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Evaluation of Calculation Algorithms for photon Beam dose in Heterogeneous Medium

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Abstract

The success of the implementations of a radiotherapy treatment planning system is determined by the ability of the dose calculation algorithms to reproduce the algorithm input data, and in most cases the agreement was found within ±2%. Varian linear accelerator DMX, TPS Eclipse (version 10.33) is used and absolute dosimetry and relative dosimetry system (PTW, Freiburg, Germany) and 2D array were also used. The Calculation of Analytical Anisotropic Algorithm (AAA) is more accurate than the Pencil beam Algorithm (PBC) in heterogeneity medium in comparison with practical measurement. The extent of the effort required to carry out a validation study of the complexity of that described here precludes its use as a routine component of TPS commissioning. Our realistic recommendation is that commissioning includes tests aimed at confirming that raw beam data have been entered correctly and that the operation of the system is understood. Finally, the study tell us that the observed deviations between TPS calculated using Eclipse version 10.33 and measured dose in the present of heterogeneous medium are well within the tolerance levels and the study also show that the use of Eclipse (version 10.33) TPS, AAA algorithm records significant improvement than the previous TPS versions especially in the present of low density inhomogeneity.

Keywords

Treatment planning system- photon beam- Algorithms- Heterogeneous Medium.

INTRODUCTION

Many calculation algorithms are used in treatment planning systems (TPSs) for external beam radiotherapy. The algorithm input data required to implement a treatment unit in the TPS which generated by PBC and AAA are the beam reference data needed for the subsequent evaluation of the dose calculation algorithm. While the problems associated with conventional measurements, like as detector limitations and accelerator stability can be circumvented. The ability of the virtual photon accelerator to generate total dose of both primary and phantom-scattered components were used to study the performance of two dose calculation algorithms in the presence of air medium like lung organ. Studies of the beam model and the handling of patient-specific insertion in the dose calculation algorithm were possible due to the ability for utilizing photons and evaluating the accuracy achievable in anthropomorphic phantoms based on patient X-ray computed tomography data (CT).

Planning step has important role in treating cancer patients using radiotherapy to ensure that the target region is treated, while patient organs are not too severely injured in the process. These simulations must be beforehand done to estimate the radiation dose distribution in the patient. In these simulations the target region and patient organs are defined as three-dimensional regions that can be used to estimate the amount of dose delivered to each region. This information is then used to determine how the patient should be treated.

In the software for radiotherapy treatment planning there is a need to have several different representations of three-dimensional regions, for example as a set of parallel two-dimensional contours, as a point-cloud, as a binary three-dimensional image, as a surface, and as a three dimensional Euclidian distance map. These different representations are used as input to dose calculation algorithms, visualization, for transforming regions between different image modalities, and also for persistent storage.

The dose calculation simulates a treatment performed according to the specified treatment plan to estimate the radiation dose delivered to the patient. As touched upon earlier, the dose distribution in the body can be calculated using the information from the CT image. At each point that the radiation beam passes through the dose deposited stands compatible with the intensity of the corresponding voxel from the CT image.

The use of multileaf collimator (MLC) -based for conformal radiotherapy enables the treating team to use many techniques using a number of field segments to point out accepted dose distributions in various treatment sites as well as other volumes of interest. The location of the treated volume and type of surrounding tissue and organs affect the penetration of the field segments according to the density of these organs. The presence of such heterogeneities affects the calculated dose which is a direct result of the ability of the algorithm to correct account for transportation in such heterogeneities due to the algorithm accuracy. [1]

Two types of correction-based algorithms are commercially available in modern clinical treatment planning systems, namely pencil beam algorithm (PBC) and the analytical anisotropic algorithm (AAA). The PBC algorithm uses data derived from Monte Carlo simulations to calculate the dose at each point in space around the incident beam assuming that any collimated photon beam is composed of a large number of narrow pencil beams of photons. The total dose is calculated by superposition of pencil beam dose kernels at each point around the incident beam.

The second algorithm (AAA) , as an example of more advanced superposition/convolution methods , is able to incorporate electron and secondary photon transport in an approximate way for dose calculations in a heterogeneous medium. To account for the presence of in homogeneities, simple density scaling of the kernels is applied so that the secondary electron transport is only modeled macroscopically. Both AAA and PBC were proved to produce inaccurate dose distribution in media with complex heterogeneities in certain circumstances. [2]

After machine's installation, a set of functionality, geometric, dosimetric and data transfer have been performed. The dosimetric tests include dose calculations in water, heterogeneous phantoms and verifications. Data transfer tests were run for every imaging device. Functionality and geometric tests were run properly. Verification of the two-photon dose calculation engines are available on the Eclipse (version 10.33) commercial radiotherapy treatment planning system. The performance of the pencil beam convolution and the AAA algorithms was examined for 6, 15 MV beams, under a range of clinically relevant irradiation geometries. Comparisons against measurements were carried out in terms of absolute dose, thus assessment of the accuracy of monitor unit (MU) calculations was also carried out using the dosimetry tools for evaluation and comparison between data measurement and calculation with the two TPS algorithms. [3, 4]

Measuring Instrumentation and Techniques:-

In the present study: DMX 2300 linear accelerator (Varian) was used with dual photon energies 6 and 15 MV. Beam profiles and Percentage depth dose (PDD) curves were measured for both energies with a fully Automatic water phantom (PTW, Freiburg, Germany) equipped with thimble type ionization chamber detectors for relative measurements. Absolute dose measurements were performed with an ionization chamber (Farmer 30013 0.6cc PTW, Freiburg, Germany) Famer chamber 0.6 cc) was calibrated in $N_{D,w}$ absorbed dose to water calibration factor according to the IAEA TRS-398 dosimetry protocol and connected to electrometer model UNIDOS PTW, Freiburg, Germany . A 2D array (model PTW) in addition to Relative dosimetry system mentioned above were used with PTW automatic water phantom and some ready pack X- ray for verification and evaluation of PDD in heterogeneous medium .

To evaluate the global performances of the dose calculation algorithm, comparisons of measured and calculated doses were performed for clinical cases .This study was performed to assess the Eclipse TPS before its using in 3D CRT .The clinical commissioning tests described in this study are based on the use of CIRS Thorax phantom (Fig. 1) .

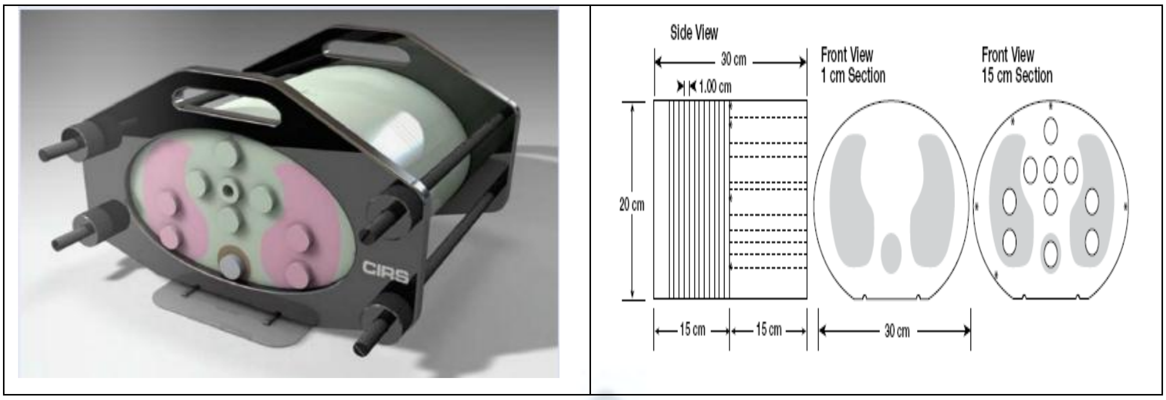

Fig. (1): CIRS Thorax phantom

The CIRS Model 002LFC IMRT Thorax Phantom for Film and ion chamber dosimetry is designed to address the complex issues surrounding commissioning and comparison of treatment planning systems while providing a simple yet reliable method for verification of individual patient plans and delivery.

The 002LFC (30 long x 30 wide x 20 thick in cm) is elliptical in shape and properly representing an average human torso in proportion, density and two-dimensional structure. The phantom is constructed of proprietary tissue equivalent epoxy materials. Linear attenuations of the simulated tissues are within 1% of actual attenuation for water and bone, and within 3% for lung from 50 keV to 15 MeV.

Tissue equivalent interchangeable rod inserts accommodate ionization chambers allowing for point dose measurements in multiple planes within the phantom. Hole placement allows verification in the most critical areas of the chest as show in Fig. (1).

CT Data acquisition

-CT scanning was performed with a Siemens CT adaptive for Radiotherapy (flat couch top).Slices, acquired over the entire length of the phantom, were of thickness 5 mm with a table increment of 5 mm for the head first supine .The x-ray tube was operated at 120 kVp. The used reconstruction algorithm was that which is recommended by the manufacturer for the particular anatomical region of the phantom. For the TPS to compute in homogeneity corrections based on CT data, conversion of Hounsfield number to electron density was necessary. Conversion factors were established using the CIRS phantom.

Test Cases :

To evaluate different arrange of field size and in-homogeneity effect on the dose distribution measured by ionization chamber, we carry out the following tests:

Test 1: Testing the reference conditions based on CT data

The purpose of this test is to verify the calculation for the reference field. A 10 cm x 10 cm field with a gantry angle of 0° and collimator angle of 0° is used to confirm the basic beam data.

Test 2: Oblique incidence, lack of scattering and tangential fields

The purpose of this test is to verify calculations in case of lack of scattering for the tangential field. A 15 cm x 10 cm field with a gantry angle of 90° and collimator angle depending on the wedge orientation

Test 3: Significant blocking of the field corners

The purpose of this test is to verify the calculation for the blocked field. Use a 14 cm x 14 cm field with a collimator angle of 45° blocked to a 10 cm x 10 cm field with standard blocks or with the MLC.

Test 4: Four field box

This technique is used in many radiotherapy hospitals and the purpose of this test is to verify the calculation of the dose delivered with an individual beam and the total dose from four fields.

Treatment planning

Dose distributions resulting from the beam configuration determined at simulation and used for treatment were calculated using the Eclipse planning system. The photon algorithm employed was based on AAA and PBC Algorithms. It should be noted that absolute and not relative doses were measured, calculated and compared as described in the next section. Geometrical phantom for lung and bone volumes in TPS Eclipse model was shown in Fig. (2).

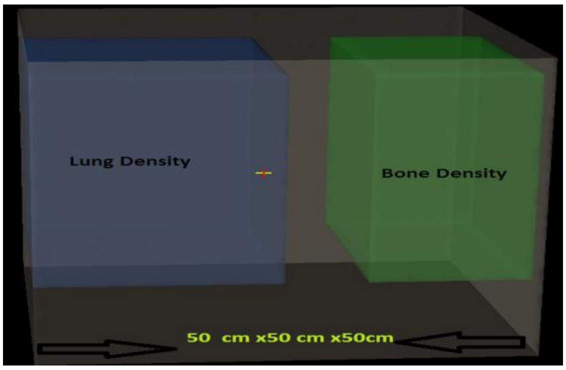

Fig (2): Geometrical phantom for lung volume and Bone Volume in TPS Eclipse model

Results and discussion:-

Different arrange of field sizes (symmetry – Asymmetry) and different density area to evaluation dose calculation difference between the used algorithms.

Table 1: Monitor units calculated by Pencil Beam and AAA Algorithms for 6 MV photon beam normalization depth = 10 cm in standard water phantom (30 cc), 200 MU dose given:

Field Size cm^2	Monitor Units		Percentage differences %
	PBC	AAA	
2x2 corner	131.9	132.8	**0.677**
3x3 corner	132.5	133.1	**0.45**
4x4 corner	132.7	133.6	**0.673**
2x30 in 30x30 cm off –axis at +X=10 cm	127.3	129.1	**1.39**
2x30 in 30x30 cm off –axis at +X=5 cm	128.3	130.2	**1.459**
5x30 in 30x30 cm off –axis at +X=10 cm	132.5	133.2	**0.525**
5x30 in 30x30 cm off –axis at +X=5 cm	**132.0**	**133.3**	**0.975**

Table 2: Monitor units calculated by Pencil Beam and AAA Algorithms for 15MV photon beam normalization depth = 10 cm in standard water phantom (30 cc), 200 MU dose given:

Field Size cm^2	Monitor Units		Percentage differences %
	PBC	AAA	
2x2 corner	143.9	145.8	**1.3**
3x3 corner	145.5	147.1	**1.08**
4x4 corner	147.8	149.5	**1.13**
2x30 in 30x30 cm off –axis at +X=10 cm	141.3	143.1	**1.257**
2x30 in 30x30 cm off –axis at +X=5 cm	140.3	143.2	**2.025**
5x30 in 30x30 cm off –axis at +X=10 cm	146.5	148.2	**1.147**
5x30 in 30x30 cm off –axis at +X=5 cm	**145.0**	**147.9**	**1.96**

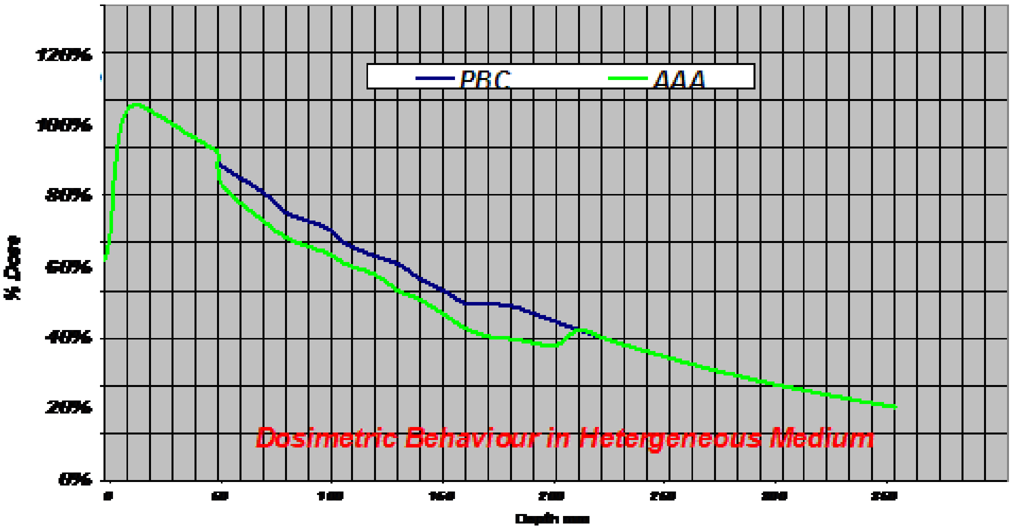

Fig. (3): Comparison PDD between AAA and PBC algorithms for lung volume (density 0.29) generator in Eclipse treatment System for 6 MV photon beam field size 20x 20 cm^2. (Not normalized to Maximum)

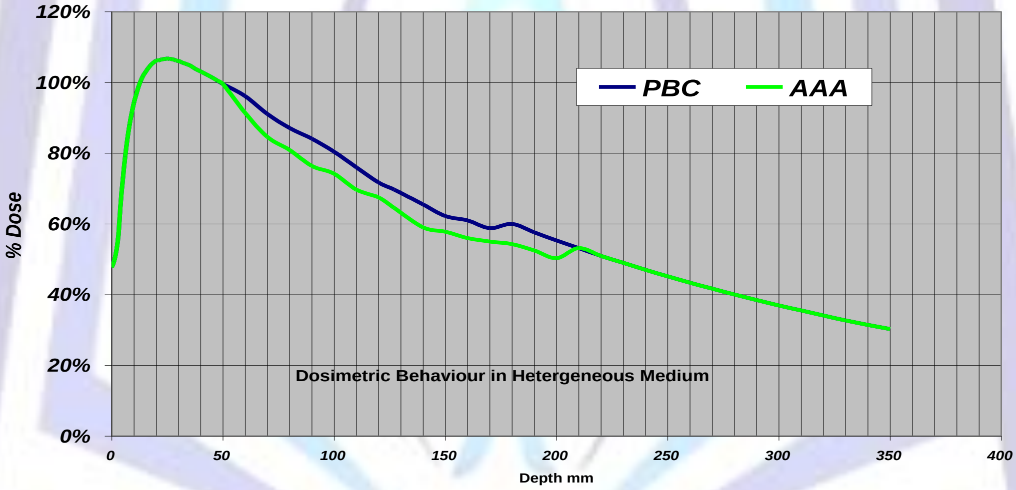

Fig. (4): Comparison PDD between AAA and PBC algorithms for lung volume (density 0.29) generator in Eclipse treatment system for 15 MV photon beam for field size 20x 20 cm^2 (normalized to Maximum)

-As shown in Figures (3 , 4) the percentage depth dose (PDD) distributions for the 6 MV and 15 MV photon beam give good agreement between PBC and AAA, with an average deviation before and after the heterogeneity region within the 3% in all evaluated points, respecting the recommended acceptability criteria by ICRU. Treatment planning results overestimated the dose inside this zone and after it, especially for a 20 cm x 20 cm field size highlights the limitations of the PBC algorithms. From the two figures, the main differences are found for the larger field size.

- The TPS calculates the contribution of scattered radiation more accurately as field size increases from 5 cm x 5 cm to 10 cm x 10 cm and the slab of in homogeneity lies at sufficient distance from the point of measurement to fulfill electron equilibrium conditions, but this change is not observed for field sizes 15 cm x15 cm and 20 cm x 20 cm or more up to maximum field size 40 x40 cm for the two energies as well as for the two algorithms. [7, 8]

Case of Lung as low density organ :-

-The selected treatment for the Lung was a Treatment by Four fields technique with different weight expressed as number of MU. We used a 2D array for comparing two algorithms to achieve the difference between them in heterogeneous media.

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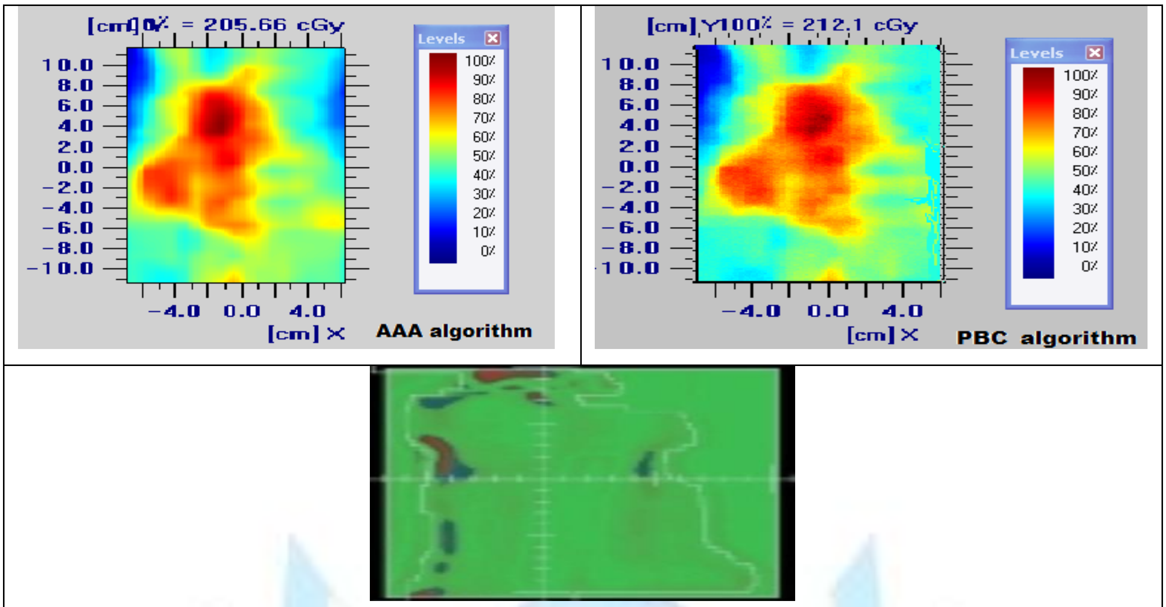
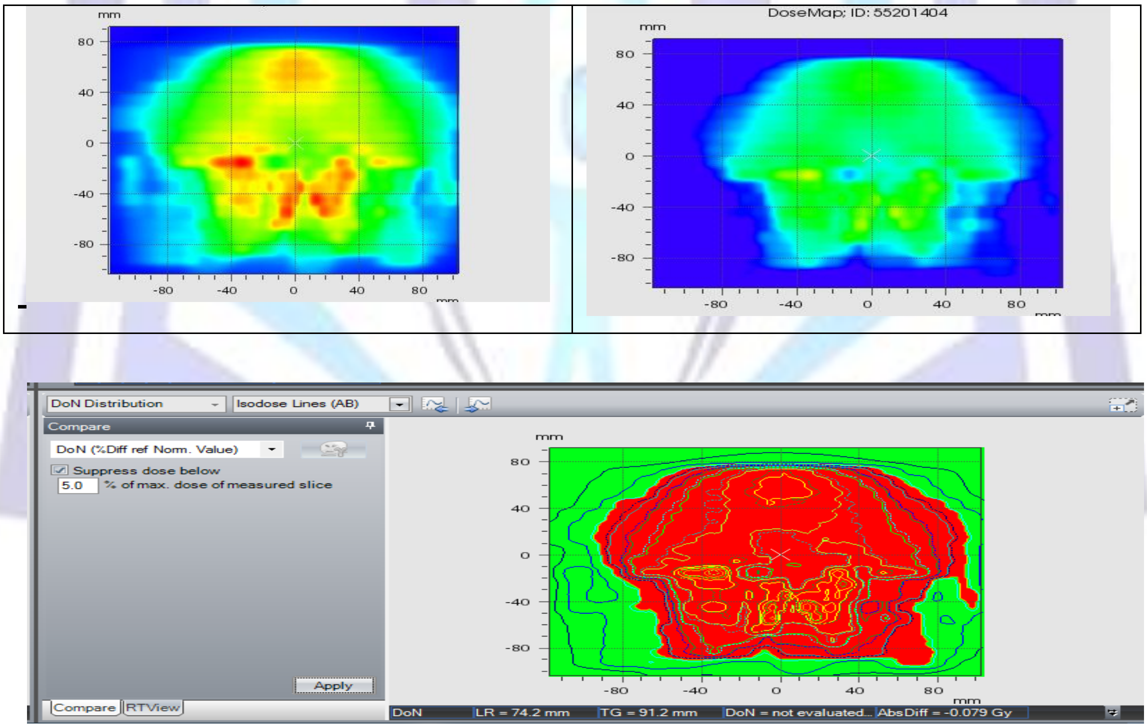


Different Between AAA and PBC algorithms

Fig (5): Comparison between AAA algorithm results and PBC algorithm For Lung Case.

Case of Head and Neck :-



- **Fig (6): Comparison between AAA algorithm results (right) and PBC algorithm (left). For Head & Neck Case**

-TPS quality assurance testing by comparing calculation result obtained by different calculation algorithms using 2D array and Gamma test and difference between two plan .as in figs.(5,6) shown the difference value between PBC and AAA Algorithm

-As shown in two figs. (5,6) the difference between two algorithms about 4.2 % for 20 lung and Head & Neck patients-these results were in agreement with practical measurements with ionization chamber as absolute dosimetry. The good agreement between the planning and experimental dose using 2D array, in contrast to the treatment planning tools predictions, highlights the limitations of the PBC algorithms. As illustrated in Figures (5, 6). [9, 10, 11, 12]

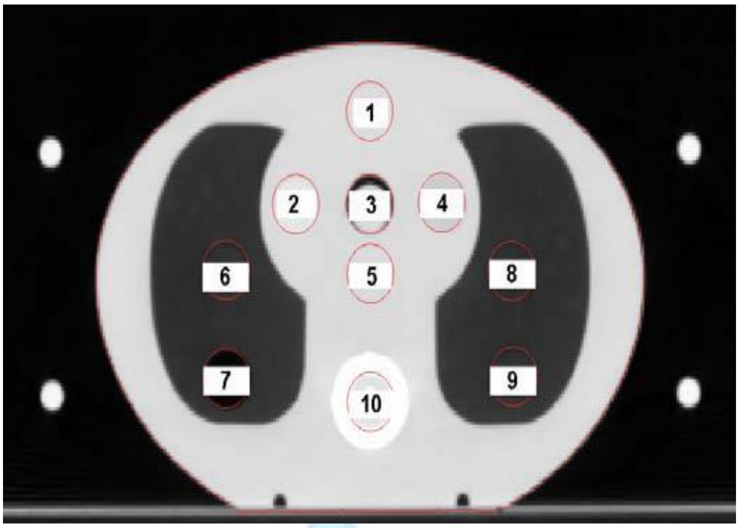


Fig (7):- Cross section View for CIRS Thorax phantom
And point for measure ion chamber

Calculated versus measured doses :

-Note that these are absolute and not relative doses. No normalization of the calculated to the measured data sets has been performed. Percentage deviation and agreement between AAA calculation and those measured by ionization chamber due to AAA in nearly equal to measurements

Test 1: Energy 6 MV

measuring point	Calculated dose(cGy) PBC	Calculated dose (cGy) AAA	Measured dose (cGy)	Deviation (%)	Agreement criterion (%)
1	2.28	2.334	2.323	0.54	2
3	1.932	2.000	1.999	0.05	2
5	1.65	1.710	1.722	-0.61	2
9	0.120	0.161	0.145	1.34	3
10	1.200	1.261	1.257	0.19	3

Energy :- 15 MV

measuring point	Calculated dose (cGy) PBC	Calculated dose (cGy) AAA	Measured dose (cGy)	Deviation (%)	Agreement criterion (%)
1	2.243	2.268	2.267	0.07	2
3	1.976	2.000	2.016	-0.79	2
5	1.723	1.770	1.787	-0.84	2
9	0.152	0.176	0.160	0.79	4
10	1.356	1.410	1.444	-2.21	3

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Test 2 : Energy 6 MV

measuring point	Calculated dose (cGy) PBC	Calculated dose (cGy) AAA	Measured dose (cGy)	Deviation (%)	Agreement criterion (%)
1	1.94	2.1	2.073	-3.03	3

Energy 15 MV

measuring point	Calculated dose (cGy) PBC	Calculated dose (cGy) AAA	Measured dose (cGy)	Deviation (%)	Agreement criterion (%)
1	1.953	2.2	2.083	-3.03	3

Test 3 : Energy 6 MV

measuring point	Calculated dose(cGy) PBC	Calculated dose (cGy) AAA	Measured dose (cGy)	Deviation (%)	Agreement criterion (%)
1	1.92	2.00	1.97	1.77	3

Energy 15 MV

measuring point	**Calculated dose(cGy) PBC**	**Calculated dose (cGy) AAA**	**Measured dose (cGy)**	**Deviation (%)**	**Agreement criterion (%)**
1	1.95	2.00	2.033	-1.63	3

Test 4 :-Energy 6 MV.

measuring point		**Calculated dose (cGy) PBC**	**Calculated dose (cGy) AAA**	**Measured dose (cGy)**	**Deviation (%)**	**Agreement criterion (%)**
5	F1: 0°	43.5	50.0	50.4	-0.88	2
	F2: 90°	45.0	50.0	50.2	-0.45	3
	F3: 270°	44.2	50.0	49.9	0.25	3
	F4: 180°	46.6	50.0	48.2	3.77	3
	Σ	179.3	200.00	198.7	0.654	
6	F1: 0°	3.45	3.7	3.60	0.39	3
	F2: 90°	32.0	34.0	33.75	0.51	3
	F3: 270°	66.0	68.20	67.66	1.08	3
	F4: 180°	3.66	4.30	4.08	0.87	3
	Σ	105.11	110.20	109.09	1.29	

10	F1: 0°	3.5	3.68	3.69	-0.21	3
	F2: 90°	3.76	4.20	3.95	0.69	3
	F3: 270°	3.76	4.20	3.96	0.48	3
	F4: 180°	63.2	64.4	64.01	9.11	3
	Σ	74.22	77.48	75.61	5.57	

Energy 15 MV

measuring point		Calculated dose (cGy) PBC	Calculated dose (cGy) AAA	Measured dose (cGy)	Deviation (%)	Agreement criterion (%)
5	F1: 0°	46.5	50.00	50.10	-1.93	2
	F2: 90°	46.2	50.00	51.46	-2.85	3
	F3: 270°	45.6	50.00	51.70	-3.41	3
	F4: 180°	47.2	50.00	49.85	0.30	3
	Σ	185.5	200.00	203.11	-1.53	
6	F1: 0°	3.34	3.50	3.34	0.31	4
	F2: 90°	36.6	36.90	37.24	-0.68	3
	F3: 270°	63.0	63.20	63.66	-0.90	3
	F4: 180°	4.10	4.30	4.89	-1.18	4
	Σ	107.04	107.9	109.13	-1.13	
10	F1: 0°	36.75	39.40	41.45	-4.03	3
	F2: 90°	3.4	3.50	3.23	0.53	4
	F3: 270°	3.45	3.50	3.53	-0.06	4
	F4: 180°	60.70	63.80	67.45	-7.32	3
	Σ	104.3	110.2	115.6	-4.74	

Conclusion

- According to the results for Comparison, it can be shown that the algorithms of AAA have some accuracy in calculation through heterogeneous medium like that used in current study lung (low electronic density organ).

- Consequently, the results of this work provide evolution for the errors introduced by the TPS while providing in essence the overall uncertainty in the established patient treatment process. These leads to that there are limitations to the accuracy with which performance of a TPS can be evaluated in a clinically relevant situation.

- When evaluating treatment planning systems one must remember that they are very complex systems which may approach the problem in different ways. In this study, we have tried to evaluate the effect of the heterogeneity and the scatter volume on the accuracy of dose for patient in some real handled conditions. Other aspects are not studied in this work also has to consider the models/algorithms for optimizing intensity-modulated beams both for dynamic and static MLC delivery like IMRT techniques comprising of small segments may bring up new problems for the dose calculation models and it will be our main forgoing study point .

- According current study, the 2D array has a very high accuracy when comparing the two algorithms – with easy setup and good analysis software.

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Figures

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