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TREATMENT PLANNING SYSTEM COMMISSIONING OF THE ECLIPSE PBC DOSE CALCULATION ALGORITHM FOR THE VARIAN CLINAC iX S/N 5052

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Abstract – **The commissioning of the Treatment Planning System (TPS) is an important part of the commissioning of a new linear accelerator (linac). In this work, we evaluated the performance of the Pencil Beam Convolution (PBC) algorithm configured for the new Varian Clinac iX (S/N 5052) at the University Clinic of Radiotherapy and Oncology in Skopje. The evaluation was performed in two stages. In the first stage, we used a workspace of the TPS itself, called "Beam Analysis", in which the system itself calculates the depth dose and profile curves for a water phantom and compares them with those measured during the commissioning of the accelerator. In the second stage, we created, calculated and irradiated 9 test plans on a polystyrene phantom "OPERA" and measured the dose in a point with a system for absolute dosimetry and then compared the measurements with the calculations. In both stages, the results of the comparison were below 3%, in most clinically relevant cases below 2%, which indicates that the PBC algorithm can safely be commissioned for clinical use.**

Keywords – **TPS commissioning, PBC algorithm, Eclipse TPS**

1. INTRODUCTION

The modern radiation therapy treatment planning is a complex process. One of the key components of the process, which only recently started to receive the due attention, is the computerized system for the planning of the treatment. After some serious accidents worldwide, the International Atomic Energy Commission (IAEA) developed series of documents [1, 2] containing general and more detailed recommendations concerning the commissioning of the treatment planning systems (TPS).

At the University Clinic of Radiotherapy and Oncology in Skopje, Macedonia, a new linear accelerator Varian Clinac iX S/N 5052 was recently installed and the commissioning beam data measurements were performed. The measured beam data was imported into the existing treatment planning system at the Clinic – VMS Eclipse ver.10 and with this data, the Pencil Beam Convolution (PBC) treatment planning algorithm was configured. This work reports the performed measurements and the obtained results in the process of the commissioning of this algorithm for clinical use.

2. MATERIALS AND METHODS

The commissioning of the PBC algorithm of the Eclipse TPS was performed in two stages.

In the first stage, we used a specific workspace of the TPS itself, called Beam Analysis [3], in which the system calculates the depth doses and the beam profiles on a virtual water phantom by using the configured algorithm, and compares them with the measured ones.

In the second stage, we used a polystyrene phantom called "OPERA" to evaluate the behavior of the calculation model by performing measurements with ionization chamber and comparing the calculated and measured results.

2.1. Evaluation based on "Beam Analysis" Workspace

As stated before, the workspace "Beam Analysis" is an integral part of the TPS Eclipse. In it, the TPS creates a virtual water phantom and calculates the depth dose curves and the beam profiles and then compares them with those measured during the commissioning of the linac. The depth dose curves were normalized in the maximum of the curve, while the profiles were normalized in the center of each profile.

For the depth dose curves, for each field size, the system provides the following comparison results: depth difference in millimeters at maximum dose, depth difference in millimeters at 50% dose, dose difference in percent at 100 mm depth and dose difference in percent at 200 mm depth. In addition, we evaluated the curve that gives the dose difference at different depth and from this curve we established the maximal dose difference between the calculated and the measured depth dose curve.

For the profiles, the system provides the distances between certain dose levels of the measured and calculated profile (ex. distance between the points of the measured and calculated profile where the dose is 80% of the dose at the central axis). We believe that it is even more important to evaluate the maximal dose difference in the flattened area of the profiles. Therefore, for every field size and depth we created an excel worksheet in which we imported the measured and the calculated results and evaluated the maximal dose difference in the flattened area of the profiles. The flattened area of the profile is defined as the central 80% of the field width. The field width is the distance between points of 50% dose (Fig. 1).

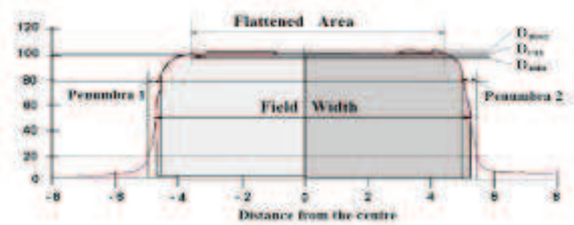

Fig. 1 – Definition of flattened area of a beam profile

2.2. Evaluation based on ionization chamber measurements

For the second stage of the evaluation we used the polystyrene phantom "OPERA" (Fig.2).

We made CT scans of the phantom in three positions (Fig.3), imported the scans in the TPS and created 9 treatment plans. All treatment plans were calculated by using the "No normalization" option in the "Plan Normalization Options" [4, 5]. We irradiated the plans and measured the dose with a Farmer type chamber in a specified point for each plan. The dosimetric system that we used was Scanditronix Welhoffer system consisting of a Farmer type chamber FC-65G and electrometer Dose1. The measurements were corrected for the daily deviation in the output of the linac and for the attenuation of the treatment couch top.

2.2.1. Test 1 – Testing calculation for reference conditions

For this test, the CT shown on Fig.3a was used. The phantom was positioned in a setup where the source to phantom distance (SPD) was 100 cm. Two fields were used - one with 6 MV photons and another with 15 MV photons. For both fields the field size was 10x10 cm^2, the gantry and collimator angles were 0º. The field weight was such that by each of the fields 100 MU were delivered. The measurement point is marked with the green cross on Fig.3a. It is a point at 5 cm depth and for this point the calculation and the measurement were compared.

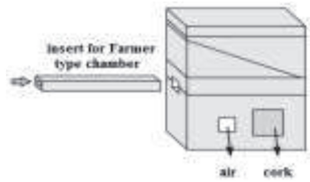

Fig. 2 – "OPERA" phantom

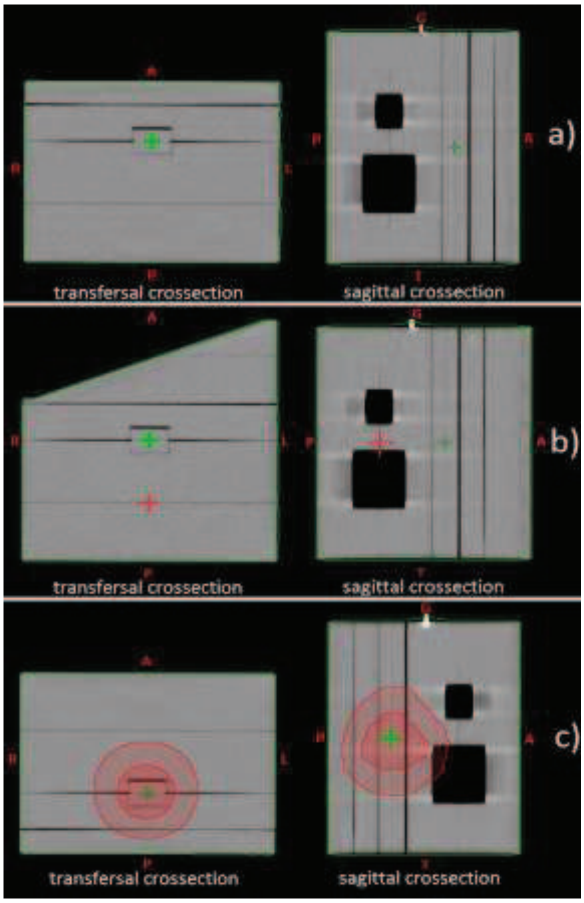

Fig.3 – CT scans used in different plans

2.2.2. Test 2 – Testing calculation in case of a lack of scattering for a tangential field

For this test, the CT shown on Fig.3b was used. The phantom was positioned in an isocentric setup with the isocenter as shown on Fig.3b – marked with the green cross. Two rectangular fields were used - one with 6 MV photons and another with 15 MV photons. For both fields the field size was 10x15 cm^2, the gantry angle was 270º and the collimator angle was 90º. Both fields were with dynamic wedges – Enhanced Dynamic Wedge 60 º (EDW60). The prescribed daily dose was 2 Gy and the weight of both fields was equal. The dose was measured at the isocenter (green cross on Fig.3b).

2.2.3. Test 3 – Testing automatic margin function and customized blocking with MLC

A target contour was drawn on the CT shown on Fig.3c and automatically expanded. The phantom was positioned in a setup where the SPD = 100 cm. Two identical fields with MLC (one with 6MV one with 15MV) were fitted automatically to the expanded target structure with a circular margin of 0.7 mm. The gantry and collimator angles were 0º. The prescribed daily dose was 2 Gy and the field weights were such that 40% of the dose was delivered with the 15 MV field while 60% of the dose was delivered with the 6 MV field. That yielded 103 MU for the 15 MV field and 101 MU for the 6 MV field. The point where we compared the measurement and the calculation was at 10 cm depth (marked with the green cross on Fig. 3c). In this test, the two inhomogeneities of the phantom (the air filled space and the cork filled space) were in the path of the beams, so their influence on the MU calculation could be evaluated.

2.2.4. Test 4 – Testing calculation in case of a significant blocking of the field corners

For this test, the CT shown on Fig.3a was used. The phantom was positioned in an isocentric setup, with the isocenter as shown on Fig.3a – marked with the green cross. This was also the measurement point. Two fields were used, one with 6 MV and another with 15 MV. For both fields the gantry angle was 0º, and the collimator angle was 45º. The field size defined by the collimator jaws was 14x14 cm^2 and the four field corners were blocked with the MLC leaving an opening of 10x10 cm^2 (Fig.4).

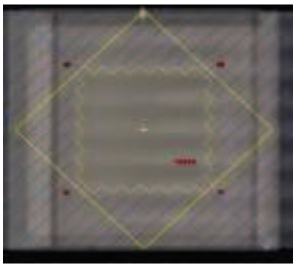

Fig. 4 – Beam Eye View for test 4 – a significant blocking of field corners

The prescribed daily dose was 2 Gy and the weight of both fields was equal.

2.2.5. Test 5 – Testing calculation in case of an oblique incidence with irregular field and blocking of the center of the field

For this test, the CT shown on Fig.3b was used. The phantom was positioned in an isocentric setup, with the isocenter shown on Fig.3b – marked with the red cross. The measurement point is marked with the green cross on the same figure. It is 5 cm above the isocenter. Two fields were used, one with 6 MV and another with 15 MV. For both fields the gantry angle was 320º, and the collimator angle was 90º. The field size defined by the collimator jaws was 12x13 cm^2 and an L-shaped field was created by blocking off 5x8 cm^2 of the field (Fig.5).

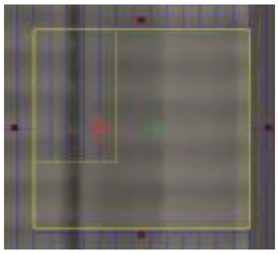

Fig. 5 – Beam Eye View for test 5 – an oblique incidence with irregular field and blocking of the field center

On Fig.5 the isocenter position is shown with the red cross and the measurement position is shown with the green cross. The prescribed daily dose was 2 Gy and the weight of both fields was equal.

2.2.6. Test 6 – Testing calculation in case of a four field box

For this test, the CT shown on Fig.3a was used. The phantom was positioned in an isocentric setup, with the isocenter as shown on Fig.3a – marked with the green cross. This was also the measurement point. A four field box test plan was created with 15 MV fields and gantry angles 0º, 90º, 180º and 270º. For each field the collimator angle was 0º and a MLC was placed with an orientation typical for most clinical cases that employ this technique. The prescribed daily dose was 2 Gy and the weights of all four fields were equal.

2.2.7. Test 7 – Testing calculation in case of a typical plan for irradiation of rectal cancer

This was a test plan for evaluating the irradiation of a typical rectal cancer case. For this test, the CT shown on Fig.3a was used. The phantom was positioned in an isocentric setup, with the isocenter as shown on Fig.3a – marked with the green cross. This was also the measurement point. A three field test plan was created with prescribed daily dose of 2 Gy. The gantry angles of the fields were 0º, 90º and 270º. For each of the fields the collimator angle was 90º and a MLC was placed with an orientation typical for most clinical cases that employ this technique. The field with gantry angle 0º was with 6 MV, and the other two fields were with 15 MV and EDW60. The weight of the field with gantry 0º was 60%, while each of the other two fields delivered 20% of the dose.

2.2.8. Test 8 – Testing calculation in case of a typical plan for irradiation of brain tumors

This was a test plan for evaluating the irradiation of a typical brain tumor case. For this test, the CT shown on Fig.3a was used. The phantom was positioned in an isocentric setup, with the isocenter as shown on Fig.3a – marked with the green cross. This was also the measurement point. A three field test plan was created with prescribed daily dose of 2 Gy. For two of the fields (with 15 MV, EDW10, gantry angles 90º and 270º and collimator angles 0º and 90º respectively) the couch rotation was 0º, while for the third field (6 MV, gantry angle 45º, collimator angle 90º) it was 90º. The weight of the field with a couch angle 90º was 20%, while each of the other two fields delivered 40% of the dose.

2.2.9. Test 9 – Testing calculation in case of a typical plan for irradiation of head and neck cancer

This was a test plan for evaluating the irradiation of a typical head and neck cancer case. For this test, the CT shown on Fig.3a was used. The phantom was positioned in an isocentric setup, with the isocenter as shown on Fig.3a – marked with the green cross. This was also the measurement point. A typical four field test plan was created with prescribed daily dose of 2 Gy. The four fields are described in Table 1.

Table 1. Field description for head and neck case

Gantry angle (º)	Coll. angle (º)	Nom. En. (MV)	Weight (%)	EDW
140	0	6	12.5	30
60	90	6	37.5	30
300	90	6	37.5	30
220	0	6	12.5	30

For each of the fields a MLC was placed with an orientation typical for most clinical cases that employ this technique.

3. RESULTS

3.1. Evaluation based on "Beam Analysis" Workspace

In Tables 2 and 3, we present the results from the comparison of the measured and the calculated depth dose curves in the "Beam Analysis" workspace of "Eclipse" for 6 MV and 15 MV photons, respectively.

Table 2. Difference between calculated and measured depth dose curve for 6 MV photons

Square field size (cm)	Max. dose differ. (%)	Depth differ. (mm) at max. dose	Depth differ. (mm) at 50% dose	Dose differ. (%) at 100 mm depth	Dose differ. (%) at 200 mm depth
3	0.50	0.05	0.15	0.30	0.03
4	0.60	0.05	0.03	0.37	0.01
6	0.50	0.05	0.10	0.30	0.01
8	0.52	0.05	0.15	0.32	0.07
10	0.47	0.05	0.12	0.31	0.01
12	0.50	0.05	0.10	0.32	0.01
15	0.40	0.05	0.15	0.29	0.04
20	0.41	0.05	0.02	0.31	0.04
25	0.42	0.05	0.15	0.29	0.03
30	0.40	0.05	0.26	0.20	0.05
35	0.37	0.05	0.13	0.22	0.03
40	0.33	0.05	0.04	0.22	0.03

Table 3. Difference between calculated and measured depth dose curve for 15 MV photons

Square field size (cm)	Max. dose differ. (%)	Depth differ. (mm) at max. dose	Depth differ. (mm) at 50% dose	Dose differ. (%) at 100 mm depth	Dose differ. (%) at 200 mm depth
3	0.43	0.05	0.16	0.28	0.04
4	0.43	0.05	0.05	0.23	0.01
6	0.43	0.05	0.97	0.23	0.04
8	0.43	0.05	0.52	0.26	0.02
10	0.40	0.05	0.28	0.19	0.06
12	0.31	0.05	0.02	0.16	0.02
15	0.43	0.05	0.04	0.25	0.04
20	0.33	0.05	0.07	0.16	0.01
25	0.36	0.05	0.08	0.19	0.04
30	0.30	0.05	0.20	0.21	0.01
35	0.27	0.05	0.16	0.18	0.03
40	0.33	0.05	0.19	0.15	0.02

From the Tables 2 and 3, it can be seen that the differences in the depth dose curves are very small and therefore quite acceptable. For example, the maximal dose difference for 6 MV photon beam is less than 0.6%, while for the 15 MV photon beam it is less than 0.5%.

Concerning the evaluation of the difference of the measured and calculated profiles, the "Beam Analysis" workspace calculates the difference (in mm) in the off-axis distance at different dose levels for the left side and the right side of the profiles. In Table 4, we present the maximal values of these differences for 80% and 50% dose, for all the depths of measurements for the different fields.

Table 4. Maximal off-axis distances differences (mm) at different dose levels for all the depths of measurements for different field sizes

Maximal off-axis distance difference of the:	For fields	
	≤ 30 cm	> 30 cm
80% dose at the left side (mm)	0.64	2.0
80% dose at the right side (mm)	0.72	3.3
50% at the left side dose (mm)	0.64	1.1
50% dose at the right side (mm)	0.88	1.3

The values for the fields smaller than 30 cm were found to be quite acceptable. For the fields greater than 30 cm (i.e. 35 cm and 40 cm), because of the size of the fields, we had to use a calculation grid of 0.5 cm (instead of grid size 0.25 cm which we used for smaller fields) which also influenced the obtained results.

Concerning the beam profile differences, in addition to the results provided by the "Beam Analysis" workspace, we performed an evaluation of the dose differences within the flattened area. In Tables 5 and 6, the maximal dose differences (in %), between the calculated and the measured beam profiles are given, for all measured field sizes and depths, within the flattened area of the profiles, for 6 MV and 15 MV photon beams respectively.

Table 5. Maximal dose differences between the calculated and the measured profile within the flattened area (%) for 6 MV photon beam

Field size (cm) \ Depth (cm)	1.6	5	10	20	30
3	0.45	0.90	0.82	0.33	2.07
4	0.50	1.40	1.41	0.84	1.61
6	0.30	1.17	1.02	0.41	0.4
8	0.25	0.64	0.9	0.73	0.57
10	0.70	0.51	0.69	1.05	1.95
12	0.40	0.60	0.79	1.42	2.06
15	0.61	0.68	0.64	1.65	2.59
20	0.41	0.87	0.86	1.74	2.79
25	0.49	0.67	0.62	0.72	1.96
30	0.49	0.67	0.62	0.72	1.96
35	0.29	0.62	0.82	0.42	1.05
40	0.78	1.22	1.14	0.96	0.66

Table 6. Maximal dose differences between the calculated and the measured profile within the flattened area (%) for 15 MV photon beam

Field size (cm) \ Depth (cm)	1.6	5	10	20	30
3	0.30	0.27	0.53	1.40	2.41
4	0.89	0.94	0.52	2.05	1.27
6	0.75	0.73	0.98	0.94	0.87
8	0.60	0.89	1.09	0.88	0.76
10	0.80	0.84	0.94	0.80	1.00
12	0.90	1.10	1.00	0.69	1.40
15	0.92	1.10	1.21	1.38	1.80
20	1.29	1.25	0.95	1.39	2.46
25	1.49	1.13	1.10	1.49	2.36
30	1.37	1.02	1.11	1.44	1.99
35	0.86	1.02	0.95	0.82	1.14
40	1.26	1.27	1.21	1.04	0.82

From Tables 4 and 5, it can be seen that for both photon energies, for all depths and field sizes, the maximal dose difference is smaller than 3%, while for the more significant depths (less than 20 cm) the differences are even less than 1.5%. This is an acceptable result and the "Beam Analysis" workspace justifies the clinical use of the PBC algorithm for a three-dimensional conformal radiotherapy treatment planning.

3.2. Evaluation based on ionization chamber measurements

The results from the tests performed with the "OPERA" phantom are given in Table 7. All the measurements were corrected for the daily deviation in the output of the linac. The measurements where the beam traversed through the treatment couch top were also corrected for its attenuation.

Table 7. Results of the tests performed with the "OPERA" phantom

Test No.	Field	MU	Calculated Dose (cGy)	Measured dose (cGy)	Relative Difference (%)
1	6 MV	100	87.1	86.90	-0.23
	15 MV	100	95.2	95.46	0.27
2	6 MV	183	100.1	98.54	-1.58
	15 MV	147	100.6	99.08	-1.53
3	6 MV	101	66.7	66.26	-0.66
	15 MV	103	78.6	78.70	0.13
4	6 MV	101	98.3	97.99	-0.32
	15 MV	94	99.1	99.35	0.25
5	6 MV	127	126.6	125.18	-1.13
	15 MV	109	122.2	120.61	-1.32
6	g=180	52	49.9	49.71	-0.38
	g=90	52	49.7	49.39	-0.63
	g=0	47	49.9	50.26	0.72
	g=270	52	49.7	49.5	-0.40
		Sum	199.2	198.86	-0.17
7	g=90	70	40.4	40.22	-0.45
	g=0	121	119.6	119.72	0.10
	g=270	69	40.4	39.31	-2.77
	Sum		200.4	199.25	-0.58
8	g=270	95	80.1	78.93	-1.48
	g=90	89	80.1	79.02	-1.37
	couch=90	43	39.8	39.62	-0.45
	Sum		200.0	197.57	-1.23
9	g=140	44	24.6	24.26	-1.4
	g=60	106	74.3	72.98	-1.81
	g=300	107	74.4	73.35	-1.43
	g=220	44	24,7	24.17	-2.2
	Sum		198.0	194.76	-1.66

The results given in Table 7 are all within 3%, which justifies the clinical use of the PBC algorithm for a three-dimensional conformal radiotherapy treatment planning.

4. CONCLUSION

From the results obtained from the "Beam Analysis" workspace of the Eclipse TPS, the differences between the measured and the calculated depth dose curves were found to be less than 0.6% for 6 MV and 0.5% for 15 MV. For all the depths the dose difference between the beam profiles was found to be less than 3% and for the clinically significant depths even less than 1.5% within the flattened area. The measurements with the "OPERA" phantom confirmed that the difference between the planned dose and the delivered dose will be less than 3%, and for the clinically significant cases usually less than 2%. All these results justify the clinical use of the PBC algorithm for a three-dimensional conformal radiotherapy treatment planning, as it is configured for the Varian Clinac S/N 5052 at the University Clinic of Radiotherapy and Oncology in Skopje, Macedonia.

5. REFERENCES

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