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An institutional experience of quality assurance of a treatment planning system on photon beam

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A R T I C L E   I N F O

A B S T R A C T

Aim: The purpose of the present study is to show the application of the IAEA TRS-430 QA procedures of Eclipse^{TM}v7.5 TPS for photon energies. In addition, the trends of the deviations found in the conducted tests were determined.

Background: In the past, the lack of complete TPS QA procedures led to some serious accidents. So, QA in the radiotherapy treatment planning process is essential for determination of accuracy in the radiotherapy process and avoidance of treatment errors.

Materials and methods: The calculations of TPS and measurements of irradiations of the treatment device were compared in the study. As a result, the local dose deviation values (δ_1: central beam axis, δ_2: penumbra and build up region, δ_3: inside field, δ_4: outside beam edges, δ_{50-90}: beam fringe, RW_{50}: radiological width) and their confidence limit values (including systematic and random errors) were obtained.

Results: The confidence limit values of δ_4 were detected to increase with expanding field size. The values of δ_1 and δ_3 of hard wedge were larger than open fields. The values of δ_2 and δ_{50-90} of the inhomogeneity effect test were larger, especially than other tests of this study. The average deviation was showed to increase with the rise of the wedge angle. The values of δ_3 and δ_4 of lung irradiation were outside tolerance.

Conclusions: The QA of TPS was done and it was found that there were no reservations in its use in patient treatment. The trend of the deviations is shown.

1.   Background

In recent years, complexity of TPS has increased significantly and this has led to the requirement for a comprehensive quality assurance (QA) guidelines. Increased attention has been paid to quality assurance of treatment planning systems by many researchers,[2,3,6] several national and international organizations.[1,4,5,7]

In the past, the lack of complete TPS QA procedures led to some serious accidents. So, QA in the radiotherapy treatment planning process is essential for determination of
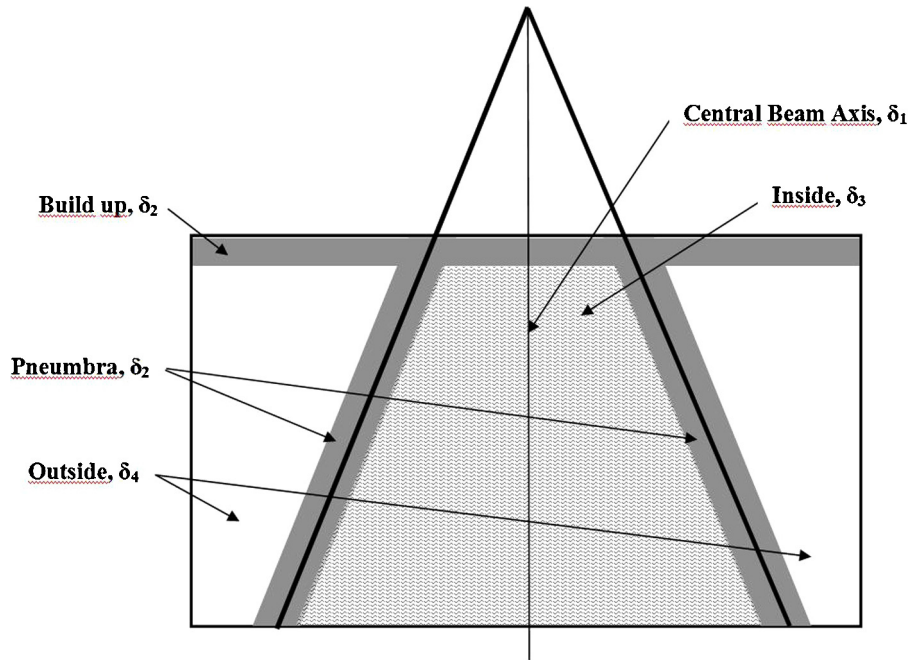
Fig. 1 – Definition of different regions in a radiation beam, based on the magnitude of the dose and dose gradient (adapted from Ref.[8]).

accuracy in the radiotherapy process and avoidance of treatment errors.[1]

1.1. QA guidelines

A number of task groups[1,5,8] over the past several years have developed guidelines and protocols for systematic QA of 3D radiotherapy treatment planning systems (TPSs), including specific QA aspects of a TPS, such as anatomical description, beam description, dose calculations, and data output and transfer. Many studies have been performed to address specific problems associated with treatment planning and dose calculation procedures.[9–12] Some studies[13–16] were related to the performance of a specific TPS.

The general requirements of QA of TPS in radiotherapy have already been discussed in the literature.[1–3] Some reports[1–4] have been published to help physicists in the implementation of a comprehensive QA program. Comprehensive report of IAEA for QA is called TRS-430 report.[1]

TRS-430 report[1] includes four steps of QA program; acceptance tests, commissioning, periodic QA program and patient specific QA. The acceptance test is applied to verify functionality and quantity agreement with the specification report attached by manufacturer. The commissioning consists of two different processes. One includes dosimetric study to verify the performance of the dose calculation generated by the TPS. The others are non-dosimetric verifications to verify the functionality of the tools of TPS. Periodic QA program is implemented to verify reproducibility of planning in accordance with that established at commissioning. Patient specific QA is performed to verify the treatment process as a whole.

1.2. Criteria of acceptability

AAPM TG 53 report[5] and several researchers[2,17,18] have defined different criteria of acceptability of various regions that can be defined in terms of dose and dose gradient in a photon beam, as shown in Fig. 1. Venselaar et al.[17] has defined a set of criteria of acceptability based on different tolerances for δ (local dose deviation) based on the knowledge that dose calculation algorithms provide a better accuracy in the high dose and small dose gradient region of the beam than in others. These reports[2,5,17] have proposed different tolerances for the various regions in a photon beam, as given in Table 1.

Deviations between results of calculations and measurements can be expressed as a percentage deviation of the local dose according to Venselaar et al.[17]

$$\delta = 100\% \times \left(\frac{D_{cal} - D_{meas}}{D_{meas}} \right) \tag{1}$$

where D_{cal} and D_{meas} are calculated dose at particular point in the phantom and measured dose at the same point in the phantom, respectively. In low dose regions where the points were outside the penumbra or under a block, an alternative comparison was made accordingly to Venselaar et al.[17]

$$\delta = 100\% \times \left(\frac{D_{cal} - D_{meas}}{D_{meas,cax}} \right) \tag{2}$$

where $D_{meas,cax}$ is dose measured at a point at the same depth on the central axis of the open beam. If a study consisting of many points is evaluated, some statistical assessment can

Table 1 – The local dose deviations of different dose regions in photon beam.

Local dose deviation	Region definition	Dose magnitude and dose gradient
δ_1	○ PDDs: for data points on the CAX beyond the depth of d_{max}	○ High dose ○ Small dose gradient
δ_2	○ PDDs: for data points in the build-up region ○ Profiles: for data points in the penumbra, and in regions close to interfaces of inhomogeneities regions	○ High dose ○ Large dose gradient
δ_3	○ Profiles: for data points beyond d_{max}, within the beam but outside the CAX	○ High dose ○ Small dose gradient
δ_4	○ Profiles: for data points off the geometrical beam edges and below shielding blocks, generally beyond d_{max}	○ Low dose ○ Small dose gradient
RW_{50}	○ Profiles: The radiological width, defined as the width of a profile measured at half its height compared to the value at the beam axis	–
δ_{50-90}	○ Profiles: The distance between the 50% and the 90% point (relative to the maximum of the profile) in the penumbra	–

be performed on the calculation points and the measurement points. Accordingly, confidence limit, Δ, is as follows:

$$\Delta = |\text{average deviation}| + 1.5 \times SD \qquad (3)$$

where SD is the standard deviation.[17,18] In Eq. (3), the factor 1.5 is chosen rather arbitrarily, but it was useful for this purpose in clinical practice.[18,19] If a factor greater than 1.5 was used in Eq. (3), this would emphasize the random errors, while a factor smaller than 1.5 would increase the relative importance of systematic deviations.

The tolerances of δ as defined in Table 4 can be applied to the confidence limit. At photon beam dose calculation, the three different levels of complexity of geometry are given in Table 2.

The evaluation of absolute and relative dose tests was used in percent difference between the result of TPS MU calculation and the result of independent MU calculation. According to the TRS-430 report,[1] criteria of acceptability recommend that percent difference must be ≤2% for using no accessories, no beam modifiers and no inhomogeneity. Otherwise, difference must be ≤3%.

In case the TPS fails to meet these accuracy requirements, the NCS report[7] suggests the following:

(i) Check the basic beam data entered in the TPS and the test beam data set.
(ii) Adjust the model parameters.

(iii) Restrict the clinical use of the TPS to geometries that passed the test.
(iv) Inform the vendor about the findings.

1.3. QA procedure in TPS

A number of authors[20–23] have implemented dosimetric and non-dosimetric tests of QA procedure into TPS with the guidance of the IAEA TRS 430 report. These authors have reported that the most critical difference occurred for oblique incidence, oblique incidence-off axis, shaped fields and off axis-wedged.

Some reports[24–26] have demonstrated differences of algorithms for various special regions.

2. Aim

The purpose of the present study is to show the application of the IAEA TRS-430 QA procedures of Eclipse™v7.5 TPS for photon energies by using a dosimetric measurement system. As a result of calculations and measurements from test plans, local dose deviation values were obtained as δ_1 (central beam axis), δ_2 (penumbra and build up region), δ_3 (inside field) and δ_4 (outside beam edges), δ_{50-90} (beam fringe), RW_{50} (radiological width) and their confidence limit values (including systematic and random errors). In addition, the trends of the deviations found in the conducted tests were determined.

Table 2 – The different levels for complexity of geometry for photon beam dose calculation.

Geometry	Definition	
	Phantom	Beam arrangement
Simple geometry	Homogeneous phantoms	○ Rectangular field size ○ Variation of SSD ○ Oblique incidence
Complex geometry	Non-homogeneous phantoms	○ Fields with wedge ○ Irregular field ○ Asymmetric collimator settings ○ Missing tissue
More complex geometries	Non-homogeneous phantoms	○ Combinations of complex geometry

Table 3 – Details of dosimetric tests performed on TPS in the present study.

Test type	Test	Test geometry	Energy (MV)	Field size (cm × cm)	Depth (cm)	Measurement systems	Note
					Detail		
Photon beam commissioning	1	Square fields	6, 18	3×3, 5×5, 10×10, 35×35	d_{max}, 5, 10, 20	WP, PFD[3G]	
	2	Rectangular fields	6, 18	5×35, 35×5			
	3	Asymmetric fields	6, 18	$X_1 = 2$, $X_2 = 8$, $Y_1 = 3$, $Y_2 = 7$, $X_1 = 5$, $X_2 = 5$, $Y_1 = 0$, $Y_2 = 10$			
	4	Shaped fields	6, 18	Cord and corner block convex and concave aperture			
	5	Source to surface distance depence	6, 18	10×10			SSD: 90 cm, 100 cm, 110 cm
	6	Hard wedge	6, 18	5×5, 10×10, 20×30 (only 15×30 for 600 W)			15°, 30°, 45°, 60° Ws
	7	Dynamic wedge	6, 18	5×5, 10×10, 10×20	10	WP, FC23-C, EDR2	15°, 45° EDWs
	8	Oblique incidence	6, 18	10×10	d_{max}, 5, 10	WP, PFD[3G]	Gantry angle: 330°
	9	Missing scatter	6, 18	20×20	15	SP34, FC23-C	
	10	Buildup behavior	6, 18	5×5, 10×10, 20×20	$0.2 - d_{max}$	SP34, PPC05	
	11	Density correction	6, 18	15×10	5.5	SP34-RP, FC23-C, EBT2	With created special phantom
Operational tests	12	Algorithm choice					TPS has single algortihm licence. So test wasn't performed
	13	Inhomogeneity corrections	6, 18	It was used fields of Test 27.a			a. Modified Batho, b. B. Batho power Law, c. Equivalent TAR
	14	Calculation validity	6, 18	It was used fields of Test 25.b			
	15	Calculation grid	6, 18	10×10	$0 - d_{max}$		Calc. grid = 1.25, 2.5, 10 mm
Absolute and relative dose tests	16	Open fields	6, 18	5×5, 10×10, 30×30	Isocentre		Box technique, different beam weights
	17	Tangential Fields	6, 18	10×10, 20×20			Tangential technique, MLC
	18	Wedged fields	6, 18	5×5, 10×20, 20×20			Lateral fields + AP field, different beam weights
	19	MLC shaped fields	6, 18	It was added MLC to fields of Test 16			Box technique, different beam weights
	20	Inhomogeneity corrections	6, 18	It was used fields of Test 27.a-b			Modified Batho, same beam weights
	21	Off-axis calculations	6, 18	20×20			AP and PA fields, also 30° W
Overall clinical tests	22	Open field	6, 18	5×5, 10×10, 20×20	Isocentre	SP34, FC65-G	Box technique, different beam weights
	23	Blocking field	6, 18	It was added MLC to fields of Test 22			
	24	Wedged field	6, 18	10×10, 20×20			15°, 30° Ws and AP- PA fields

Table 3 (Continued)

25	CT planning for cranium irradiation	6	a. Lateral fields b. Lateral + vertex fields	RP, TLD-100	Clinically, the most accordance with MLC, beam weight, dose prescription and accessory was selected
26	CT planning for Head and Neck irradiation	6	a. Lateral fields b. Five field techniques[a]		
27	CT planning for Lung irradiation	18	a. AP and PA fields b. Box technique		

Ref., reference; MLC, multileaf collimator; W, wedge; EDW, enhanced dynamic wedge; CT, computed tomography; AP, anterior–posterior; PA, posterior–anterior; WP, water phantom; SP34, solid water phantom; RP, RANDO® phantom; PFD3G, photon field diode; FC65-G, 0.65 cm³ FC65-G ion chamber; FC23-C, 0.23 cm³ FC23-C ion chamber; PPC05, PPC05 type parallel plane ion chamber; EDR2, EDR2 film; EBT2, gafchromic EBT2 film; TLD, thermoluminescent dosimeter.

[a] Adapted from Ref. 28.

3. Materials and methods

The commissioning procedure of the IAEA TRS-430 for clinical photon beams was implemented for pencil-beam convolution algorithm of Eclipse^{TM}v7.5 (Varian Medical Systems, Palo Alto, CA, USA) TPS that was installed to beam data of Clinac DHX (2300 CD) linear accelerator (Varian Medical Systems, Palo Alto, CA, USA). Clinac DHX linear accelerator generates 6 MV and 18 MV photon energy beams (quality index: $TPR_{20/10}$, $TPR_{20/10} = 0.6646$ for 6 MV and $TPR_{20/10} = 0.7871$ for 18 MV). After the assembly of Clinac DHX linear accelerator, acceptance tests were implemented and performed to verify it within recommended specific tolerance. For beam data for TPS, measurements were carried out by the RFA-300 3D radiation field analysis system (Wellhöfer Dosimerie GmbH, Schwarzenbruck, Germany) controlled by OmniPro-Accept v6.5 software and silicon semiconductor diode detectors (Wellhöfer Dosimerie GmbH, Schwarzenbruck, Germany).

In this commissioning procedure, results of the calculation of the plan at the TPS and were compared with those of the measurement taken from the treatment device in this study. A TPS calculation grid size of 5 mm was preferred for all tests because of clinically relevant general use. As a result of the comparison of test plans, local dose deviation values were obtained as δ_1, δ_2, δ_3, δ_4, δ_{50-90} and RW_{50} and confidence limit values calculated. In addition, the trends of the deviations found in the conducted tests were determined.

3.1. Commissioning of TPS

The photon beam commissioning tests, operational tests, absolute and relative dose tests, overall clinical tests are all detailed in Table 3.

3.1.1. Machine capabilities and beam tests
In this process, there are non-dosimetric tests that are involved in the machine or beam definition and use. These tests are performed to check and document the description, limitations, settings and display etc. of the machine.

3.1.2. Photon beam commissioning tests
These tests aim to compare the measurement dose and the calculated dose by TPS. The central axis percentage depth dose and beam profile measurements were made by using the RFA-300 3D radiation field analysis system controlled by OmniPro-Accept v6.5 software. The absolute dose measurements were performed with 0.65 cm³ FC65-G, 0.23 cm³ FC23-C farmer type ion chambers and PPC05 parallel plane chamber connected to DOSE1 electrometer. The film dosimetry measurements were implemented with EBT2, EDR2 films (Gafchromic EBT2, International Speciality Products, Wayne, NJ; EDR2 films, Eastman Kodak120 Company, Rochester, NY) and a digitizer (VIDAR Dosimetry PRO Advantage, Vidar Systems Corporation, Hendon, VA).

The performance of TPS was investigated the difference between calculated and measured dose values as a percentage of the dose measured locally. So, local dose deviation values were obtained as δ_1, δ_2, δ_3, δ_4, δ_{50-90} and RW_{50} and confidence

Table 4 – According to complexity of geometry, proposed values of the tolerance for percentage deviation of dose at different local.

Tolerance	Simple geometry	Complex geometry	More complex geometry
δ_1 (central beam axis) High dose, small dose gradient	% 2	% 3	% 4
δ_2 (buildup region of central axis and penumbra region of profiles) High dose, large dose gradient	2 mm or % 10	3 mm or % 15	3 mm or % 15
δ_3 (outside central beam axis region) High dose, small dose gradient	% 3	% 3	% 4
δ_4 (outside beam edges) Low dose, small dose gradient	% 3	% 4	% 5
RW_{50} (radiological width)	2 mm or % 1	2 mm or % 1	2 mm or % 1
δ_{50-90} (beam fringe)	2 mm	3 mm	3 mm

limit values calculated. Confidence limit values were evaluated according to Table 4.

3.1.3. Operational tests

Operational tests aim to confirm that the function of TPS is performed whenever a various operational issues related to dose calculations, such as grid size, algorithm choice, inhomogenity correction, etc., are changed.

3.1.4. Absolute and relative dose tests

These tests are intended to confirm the accuracy of the basic monitor unit (MU) calculation method for different fields, accessories and media. At this stage, compared are the results of TPS MU calculation and the results of independent MU calculation. Measured beam data of Varian Clinac DHX for independent MU calculation are used. According to the TRS-430 report,[1] the criteria of acceptability recommend that a percent difference must be ≤2% for using no accessories, no beam modifiers and no inhomogeneity. Otherwise, the difference must be ≤3%.

3.2. Overall clinical tests

Overall clinical tests are aimed to confirm that the absolute dose delivered is in the expected tolerance range after a specific clinic plan is prepared through a total planning process. The absolute dose measurements were performed with 0.65 cm³ FC65-G connected to DOSE1 electrometer, calibrated TLD at SP34 solid water phantom (including RW3 material) and RANDO® Phantom (the Phantom Laboratory, Salem, New York, USA). All measurements were performed 3 times. Position of all measurement points is given in Fig. 2. Confidence limit values were evaluated according to Table 4.

4. Results

Although many conditions of field size or measurement depth in each test are given in Table 3, Table 5 only shows results of one parameter. These are confidence limit values (calculated with Eq. (3) with results of all field sizes and all measurement depths in each test.

4.1. Commissioning of TPS

4.1.1. External beam plans: machine capabilities and beams

At this process, the IAEA TRS 430 checklist was satisfactorily performed to Eclipse™ v7.5 TPS and specifications determined by vendor were provided.

4.1.2. Photon beam commissioning

Results of photon beam commissioning were evaluated separately with respect to each energy and confidence limits of individual measurement type (%DD, profile, point dose) in detail (Table 5).

Results of the square field test were found to be satisfactory. These results were within the tolerance limits. Notably, it was detected that confidence limit values of δ_4 increase with expanding field size. The same results were found in the test of rectangular fields.

Results of δ_1 and δ_3 of the hard wedge were larger than for open fields. These results were within the tolerance limits. Additionally, it was showed that mean deviations of δ_2 for %DD increase with expanding field size for each wedge angle. Remarkably, confidence limit values of δ_2 were larger than open fields. At the same time, results of the dynamic wedge were within the tolerance limits. It was detected that the δ_4 values of the hard wedge and dynamic wedge increase with expanding field size and rising wedge angles (Table 5).

At oblique incidence tests, it was found that δ_2 confidence limit values of %DD are outside the tolerances, while the others are within tolerances.

According to missing scatter tests, the results were satisfactory. At investigation of build-up area, it was determined that values of δ_2 decrease with expanding depth and field size.

For inhomogeneity effect tests, values of δ_3 for low energy were found outside the tolerances because of high SD (Table 5).

4.1.3. Operational tests

Algorithm choice test of operational tests could not be investigated because of the fact that it has a single algorithm licence. It was observed that TPS used inhomogeneity correction effectively. Furthermore, whenever a parameter relevant to the dose calculation is changed, dose calculations are set to be invalid or changing interactively. It was noticed that dose TPS used calculation grid size, this effect being particularly important at large dose gradient area.

Table 5 – Results of photon beam commissioning performed on TPS.

Test number	Test geometry	Energy (MV)	Number of points[a]	%DD		Profile				
				δ_1 (%)	δ_2 (mm)	δ_2 (mm)	δ_3 (%)	δ_4 (%)	δ_{50-90} (mm)	RW_{50} (mm)
1	Square fields	6	SaP	1.00	1.03	1.65	0.90	5.30 [f↑, d↓]	1.78	2.38 [f↑]
		18	SaP	0.90	1.20	1.70	1.27	4.96 [f↑, d↓]	1.10	2.89 [f↑]
2	Rectangular fields	6	SaP	0.79	1.27	1.00	0.97	3.28 [f↑, d↓]	1.53	0.78 [f↑]
		18	SaP	1.26	2.25	1.27	1.65	3.73 [f↑, d↓]	0.99	1.63 [f↑]
3	Asymmetric fields	6	SaP	1.42	1.48	1.37	0.72	3.05 [f↑, d↓]	1.63	1.41 [f↑]
		18	SaP	1.17	1.53	1.06	1.90	3.10 [f↑, d↓]	1.72	1.32 [f↑]
4	Shaped fields	6	SaP	2.07 [b↑]	1.68	1.64 (5.85)	0.71	5.70 [f↑, d↓]	2.36	1.73 [f↑]
		18	SaP	2.40 [b↑]	2.54	1.73 (5.25)	1.37	5.51 [f↑, d↓]	1.35	2.56 [f↑]
5	Distance depence	6	SaP	1.40 [ssd↓]	1.68 [ssd↓]	1.47	0.68	3.10	1.41	1.30
		18	SaP	1.62 [ssd↓]	1.97 [ssd↓]	1.33	1.39	2.82	1.45	1.25
6	Hard wedge	6	SaP	1.33	2.74 [f↑]	1.36	1.13	4.74 [f↑, d↓, w↑]	1.74	0.65 [f↑]
		18	SaP	1.22	3.69 [f↑]	1.30	1.10	4.54 [f↑, d↓, w↑]	1.32	0.91 [f↑]
7	Dynamic wedge	6	SaP	–	–	2.30	1.90	3.73 [f↑,w↑]	1.90	1.62
		18	SaP	–	–	1.89	1.56	4.1 [f↑,w↑]	2.11	1.92
8	Oblique incidence	6	SaP	0.70	4.00	1.10	0.85	3.66 [d↓]	0.63	0.55
		18	SaP	1.00	3.45	0.83	1.06	2.48 [d↓]	1.13	0.30
9	Missing scatter	6	15	–	–	–	1.17	–	–	–
		18	15	–	–	–	2.28	–	–	–
10	Build-up region (without 0.2 cm)	6	18	–	% 0.60–7.40 [d↓]	–	–	–	–	–
		18	27	–	% 0.20–53.95 [d↓]	–	–	–	–	–
11	Inhomogeneity effect	6	SaP	–	–	2.62	4.83	3.61	1.75	1.25
		18	SaP	–	–	3.82	2.70	5.11	2.00	1.00

The trends of deviations depending on depth, field size, shaped field, source to surface distance, wedge angle are denoted by [d↑↓], [f↑↓], [b↑↓], [ssd↑↓], [w↑↓], respectively. For example; it has been denoted that, when the depth is increased, the increasing of dose deviation is showed in the form [d↑], while the reduction of dose deviation is showed in the form [d↓].

The results which are outside the tolerance limits are italicised.

[a] SaP, scanned all point (measurement precision was accepted 0.1 cm, such as obtained point number is 130 for 1D profile measurement of 10 cm × 10 cm field size (%DD and Profile).
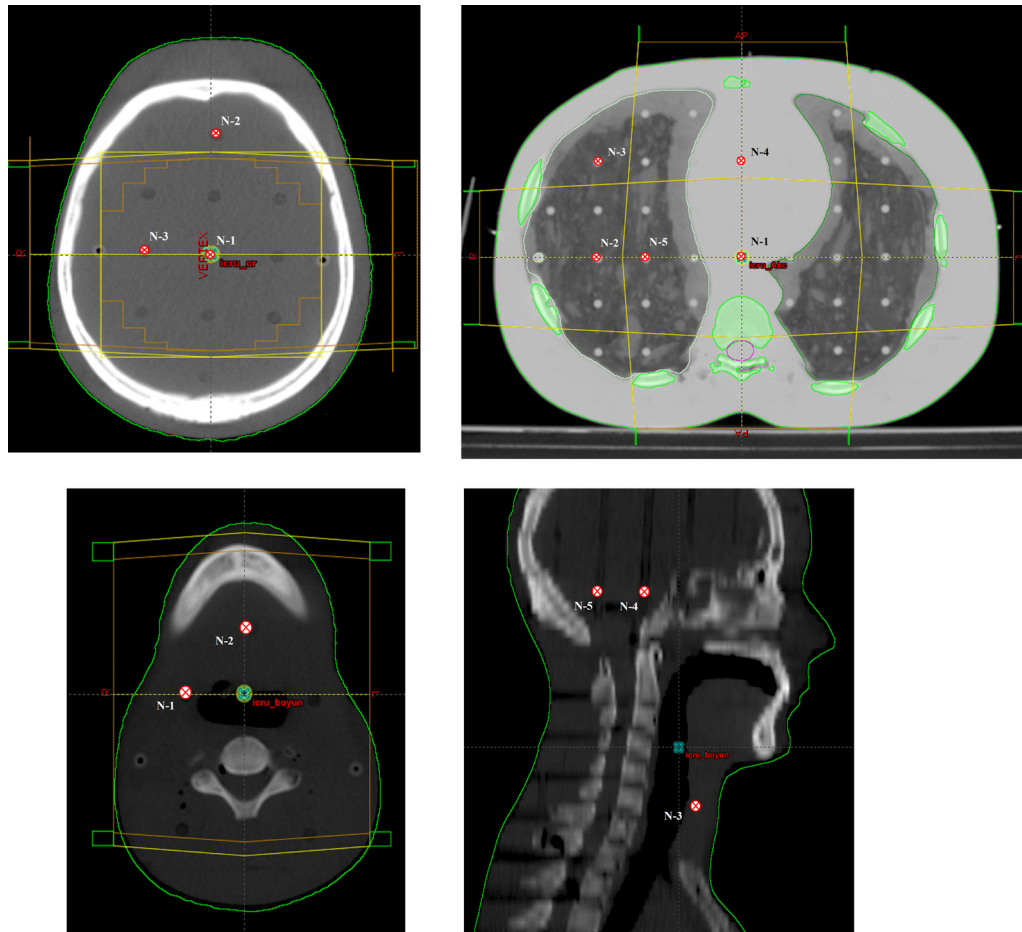
Fig. 2 – Positions of all measurement points at overall clinical tests.

4.1.4. *Absolute and relative dose tests*

Test results were evaluated in terms of percent deviation (mean ± SD) value (Table 6). Many results of investigation were found to be satisfactory. But results of the off-axis points test using asymmetric fields for all photon energies were without the tolerance limits (Table 6).

4.2. *Overall clinical tests*

Clinical tests were performed on homogenous solid phantom and rando-phantom. Although the results of open field, blocking field tests, were found within the tolerance limits, results of wedged field were outside the tolerance limits, especially for high energy. Significantly, it was showed that average deviations increase with the rise of wedge angle. CT planning for treatment was adapted to the treatment techniques used in the clinic (such as the head and neck five-field technique[28]). While test results of cranium irradiation were found within the tolerances, values of δ_3 and δ_4 of lung irradiation were outside the tolerance limits. Reasons for the discrepancy could include the choice of beam quality or the presence of low density tissue. For head and neck irradiation, confidence limits were found in high values because of high SD that is based on setup error in five-field techniques. The region near the spinal cord is sensitive to set up errors because of a high dose

gradient. But the resultant high dose gradient of this technique is not near to critical organs as the spinal cord.

5. Discussion

In this study, we commissioned Varian Eclipse[TM]v7.5 TPS in accordance with the procedure of the IAEA TRS-430 for clinical photon beams.

The accuracy of the dosimetric calculation of Eclipse[TM] TPS v7.5.18 has been implemented and reported in detail by Camargo et al.[21] It was reported that the most critical difference occurs for oblique incidence, oblique incidence off axis, shaped fields and off axis wedge. The QA of Eclipse[TM] TPS v7.3.10 has been reported in detail by Jamema et al.[20] According to that report, it was determined that oblique incidence calculation does not show a variation outside the tolerance limits. However, for open and wedged asymmetric fields, variation out of the tolerance was found at several points in the penumbral region.

In this study, it was found that deviations occur for δ_2 of %DD for oblique incidence test, δ_2 of %DD for hard wedge, δ_2 of profiles for dynamic wedge. In addition, the δ_4 of profiles (dose outside the field) was determined outside the tolerances for many tests. Especially, the δ_4 of shaped field, hard wedge

Table 6 – Results of absolute and relative dose tests performed on TPS.

Test number	Test geometry	Energy	Deviation (% (mean ± SD))	Note
1	Open fields	6 MV	0.16 ± 0.4	5 cm × 5 cm, 10 cm × 10 cm, 30 cm × 30 cm
		18 MV	−0.08 ± 0.7	
2	Tangential fields	6 MV	0.53 ± 0.1	10 cm × 10 cm, 10 cm × 20 cm
			1.13 ± 0.0	10 cm × 20 cm (MLC shielding)
		18 MV	0.77 ± 0.3	10 cm × 10 cm, 10 cm × 20 cm
			2.74 ± 0.0	10 cm × 20 cm (MLC shielding)
3	Wedge fields	6 MV	−1.06 ± 1.0	5 cm × 5 cm, 10 cm × 20 cm, 20 cm × 20 cm
		18 MV	0.16 ± 1.6	
4	MLC shielding fields	6 MV	0.37 ± 0.6	5 cm × 5 cm, 10 cm × 10 cm, 30 cm × 30 cm
		18 MV	0.91 ± 0.4	
5	Inhomogenity correction	6 MV	0.43 ± 1.3	2 fields, MLC shielding plan
			1.00 ± 1.8	4 fields, MLC shielding plan
		18 MV	0.19 ± 1.0	2 fields, MLC shielding plan
			1.80 ± 2.1	4 fields, MLC shielding plan
6	Off-axis points	6 MV	−0.10 ± 1.3	Open fields
			3.52 ± 0.4	Asymmetric fields
			0.12 ± 1	Open fields, 45 wedge fields
		18 MV	−0.71 ± 1.4	Open fields
			3.51 ± 0.6	Asymmetric fields
			−0.60 ± 0.7	45 wedge fields

The results which are outside the tolerance limits are italicised.

and dynamic wedge increased with expanding field size and rising wedge angles (Table 5).

At tests of hard and dynamic wedge fields, the increased deviation between measurement and calculation can depend on resultant small errors of basic beam data as wedge profiles and wedge transmission factors.

Build-up dose tests were observed to show a large difference for depth from 0.2 cm to d_{max}. User guideline of Eclipse suggested to change the grid size of calculation. When the 5 mm grid size was changed to the smallest grid size available of 1.25 mm, the variation in the dose calculation in the build-up region was reduced. Hence, it was decided that for patients involving (skin tumors) build-up region dose calculation, smaller grid size should be used.[20]

In the study of the TRS 430 report[1] used by Murugan et al.,[22] the result yields were declared to find a max. deviation of 2.38% (tolerance: 2%) for all simple tests and 5.94% (tolerance: 5%) for complex tests in the presence of inhomogeneity, beam modifiers or beam modifiers with asymmetric field. In this study, values of δ_2 (penumbra) and δ_{50-90} (beam fringe) of inhomogeneity effect test were larger, especially than other tests.

In the study by Engelsman et al.,[24] the differences in beam fringe and penumbra width increased with increasing beam energy. For the Modified Batho algorithm, the comparison results of penumbra values were up to 4.3 mm (penumbra) and 6.3 mm (beam fringe) for the low energy beams ($\leq$8 MV), while these results were up to 8.5 and 10.0 mm for the high energy beams ($\geq$15 MV).

In the study by Healy and Murry,[25] it was reported that the Eclipse[TM] analytical anisotropic algorithm (AAA) generally perform better than the PBC algorithm of Eclipse[TM], but both algorithms did not meet tolerances for asymmetric wedge fields.

In operational tests of this study, it was found that TPS was used effectively in all functions. Results of absolute and relative dose tests were satisfactory. Only results of the off-axis

points test asymmetric fields using for each photon energies were outside the tolerance limits (Table 6). Jamema et al.[20] reported that results of tests were satisfactory.

According to the study of Gershkevitsh et al.,[26] the pilot study included many hospitals, different TPSs, a variety of algorithms of TPS and several beam qualities. The result yields of the pilot study found a better agreements between calculations and measurements for more advanced algorithms (changes in lateral electron and photon transport are approximately modeled). At the same time, pilot study indicated that larger deviations are observed for higher beam energies.

At overall clinical tests of this study, average deviations were showed to increase with a rising wedge angle. In addition, δ_3 and δ_4 of lung irradiation were outside the tolerance (Table 7). Engelsman et al.[24] reported that deviations of up to 3.5% between calculated and measured values of the dose at the ICRU reference point (δ_3) were found. In the report by Engelsman et al.,[24] the PBC algorithm with one-dimensional corrections, the modified Batho algorithm and the equivalent path length algorithm were investigated. In the AAPM Report 85,[27] it is recommended to use photon beams of energy of 12 MV or less for non-small-cell lung cancer therapy because of loss of electron equilibrium within and adjacent to the lung. Low energy beams should be used for low density tissues. Following this study, lung irradiation of our clinic should use only 6 MV or combinations of 6 and 18 MV.

6. Conclusion

At commissioning of Eclipse[TM] TPS, it has been observed that the conducted test is generally within tolerance and is outside the tolerances in some cases. So, there is no need to follow the recommendations of the NCS report.[7] In addition, the trends of the deviations found in the conducted tests were determined. Only the errors found in this study for the parameters

Table 7 – Results of overall clinical tests performed on TPS.

Test number	Test geometry	Energy	δ_3		δ_4		Note
			Deviation (% (mean ± SD))	Confidence limit	Deviation (% (mean ± SD))	Confidence limit	
1	Open field	6 MV	1.13 ± 0.8	2.33	−1.84 ± 0.4	2.44	
		18 MV	0.83 ± 1.2	2.63	−1.98 ± 0.5	2.73	
2	Blocking field	6 MV	0.85 ± 0.4	1.45	−0.77 ± 0.2	1.07	MLC
		18 MV	0.57 ± 0.4	1.17	−0.92 ± 0.4	1.52	
3	Wedged field	6 MV	1.39 ± 0.7	2.44	−3.39 ± 1.6	5.79	15° W
			2.04 ± 0.2	2.34	−3.85 ± 2.7	7.90	45° W
		18 MV	1.54 ± 1.1	3.19	−3.94 ± 1.7	6.49	15° W
			3.05 ± 0.9	4.40	−4.81 ± 3.1	9.46	45° W
4	CT planning for cranium irradiation	6 MV	1.35 ± 1.6	3.75	−2.80 ± 0.7	3.85	a. Lateral f
			−0.44 ± 0.8	1.64	−2.47 ± 0.6	3.37	b. Lateral + vertex f
5	CT planning for head and neck irradiation	6 MV	1.86 ± 1.8	4.56	−2.36 ± 0.5	3.11	a. Lateral f.
			0.40 ± 6.4	1000	−6.55 ± 0.4	7.15	b. Five F. techniques[a]
6	CT planning for lung irradiation	18 MV	2.73 ± 2.7	6.78	−7.75 ± 0.4	8.35	a. AP, PA f.
			0.67 ± 1.2	2.47	−7.13 ± 0.6	8.03	b. Box technique

The results which are outside the tolerance limits are italicised.

[a] Adapted from Ref. 28.

used in patient treatment planning have to be considered. This procedure must be performed entirely after the upgrade of TPS.

This study confirmed the correctness of the beam data entered in the TPS during the commissioning. With commissioning tests, it was identified as a baseline data for an ongoing QA program.

Conflict of interest

None declared.

Financial disclosure

REFERENCES

1. IAEA. *Commissioning and quality assurance of computerized treatment planning systems for radiation treatment of cancer, Technical Reports Series No 430*. Vienna: IAEA; 2004.
2. Van Dyk J, Barnett RB, Cygler JE, Shragge PC. Commissioning and quality assurance of treatment planning computers. *Int J Radiat Oncol Biol Phys* 1993;**26**:261–73.
3. Shaw JE. *A guide to commissioning and quality control of treatment planning systems. Report No. 68*. York: IPEMB; 1996.
4. SSRMP. *Swiss Society for Radiobiology and Medical Physics. Report 7: quality control of treatment planning systems for teletherapy*; 1997, ISBN 3-908125-23-5.
5. Fraass B, Doppke K, Hunt M, Kutcher G, Starkschall G, Stern R, et al. American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: quality assurance for clinical radiotherapy treatment planning. *Med Phys* 1998;**25**:836–1773.
6. Mayles WPM, Lake R, McKenzie A, Macauly EM, Morgan HM, Jordan TJ, et al. *Physics aspects of quality control in radiotherapy. IPEM Report No. 81*. York: IPEMB; 1999.
7. NCS. *Quality assurance of 3-D treatment planning systems for external photon and electron beams: practical guidelines for initial verification and periodic quality control of radiation therapy treatment planning systems*. Delft: NCS; 2006.
8. Mijnheer B, Olszewska A, Fiorino C, Hartmann G, Knöös T, Rosenwald J-C, et al. *Quality assurance of treatment planning systems. Practical examples for non-IMRT photon beams*. Brussels: ESTRO; 2005.
9. Nisbet A, Beange I, Vollmar HS, Irvine C, Morgan A, Thwaites DI. Dosimetric verification of a commercial collapsed cone algorithm in simulated clinical situations. *Radiother Oncol* 2004;**73**:79–88.
10. Cheng CW, Das IJ, Tang W, Chang S, Tsai JS, Ceberg C, et al. Dosimetric comparison of treatment planning systems in irradiation of breast with tangential fields. *Int J Radiat Oncol Biol Phys* 1997;**38**:835–42.
11. Davidson SE, Ibbott GS, Prado KL, Dong L, Liao Z, Followill DS. Accuracy of two heterogeneity dose calculation algorithms for IMRT in treatment plans designed using an anthropomorphic thorax phantom. *Med Phys* 2007;**34**: 57–1850.
12. Paelinck L, Reynaert N, Thierens H, De Neve W, De Wagter C. Experimental verification of lung dose with radiochromic film: comparison with Monte Carlo simulations and commercially available treatment planning system. *Phys Med Biol* 2005;**50**:69–2055.
13. Miften M, Wiesmeyer M, Kapur A, Ma CM. Comparison of RTP dose distributions in heterogeneous phantoms with the BEAM Monte Carlo simulation system. *J Appl Clin Med Phys* 2001;**2**:21–31.
14. Van Esch A, Tillikainen L, Pyykkonen J, Tenhunen M, Helminen H, Siljamaki S, et al. Testing of the analytical anisotropic algorithm for photon dose calculation. *Med Phys* 2006;**33**:48–130.
15. Knöös T, Ceberg C, Weber L, Nilsson P. Dosimetric verification of a pencil beam based treatment planning system. *Phys Med Biol* 1994;**39**:28–1609.
16. Aspradakis MM, Morrison RH, Richmond ND, Steele A. Experimental verification of convolution/superposition photon dose calculations for radiotherapy treatment planning. *Phys Med Biol* 2003;**48**:93–2873.
17. Venselaar J, Welleweerd H, Mijnheer BJ. Tolerances for the accuracy of photon beam dose calculations of treatment planning systems. *Radiother Oncol* 2001;**60**:191–201.
18. Welleweerd J, van der Zee W. Dose calculations for asymmetric fields using Plato version 2.01. In: Proceedings of 17th Annual ESTRO Meeting. *Radiother Oncol* 1998;**48**:134.
19. Venselaar J, Welleweerd H. Application of a test package in an intercomparison of the photon dose calculation performance of treatment planning systems used in a clinical setting. *Radiother Oncol* 2001;**60**:203–13.
20. Jamema SV, Urpeti RR, Sharma S. Commissioning and comprehensive quality assurance of commercial 3D treatment planning system using IAEA Technical Report Series-430. *Australas Phys Eng Sci Med* 2008;**31**:207–15.
21. Camargo PL, Rodrigues LN, Furnari L. Implementation of a quality assurance program for computerized treatment planning systems. *Med Phys* 2007;**34**:36–2827.
22. Murugan A, Valas XS, Thayalan K, Ramasubramanian V. Dosimetric evaluation of a three-dimensional treatment planning system. *J Med Phys* 2011;**36**:15–21.
23. Kragl G, Albrich D, Georg D. Radiation therapy with unflattened photon beams: dosimetric accuracy of advanced dose calculation algorithms. *Radiother Oncol* 2011;**100**:417–23.
24. Engelsman M, Damen EM, Koken PW, Van't Veld AA, Van Ingen KM, Mijnheer BJ. Impact of simple tissue inhomogeneity correction algorithms on conformal radiotherapy of lung tumours. *Radiother Oncol* 2001;**60**:299–309.
25. Healy BJ, Murry RL. Testing of a treatment planning system with beam data from IAEA TECDOC 1540. *J Med Phys* 2011;**36**:107–10.
26. Gershkevitsh E, Schmidt R, Velez G, Miller D, Korf E, Yip F, et al. Dosimetric verification of radiotherapy treatment planning systems: results of IAEA pilot study. *Radiother Oncol* 2008;**89**:338–46.
27. American Association of Physicists in Medicine. *Report 85: tissue inhomogeneity corrections for megavoltage photon beams, Radiation Therapy Committee Task Group 65*. College Park, MD: AAPM; 2004.
28. Fogliata A, Cozzi L, Bieri S, Bernier J. Critical appraisal of a conformal head and neck cancer irradiation avoiding electron beams and field matching. *Int J Radiat Oncol Biol Phys* 1999;**45**:8–1331.