Original Article

Commissioning of a Commercial Secondary Dose Check Software and Clinical Implementation for the Magnetic Resonance-guided Linear Accelerator Adaptive Workflow

José Alejandro Rojas-López[1,2], Alexis Cabrera-Santiago[3,4], Jorge Ramiro Corral-Beltrán[5], Albin Ariel García-Andino[6]

[1]Department of Radiotherapy, Hospital Angeles Puebla, Av. Kepler, Reserva Territorial Atlixcáyotl, Puebla, [3]Department of Radiotherapy, Almater Hospital S.A. de C.V., Av. Álvaro Obregon, Segunda, [4]Department of Radiotherapy, Oncology Medical Specialties Center, Av Claridad, Plutarco Elías Calles, Mexicali, Baja California, [5]Department of Radiotherapy, Christus Muguerza High Specialty Hospital, Miguel Hidalgo y Costilla, Obispado, Monterrey, Nuevo León, México, [2]Department of Physics, Faculty of Astronomy, Mathematics, Physics and Computing, National University of Córdoba, Av. Medina Allende, X5000 Córdoba, Argentina, [6]Department of Applications, PTW-Latin America, Av. Evandro Lins e Silva, Sala, Barra da Tijuca, Rio de Janeiro, Brazil

Abstract

Purpose: The purpose of this study was to report the commissioning the secondary dose calculation software ThinkQA (TQA) for an magnetic resonance-guided linear accelerator (MR-linac). **Methods:** The Medical Physics Practice Guideline 5.a. (MPPG5a) tests, and dose in inhomogeneities, beam profiles, and depth dose curves were calculated and compared between Monaco and TQA. Five intensity modulated radiotherapy (IMRT) plans (anal, abdominal, head and neck, prostate, and lung), based on TG-244 guidelines were evaluated varying the gamma criteria. Furthermore, the initial and adapted plans for the first session for 17 patients in different anatomical regions were calculated in TQA using different gamma criteria. For five patients, six measurements were made at different fractions using ArcCheck and compared with TQA. **Results:** The majority of tests met the tolerances defined in the MPPG5a with the exception of dose profiles (>10%), and large multileaf collimator-shaped fields with extensive blocking (>2%). For the IMRT plans, tight criteria such as 2%/2 mm may not be suitable for all scenarios. Thus, we adopt a reasonable 3%/2 mm without compromising the quality of the plan that included significant high-to-low-density interfaces. It is observed that, the values obtained for clinical cases are in the range from 94.6% to 99.8% (TQA), 97.0% to 99.6% (ArcCheck), except in a prostate case with 87.8% (TQA) and 99.3% (ArcCheck). **Conclusion:** We commissioned TQA as a secondary dose calculation for MR-linac and we introduced it clinically for adaptive treatment workflow using 3%/2 mm with 95% as tolerance limit and 90% as action limit.

Keywords: Adaptive, IMRT, magnetic resonance-guided linear accelerator, QA, secondary dose check

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Introduction

The Elekta Unity magnetic resonance-guided linear accelerator (MR-linac) has a 7 MV free flattening filter, with a source to the isocenter (SAD) equal to 143.5 cm, a maximum field size of 57.4 cm × 22 cm, a maximum dose rate of 425 MU/min to the isocenter regardless of calibration depth. Beam collimation consists of jaws (crossplane) and a 160-leaf multileaf collimator (MLC) (inplane), which has a leaf width of 7.2 mm in the isocenter plane.[1] It has a 1.5T Philips MR unit, which allows adaptive treatments to be delivered in each treatment session through two strategies, adapting to position or shape, which involves modifications in the position or shape of the contoured structures. Thus, adaptive radiotherapy guided by MR imaging entails additional challenges in patient-specific quality assurance (PSQA), since the initial plan approved by the radiation oncologist is not delivered to the patient, but from the first treatment session, the plan is modified and adapted to the patient's daily anatomy. Therefore, it becomes essential for the medical physicist to have secondary dose calculation tools to evaluate the dose delivered in each session.

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Address for correspondence: Mr. José Alejandro Rojas-López, Department of Radiotherapy, Hospital Angeles Puebla, Av. Kepler 2143, Reserva Territorial Atlixcáyotl, 72190, Puebla, Mexico.
E-mail: alejandro.rojas.lopez@mi.unc.edu.ar

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The necessity for an efficient and accurate secondary dose calculation is especially critical in the setting of online adaptive planning as a new treatment plan is generated for each fraction.[2] There are currently only preliminary reports of purpose-built software for Elekta Unity and one report for commercial software RadCalc.[2,3] In this work, we reported the results of commissioning the secondary dose calculation software ThinkQA (TQA) by DOSIsoft, approved by the Food and Drug Administration in early 2024. To our knowledge, there are no other reports in the literature describing the commissioning and evaluation of this commercial product for use with the Elekta Unity MR-linac.

Materials and Methods

Unity characterization

The Almater Hospital Elekta Unity was calibrated in a BeamScan® three-dimensional (3D) MR water tank to 1 cGy per MU in water at isocenter at a depth of 5 cm (138.5 cm SSD) at gantry 0°. The reference dose was performed with an Exradin® A19 MR cylindrical chamber (Standard Imaging, Wisconsin, United States) and a PC Electrometer (Standard Imaging, Wisconsin, United States). The chamber was placed antiparallel to the magnetic field, following published recommendations.[4]

During commissioning, cryostat dose attenuation measurements were obtained using the cryostat characterization tool by placing a Farmer 30010 (PTW, Freiburg, Germany) ionization chamber at the isocenter. The cryostat attenuation was up to 1.2% for all gantry angles.

Dose profiles were acquired in a 3D water tank using a Semiflex ionization chamber and MicroDiamond detector (PTW, Freiburg, Germany). The description of these procedures was reported by Rojas-López *et al*.[5]

ThinkQA overview

TQA version 2.0.0.60 is a software suite provided by DOSIsoft that provides an independent secondary dose check. It calculates the dose distribution in a 3D patient model, based on the imported treatment planning system (TPS) DICOM data.[6] TQA software suite requires a physical server Nvidia Quadro series 2000, CPU 8 cores, 16 threads, RAM 32 GB, 1 Gbps, and 3 × 4 TB for hard disk.

In the Unity model, the measurement conditions must consider a distance from the radiation source to the isocenter (SAD) of 143.5 cm, at 10 cm depth, for a field of 10 cm × 10 cm in a water phantom at gantry 90º. For this MR-linac, the output was 0.866 cGy/MU under these conditions and it was obtained in Monaco TPS v5.51.11.

The dimension of the voxels within the TQA dose grid is always 2 mm^3. TQA computes the dose as dose-to-water ($D_{w,w}$) with the point kernel collapsed cone convolution algorithm (CCC). To compare CCC and Monte Carlo (MC) TPS dose, the original $D_{w,w}$ CCC dose must be converted into the quantity $D_{m,m}$ CCC by a voxel conversion factor (water to medium) VCF_w^m, as shown in Equation 1, based on the mass density. This factor is related, but not equal to the stopping power ratio. TQA only performs dose calculations and not monitor units (MUs) due to the internal design of the software (private communication with DOSIsoft).

$$D_{m,m}CCC = D_{w,w}CCC \times VCF_w^m \quad [1]$$

For each phantom density, this ratio is calculated for all voxels with a dose value >50% of D_{max}. The median of each cloud of dose ratios is used to define the conversion factor versus mass density.[6]

In TQA, no characterization is made to identify the charged particles in the build-up region according to their origin. All charged particles potentially emitted from the treatment head or the cryostat device are not involved in dose calculation. A simple analytical model based on an exponential form is adjusted in common conditions (square fields) so that an additional dose covers the difference between the actual dose and the calculated point kernel dose.

In TQA, the Lorentz force effect is described using a warped point kernel computed in water in a 1.5T magnetic field. TQA uses the double fit method to describe the energy distribution along the cone axis in the magnetic field B_0 more accurately.[6] The electron return effect is not taken into account in TQA. The CCC shows a dose deficit upstream and a dose excess downstream at each tissue-air interface, compared to the true value.

Relative beam data

There was modeled in Monaco TPS v. 5.51.11 squared fields for sizes 2 cm × 2 cm, 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, and 2 cm × 20 cm at gantry 0º, for depths of 5 and 10 cm, in SAD configuration, in a water equivalent virtual phantom with similar dimensions of the water tank. Dose calculation was performed with a 1 mm grid size and 0.5% uncertainty per plan.

TQA calculated only 3D doses in the volumes contoured. Thus, in all cases for commissioning, small volumes of 0.1 cm^3 were contoured in Monaco in three directions (x, y, z). For secondary dose calculation, the CT images, dose, contours, and plan files were exported to TQA.

To establish a comparison between the data, all dose profiles were normalized to a depth of 5 cm for the percentage dose depth (PDD) and to the central axis for the in-plane and crossplane profiles. To quantify the variations, the differences between the curves obtained in the TPS and TQA with respect to the reference measurements obtained during commissioning were calculated.

Output factors

Output factors were measured in accordance with recommendations by the American Association of Physicists in Medicine (AAPM) Task Group 74[7] in water with a MicroDiamond detector positioned at the isocenter at 10 cm depth for fields <10 cm × 10 cm and Semiflex ionization chamber for fields >10 cm × 10 cm. The doses calculated in

Monaco TPS and TQA were recorded and normalized to the 10 cm × 10 cm field size for comparison.

Dose in inhomogeneities

A single 10 cm × 10 cm beam at gantry 0º, 200 MU was calculated in Monaco in a water-air-water phantom, as shown in Figure 1. Dose calculation was performed with a 1 mm grid size and 0.5% uncertainty per plan. Small volumes of 0.1 cm^3 were contoured each 1 cm along the z-direction for comparison with TQA.

Multileaf collimator transmission

The isocentric configuration was used, and 10 cm of solid water for backscatter was placed. We measured the dose at 5 cm depth, with a 10 cm × 10 cm field and 200 UM, applying the correction factors with the Exradin® ionization chamber oriented antiparallel to the magnetic field.

The measurements were compared with those calculated by the TPS and TQA. Monaco is not allowed to cover the field only with the diaphragm. To make a field with only leaves, two open fields with the size of the minimum leaf gap were built at the corners of the maximum field.

Patient-specific quality assurance

Five intensity-modulated (IMRT) step-and-shoot plans (anal, abdominal, head and neck, prostate, and lung) based on AAPM TG-244 guidelines[8] were imported to the TPS and delivered on the MR-linac system. The measurements for commissioning were evaluated using the clinical gamma criteria used in the hospital of 3.0%/2.0 mm with the ArcCheck®-MR device (SunNuclear, Melbourne FL, United States).

The plans were exported to TQA and the doses were recorded and compared with Monaco varying the gamma criteria (3.0%/2.0 mm, 5.0%/2.0 mm, 2.0%/2.0 mm, 3.0%/3.0 mm). The analysis in TQA includes the planning target volume (PTV), the organs at risk (OAR), and TQA automatically creates high dose (max value-90% of max value), high gradient (90%-50%), mean dose (50%-30%), and low dose (30%-10%) structures for evaluation. It has γ concordance tables by volume that contains several indicators for each volume. The gamma agreement index (GAI) is the percentage of γ index values ≤1 in the examined volume.

Treatment planning system commissioning

The AAPM Medical Physics Practice Guideline 5.a.(MPPG5a)[9] recommended tests for photon beams were performed in a water equivalent virtual phantom for TQA, excluding tests 5.1 and 5.9 (not applicable). Those tests were performed and calculated in the TPS and compared with TQA values. The fields defined for the tests are shown in Figure 2 for small MLC-shaped field, large MLC-shaped field with extensive blocking, off-axis MLC-shaped field, asymmetric field at minimal anticipated SSD, and 10 cm × 10 cm field at oblique incidence (30°).

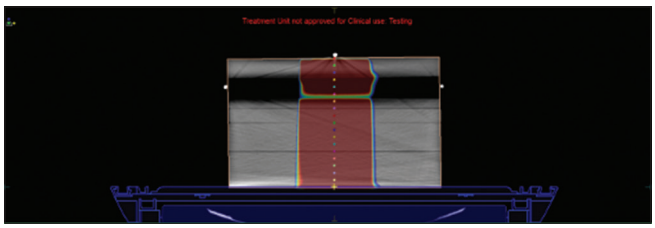

Figure 1: Dose distribution in water-air-water surfaces calculated in Monaco

Evaluation for online adaptive treatments

We evaluated the secondary dose check for the first 18 cases (6 brain, 4 prostate, 2 rectum, 2 bones, 1 breast, 2 head and neck, 1 retroperitoneum) treated on the MR-linac since their clinical implementation. First, to determine variations between the initial plan (session 0) and the adapted plan for the first session, we calculated the GAI by the gamma criteria 5.0%/2.0 mm and 3.0%/2.0 mm in both cases.

Second, we compared the GAI using the described gamma criteria obtained in six fractions along the treatments for five patients (2 prostates, 1 breast, 1 bone, and 1 brain) considering the initial plan (fraction 0) the first three fractions, and the mid-and last-treatment fractions. The comparison is performed by TQA calculated values and measured values using the ArcCheck®-MR device, taking as reference the PSQA using ArcCheck®-MR with 3%/2 mm criteria. The tolerance of 95% for global gamma was developed as a passing criterion. In cases where the TQA calculation showed a global gamma below 95%, but the ArcCheck measurement exceeded 95%, the calculation result was evaluated in TQA using the 5%/2 mm criterion. If the criterion was not reached, the plan was reoptimized. The workflow followed in the center is shown in Figure 3, considering that the mean time taken by TQA for dose calculation during online QA is 2 min.

For statistical analysis, a paired *t*-test for normally distributed data was performed with a $P = 0.05$ to establish statistically significant differences.

Results

Relative beam data

The dose profiles measured and calculated by the TPS and TQA are presented in Figure 4. For all analyzed fields (2 cm × 2 cm, 10 cm × 10 cm and 15 cm × 15 cm), in the in-plane and crossplane directions, the greatest discrepancies between the measured and calculated profiles occurred in the high gradient region (80%–20%), which coincides with the field edge and where a rapid dose falloff occurs. Despite the known impact of the magnetic field, particularly in the cross-plane direction for small fields, adequate correspondence was achieved. The maximum deviation in small fields was 7.9% for the TPS and 7.1% for TQA.

The measured PDD curves were compared with those calculated by the TPS and TQA for the analyzed fields. It was observed that the greatest discrepancies consistently occurred in the build-up region for all evaluated fields, where the

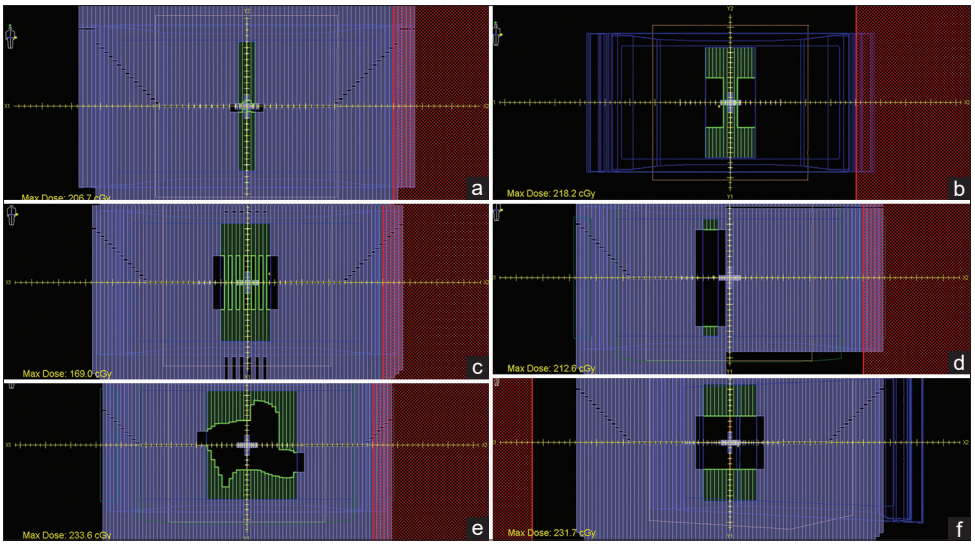

Figure 2: Multileaf collimator (MLC)-shaped fields for Medical Physics Practice Guideline 5.a guidelines. The fields corresponded to small MLC-shaped field (a), large MLC-shaped field with extensive blocking (b and c), off-axis MLC-shaped field (d) asymmetric field (e), and 10 cm × 10 cm field at oblique incidence (f)

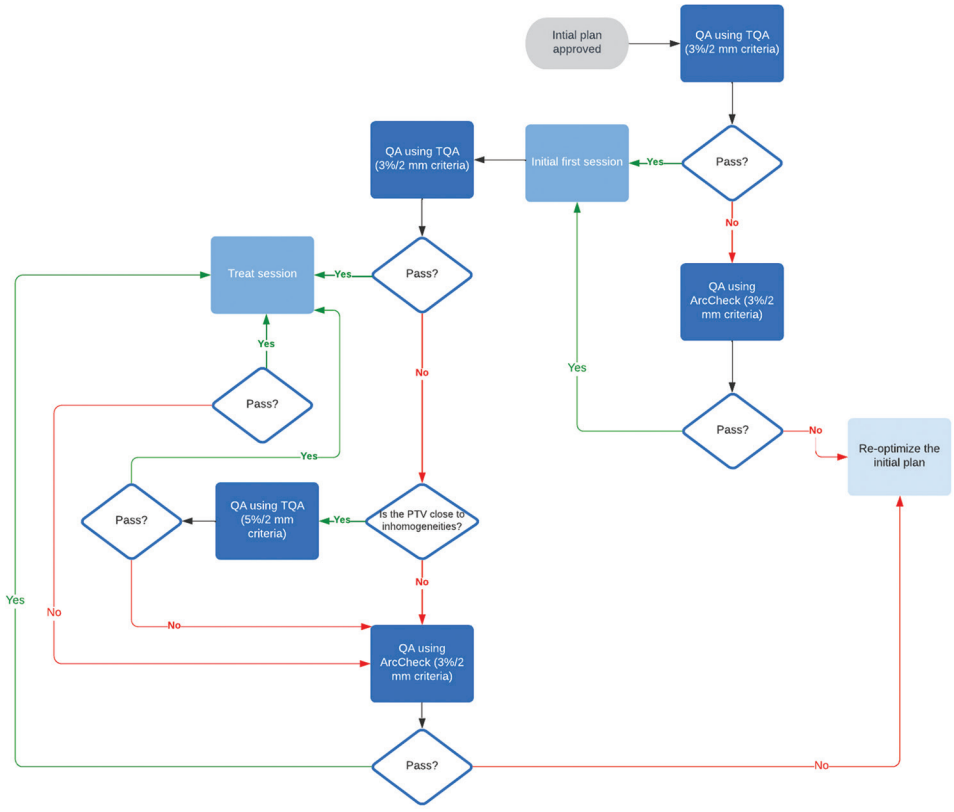

Figure 3: Institutional workflow for PSQA in magnetic resonance-guided linear accelerator for adaptive treatments using ThinkQA and ArcCheck

calculation algorithms underestimated the dose. Furthermore, these discrepancies increased as the field size increased, as illustrated in Figure 5.

Output factors

The output factors for TPS and TQA are reported in Figure 4. The differences taken as reference measured values are up to 3.9% for fields smaller than 4 cm × 4 cm for TQA. For TPS, the values are in agreement lower than 1.0% for fields larger than 2 cm × 2 cm, as shown in Table 1.

Dose in inhomogeneities

The difference between TPS and TQA calculated values is up to 30% in the interface water-air, showing dose underestimation

Table 1: Output factor comparison for measured and calculated by thinkQA and treatment planning system values

Nominal field size (cm)	Output factor TQA	Output factor TPS	Difference TQA versus TPS (%)	Measured output factor	Difference TQA versus measured (%)
1	0.647	0.639	−1.18	0.662	2.25
2	0.846	0.814	−3.85	0.814	−3.86
4	0.930	0.900	−3.35	0.897	−3.75
5	0.940	0.921	−2.08	0.921	−2.13
10	1.000	1.000	0.00	1.000	0.00
15	1.045	1.051	0.60	1.051	0.59
20	1.075	1.071	−0.36	1.073	−-0.17

TPS: Treatment planning system, TQA: ThinkQA

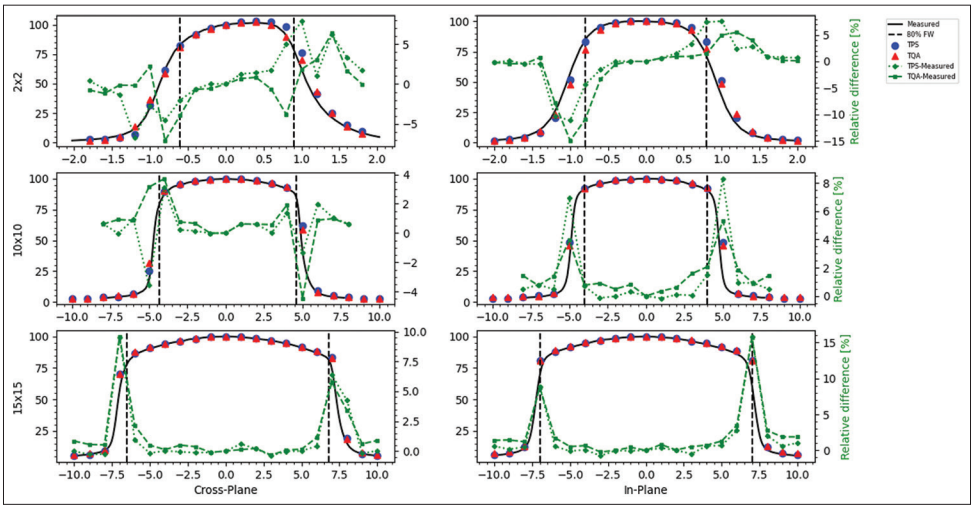

Figure 4: Comparison of measured, ThinkQA and treatment planning system beam profiles

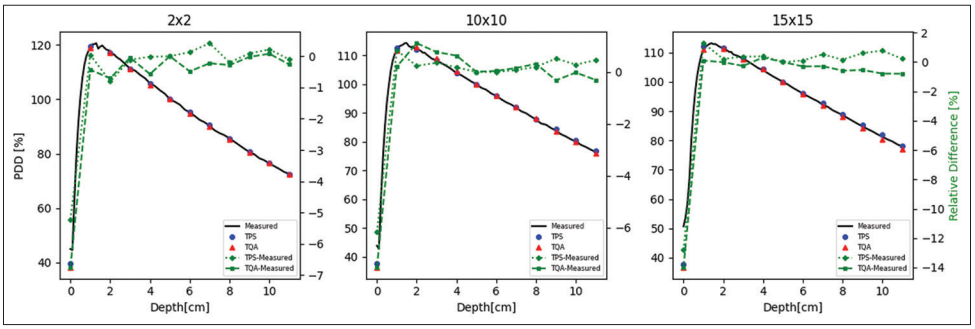

Figure 5: Comparison of measured, ThinkQA and treatment planning system percentage depth dose curves

for TQA doses. The dose is overestimated for TQA up to 80% in the interface air-water. Exit dose is underestimated for TQA in 30%, as shown in Figure 6.

Multileaf collimator transmission

The MLC transmission was 0.25%, 0.60%, and 0.50% for measured, TPS, and TQA, respectively

Patient-specific quality assurance

The GAI for the 3%/2 mm criterion is higher than 95% for PTVs in all cases, with the exception of prostate (91.4% for PTV_5600 and 94.5% for PTV_6800) and lung (74.9%) cases. For PTVs, using the criterion 5%/2 mm, the GAI increases in all cases. However, the lung case did not meet the expected value (89.2%), as shown in Figure 7. These values could be related to the CCC algorithm used in TQA regarding the MC algorithm.

In terms of OARs, the GAI 3%/2 mm is higher than 95% for the majority of cases. The OARs with lower than 95% were stomach, larynx, and lungs, as shown in Figure 8. These OARs had in common the presence of air cavities, showing dose overestimation with the CCC algorithm used in TQA. Furthermore, mean and maximum doses were reported for PTVs and OARs, as shown in Figure 9. Mean differences were lower than 2.5% and outliers were up to 9.7% for small structures such as the penile bulb.

The isodose structures created automatically by TQA met GAI 3%/2 mm of 95% excluding lung cases. This case showed a GAI 5%/2 mm higher of 92.5% for a high-dose structure [Figure 10].

In addition, dose differences calculated for TQA and TPS were studied by dose measurement using ArcCheck®-MR. The criteria used was 3%/2 mm and the gamma index was higher than 98% in all cases.

Treatment planning system commissioning

Results from the MPPG5a evaluation are described in Table 2. The majority of tests met the tolerances defined in the MPPG5a report with the exception of dose profiles, and large MLC-shaped fields with extensive blocking. This is related to the dose calculation algorithm of TQA and the evaluation of high gradients in the dose profiles.

Evaluation for online adaptive treatments

The approved initial treatment plan, in the context of adaptive radiotherapy with MR-linac, is never delivered to the patient, since this plan is taken as a reference to modify the beam fluence through MLC shapes based on the patient's daily anatomy. Therefore, the first treatment fraction and subsequent fractions must be verified through a QA. Table 3 shows the GAI obtained for the 18 cases that have been treated in the MR-linac for fractions 0 and 1 using the 3%/2 mm criterion in TQA. The values obtained using the 5%/2 mm criterion are not shown in the work, although it was found that in all cases the GAI is greater than 97.0% with this criterion. The comparison showed that there were no statistically significant differences between both fractions. For the breast case, a decrease in GAI is observed. However, establishing an action limit equal to 90.0%, the result is acceptable. This decrease is determined by the fact that the lesion is located in an area of tissue-air inhomogeneities, which means that the CCC algorithm has limitations. Furthermore, in cases where there are abrupt changes in densities, a more broadened criterion may be suggested, such as 5%/2 mm, complemented with a PSQA measurement using the ArcCheck®-MR. In addition, it would be interesting for future implementation

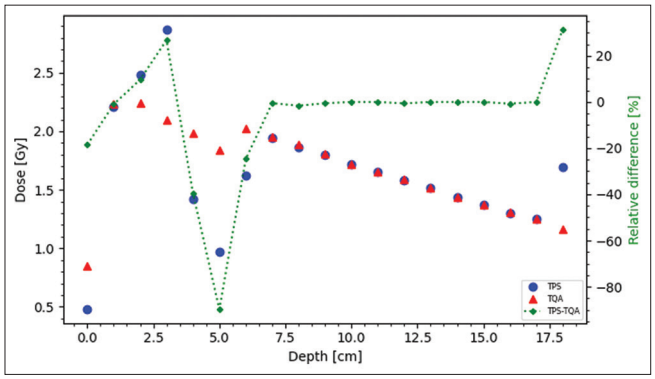

Figure 6: Depth-dose comparison between treatment planning system and ThinkQA values in a simple geometry setup with inhomogeneities

Table 2: Medical physics practice guideline 5.a tests for unity in thinkQA

Test	Result (%)	Tolerance (%)
Dose in test plan versus reference calibration condition	0.4	±0.5
TPS data versus commissioning data	See [Figures 2 and 3]	±2
Small MLC-shaped field	1.0	±2
Large MLC-shaped field with extensive blocking	3.5	±2
Off-axis MLC shaped field	−4.0	±5
Asymmetric field at minimal anticipated SSD	−3.8	±5
10×10 field at oblique incidence (30°)	−2.1	±5

TPS: Treatment planning system, MLC: Multileaf collimator, SSD: Source-surface distance

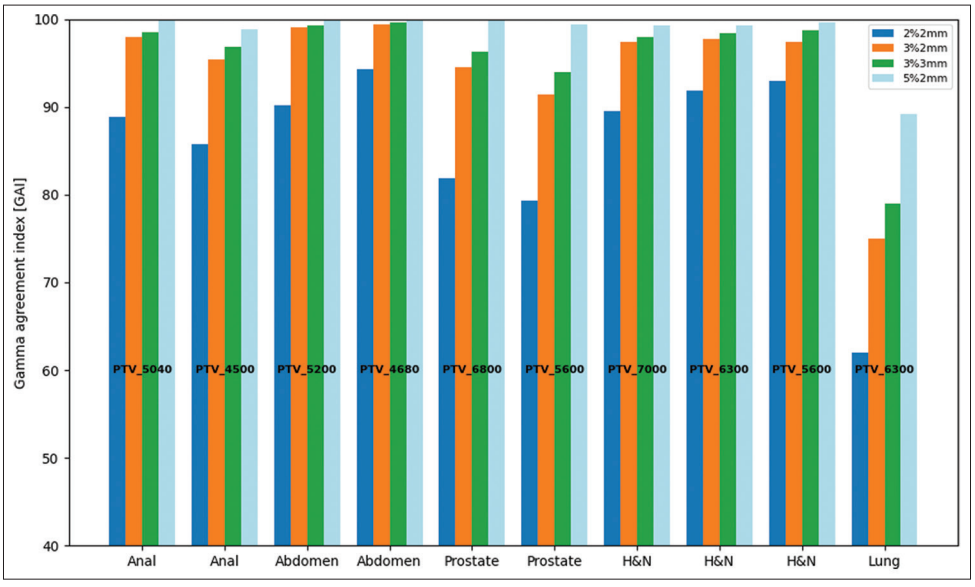

Figure 7: Gamma index agreement for the criteria used to evaluate planning target volume (PTV)s in plans analyzed for different anatomical sites

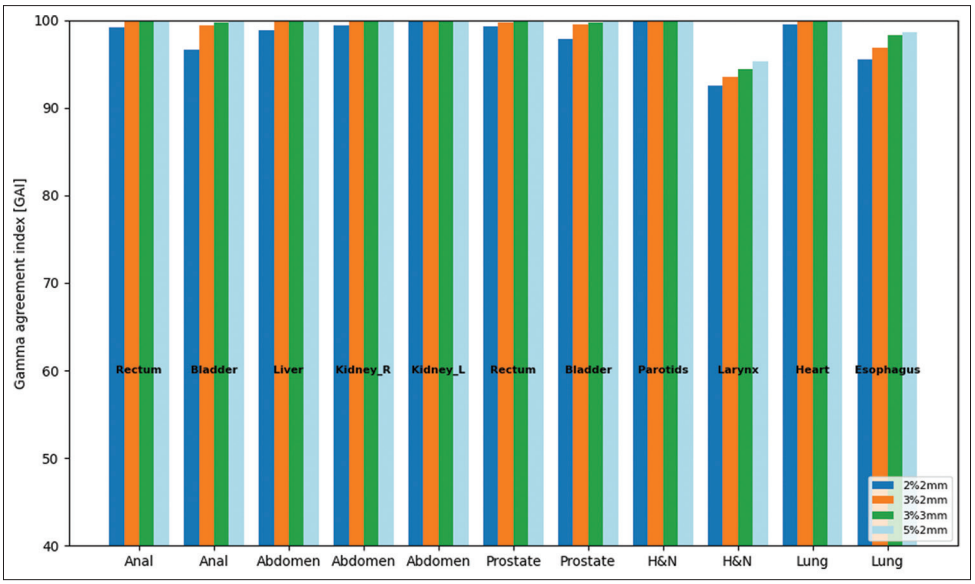

Figure 8: Gamma index agreement for the criteria used to evaluate organs at risks in plans analyzed for different anatomical sites

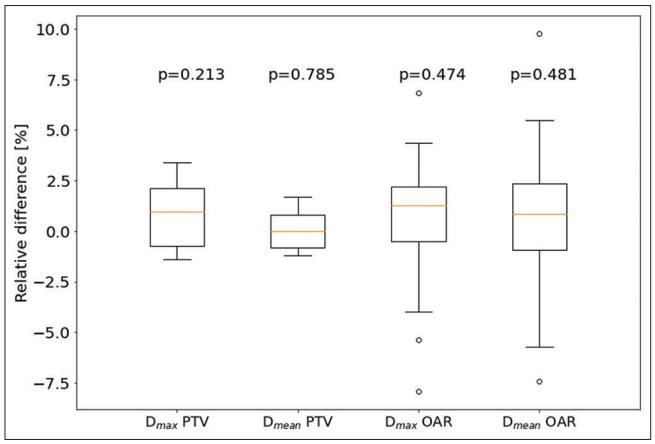

Figure 9: Relative differences for maximum and mean dose for dose calculated in treatment planning system and ThinkQA for planning target volume (PTV)s and organs at risk

for radiosurgery of brain tumors with less or no margin the introduction of the criterion 2%/1 mm. For brain cases using this criterion for fractions 0 and 1, the GAI is 89.8% ± 6.1% and 89.9% ± 6.0%, respectively.

The complementarity of the PSQA using a secondary dose calculation and a direct measurement in the MR-linac through the ArcCheck®-MR is shown in Figure 11. This figure presents the behavior of the GAI obtained in 6 different sessions of various clinical cases for different anatomical sites and also considering fraction 0. The results presented correspond to calculations using TQA and measurements made with ArcCheck®-MR for each fraction. 95.0% was used as a tolerance limit and 90.0% as an action limit. It is observed that, on average for each plan, the values obtained are within these limits, from 94.6% to 99.8% with TQA, and from 97.0% to 99.6% with ArcCheck®-MR, except in several fractions for a prostate case (87.8% with TQA, and 99.3% with ArcCheck®-MR). In this case, the measurements with ArcCheck®-MR corresponded to values >98.0%. Furthermore, GAIs calculated with TQA in these cases using the 5%/2 mm criterion were greater than 97.0% (data not shown).

Table 3: Gamma agreement index for the clinical cases treated in the magnetic resonance-guided linear accelerator according to the anatomical site in the fraction 0 (initial plan) and fraction 1 using the 3%/2 mm criterion

Anatomical site	Number of cases	Fraction 0-3%/2 mm	Fraction 1-3%/2 mm
Prostate	4	96.7±3.5	97.1±3.0 (*P*=0.092)
Brain	6	98.6±1.5	99.2±0.8 (*P*=0.112)
Rectum	2	98.6±0.3	98.8±0.2 (*P*=0.056)
Head-and-neck	2	97.5±2.1	97.5±2.1 (*P*=0.295)
Bones	2	97.7±0.1	96.7±1.0 (*P*=0.211)
Retroperitoneum	1	99.6	99.6
Breast	1	97.0	93.9
Total	17	97.7±2.2	97.9±2.1 (*P*=0.215)

Discussion

The determination of dose distribution with steep and sharp gradients requires PSQA in order to verify the calculated dose before treatment delivery, ensuring accuracy and safety of the treatment planning[10] identifying and resolving any errors before patient treatment. To ensure correct evaluations, it is mandatory to commission the algorithms for independent check of MU calculations for intensity-modulated plans. Thus, the AAPM Task Group 219 makes recommendations on the clinical implementation of secondary dose calculation programs,[11] and Task Group 218 has established tolerance limits and methodologies for IMRT dose verifications for 1D, 2D, and 3D strategies,[12] considering quality evaluations without risking harm to the patient

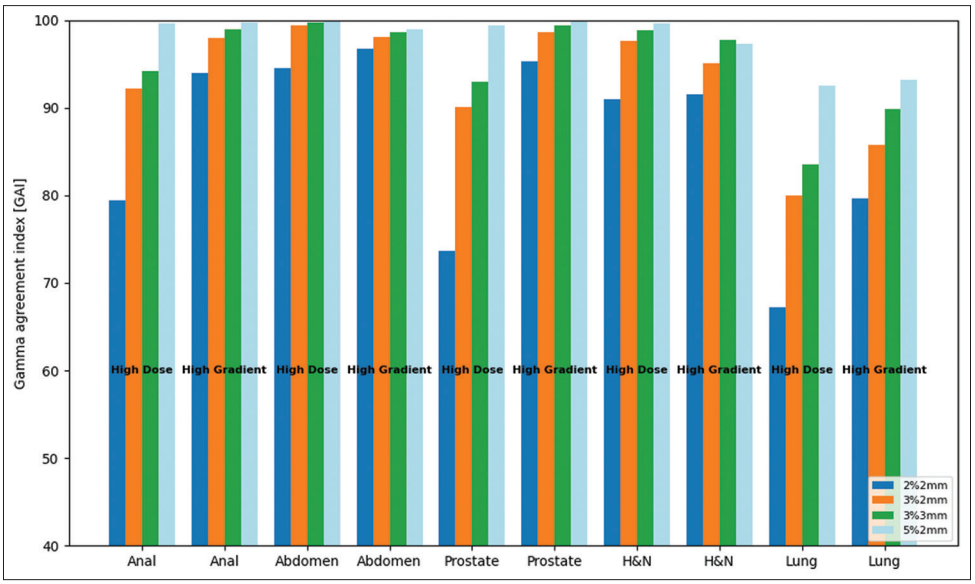

Figure 10: Gamma index agreement for the criteria used to evaluate isodose structures created in ThinkQA for plans analyzed for different anatomical sites

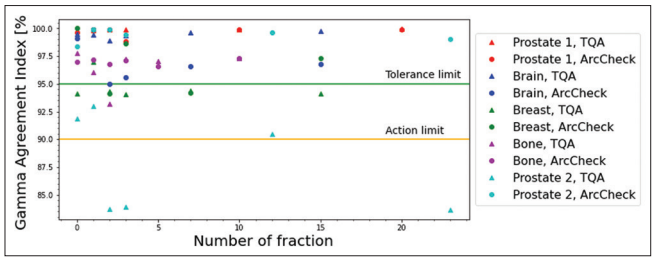

Figure 11: Gamma agreement index for diverse cases for different anatomical sites according to the number of fractions using the criterion 3%/2 mm. The plotted values corresponded with ThinkQA (circles) and ArcCheck (triangles). The green-dotted horizontal line is the tolerance limit and the yellow-dotted horizontal line is the action limit

The introduction of intensity modulated dose distributions in the presence of magnetic fields has many complications due to the need to consider ERE and electron streaming effects.[13] These effects are well characterized in Monaco TPS based on the MC algorithm. However, to detect clinically relevant errors in radiation delivery, dose distribution has to be calculated by an independent dose algorithm and measured.

In particular, TQA offers a solution for independent dose calculation for treatments delivered on the MR-linac Unity. The dose algorithm used in TQA is CCC and it is known that collapsed cone algorithms have come limitations compared to MC,[10] in particular in inhomogeneity interfaces[14] and for small fields, due to the relation of stopping powers and lack of lateral electron equilibrium, respectively.

During the commissioning of TQA following the MPPG5a tests, the modeled beams showed acceptable correspondence. Regarding dosimetric data, the higher differences described in this work for output factors regarding the measured values were evaluated for small fields. These results are associated with the CCC algorithm that has limitations in considering the lateral electron equilibrium in small fields. Furthermore, the differences could be attributed to the phantom scatter from the sides of the field into the axis (energy transport phenomena) and the variable contribution of the head scatter computed.

The dose evaluation in inhomogeneities showed discrepancies between 30% and 80% on the water-air surfaces and at exit dose. These limitations in dose calculation are reported in TQA technical documentation.[6] The overestimated dose at air-water and underestimated dose at water-air surfaces are associated with the CCC algorithm. In particular, the curvature of the warped point kernel used by CCC corresponds only to that observed in water and the density scaling process cannot reproduce the increase in radius of curvature in low-density regions.[6] Moreover, as soon as the electrons enter the air, their mean free path length will be long compared to their helical radius. Therefore, the helical path can be followed without interaction and the electrons will re-enter the phantom. This will cause a severe skin dose increase at the exit area of the beam. The ERE also takes effect at each low-density interface in the patient (air cavities and lungs). This effect is limited to about 10 mm wide zones on both sides of the interface. However, the dose difference in presence of inhomogeneities could be reduced by the use of multiple coplanar IMRT fields.[15]

In relation to PSQA commissioning, for IMRT cases, the PTVs included significant high-density to low-density interfaces. In the head-and-neck plan, there are large air pockets in the larynx next to soft tissue included in the PTV. The lung plan has considerable air-tissue interfaces and in the prostate plan, there are bone-soft tissue interfaces inside the PTV. TQA considers the magnetic field in a general sense but it does not take into account effects across interfaces such as the ERE. So for clinical cases, in particular lung treatments, there are

some discrepancies in dose calculation between CCC and MC algorithms and it is necessary to account for these limitations in choosing the acceptance criteria for a secondary check calculation. This works evince that tight criteria using TQA such as 2%/2 mm may not be suitable for all scenarios. In that case, it is recommended to adopt a reasonable criterion such as 3%/2 mm without compromising the quality of the plan. This criterion showed GAI higher than 95.0% as tolerance limit and 90.0% as action limit using TQA and PSQA measured with ArcCheck®-MR passed in all cases. This criterion is in agreement with Task Group 218, where a 90% for 3%/2 mm is recommended.[12] In addition, the gamma criterion 5%/2 mm could be adopted for special cases where the tumor is located in inhomogeneities. This criterion is suggested based on the first clinical PSQA obtained in our clinic, considering the limitations of the software, without compromising the quality of the treatment, as evinced by the measurements using ArcCheck®-MR with a tighter criterion.

It is important to mention that PSQA calculated by a secondary dose check, for MR-linac plans in an adaptive workflow, could replace the measurement using a dedicated phantom like ArcCheck®-MR. In this work several advantages were presented for performing PSQA using secondary 3D dose verification through TQA, which correspond to the fact that performing a PSQA measurement using ArcCheck®-MR to the initial plan makes little sense since that plan never is delivered to the patient in an adaptive workflow. In addition, in a radiotherapy center, time spent in the bunker is expensive,[16] and PSQA may spend too much time in a center with a high workload. Therefore, considering also that the QA measured in a phantom are not completely equivalent to the dose distribution delivered in the patient's anatomy since the dose is recalculated in the phantom's computed tomography images, the measurement in a phantom does not verify the dose calculation algorithm, and that dose calculation by means of redundant software consumes less time of the medical physicist to perform QA unlike direct measurements in the bunker. The disadvantage of using TQA is that errors in dose delivery for highly modulated plans that may come from mechanical components such as the MLC are not detected by the software and can only be observed with a measurement on a phantom, in addition to lesions located in an area with inhomogeneities, TQA can show low GAI, which can generate delays in the delivery of daily treatment if it is decided to re-optimize the plan. However, it is important to evince that mechanical or dosimetric error in dose delivery can be minimized with a strict QA program for the linac in the center, complying the recommendations of Task Group 142,[17] International Commission on Radiation Units 97[18] and local radiation protection regulations.[19]

In this work, we present a strategy for the use of TQA in each treatment fraction without the need of PSQA measurements. In case that TQA result fails, it is necessary to perform a posttreatment verification with ArcCheck®-MR of that fraction, to corroborate that the treatment meets the quality standards, as we shown for direct measurements in different treatment sessions for diverse anatomical sites, as shown in the workflow proposed. The failures exhibited in this work did not compromise the quality of the treatments, as evinced by the measurements with ArcCheck®-MR.

The calculated values by the secondary dose check work for subsequent adaptive sessions, limiting the time-consuming measurements of each fraction. In the work of Graves *et al*.[2] similar results were described for RadCalc software for 2D gamma analysis. They reported that tight criteria such as 2%/2 mm produced gamma pass rates that were sufficiently low as to not provide any useful information. An advantage of TQA regarding RadCalc is the 3D dose evaluation rather than point or 2D dose.

Future work should include the evaluation of the sensitivity and variability of dose for each fraction in accordance with adapt to position and adapt to shape strategies for clinical cases. Furthermore, it will be studied the relation between the GAI for TQA and errors detected by log files.

Conclusion

We commissioned the TQA software suite as secondary dose calculation for patient-specific pretreatment quality assurance (PSQA) for Elekta Unity MR-linac. The use of 3D dose evaluation is suitable for the majority of cases, including regions in the presence of inhomogeneities using the 3%/2 mm criterion.

Special care should be taken in using TQA for plans with small volume evaluation and when using small field sizes, due to the lack of accuracy in dose calculation in those cases.

The use of TQA for PSQA in IMRT for MR-linac could be used routinely for the majority of cases, reducing the time for direct measurements in the bunker. In addition, special care should be taken when the gamma agreement criterion is not reached, and PSQA using a dedicated phantom like ArcCheck®-MR can complement the QA evaluation. Furthermore, for complex cases, the use of secondary dose check software should not replace dose measurements for the plan because there could be errors in dose delivery not detected with a single dose comparison using two calculation algorithms.

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Conflicts of interest

There are no conflicts of interest.

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