·Technology and Methods·

Independent verification of monitor unit calculation for radiation treatment planning system

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[Abstract] Background and Objective: To ensure the accuracy of dose calculation for radiation treatment plans is an important part of quality assurance (QA) procedures for radiotherapy. This study evaluated the Monitor Units (MU) calculation accuracy of a third-party QA software and a 3-dimensional treatment planning system (3D TPS), to investigate the feasibility and reliability of independent verification for radiation treatment planning. **Methods:** Test plans in a homogenous phantom were designed with 3-D TPS, according to the International Atomic Energy Agency (IAEA) Technical Report No. 430, including open, blocked, wedge, and multileaf collimator (MLC) fields. Test plans were delivered and measured in the phantom. The delivered doses were input to the QA software and the independent calculated MUs were compared with delivery. All test plans were verified with independent calculation and phantom measurements separately, and the differences of the two kinds of verification were then compared. **Results:** The deviation of the independent calculation to the measurements was (0.1 ± 0.9)%, the biggest difference fell onto the plans that used block and wedge fields (2.0%). The mean MU difference between the TPS and the QA software was (0.6 ± 1.0)%, ranging from −0.8% to 2.8%. The deviation in dose of the TPS calculation compared to the measurements was (−0.2 ± 1.7)%, ranging from −3.9% to 2.9%. **Conclusions:** MU accuracy of the third-party QA software is clinically acceptable. Similar results were achieved with the independent calculations and the phantom measurements for all test plans. The tested independent calculation software can be used as an efficient tool for TPS plan verification.

Key words: Treatment plan verification, independent calculation, phantom measurement, quality assurance

Treatment Planning Systems (TPSs) are some of the commonly used tools for radiotherapy. In designing treatment plans, TPS uses field parameters and prescribed doses to calculate the monitor units (MU). In each TPS, verifying the accuracy of the dose calculation is an important part of commissioning tests, and also plays an important part in quality assurance (QA) procedures for tumor radiotherapy[1,2]. For the complex treatment planning, such as the intensity-modulated radiotherapy (IMRT) plans, dose verification should be performed for each case.

Currently, there are two methods to verify TPS dose calculations. The first method is to transfer the treatment planning to a phantom to develop the verification plan, where radiotherapy is performed according to the calculated verification plan. At the same time, the actual dose is measured with an ionization chamber at a defined position in the phantom, which is then compared to the treatment planning dose at this position to determine the deviation calculated by TPS[3,4]. The second method is to calculate the MU of each field by third-party software or by hand, which is then compared with the MU calculated by TPS[5,6]. These two methods can verify the accuracy of doses calculated by TPS both directly and indirectly. The verification software of the second method requires preverification with the direct measurement method. By measurements of a series of test plans, the authors have verified a commercial QA software and TPS dose calculation accuracy, and evaluated the reliability and range of errors of independent verification of TPS MU calculation by the QA software.

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Materials and Methods

Plan design

A series of plans were designed with 8-MV photon beams of an electron linear accelerator (Presice Desktop, Elekta) on TPS (Pinnacle, version 8.0, ADAC). Based on Report No. 430 of the International Atomic Energy Agency (IAEA), the radiation fields of the test plans included square, rectangular, wedge, block, and multileaf collimator (ML C) irregular fields, and different source-to-surface distances (SSDs) were considered. According to the definitions and the consensus of a report from the International Commission on Radiation Units and Measurements (ICRU)[7,8], and to facilitate measurement and calculation, the dose reference points of all test plans were placed 10-cm deep at the radiation field axis. The design calculation and verification were performed with a uniform density solid water phantom (RW3, IBA Company). The phantom was 30 cm × 30 cm × 30 cm with a density of 1.05 g/cm^3.

Test plans of the open fields There were five groups in total, comprising three square field plans of 5 cm × 5 cm, 10 cm × 10 cm, and 20 cm × 20 cm, and two rectangular fields of 10 cm × 20 cm and 20 cm × 10 cm. The SSDs were 90 cm, 100 cm, and 110 cm, respectively. For those with a 10-cm, 90-cm and 100-cm depth SSDs were corresponded to the commonly used source-to-axis distance (SAD) and SSD techniques.

Test plans of the wedge fields The SSDs for the wedge fields were 90 cm and 100 cm. Other conditions were similar to those of the open fields.

Central blocking plan The field center was blocked by 3 cm, and the dose reference point was designed to be at 3 cm off and 10 cm deep of the central field axis. The radiation field was 20 cm × 10 cm and the SSDs were 90 cm and 100 cm.

Test plans of the irregular fields There were two kinds of irregular fields, including low melting-point block and MLC irregular fields. There were blocks at the four deflection points of the fields. Figure 1 shows the schematics of the two fields. The set of collimator diaphragms were 5 cm × 5 cm, 10 cm × 10 cm, and 20 cm × 20 cm. SSD was 90 cm. The complexities of the simultaneous use of irregular and wedge fields were also taken into consideration in the test plan.

Plan transferring

The TPS plan was transferred according to the radiotherapy protocol of Digital Imaging and Communications in Medicine (DICOM RT) to the third-party QA software IMSure and to the accelerator server.

Dose measurement

Plans designed by TPS were measured in the phantom by using a thimble ionization chamber with the volume of 0.65 cm^3 (FC65G, Scanditronix Wellhofer) and a DOSE-1 dosimeter (IBA), and the absorption dose was calculated according to IAEA Report No. 277[9]. The commonly used radiation fields were measured in the phantom and were then compared with the results calculated by TPS and the verification software. Because the dose reference point was at 10 cm of the central axis, SSD 90 cm was equivalent to treatment with the isocenter SAD method. The dose reference point was chosen at 3 cm off and 10 cm deep of the central axis when the central blocked fields were applied, which simulated the situation of nasopharyngeal carcinoma when the spinal cord should be covered. Due to the restriction of the measurement phantom size, the maximum radiation field was 20 cm × 20 cm.

The difference of the dose calculated by TPS and the measurement results was DiffD = $(D_{TPS} - D_{Measured}) / D_{Measured} \times 100\%$.

Independent dose verification

The software used for verify dose calculation was IMSure QATM (Version 3.0, StandImage Company). Geometric parameters, tissue maximum-dose ratios, scatter factors of the collimator, and the total scatter factor of the radiation field should be input into the software. The software comprised two functional modules. One was to calculate and verify the point doses and the fluencies planned by IMRT plans by using a three-source model[10]. The second was about the MU calculation module used in the present study. This module used the Khan's method[11] of calculation, which was similar to routinely used manual calculations that directly use the dose data of the therapeutic equipment input by users and radiation field and prescribed dose conditions to calculate MU. The formula for transferring prescribed dose into MU was (1).

$$MU=\frac{RxDose\ /\ IsoDoseLine}{TMR \times OCR \times WF \times TF \times Sc(FS) \times SP(FS') \times CF \times UF \times InvSqCorr} \quad (1)$$

Definitions of each parameter are shown in Table 1. The verification software was able to calculate the dose away from the axis. For plans input according to the DICOM RT protocol, it can identify the surface contour of the patient automatically and modify the calculated depth manually. Thus, it can be used to calculate some radiation fields that cannot be calculated manually, such as tangential fields. The verification software deal with the solid phantom as a uniform water phantom, because of the differences between solid water density and water density, the calculation depth in the QA software should be scaled to the water depth. The formula for transforming the measured depth of solid water dm to water depth d_w was (2).

$$d_w = d_m \times \rho_m \quad (2)$$

The difference of the independent calculation and the measured results is DiffMU1 = $(MU_{Indt} - MU_{delivery}) / MU_{delivery} \times 100\%$.

Where MU_{Indt} is the MU that is calculated by using the measured dose of the point of interest as the prescribed dose, and $MU_{delivery}$ is the actual MU.

The relative difference of the TPS plan and the result of the independent verification can be calculated by using the TPS calculated dose as the prescribed dose:

DiffMU2 = $(MU_{TPS} - MU_{Indt}) / MU_{Indt} \times 100\%$.

Where MU_{TPS} is the MU calculated by TPS, and MU_{Indt} is the MU obtained by the verification software of the same plan.

Results

Actual measurement verification

Each test plan was implemented on a linear accelerator to the phantom and measured by ionization chamber. At the same time, TPS plans were transferred to the QA software through the DICOM RT protocol. This software was able to identify the doses of the reference points at each planned radiation field, and then the MU of each radiation field was calculated with formula (1). DiffMU2 stood for the difference of MU calculated with the TPS and QA software, which was the verification of the TPS results by

Table 1 The parameters and correction factors used for the independent calculation software

Parameter Factor	*Symbol*	Definition
Prescribed dose	*RxDose*	The prescribed dose to the calculation point, in cGy
Isodose line	*IsoDsoeLine*	The isodose line intended at the calculation point, in %
Field size	*FS* (*FS'*)	Equivalent squares for the open (blocked) fields
User factor	*UF*	A generic correction factor chosen by the physicist
Wedge factor	*WF*	Wedge factor at the calibration depth and calibration field size
Tray factor	*TF*	Attenuation factor due to block tray
Tissue-maximum ratio	*TMR*	Dose rate at a depth relative to the dose rate at the maximum dose depth for the same field size
Off-center ratio	*OCR*	Dose rate at an off-center position relative to the dose rate of the central axis position at the same depth
Calibration factor	*CF*	Calibration factor, in cGy/MU
Collimator factor	*Sc*	Dose rate in the air at a given field size relative to that for the reference field size
Phantom scatter factor	*Sp*	Phantom scatter factor, calculated by $Sp=S_{cp}/S_c$
Inverse squares correction factor	*InvSqCorr*	$InvSqCorr=[(SCD+d_{cal})/(PSSD+ProjectedDepth)]^2$

the software.

Open field testing As shown in Table 2, for all test plans of regular open fields, the difference of the independent verification and the actual measurement results at a 10 cm × 20 cm field was 1.1%, the other differences were within 1%. Most of the differences between those calculated by TPS and those actually measured were less than 1% (one group of a 5 cm × 5 cm square field with SSD of 110 cm had a relatively greater result). The differences between the TPS calculations and the measured values of the irregular open field formed by low-melt lead blocks and MLC were less than 3%. In addition, the differences between the QA software results and measured results were less than 1.1%.

Wedge field testing The test results of the wedge fields are shown in Table 3, including regular wedge fields and irregular fields formed by blocks. The mean difference between the independent calculations and the actual measurements was 0.5%, with a maximum difference of 2.0%. The mean difference of the TPS result and the actual measurement was 1.7%, with a maximum difference of 3.9%; as compared with the independent verification, the mean difference was 0.9%, with a maximum of 2.4%.

Table 2 Test results for the open fields

Field size (cm)	SSD (cm)	Block or MLC	Measurement vs. IMSure			Measurement vs. TPS			IMSure vs. TPS		
			IMSure(MU)	Given(MU)	$Diff_{MU1}$(%)	TPS(cGy)	Measu(cGy)	$Diff_D$(%)	IMSure(MU)	TPS(MU)	$Diff_{MU2}$(%)
5 × 5	90		100.2	100	0.2	75.4	75.8	0.5	99.9	100	0.1
	90	Block	99.6	100	−0.4	70.5	71.1	0.9	99.5	100	0.5
	90	MLC	100.2	100	0.2	72.1	74.2	2.9	99.9	100	0.1
	100		99.2	100	−0.8	62.4	62.1	−0.5	99.7	100	0.3
	110		99.0	100	−1.0	52.5	53.3	1.5	99.6	100	0.4
10 × 10	90		99.8	100	−0.2	82.5	82.5	0.0	99.7	100	0.3
	90	Block	99.3	100	0.7	77.5	78.1	0.8	100.2	100	−0.2
	90	MLC	100.3	100	−0.3	80.3	82.1	2.2	100.1	100	−0.1
	100		99.6	100	−0.4	68.5	67.9	−0.9	100.2	100	−0.2
	110		99.2	100	−0.8	57.7	58.1	0.7	100.1	100	−0.1
20 × 20	90		100.7	100	0.7	89.9	89.1	−0.9	99.4	100	0.6
	90	Block	100.9	100	0.9	85.1	84.1	−1.2	98.8	100	1.2
	90	MLC	99.9	100	−0.1	87.4	88.3	1.0	99.2	100	0.8
	100		100.7	100	0.7	74.5	74.2	−0.4	99.0	100	1.0
	110		100.4	100	0.4	62.6	62.8	0.3	100.1	100	−0.1
10 × 20	90		99.7	100	−0.3	85.0	85.8	0.9	100.5	100	−0.5
	100		98.9	100	−1.1	70.4	71.5	1.6	100.8	100	−0.8
20 × 10	90		99.9	100	−0.1	86.1	85.9	−0.2	100.3	100	−0.3
	100		100.3	100	0.3	71.4	71.5	0.1	100.8	100	−0.8
Mean ± SD					−0.1 ± 0.6			0.5 ± 1.1			0.1 ± 0.6

SSD, sourse to surface; MLC, multleaf collimator; TPS, treatment planning system; SD, standard deviation.

Table 3 Test results for wedge fields

Field size (cm)	SSD (cm)	Block or MLC	Measurement vs. IMSure			Measurement vs. TPS			IMSure vs. TPS		
			IMSure(MU)	Given(MU)	$Diff_{MU1}$(%)	TPS(cGy)	Measu(cGy)	$Diff_{D}$(%)	IMSure(MU)	TPS(MU)	$Diff_{MU2}$(%)
5 × 5	90		199.4	200	-0.3	40.1	40.7	-1.5	196.0	200	2.0
	90	Block	196.3	200	-1.9	37.7	38.1	-1.1	195.4	200	2.4
	100		198.5	200	-0.8	33.4	33.8	-1.2	195.9	200	2.1
10 × 10	90		203.0	200	1.5	44.6	46.2	-3.5	197.5	200	1.3
	90	Block	200.5	200	0.3	42.5	43.1	-1.4	197.2	200	1.4
	100		200.9	200	0.5	37.2	37.9	-1.8	197.2	200	1.4
20 × 20	90		203.2	200	1.6	50.4	52.4	-3.8	197.2	200	1.4
	90	Block	204.0	200	2.0	47.4	49.3	-3.9	197.4	200	1.3
	100		202.9	200	1.5	42.0	43.1	-2.6	198.5	200	0.8
10 × 20	90		203.6	200	1.8	47.3	48.3	-2.1	201.5	200	-0.7
	100		202.6	200	1.3	39.6	39.9	-0.8	200.9	200	-0.4
20 × 10	90		200.2	200	0.1	47.6	47.5	0.2	200.7	200	-0.3
	100		199.0	200	-0.5	39.6	39.2	1.0	201.4	200	-0.7
Mean ± SD					0.5 ± 1.2			-1.7 ± 1.5			0.9 ± 1.1

Only a 60-degree wedge is used in the Elekta Precise Desktop Accelerator.

Central-blocked field The differences between the software verification result and the measured result of the central blocked fields with two techniques (SSD and SAD) were 0.2% and 0.4%, respectively. The differences of TPS calculation and the actual measurement of these two techniques were 2.9% and 2.1%. The differences with the independent verification results were 2.8% and 2.5%, respectively (Table 4). Under such complex geometric situations, the error of this simple independent MU calculation was small and the TPS verification results by the QA software were similar to the actual measurement verification.

Table 4 Test results for the central blocked fields

Field size (cm)	SSD (cm)	Measurement vs. IMSure			Measurement vs. TPS			IMSure vs. TPS		
		IMSure(MU)	Given(MU)	$Diff_{MU1}$(%)	TPS(cGy)	Measu(cGy)	$Diff_{D}$(%)	IMSure(MU)	TPS(MU)	$Diff_{MU2}$(%)
20 × 10	90	199.3	200	-0.4	156.1	159.4	2.1	195.2	200	2.5
	100	200.4	200	0.2	128.3	132.1	2.9	194.6	200	2.8

Abbreviations as in Table 2.

Comparisons of the verifications of the calculation software and the measured results

The verification standards for the open field plan, irregular field plan, wedge field and central-blocked field plan were deemed to be less than 2%, 3%, and 5%, respectively. The comparison plot between the mean differences and the standard deviations of measurement verification and the independent calculation verification of the TPS plans are in Figure 2. As shown in the figure, for the test plans of open, irregular, and central-blocked fields, the difference of the two verification methods was within 1%. The difference of the wedge field verification result was within 3%, indicating consistency between the two methods.

Discussion

With the increased application of TPS for tumor radiotherapy, quality assurance of the TPS plan design is becoming more and more important. The accuracy of the TPS plan is not only associated with its calculation model, but also dependent on data acquisition by the clinical equipment, module accuracy, and the complexities of the plan. Its calculated results should be verified by third-party software or measurements to ensure its clinical efficacy. In recent years,

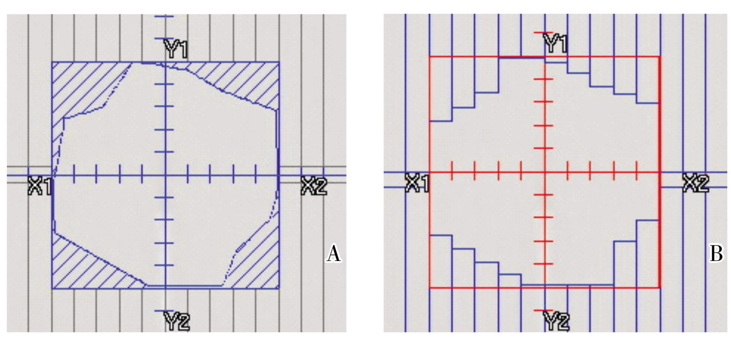

Figure 1 Two types of irregular fields

A, created with jaws and blocks; B, shaped by multileaf collimator

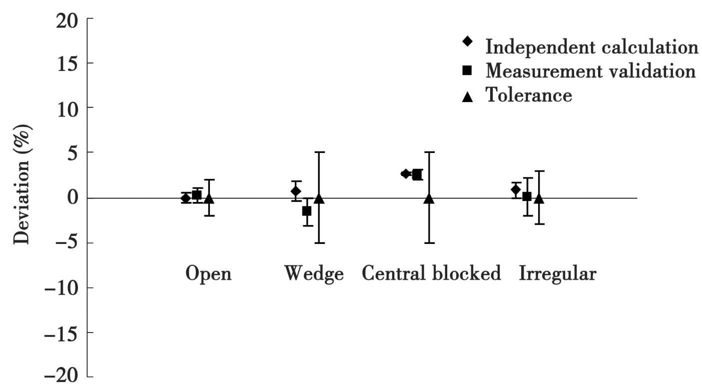

Figure 2 The comparison results between measurement validation and independent calculation validation for four team plans

some developed countries and international institutions of radiation and physics have released guidelines to ensure the quality of TPS and radiation treatment plans[1,2,12].

The best way to verification a radiotherapy plan is to measure the delivered plan. Yet, because it is impossible to in vivo verify the plan for every patient who undergoes radiotherapy, the phantom plan measurement is used to ensure dose accuracy[3,4]. However, because the measurement is time-consuming and takes therapeutic equipment offline, no center can actually measure each patient. Instead, verification is performed with QA software or by manual calculations[5,6]. The dose calculation software should undergo clinical verification before putting it into clinical use, and the same with third-party verification software. Verification tasks include the verification of the geometric data of radiation equipment and the entered data for physical measurements, calculation models, and dose calculation results.

As for the commercial software used here, the calculation accuracy was validated to meet clinical demand by the actual measurement of the selected test plans. The differences between the calculated results and measured results of the various geometric fields were (0.1 ± 0.9)%. In addition, for those with central blocks, the deviation was also within an acceptable range. The comparisons of the actual measurements and the independent calculations of the TPS treatment plan showed that the results were similar. And for the central-blocked fields, the two results were also consistent. For all tested fields, the differences between independent calculated and measured results were within 2%, and the differences of MU between results calculated by the verification software and results calculated by TPS were less than 3%, indicating that the software is applicable for clinical use for MU calculation and dose verification.

The verification of TPS with measurement method showed that the accuracy of all TPSs tested in the present study was satisfactory, with a mean deviation of -0.2%, a standard deviation of 1.7%, and a relative deviation range between -3.9% and 2.9%. For rectangular fields like 10 cm × 20 cm and 20 cm × 10 cm, the central dose of the field should be similar if calculated with the equivalent radiation field method (the ratio of the circumference to the area). The same is true for wedge field calculations. However, the difference of the doses at 10 cm from the central axis of the two rectangular fields was 1.4%, which is probably due to the different scatter doses of the collimator system caused by different locations of the upper and lower collimators. It appears that the equivalent method (irrespective of the impact of the locations of the lower and upper collimators on field output) adopted by TPS or the QA verification software for irregular fields may compromise the calculation accuracy of rectangular fields.

Through the independent verification and measurement verification of the TPS calculations, we get to know the error and standard deviation of the calculated doses by these two types of software, which can further ensure the quality of TPS. Numerous clinical studies are still needed to verify the doses calculated from TPS. Verification of TPS dose accuracy by different calculation methods have been widely used in other countries, though it has not been seen in China. According to our investigation and other literatures[13,14], independent dose calculation software appears to be a reliable QA tool for TPS, which can ensure dose calculation accuracy and therapeutic effect.

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