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Research Paper

How Do Pencil Beam Sizes Influence Central Axis Dose Calculations in Theraplan Plus Treatment Planning System?

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Abstract

Most radiotherapy treatment planning systems (TPS) utilize pencil beam (PB) algorithm for the computation of dose distributions. Each commercial TPS will differ slightly in approach. This study assesses the influence of different PB sizes on the accuracy of Theraplan plus (TPP) dose calculations. Theraplan plus (version 3.8) at Department of Radiation Oncology, University College Hospital, Ibadan, Nigeria contains measured (published) central axis data (CAD) for a telecobalt unit at depths 0.5 – 30 cm. Dose calculations for CAD were performed by the TPS for radiation square fields 4 – 35 cm2 using PB sizes, 0.5, 0.75, 1.0, 1.25 and 1.50 cm sequentially. Statistical comparisons of the resulting doses with the measured were performed using SPSS. Theraplan plus resulted in calculated doses that are predominantly higher than the measured values. The percentage increase ranged from 0.01 - 0.72 %, with the maximum obtained at 30 cm x 30 cm, depth 10 cm, PB size 1.5 cm. Dose calculation accuracy increased from 99.72 – 99.98 % and 99.82 – 99.91 % as the PB size decreased from 1.5 – 0.5 cm for fields 4 x 4 cm2 and 30 x 30 cm2 respectively. Central axis data comparisons at PB size 0.75 cm showed the greatest resemblance with the pattern obtained at 1.0 cm (by default). Pencil beam sizes greater than 1.0 cm tends to reduce the accuracy of TPP dose calculations. The use of 0.75 cm size in TPS may also be reasonable for dose calculations. Dosimetry evaluation including off-axis data comparisons is suggested for further clarifications.

Key words: Theraplan plus, central axis data, dose calculations, pencil beam size

Introduction

Due to possible loss of electronic equilibrium, dose calculations in heterogeneous media using a treatment planning system (TPS) may give rise to substantial errors. Three different dose calculation algorithms namely pencil beam (PB), collapsed cone (CC) and Monte-Carlo (MC) are applicable for use on computerized radiotherapy treatment planning systems. The PB and CC algorithms in particular are more relevant to dosimetry in photon beams. The CC algorithm implements various approximations in the Physics of radiation transport, which reduces the calculation time to levels that are acceptable for clinical practice. The PB algorithm as a technique assumes that any collimated photon beam incident on the patient is actually a conglomeration of lots of smaller, narrow "pencil beams". Each of these pencil beams has a central axis ray along which it deposits some dose. The dose deposition pattern varies with the intensity and the spectrum of the beam that is incident on the patient. Though the technique is very fast, it is not without limitations. This is because PB algorithms use a one-dimensional density correction which does not accurately model the distribution of secondary electrons in media of different densities [1, 2]. Notwithstanding, most commercial radiotherapy treatment planning systems, such as THERAPLAN Plus (TPP), utilize pencil beam algorithm for the calculation of radiation dose distributions. Different versions of the PB dose calculation process are available and each commercial TPS will differ slightly in approach. THERAPLAN Plus is a 3D-TPS programme that is entirely Windows-based. Over the years, TPP has proven to be a useful tool for treatment planning in both teletherapy and brachytherapy. Its application in external beam radiotherapy often involves the use of PB size 1.0 cm by default. However, this value is not an invariable but subject to changes in relation to the dosimetric goal of treatment planning. This study therefore investigates the influence of PB sizes 0.5, 0.75, 1.0, 1.25, 1.50 cm on central axis data (CAD) comparisons vis-à-vis the accuracy of TPP dose calculations at the foremost tertiary health institution in Nigeria.

Materials and Methods

Theraplan Plus V. 3.8 (MDS Nordion) TPS available at the Department of Radiation Oncology, University College Hospital (UCH), Ibadan, Nigeria comprises eleven modules. The most commonly used features include Unit Modeling (UM), Patient Registration (PR), Patient Data Acquisition (PDA), Anatomy Modeling (AM), External Planning (EP) and Dose Volume Histograms (DVH) in a progressive order. The TPS is being commissioned for external photon beam treatment planning on Bhabhatron II Co-60 unit (Panacea Medical Ltd., India). Prior to application of Theraplan Plus TPS, the mechanical and radiation information on the treatment unit have to be inserted in the Unit Modelling module. The TPP system typically contains measured (published by the British Journal of Radiology, BJR) central axis data for a telecobalt unit at depths 0.5, 1 – 20, 22, 24, 26, 28 and 30 cm. After the data input, the system has to calculate certain functions, which are necessary for the algorithms calculating the dose distribution. Dose calculations for CAD were performed by the TPS for radiation square fields 4x4, 6x6, 8x8, 10x10, 12x12, 15x15, 20x20, 25x25, 30x30 and 35x35 cm2 using PB sizes, 0.5, 0.75, 1.0, 1.25 and 1.50 cm sequentially. In order to verify the system calculation accuracy, the system utility was used for comparisons of measured and calculated central axis and data. The results are presented in tables and charts. Statistical analysis which include student t-test and creation of box-and-whisker plots to facilitate CAD comparisons was performed using SPSS version 13. The threshold for statistical significance was $P \leq 0.05$. Each set of data comprises input/calculated central axis doses and their differences for a given square field at a specific pencil beam size. This study investigates CAD comparisons for ten radiation fields and varying (five) PB sizes. Therefore, the data generated on the TPP and acquired for statistical analysis in this study comprises 50 sets.

Results

Descriptive statistics of input-calculated dose differences and one-way analysis of variance (ANOVA) for radiation fields 4 x 4 cm – 12 x 12 cm and 15 x 15 cm – 35 x 35 cm are presented in Tables 1a and 1b respectively. Figures 1 – 5 show box-and-whisker plots for input-calculated dose (CAD) differences using pencil beam sizes, 0.5, 0.75, 1.0, 1.25 and 1.50 cm respectively. THERAPLAN Plus resulted in calculated doses that are predominantly higher than the input (measured) values. The percentage increase ranged from 0.01-0.72 %, with the maximum obtained at 30 cm x 30 cm, depth 10 cm, PB size 1.5 cm. Dose calculation accuracy increased from 99.72 – 99.98 % and 99.82 – 99.91 % as the PB size decreased from 1.5 – 0.5 cm for fields 4 x 4 cm2 and 30 x 30 cm2 respectively. In some cases, TPP brought about calculated central axis doses that were lower that the input data. The percentage reduction ranged from 0.01 – 0.97 % with the maximum obtained at 4 cm x 4 cm, depth 4 cm, PB size 1.5 cm. Positive differences (measured > calculated doses) in CAD comparisons across the 26 depths were primarily obtained at 4 cm x 4 cm.

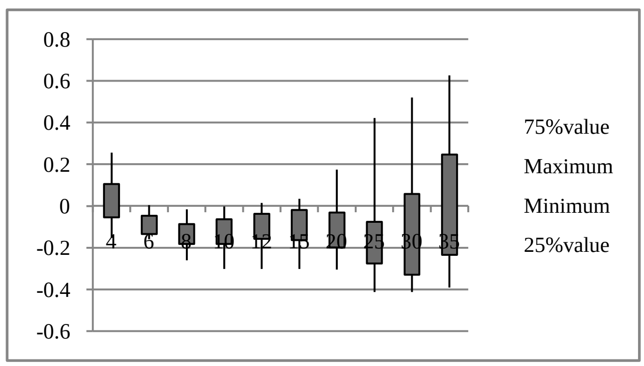

Figure 1. Box plot of input-calculated dose differences with PB size, 0.5 cm for fields 4 – 35 (cm^2).

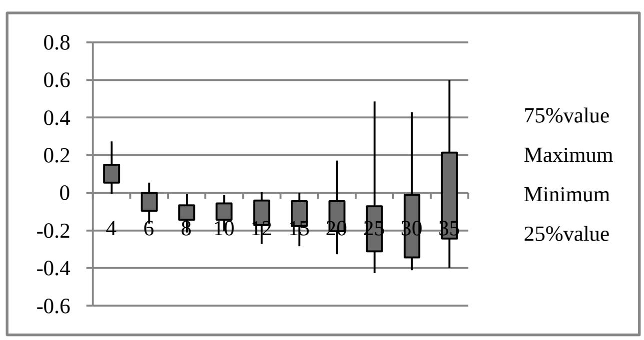

Figure 2. Box plot of input-calculated dose differences with PB size, 0.75cm for fields 4 – 35 (cm^2).

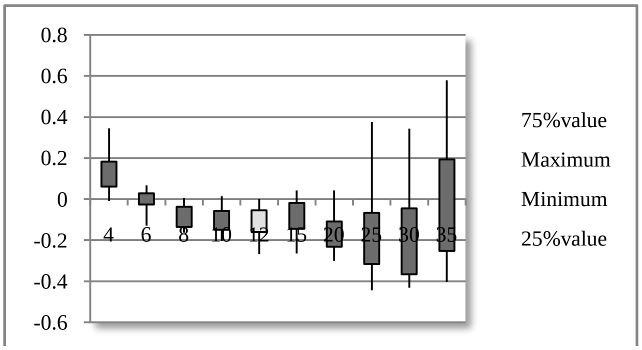

Figure 3. Box plot of input-calculated dose differences with PB size, 1.0 cm for fields 4 – 35 (cm²).

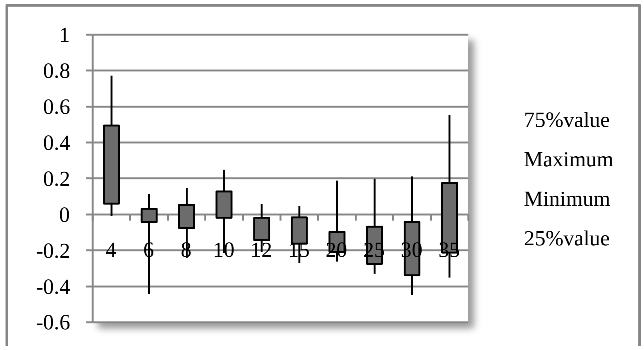

Figure 5. Box plot of input-calculated dose differences with PB size, 1.5 cm for fields 4 – 35 (cm²).

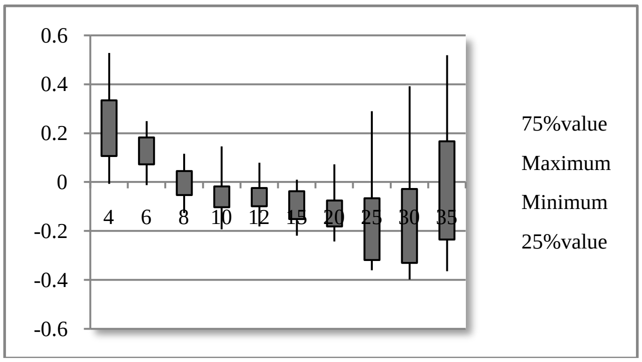

Figure 4. Box plot of input-calculated dose differences with PB size, 1.25 cm for fields 4 – 35 (cm²).

Table 1. Central axis data for 4 cm x 4 cm field obtained on TPP for different pencil beam size

Depth(cm)	Input (%)	Calculated (%)				
		PB: 0.5 cm	0.75 cm	1.00 cm	1.25 cm	1.50 cm
0.5	100.0	100.008	100.008	100.009	100.008	100.008
1	97.2	97.173	97.157	97.152	97.092	97.051
2	91.4	91.282	91.241	91.227	91.072	90.966
3	85.4	85.181	85.128	85.109	84.904	84.759
4	79.7	79.444	79.438	79.355	79.173	78.929
5	73.9	73.738	73.752	73.642	73.49	73.201
6	68.4	68.179	68.197	68.098	67.92	67.709
7	63.3	63.143	63.193	63.079	62.918	62.696
8	58.5	58.399	58.411	58.289	58.147	57.924
9	53.9	53.841	53.892	53.763	53.657	53.434
10	49.7	49.705	49.588	49.574	49.487	49.265
11	45.9	45.966	45.79	45.777	45.704	45.625
12	42.4	42.449	42.264	42.254	42.192	42.127
13	39.1	39.137	38.95	38.943	38.894	38.838
14	36.1	36.222	36.009	36.006	35.97	35.91
15	33.2	33.353	33.141	33.146	33.127	33.081
16	30.8	30.849	30.64	30.641	30.621	30.595
17	28.3	28.393	28.199	28.2	28.196	28.175
18	26.2	26.292	26.11	26.109	26.11	26.094
19	24.1	24.168	23.975	23.997	24.005	23.995
20	22.2	22.251	22.134	22.148	22.161	22.154
22	19.0	19.014	18.926	18.917	18.828	18.94
24	16.2	16.242	16.152	16.136	16.054	16.167
26	13.8	13.8	13.745	13.722	13.646	13.744
28	11.8	11.837	11.804	11.765	11.677	11.786
30	10.1	10.14	10.1	10.059	9.981	10.079

Table 2A. Student t-test using one-way ANOVA

Size	N	Mean	Std. Deviation	95% Confidence Interval for Mean	F	p-value
			4 x 4			
0.5	26	0.015154	0.1120306	-0.030096 –0.060404		
0.75	26	0.102231	0.0729917	0.072749– 0.0131713		
1.0	26	0.134077	0.0905887	0.097487–0.170666	12.519	0.000
1.25	26	0.214154	0.1464578	0.154998–0.273309		
1.5	26	0.282808	0.2504561	0.181646–0.383969		
			6 x 6			
0.5	26	-.086615	0.0519947	-0.107616- 0.065614		
0.75	26	-.038231	0.0594026	-.06222 - -0.014238		
1.0	26	-0.009423	0.0475270	-0.028620 - 0.009773	26.132	0.000
1.25	26	0.124731	0.0716712	0.095782 –0.153679		
1.5	26	-0.050577	0.1387882	-0.106635 – 0.005481		
			8 x 8			
0.5	26	-0.135346	0.0649923	-0.161597 – -0.109095		
0.75	26	-0.098577	0.0574541	-.121783 – -.075371		
1.0	26	-0.087000	0.0542299	-.108904– -.065096	18.538	0.000
1.25	26	-0.004346	0.0624218	-.029559 – .020867		
1.5	26	-0.014923	0.0889004	-.050831 – .020985		
			10 x 10			
0.5	26	-.116769	.0705727	-.145274 – -.088264		
0.75	26	-.102192	.0540067	-.124006 – -.080379		
1.0	26	-.101538	.0601240	-.125823 – -.077254	22.317	0.000
1.25	26	-.057538	.0711051	-.086258 – -.028818		
1.5	26	.049692	.1026040	.008250 – .091135		
			12 x 12			
0.5	26	-.102923	.0860688	-.137687 – -.068159		
0.75	26	-.104577	.0774685	-.135867 – -.073287		
1.0	26	-.109115	.0737706	-.138912 – -.079319	1.338	0.260
1.25	26	-.070192	.0581894	-.093695 – -.046689		
1.5	26	-.079692	.0815234	-.112620 – -.046764		

Table 2B. Student t-test using one-way ANOVA delight

Size	N	Mean	Std. Deviation	95% Confidence Interval for Mean	F	p-value
			15 x 15			
0.5	26	-.097500	.0975284	-.136893 – -.058107		
0.75	26	-.111462	.0832453	-.145085 – -.077838		
1.0	26	-.089269	.0811973	-.122066 – -.056473	.257	.905
1.25	26	-.095000	.0643030	-.120973 – -.069027		
1.5	26	-.095654	.0847533	-.129886 -.061421		
			20 x 20			
0.5	26	-.114077	.1107584	-.158813 – -.069341		
0.75	26	-.124231	.1115628	-.169292 – -.079170		
1.0	26	-.154731	.0830328	-.188268 – -.121193	.610	0.656
1.25	26	-.127808	.0761462	-.158564 – -.097052		
1.5	26	-.132885	.1050514	-.175316 – -.090453		
			25 x 25			
0.5	26	-.154654	.2108271	-.239809 – -.069499		
0.75	26	-.148731	.2384248	-.245033 – -.052429		
1.0	26	-.172154	.2063042	-.255482 – -.088826	.161	0.958
1.25	26	-.187346	.1669666	-.254785 – -.119907		
1.5	26	-.159000	.1450183	-.217574 – -.100426		

			30 x 30			
0.5	26	-.093346	.2749897	-.204417 – .017725		
0.75	26	-.134115	.2462768	-.233589 – -.034642		
1.0	26	-.164000	.2221693	-.253736 – -.074264	.584	.675
1.25	26	-.131731	.2252248	-.222701 – -.040761		
1.5	26	-.183731	.1689896	-.251987 – -.115474		
			35 x 35			
0.5	26	.023115	.3076961	-.101166 – .147397		
0.75	26	.000923	.2980939	-.119480 – .121326		
1.0	26	-.012769	.2906722	-.130174 – .104636	.079	.989
1.25	26	-.016500	.2467214	-.116153 – .083153		
1.5	26	-.002308	.2596844	-.107196 – .102581		

Discussion and Conclusion

Commercial TPSs use computation methods to determine dose distribution in patients from external photon beams. Advance algorithm is needed in order to achieve quick and accurate calculation of dose distribution for radiation beams. The PB size in pencil beam algorithm of the TPP planning system by default is 1.0 cm. However, the value is not an invariable and the end user can adopt another figure that is validated to be appropriate. For a given square field, such as 4 cm x 4 cm (Table 1), Theraplan normally presents dosimetric data for depths 0.5 cm (point of maximum dose for a telecobalt machine) – 30 cm. A typical presentation of CAD on the TPP system would include input and calculated doses (for a given field and a specific PB size) and their numerical differences (Mathematically, Input - Calculated doses). Therefore, it is not practical for Theraplan to display CAD doses applicable to more than one pencil beam size at a time. The essence of Table 1 is to illustrate the possible variations that could result from changes in PB size across same depths in a tissue-equivalent medium such as water. Therefore, for a given radiation field, the calculated doses vary with the PB size while the input (measured) values remain unchanged. Variations in calculated doses as compared to the measured dose are least at depth 0.5 cm which is the point of maximum dose for the a telecobalt unit. The means of the dose differences are negative (Tables 2a and 2b) in most cases indicating that the calculated values are predominantly higher than the input data across all the field sizes and depths. In previous comparative studies, the PB algorithm overestimate sizes. This would engender higher uncertainty in dose accuracy when small fields are treated. The highest positive (input > calculated dose) dose differences occurred with the 4 cm while the second highest negative dose difference (-0.442) occurred with the 6 cm^2. Several previous studies have shown the limitations of PB algorithms in the dose compared with those calculated by the CC and MC algorithms. One of the challenging issues in radiotherapy is the existence of inhomogeneities in patients. In other words, different body tissues or organs have varying densities which bring about different photon attenuations and dose absorptions. A calculation protocol in treatment planning system such as the PB algorithm should duly take this into consideration. It is expected that the pencil beam dose kernel would be stretched in a region of low density in patients to account for lower attenuation coefficient. Conversely, its dimensions would contract in anatomical regions where high densities exist. In spite of these corrections, the pencil beam algorithm still shows some level of inaccuracies with respect to inhomogeneities. In case of the dose calculation with the PB algorithm on heterogenous media, which includes the low-density region, the dose tends to be overestimated compared to the other algorithms as it hardly explains the phenomenon of the spread out electrons [3]. In the present study, it was clearly observed that the calculated doses were greater than the measured (published) data at 0.5 cm depth in all cases irrespective of the field size and the pencil beam size. This attests to the fact that the pencil kernel approach is readily prone to dose overestimation due to the presence of air at the surface of the tissue-equivalent medium. The Results of the one-way analysis of variance shows that the differences in central axis data comparisons due to varying PB sizes are statistically significant for smaller square fields 4 cm x 4 cm – 10 cm x 10cm. In other words, changes in PB sizes in the TPP dose calculation algorithm, would influence doses less significantly in field sizes greater than 10 cm^2.

A sharp increase in the variability of CAD comparisons could be noted for the small field occurs with the largest field size (35 cm x 35 cm) considered in this study for 0.5 cm, 0.75 cm and 1.0 cm. It could be observed that the sizes of the box plots are most comparable in Figure 2 involving the use of 0.75 cm PB size. At this stage of our study, it was impossible to identify the case-by-case reasons for the detected discrepancies between measured and calculated central axis doses across the various square field sizes. The relative discrepancy between measured and calculated doses are negative in most cases, indicating overestimation. There is however, no definite trend as the differences could be higher or lower at different points (depths) in the attenuating medium. In existing literature, there are yet no definitive comparative studies to assess the influence of the PB size on central axis doses comparisons on treatment planning systems. In Figure 5, the box plots for 4 cm and 6 cm at PB size of 1.5 cm show highly contrasting features. While with the 4 cm field, the central axis dose differences are much different, the next consecutive box plot (6 cm) portray that overall dose differences across the various depths have a high level of agreement with each other. It is observed that the smallest field at this PB showed the highest variability across the field heterogeneous media. This is because the PB algorithms use a one-dimensional density correction, which does not accurately model the distribution of secondary electrons in media of different density [4]. Doses are scaled according to the radiological depth along a ray line from the radiation source to the calculation point, not accounting for the effects of side and backscattered radiation. The overall agreement between the central axis doses calculated by THERAPLAN Plus kernel algorithm and the measured (published) data for varying PB sizes was within ±1%. In radiation therapy of cancer, the uncertainty of dose calculations should be below 3% in order to correlate the treatment outcome with the prescribed dose [5].

Abbreviations

TPP: Theraplan plus; TPS: Treatment planning systems; PB: Pencil beam.

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Author Contributions

OEO, ABI, UIB and MCB contribute equally to this study. All authors gave their final approval.

Competing Interests

The authors have declared that no competing interest exists.

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