dose variation inside the inhomogeneity and near the interface was calculated using AAA & XVMC algorithm.

Results: Preliminary results show that there is large variation of dose inside inhomogeneity. The maximum variation of dose inside the inhomogeneity for 1x1 cm^2 was found 40% by AAA and 4.5% by XVMC compared to measured/simulated results. For the field size of 2x2 cm^2, these figures were 27% by AAA & 3.5% by XVMC. For 5x5 cm^2 field size, the variation is small which becomes insignificant for larger fields.

Conclusion: The results presented in this work indicate that for smaller fields, XVMC algorithm gives more realistic prediction, while there is the need for caution on using AAA algorithm for dose calculations involving small area irradiation encompassing heterogeneities and low-density media.

Keywords
EGSnrc, Monte Carlo Simulation, Gafchromic Film, AAA, XVMC

Introduction

Oncology treatments employing radiation rely on a treatment planning system (TPS) for accurate dose planning. TPS based on commonly used analytical algorithms like effective path length (EPL), Batho, Modified Batho, Equivalent tissue-air ratio (ETAR) and differential scatter ratio (DSAR) has limitations upon predicting a accurate dose in biological systems encompassing inhomogeneity as well as at the interface of two different density mediums. TPS based on these algorithms does not follow the recommended acceptability criteria of +/- 3% between the delivered and calculated doses specially for small field

*Corresponding author:
N. Singh
Department of Radiotherapy, King George Medical University, Lucknow-226003, India
E-mail: navinkgmu@gmail.com

sizes as these corrections based algorithms do not take into account lateral electronic disequilibrium that takes place in such conditions [1-6].

Density variation in lung tissue also produces significant perturbation for narrow beams affecting the accuracy of dose calculation. There is a lot of ambiguity in dose assessment using different algorithms. Correction-based algorithms which correct primary photon transport only (E-depth, RTAR) and primary and scattered photon transport (ETAR) yield poor results compared to those algorithms which correct primary & scattered photons and charge particle transport [7-9]. Anisotropic Analytical Algorithm (AAA) takes into account lateral electron transport apart from correcting primary and scattered photons. The level of accuracy improves with the use of more sophisticated treatment planning algorithms where multisource modelling is included, allowing a more accurate dose prediction for small fields and non-equilibrium conditions [10-13].

The present work has been undertaken to evaluate the dose calculation accuracy of two commonly used algorithms i.e. AAA and X-ray Voxel-based Monte Carlo simulation (XVMC) for 15 MV small photon fields in a medium encompassing heterogeneity. These results have been compared with measurements performed using gafchromic film.

Material And Methods

A thoracic geometric phantom was created using tissue equivalent solid water phantom and kailwood (Pinus Wallichiana) to mimic lung. The range of HU for Kailwood obtained using 16 slices of Big Bore Philips CT simulator (Brilliance) varied between -610 to -690, average being - 630. Using the following equation:

Relative Electron Density = HU/1000 + 1

The relative electron density of the kailwood material is obtained 0.37.

Kumar et al., [14] measured the physical and radiological parameters of kailwood material experimentally using gamma rays from telecobalt machine, then found that these values were on the range of HU and relative electron density derived from CT; they have shown that the kailwood can be used as a lung equivalent material. The physical measurements of absorbed dose at different points were performed using international speciality product (ISP) Gafchromic EBT2 dosimetry film [15]. It is tissue-equivalent and has a high spatial resolution and almost flat energy responses in the energy range under consideration. Gafchromic film after exposure does not require any chemical, physical or thermal processing.

Experimental Setup

The experimental setup is shown in Figure 1. Briefly, seven Kailwood plates each measuring 25x25 cm² of varying thicknesses totaling 13 cm equivalent to the mean thickness of the adult human lung were sandwiched between 5 cm tissue equivalent solid water phantom from top and 10 cm below it. Gafchromic film EBT2 was cut into small pieces of size 5x5 cm² and was marked at one corner on the same side to maintain symmetry. These films were inserted between Kailwood plates at various points as shown in Figure 1.

The field sizes selected for this study were 1x1 cm², 2x2 cm², 5x5 cm² and 10x10 cm² at the top surface of the experimental phantom at 100 cm SSD. Dose of 2 Gy was delivered at dmax using single anterior field (Gantry angle 0 degree) of 15 MV X-rays from Elekta (Synergy) linear accelerator. PDD values along central beam for this setup were calculated using XVMC (Monaco) and AAA (Eclipse, version 10.0).

The CT image of experimental phantom was taken in the dicom format and transferred to TPS. The inhomogeneity present in the phantom was taken care of during dose calculation by CT to electron density file, which was initially measured and entered in TPS.
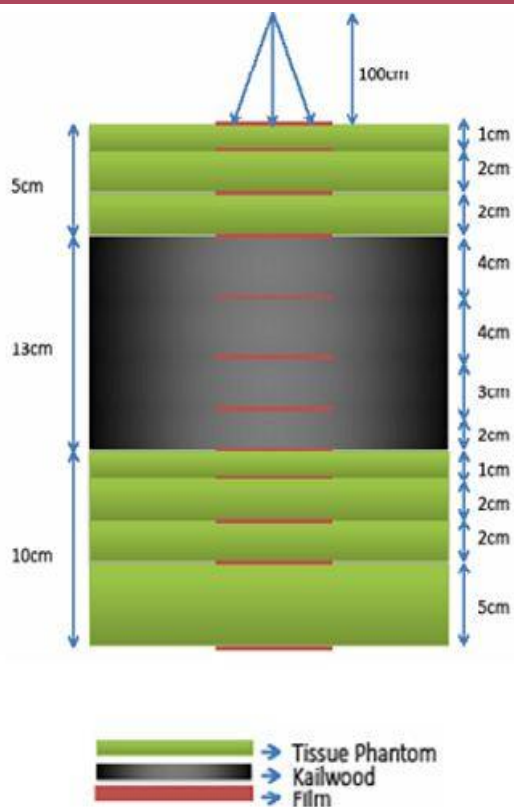
Figure 1: Experimental Setup

Film Calibration

Eight pieces of gafchromic film measuring 5x5 cm^2 was cut from the same sheet and marked on one corner to maintain the original symmetry of film during irradiation and scanning. Each of these films was placed horizontally beneath the 5 cm solid water slab and exposed to different known doses of X-rays 25cGy, 50cGy, 100cGy, 200cGy, 300cGy, 400cGy & 500cGy from 15 MV Linear Accelerator using 10x10 cm^2 field size. An EPSON EXPRESSION 10000 XL flatbed color scanner was used to scan films. All irradiated films were scanned in a professional mode with a resolution of 72 dpi (0.35 mm/ pixel) in landscape orientation to keep pixel response uniform. To ensure the reproducibility and the accuracy of results, films were selected from the same batch and stored in light tight envelopes, when not in use. A calibration curve was drawn between optical density and dose. Measurement of the density was made from

the central part of the film to minimize the non-uniformity of response. For the procedure followed in this study, our statistical uncertainty of film dosimetry is estimated to be around 2.0 %.

Monte Carlo Simulation

MC simulation was performed using DOS-RZnrc user code that comes with EGSnrc V4 2.4.0 [16, 17, 18]. It is a general purpose Monte Carlo transport code, which can take the cylindrical geometry only and therefore square fields selected for this study were converted into circular fields [19]. Mohan15.Spectrum which comes with EGSnrc code system used as the photon spectrum incident perpendicular to the phantom [20]. Electron Range Rejection, a variance reduction technique was used with parameter ESAVEIN = 2 MeV. PRESTA-II was enabled for all electron transport. The particles were transported with a cutoff energy of AP=PCUT=10 keV for photons and AE=ECUT=521 keV for electrons. The dose scoring cells used for EGSnrc/DOSRZnrc code were cylinders with radius 3 mm and height 1mm.

For simulation, the solid water phantom and kailwood are replaced with water H2OIC-RU521 and lung LUNGICRU521, respectively as defined in Report 37 of the International Commission on Radiation Units and Measurements (ICRU 37) [21, 22, 23]. The number of histories generated was sufficient to produce a statistical variance of less than 0.5% in the dose-per-incident fluence

Results

Percentage depth dose (PDD) data for field sizes of 1x1, 2x2, 5x5 and 10x10 cm^2 in a homogeneous water phantom was obtained using Monte Carlo simulation and compared with data measured using radiation field analyzer (PTW-M). For field sizes less than 5x5 cm^2, PDD was measured by a pinpoint ion chamber (PTW; 31016) and for larger field sizes, 0.125cc ion chamber (PTW; 31010) was used

for 15 MV photon beam. The results of measured PDD are close to simulated data for all field sizes (close to 2%). Figure 2 depicts the relationship between simulated data and measured data for the field size 10x10 cm².

Validation of Gafchromic Film Results against Simulation Data

Gafchromic film results were validated against Monte Carlo (MC) simulation results. Percentage depth dose data for 15 MV X-ray photon beam at 100 cm SSD for field sizes 1x1, 2x2, 5x5 and 10x10 cm² using various algorithms for the experimental setup have been plotted and compared with the results obtained using Gafchromic film and simulation [Figures 3, 4, 5 & 6]. The measured values from Gafchromic film are in good agreement with the simulation data for all field sizes (± 3%).

Film Data Vs Calculated Data using Algorithms

The dose difference (Δ) between the calculated (AAA and XVMC) and measured PDD film data for field sizes 1 × 1, 2 × 2, 5x5 and 10

× 10 cm² is calculated using relation:

For small field sizes, both algorithms AAA & XVMC overestimated the dose near the proximal end as well as inside the Kailwood. The maximum variation of dose compared to reference (measured/simulated) data inside the inhomogeneity for 1x1 cm² was found 40% by AAA, whereas it was 4.5% using XVMC. The variation at the proximal surface (Tissue/Kailwood interface) was obtained 17% using AAA and 3% by XVMC with respect to reference data.

At distal surface (Kailwood/Tissue interface), the variation is 11.7% by AAA and 4% by XVMC with respect to reference data. Beyond distal interface (at 0.5 cm), the film measurement was not feasible and therefore TPS calculated data was compared with the simulation data. At this point, AAA (statistical variance 2%) underestimates the dose by 11% and XVMC by 4%.

In the region of second buildup, dose measurements are very difficult especially in real clinical situations and therefore measurements in this region require close monitoring. Monte

$$\Delta(\%) = \frac{Calculated\left(AAA\,or\,XVMC\right)PDD - Measured\left(Film\right)PDD}{Measured\,PDD} \times 100$$
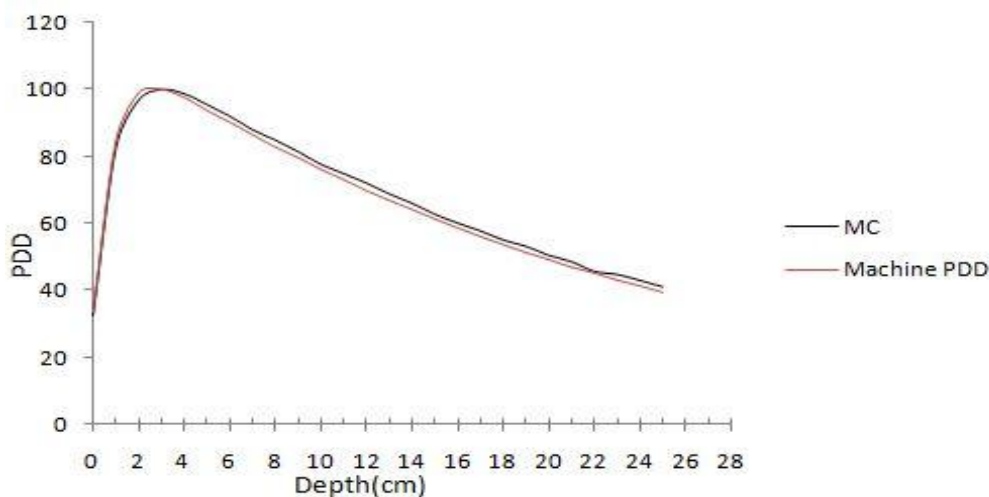
Figure 2: Variation between MC and Machine PDD Data for 15 MV Photon Beam in Homogeneous Medium for Field Size 10x10 cm²
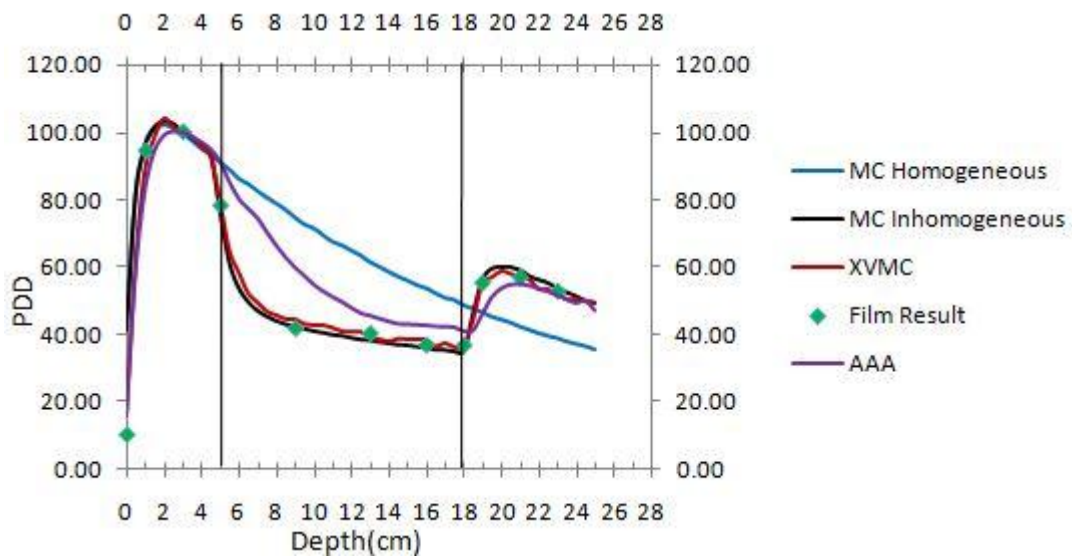
Figure 3: Variation in PDD of different Algorithms for 15 MV Photon Beam in Inhomogeneous Medium for Field Size 1x1 cm²
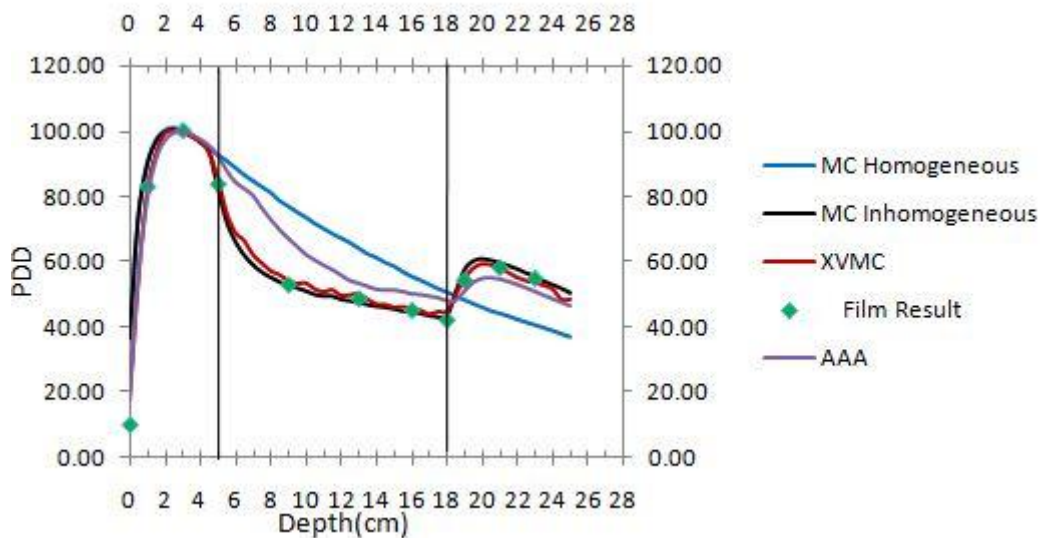

Figure 4: Variation in PDD of different Algorithms for 15 MV Photon Beam in Inhomogeneous Medium for Field Size 2x2 cm²

Carlo simulation, however, gives acceptable results. Beyond the second buildup region, the two algorithms come close to the reference dose.

For the field size of 2x2 cm², the maximum variation of dose inside the inhomogeneity was found 27% by AAA & 3.5% by XVMC. Variation at proximal interface was obtained 11% using AAA & 2.8% by XVMC. At the distal interface, this variation is 19% by AAA and 3.6% by XVMC with respect to film data. Beyond distal interface (~ 0.5 cm), there is underestimation of 5.3% by AAA and 1.6% by XVMC with respect to MC data.

For field sizes 5x5 cm², the variation between reference and calculated data is small. For AAA the maximum variation is 6.0 % and for XVMC 2.0 % inside the inhomogeneity.
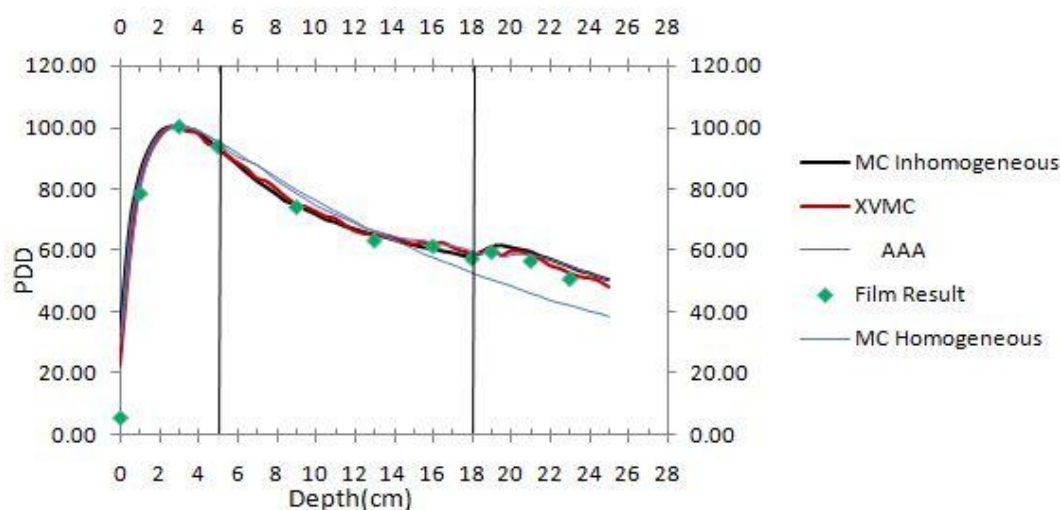
Figure 5: Variation in PDD of different algorithms for 15 MV photon beam in inhomogeneous medium for field size 5x5 cm^2.
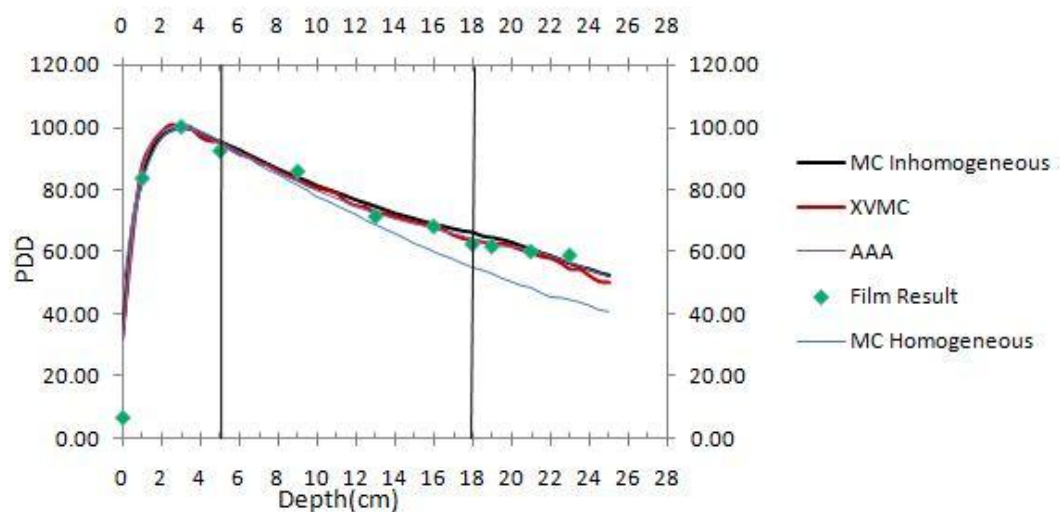

Figure 6: Variation in PDD of different algorithms for 15 MV photon beam in inhomogeneous medium for field size 10x10 cm^2.

Variation at proximal and distal interfaces is not significant. For larger fields i.e. 10 x 10 cm^2, the two algorithms are very close to reference data inside and outside inhomogeneity. At the interface, also, there is not any significant variation for larger fields. This is obvious since electronic equilibrium is not disturbed near the interface for such fields.

Discussion

For small field irradiation using high en-

ergy X-ray beams, there is the fluctuation of the absorbed dose at the proximal end because of the density variation and the reduction of secondary electrons leading to dose build-down region. At distal end, the production of secondary electrons increased due to the density difference and therefore beyond distal end electronic equilibrium is again established. Algorithms, which assume the equilibrium condition within inhomogeneity, over predict the dose since the average longitudinal range

of an electron set in motion by 15 MV X-ray beam is approximately 3 cm in water (i.e., dmax), which is elongated to approximately 8.0 cm in kailwood (density 0.37). Laterally, electrons will be scattered over a distance approximately 1/3 to 1/2 of this range, that is, approximately 2.5-4 cm, thus irradiation of kailwood with a minimum field width equal to twice this lateral range (i.e., 5-8 cm) is needed to maximize the dose along the central axis of the beam [5].

It is evident by comparing film results with TPS data that AAA algorithm is not very accurate in predicting PDD values in kailwood for small fields at the interface of two different density materials as well as inside the inhomogeneity. For field size 1×1 cm^2, 40% overdosing in kailwood is predicted by AAA inside the inhomogeneity, whereas it is 4.5% by XVMC. Da rosa et al. have reported 40% overdose near soft tissue/lung interface for 1x1 cm^2 field size and 20% for 2x2 cm^2 using AAA algorithm for 15MV photon beam [24]. For field size 2x2 cm^2, authors found that AAA and XVMC both overestimate the dose by 27% and 3.5%, respectively. In a similar study, Duch et al. found overdosing by 39% for 18MV photon beam for field size 2x2 cm^2[25]. Chetty et al. also studied the effect of low-density heterogeneity for small fields and high-energy photon beams and their results are consistent with the present study i.e. 30% dose reduction for a 2x2 cm^2 field and 15 MV photon beam [26].

Beyond distal end (~ 0.5 cm), both algorithms underestimate the dose for small fields. For field size 1x1 cm^2, the dose variation is 11% and 4% by AAA and XVMC and for 2x2 cm^2; variation is 5.3% and 1.6%, respectively with respect to the reference data.

Thus, the field size 1x1 cm^2 and 2x2 cm^2 are inadequate in the achieving lateral equilibrium in a low density medium such as kailwood and therefore there is a significant reduction in the dose. For the field size 5x5 cm^2, the electronic disequilibrium is greatly reduced; although, its

presence can still be detected. For larger fields this becomes insignificant.

At distal end (Kailwood & Tissue interface), there is dose build-up in the forward region away from the source due to a increase in the photon fluence and reduced attenuation.

Conclusion

The dose prediction accuracy of AAA and XVMC algorithm in the presence of inhomogeneity was assessed by comparing experimental measured results using gafchromic film for 15MV photon beam. The results presented in this work indicate that some differences exist between two algorithms in calculating effects of inhomogeneity in dose calculations. For smaller fields, XVMC algorithm gives a more realistic prediction (results obtained using XVMC are close to reference i.e. gafchromic film results), while there is a need for caution when using AAA algorithm for dose calculations involving small area irradiation encompassing heterogeneities and low-density media. These deviations were calculated for the single beam set-up and slab phantom with normal incidence, in reality, inhomogeneity (e.g. lung) and tumor both will have irregular shape and geometry and hence the extent of deviation may be large for actual clinical setting and irradiation techniques.

Conflict of Interest
None

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