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TECHNICAL REPORT

Use of an automated software module for monthly routine Machine QA tests

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Abstract: The goal of this work is to investigate the feasibility of implementing an automated module of a commercial software for monthly routine Linac QA tests. The AAPM TG 142 report is a reference document which includes recommendations for general Quality Assurance (QA) tests for medical linear accelerators. DoseLab software includes an AutoQA module for users to run TG-142's Machine QA tests in an automated sequence. The execution of the individual monthly tests (without DoseLab) is compared with AutoQA in terms of time consuming, reproducibility, additional data and user friendliness. The total time required was 195 minutes for single test mode, without DoseLab, and 80 minutes for AutoQA. Auto QA allows the user to analyze more parameters than single-test mode, especially for kV and MV images. Different profiles in sizes and energies are examined in minor time. The Winston-Lutz test is more quickly and complete. CBCT QA test is less laborious and no user-dependent. Reproducibility of results is verified: the coefficient of variation over 5 consecutive repeated measurements is less than 5%. The software database makes it possible to monitor the trend of different parameters over time. AutoQA module significantly reduces the time spent for QA. It also allows to get more quantitative informations and delete the user-dependent uncertainties.

Keywords: Data processing methods; Dosimetry concepts and apparatus; Hardware and accelerator control systems; X-ray detectors

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Contents

1 Introduction

Increasing complexity of radiation therapy delivery and patient setup verification need significantly more tests to be performed. The goal of a QA program for linacs is to ensure that the machine characteristics do not deviate significantly from their baseline values acquired during acceptance and commissioning phases. The QA program should be flexible enough to consider such things as institutional needs, costs, and available test equipment.

The AAPM TG 142 report [1] is a reference document which includes recommendations for general quality assurance (QA) tests of medical linear accelerators. There are specific tables according to daily, monthly, and annual reviews, along with unique tables for asymmetric jaws, wedge systems, multileaf collimator (MLC), and imaging checks. Specific recommendations and tolerances are defined for machines performing procedures such as Stereotactic Radiosurgery (SRS), Stereotactic Body Radiation Therapy (SBRT), Total Body Irradiation (TBI), and Intensity Modulated Radiotherapy (IMRT).

The report includes specific QA tests for Image-Guided Radiation Therapy (IGRT), with a section that covers radiographic imaging systems commonly integrated with medical accelerators: Megavoltage (MV) planar imaging, kV planar imaging, and MV or kV computed tomographic imaging (both serial and cone beam).

The recent TG 198 [2] provides specific procedural guidelines for performing the tests recommended in TG 142 and estimates of the time and human resources needed to complete the tests.

The guidelines are recommendations for Qualified Medical Physicists (QMPs) to use and appropriately interpret for their individual institution and clinical setting.

The time required for monthly QA will vary widely with the machine capabilities and energy choices. High performance machines with multiple energies, photon and electron, imaging, MLCs, stereotactic capabilities, etc., may require much extra time for data acquisition and analysis.

Commercial software suites may shorten the time spent assessing data and help to trend data. In this article, a commercially software Doselab provided by Varian Medical Systems is tried. The execution of some individual monthly QA tests is evaluated with a specific automated module (AutoQA) in terms of execution time, reproducibility, additional data and user friendliness.

2 Materials and methods

Our medical physics department has three TrueBeam linear accelerators (by Varian Medical Systems), one of which with High Definition 120 Leaf MLC (40 pairs of leaves 2,5 mm thick and 20 pairs of leaves 5 mm thick).

According to AAPM TG142 recommendations, we drafted up a QA protocol with monthly procedures for photon beams, summarized in table 1.

The number 1, 9 and 10 procedures (table 1) will be not taken into consideration because DoseLab is not used for their analysis.

Many checks are performed acquiring Electronic Portal Imaging Device (EPID) images. EPID provides images in digital format which can be used to quickly provide the image data required for analysis. They are easy to use and have a similar sensitivity level to films for many applications [3, 4].

Table 1. Procedures, for photon beams, included in Monthly QA protocol.

	Procedure	Details	Equipment	Tolerance
1.	X-ray output Constancy	Field $10 \times 10\,\mathrm{cm}^2$	Ion chamber	2%
2.	Photon beam profile Constancy	Flatness & Symmetry Field $10 \times 10\,\mathrm{cm}^2$	EPID	2%
3.	Light/radiation Coincidence	Field $15 \times 15\,\mathrm{cm}^2$	Radiochromic film	2 mm
4.	Leaf position accuracy	Static and arc Picket Fence	EPID	-
5.	Winston-Lutz	Gantry, collimator, couch	Cube Phantom EPID	1 mm
6.	Accurate control of Dose Rate, Leaf Speed and Gantry Speed during RapidArc delivery		EPID	2%
7.	MV and kV Imaging QA	- High Contrast Resolution - Low Contrast Sensitivity	Las Vegas Phantom/ TOR 18 FR	$\leq$ baseline $\geq$ baseline
8.	CBCT QA	- HU Calibration - Spatial Linearity Measurements - Image Uniformity Measurements - High and Low Contrast Resolution	Catphan Phantom	50 HU 0,5 mm 30 HU $\leq$ baseline and $\geq$ baseline respectively
9.	Imaging and treatment coordinate coincidence		Machine Performance Check	0,5 mm
10.	Beam output Constancy with Respiratory Gating		Portal Dosimetry	$\gamma \geq 95\%$ for test-treatment

2.1 Conventional approach (single test mode)

For procedures 2, 4 and 6 in table 1, EPID images are analyzed with EPIQA™ software. EPIQA™ (EPI-dos s.r.o.) [5] is a program that converts a dosimetric image acquired by an EPID into a dose map and compares the dose map with a reference dose distribution. It is possible to use EPIQA™ for verification of static as well as intensity modulated fields, including Volumetric Modulated Arc Therapy (VMAT) fields (named RapidArc® fields).

EPIQA™ software consists of four modules. The Machine QA Module performs beam profile analysis and evaluates flatness and symmetry constancy. Only $10 \times 10\,\text{cm}^2$ fields are examined for all beam energies in our procedure. They are compared with profiles acquired with EPID during commissioning.

RapidArc/VMAT QA Module offers a dedicated analysis tool which verifies linac performance through pre-defined tests on MLC, dose rate and gantry speed accuracy.

These tests, described in Ling et al. [6, 7], are based on the official Varian tests for RapidArc commissioning. Leaf position accuracy is estimated through Picket Fence tests delivered at stationary gantry angles and during RapidArc.

Picket fence test during RapidArc/VMAT with intentional errors is also analyzed. Test for accurate control of Dose Rate and Gantry Speed uses seven combinations of dose-rate, gantry range and gantry speed to give equal dose to seven strips in a single RapidArc/VMAT field. Test for accurate control of Leaf Speed uses four combinations of leaf speed and dose-rate to give equal dose to four strips in a single RapidArc/VMAT field.

Radiochromic film like GafChromic RTQA2 [8] is used for light field-radiation field coincidence [9]. The resultant image shows any misalignment between the light field markings and the radiation field.

For MV images, contrast detail resolution is determined by taking images of the MV Las Vegas phantom (figure 1A) with a high and low energy mode [10]. The different hole depths correspond to different object contrasts depending on the beam energy. Distribution and number of visible holes is visually compared with baseline.

To evaluate high contrast resolution and low contrast sensitivity of kV image, TOR 18 FR phantom image is acquired (figure 1B) [10]. The image is visually inspected to determine the smallest discernable group of bars visible in the image, which corresponds to a certain line pair per millimeter values, and the lowest contrast disk visible. These values are compared with baseline.
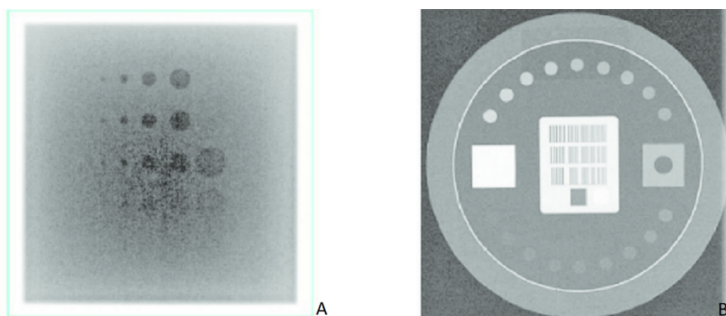

Figure 1. Planar images of imaging QA phantoms: the MV image of the Las Vegas phantom (A) and the KV image of the TOR 18 FR phantom (B).

Cube phantom is used to perform Winston-Lutz [11]. Images collected by EPID are obtained, for various positions of the collimator (seven positions), gantry (eight positions) and couch (five positions). The variation of the distance between the isocenter and the radiopaque marker is manually measured by the user in the EPID images.

All CBCT QA tests are performed using CatPhan Phantom, which is composed of different modules specific for: Hounsfield unit (HU) Calibration, Spatial Linearity Measurements, Image Uniformity Measurements, High and Low Contrast Resolution [13].

Two acquisitions, Head and Pelvis mode, are examined in Service mode within PVA Calibration on treatment workstation. ROIs are manually placed for tests: HU Calibration and Uniformity. Uniformity is evaluated as the difference between mean HU Value for the center ROI (reference value) and mean HU values for each of the peripheral ROIs. High and Low contrast resolution are only visually analyzed and compared to baseline.

2.2 Auto QA

DoseLab (version 7.0.0) is a commercial software by Varian Medical Systems [10]. It is made up of three separate software products:

- DoseLab TG-142

- FractionLab

- DoseLab Pro

DoseLab TG-142 is composed of specialized, non-patient specific software tools help medical professionals fulfill the recommendations of the AAPM Task Group 142 report.

Especially AutoQA is a module for users to run DoseLab TG-142's Machine QA tools in an automated sequence.

It automates the processes of opening images, choosing the QA modules, setting parameters for the analyses, and computing results.

It is specifically designed for experienced DoseLab users with firmly established settings used for all their routine Machine QA tests.

Analysis using any of the following tools can be automated in AutoQA, as summarized in table 2. Tolerances are defined with respect to baseline data from acceptance testing, as recommended in AAPM Task Group 142 report. For Imaging QA, the tolerances also take into account the guidance in the Doselab manual, which suggests exposure parameters based on the type of phantom used.

2.2.1 Flatness & Symmetry

Flatness and symmetry are evaluated for central horizontal and vertical profiles on EPID images. Also, Auto QA software gives field sizes (using 50% field edges) and penumbra sizes (distance between 20% and 80% field edges on all sides).

An initial measurement should be performed to generate baseline profiles and help set tolerance values for future analysis.

Multiple baseline profiles and tolerance sets can be established to account for different machines, energies, measurement devices, and/or field sizes.

Table 2. Procedures performed by AutoQA module.

Procedure	Equipment	Tolerance
Flatness & Symmetry		1%
Field size	EPID	2 mm
Penumbra sizes		2 mm
Light/radiation Coincidence	EPID - Rlf Varian Phantom	2 mm
MLC Strip Test	EPID	Failing peaks: 0,5 %
		Maximum difference: 0,5 mm
		Standard Deviation: 0,4 mm
Winston-Lutz (Multi-Image)	EPID — WL3 Varian Phantom	1 mm
VMAT/DMLC	EPID	2%
kV Imaging QA	MC2 Varian Phantom	Scaling discrepancy: 1 mm
		Spatial Resolution: 0,3 lp/mm
		Minimum uniformity: 2%
		Contrast: 2%
		CNR: 8
		Positioning offset: 2 mm
MV Imaging QA	MC2 Varian Phantom	Scaling discrepancy: 1 mm
		Spatial Resolution: 0,2 lp/mm
		Minimum uniformity: 2%
		Contrast: 2%
		CNR: 3
		Positioning offset: 2 mm
CBCT QA	Catphan Phantom	Scaling discrepancy: 2 mm
		Geometric distortion: 1 mm
		Spatial Resolution: 0,2 lp/mm
		Overall Uniformity: 8 %
		Minimum uniformity: 4%
		Contrast: 1%
		CNR: 1
		Maximum HU Deviation: 40

Considering clinical linacs use, we have decided to check the beam fields sizes and energies summarized in table 3.

For each profiles, baseline profiles and tolerances are configured into DoseLab software. Baseline profiles are acquired with EPID during commissioning and they correspond to these obtained into water phantom with ion chamber.

Table 3. Fields sizes and energies beams checked by AutoQA, for Flatness & Symmetry test.

Field Size (cm^2)	Energy (MV)	Linac
10×10	6, 10, 15, 18	
25×25		2 TrueBeam Varian
5×5	6FFF, 10FFF	
10×10		
10×10	6, 10, 15, 18	
15×15		1 TrueBeam HD Varian
5×5	6FFF, 10FFF	
10×10		

2.2.2 Light/Radiation Coincidence

Rlf Varian Phantom showed in figure 2 is supported with fiducials at known locations from the desired field edge. A $15 \times 15\,\text{cm}^2$ field image is acquired with EPID. The results box shows field sizes (using 50% field edges).
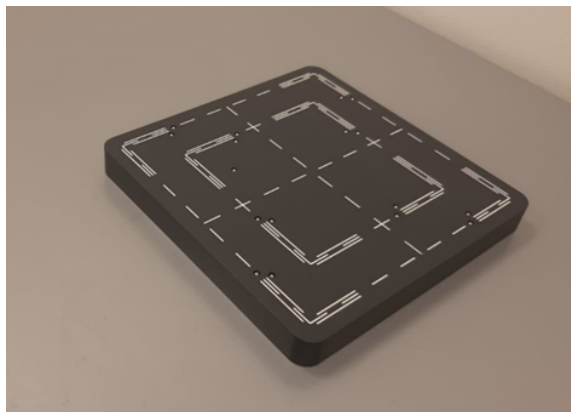

Figure 2. Rlf Varian Mobius Phantom for Light/Radiation Coincidence test.

2.2.3 MLC Strip Test

Same Picket Fence tests described above are used. Static Picket Fence tests (at 0°, 90°, 180° and 270° gantry position) are performed for one beam energy. Picket fence tests during RapidArc/VMAT with and without intentional errors are executed for two different beam energies. Specifying the MLC model allows DoseLab to overlay leaf numbers on the image, and to determine which leaves had errors. The results box for the MLC strip test analysis contains the calculated values of:

- The total number of peaks found, which equals *(number of strips) × (number of pixel rows)*

- The leaf number(s) for any leaves deemed fail to meet the tolerance

- The number of peaks outside tolerance

- The maximum deviation from a peak to a fit line

- The standard deviation of peaks to fit lines

- The iso to strip distance: the distance between the isocenter point and the center of the nearest strip.

- The average distances between the fit lines

- The calculated slopes of each peak fit lines in degrees.

The graphics of results box (figure 3) show red X's on the points which were found to be peaks outside of the tolerance setting from the fitted line and a histogram for the differences between found peaks and the fitted lines along with red lines indicating the tolerance.
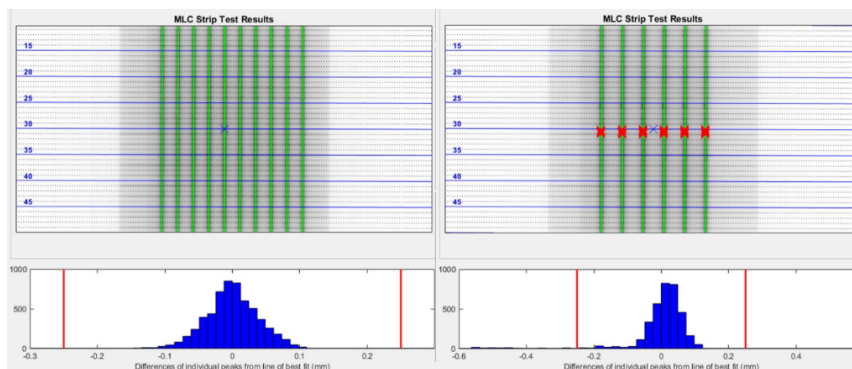
Figure 3. Part of results box for the MLC strip test analysis. Solid green lines correspond to the lines which it fit to each strip exposure. On the right, red crosses highlight the leaves with intentional error. The bottom graphic shows a histogram for the differences between found peaks and the fitted lines along with red lines indicating the tolerance.

2.2.4 Winston-Lutz (multi-image)

Winston-Lutz test are performed using a set of EPID images of WL3 Varian phantom (figure 4) for different positions of collimator (seven positions), gantry (eight positions) and couch (five positions). Setting the radiation field threshold and the center object threshold, DoseLab results box displays the maximum absolute horizontal or vertical 2D delta of all analyzed fields, as well as the maximum total delta (sum of horizontal and vertical deltas in quadrature), and mean total delta. The predicted accuracy of DoseLab is $1/3^{rd}$ of a pixel, due to the centroid algorithm used.

The field images are labeled and the offset are shown next to the images (figure 5).

Figure 4. WL3 Varian Mobius Phantom for Winston-Lutz test.

2.2.5 VMAT/DMLC tests

This tool is used to analyze pairs of images for routine VMAT-related QA presented in the article by Ling et al. [4]. A VMAT delivery, using different MLC speeds, gantry speeds, and/or dose rates to deliver bands of equal dose, is acquired with EPID. The image is divided by the open-field image to remove beam asymmetry effects (figure 6). The ROI values on each bands are then compared to each other to ensure the same dose was delivered to each area of the image. This verifies that changing MLC speeds and dose rates does not alter the dose.
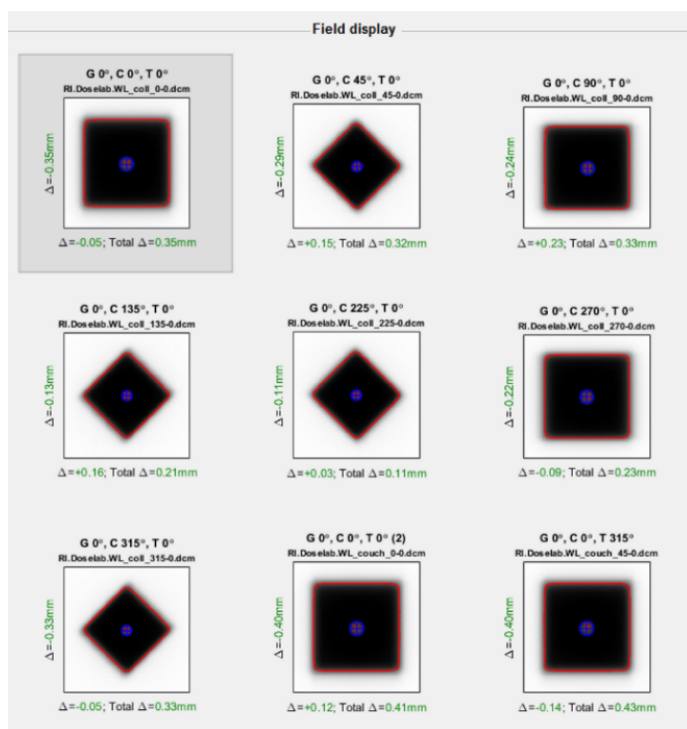
Figure 5. Graphical results of multi-image Winston-Lutz test. Radiation field edge and centroid are displayed with a red line and red X, respectively. Calculated center object edge and centroid are displayed with blue line and blue cross, respectively.
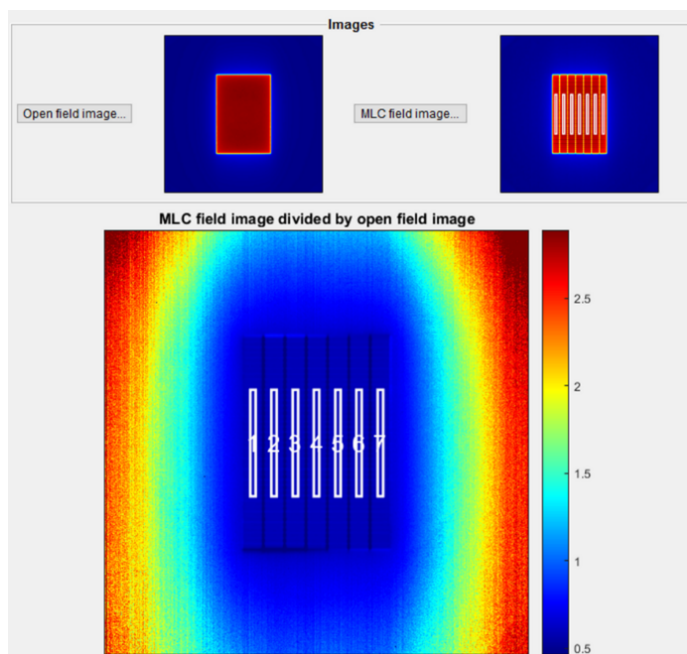

Figure 6. Graphical results of VMAT/DMLC test.

Considering clinical intendent linacs use, we have decided to perform VMAT/DMLC tests for following beam energies:

- 6, 10, 10 FFF for TrueBeam Varian

- 10, 6 FFF, 10 FFF for TrueBeam HD Varian.

All tests are executed using maximum dose rate specific for each beam.

2.2.6 MV and KV imaging QA

DoseLab's Imaging QA uses MC2 Varian Phantom images (figure 7) acquired with MV and kV flat panel to calculate:

1. Scaling discrepancy

2. Spatial resolution (50% MTF)

3. Minimum uniformity

4. Contrast

5. Contrast to Noise Ratio CNR

The Minimum Uniformity is defined as lowest uniformity value of all ROIs with uniformity calculations, where Uniformity is calculated as $\left(1 - \frac{S90 - S10}{S90 - S10}\right) \cdot 100\%$, where S90 is the 90$^{\text{th}}$ percentile of the signal level (pixel value) in the region, and S10 is the 10$^{\text{th}}$ percentile of the signal level.

The Contrast is calculated between two regions as $\frac{S_2 - S_1}{S_2 + S_1} \cdot 100\%$, where S_2 is the mean signal value in the region with the larger signal, and S_1 is the mean signal value in the region with less signal.

It is possible to select the desired tolerance set to apply to the processed results by using the drop-down box. An initial measurement is used to set baseline values for future analysis for each parameter.
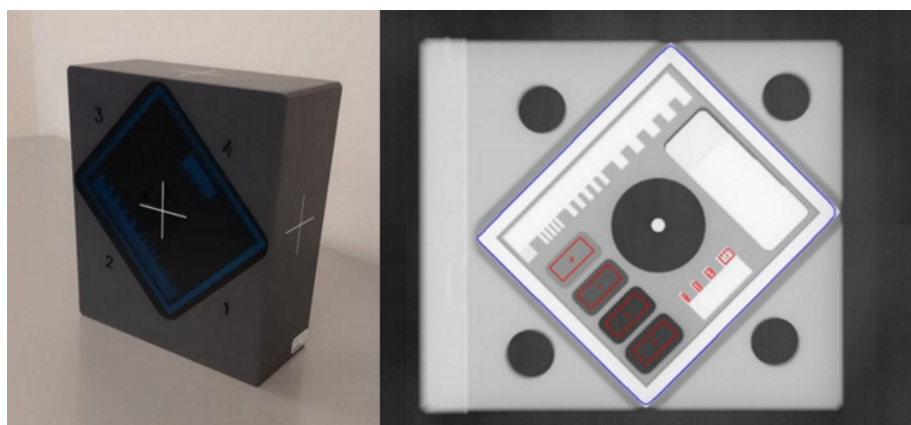

Figure 7. MC2 Varian Mobius Phantom for MV and kV Imaging QA on the left. MC2 Varian Phantom kV image on the right. Red ROIs are used to calculate results. Blue line corresponds to the phantom edge.

2.2.7 CBCT QA

Tool CBCT QA allows to analyze Catphan Phantom (figure 8) images. Twenty-two ROIs are allocated into phantom modules (figure 9) to deduce the following parameters:

1. Scaling discrepancy

2. Geometric distortion

3. Spatial resolution (50% MTF)

4. Uniformity

5. Minimum uniformity

6. Contrast

7. Contrast to Noise Ratio CNR

8. Max HU deviation

The parameters (Uniformity, Minimum uniformity and Contrast) are as defined in the previous section. Maximum HU deviation is the maximum absolute value of all calculated HU deviations for every ROI from their defined reference HU.

It is possible to select the desired tolerance set to apply to the processed results by using the drop-down box. An initial measurement is used to set baseline values for future analysis for each parameter.
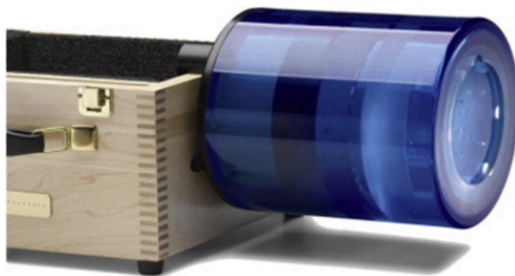
Figure 8. Catphan Phantom for CBCT QA.
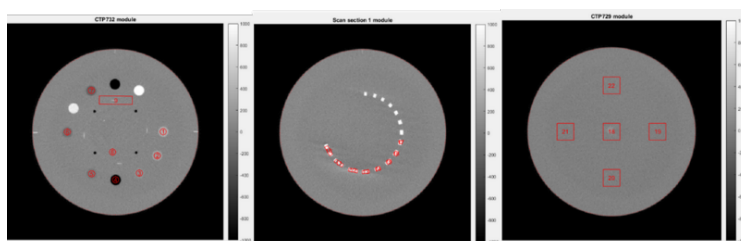
Figure 9. Catphan Phantom modules images. Red ROIs are used to calculate results.

3 Results

3.1 Conventional approach (single test mode)

Performing single tests using the conventional approach, the time required for monthly QA is reported in table 4. The measured times comply with those reported in the report AAPM report tables [2]. We have distinguished machine time from the analysis time. Analysis time includes also time to export EPID images to specific software.

Table 4. Time required for performing single tests.

Procedure	Machine Time	Analysis Time
2. Photon beam profile Constancy	10 min	20 min
3. Light/radiation Coincidence	10 min	5 min
4. Leaf position accuracy	10 min	15 min
5. Winston-Lutz	15 min	20 min
6. Accurate control of Dose Rate, Leaf Speed and Gantry Speed during RapidArc delivery	10 min	15 min
7. MV and kV Imaging QA	15 min	20 min
8. CBCT QA	10 min	20 min
Total	80 min	115 min

For procedures 2, 4, 5 and 6, specific fields have been prepared in TPS (Treatment Planning System) to speed up the images acquisition with EPID. The results of all test are written in definite Excel file.

Light field-radiation field coincidence is only visually evaluated from Gafchromic color change with respect to the marker line.

RapidArc/VMAT QA Module of EPIQA allows the user to scroll, leaf per leaf, on all loaded Picket Fence images that is only qualitative analysis: no information about leaf positions. Also Picket fence test during RapidArc with intentional errors is only qualitative checked, but the failing leafs are not known. Procedure 6 is quantitatively analyzed with RapidArc/VMAT QA Module in the same way of Auto QA, that is evaluating, for pre-defined ROIs displayed on the images, deviations from the reference value, defined as the average value of all the ROIs. Concluding all the test, it is possible to save a report file in html format.

For Winston-Lutz test, each single image is analyzed and the distance between the isocenter and the radiopaque marker is manually measured. This check results so user-dependent and time consuming.

MV and kV Imaging QA are only qualitative and user-dependent analysis.

CBCT images analysis, in Service mode, needs a lot of time, for manually ROI positioning and to obtain necessary parameters

3.2 AutoQA with DoseLab

The fields for the QA images must be precisely named for AutoQA to automatically interpret information within the DICOM image file (figure 10).

A patient test for each TrueBeam is created with fields corresponded to each automatic tests.

Machine time to execute all test is 60 minutes on average (considering four different users), including phantom positioning. The machine time is given by the time interval between the creation of the first and the last image, from Image Browser in ARIA RTM (Varian Medical System database).

Figure 10. Catphan Phantom modules images. Red ROIs are used to calculate results.

All images are manually exported into specific folder. Running tool, AutoQA automatically begins analyzing all files with the AutoQA sub-directory. All results will be classified as Pass/Warn/Fail. During processing, it is possible to open a particular test for further analysis. The analysis time is given by the processing time (about 10 minutes) from DoseLab software, plus manual review of results (about 10 minutes). It is averaged over the time taken by 4 different users.

All tests were repeated 5 times consecutively to verify the reproducibility of the system and to exclude errors introduced in the placement of the phantoms. Results show coefficients of variation for all parameters <5%, with higher values for CBCT tests attributable to variations in tube delivery.

To test the reproducibility of response of the AutoQA system only, the same images were processed 5 times and no deviation was detected.

After completing the analysis within AutoQA, all results can be saved in bulk to the DoseLab Machine QA Database (examples shown in figure 11 and figure 12) which allows us to analyze the trend of the measurements of each parameter. As example, figure 11 shows the trend of the 10×10 field size for 10FFF energy beam. It can be seen how the value gradually fell below the tolerance (at January 2022). At that time, the readout jaws calibration was performed and the measured values returned within the expected tolerances.

Another example is the trend of maximum difference leaf position for Picket fence test during RapidArc/VMAT with intentional errors; it confirms the system's ability to always correctly identify the leaf that deviates from the correct position (figure 12).

Auto QA provides options for creating and saving separate merged PDF reports. Results do not have to be transcribed into another sheet-they are all in one merged PDF report.

4 Discussion and conclusions

Based on our experience, AutoQA can significantly reduce the time spent on a monthly basis (table 5). The total time progresses from 195 minutes of single test mode with conventional approach,
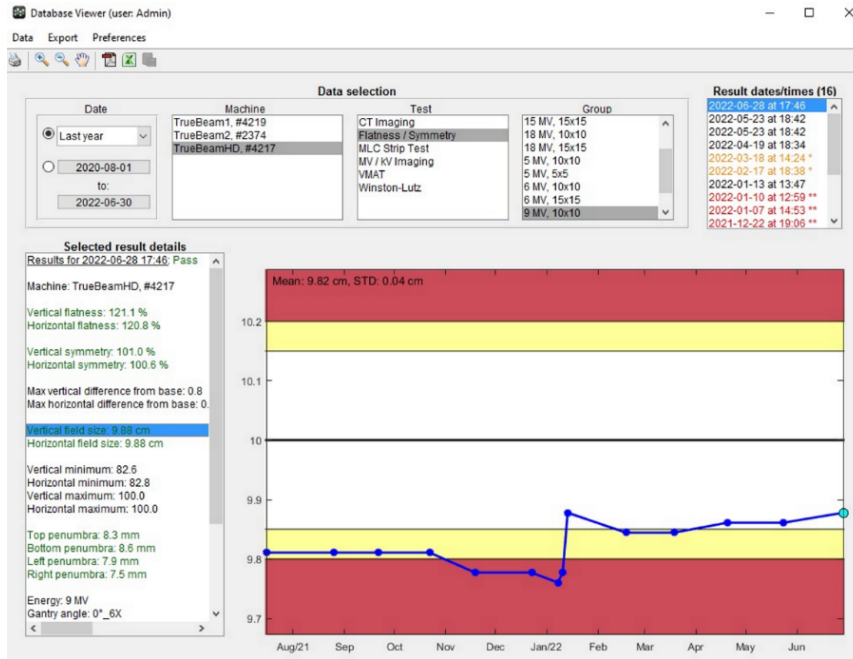
Figure 11. Example Database for AutoQA. Blu line corresponds to vertical field size trend for $10\,\text{cm} \times 10\,\text{cm}$ field of 10 FFF MV beam.
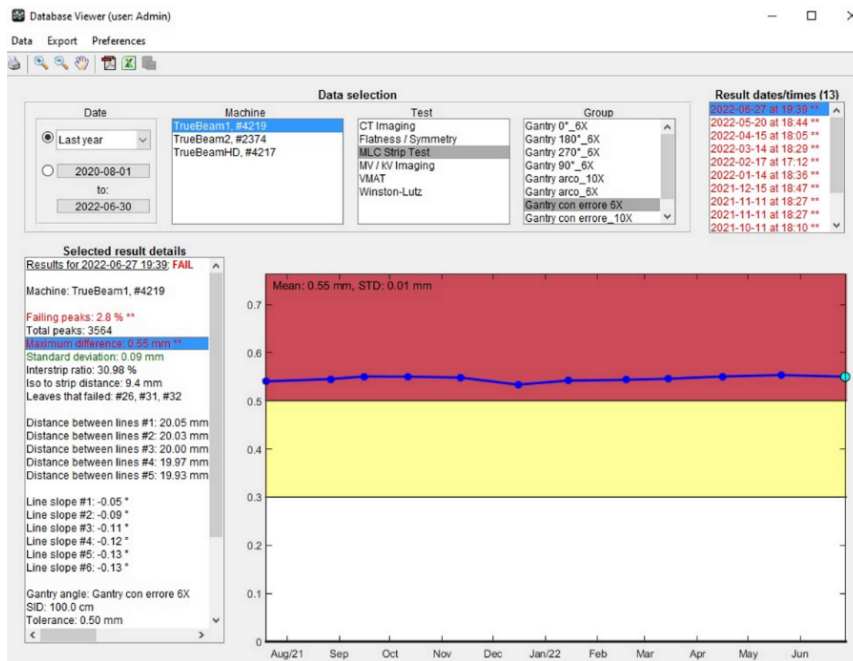

Figure 12. Example Database for AutoQA. Blu line corresponds to trend of maximum difference leaf position for Picket fence test during RapidArc/VMAT with intentional errors.

without DoseLab, to 80 minutes of AutoQA. Furthermore, the 80 minutes include more tests than the single-test mode. A shorter time is a fundamental advantage especially in a department with a considerable workload and insufficient machine time.

Table 5. Comparison between single test mode and Auto QA, in term of time consuming.

Procedure	Machine Time	Analysis Time	Total Time
Conventional Approach (Single test Mode)	80 min	115 min	195 min
Auto QA	60 min	20 min	80 min

Figure 13 clearly shows how the Auto QA system allows more data to be obtained for each procedure. Photon beam profile constancy is verified for a greater number of fields in size and energy. Also, we obtain data about field sizes and penumbra for all profiles.

The AutoQA tool allows to have a quantitative analysis for all tests, that is more information to understand any deficits in the linac components.
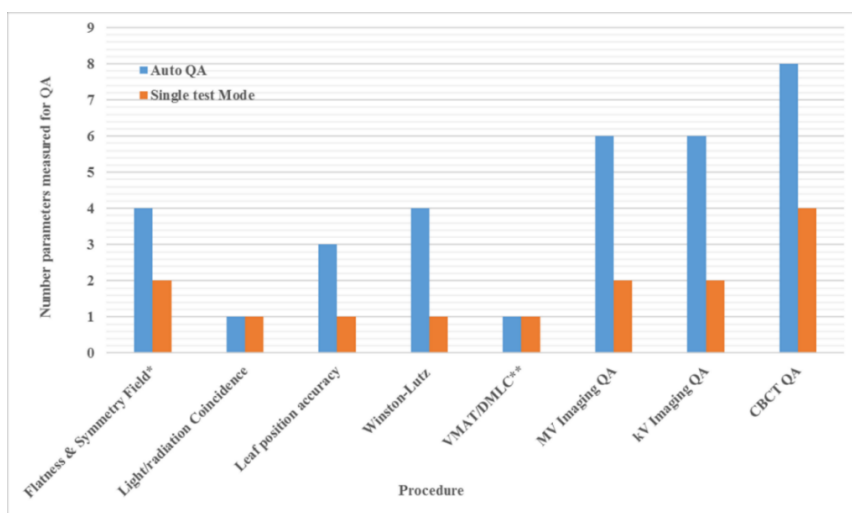

Figure 13. Number parameters measured for QA separated by procedure. * 2 sizes for each beam energy for Auto QA, 1 size for each beam energy for Single Test Mode. ** Tests for 3 beam energies for Auto QA, for 2 beam energies for Single Test Mode.

The analysis of the MLC strip test allows to know exactly the number of the leaf that does not work correctly.

The Winston-Lutz test, which is really important particularly for machines that perform SRS/SBRT treatments, is more quickly, complete and no user-dependent, because not manually measured.

kV and MV images analysis is more complete and it allow to have a more precise picture of the good image quality and the performance of the EPID.

CBCT QA, even if it includes the evaluation of the same parameters, is faster to perform than in single tests mode. All analysis results are not user-dependent and they are more user friendly. Merged pdf report is useful for reviewing the checks performed. In addition, the availability of Machine QA Database offers the great advantage of being able to examine the trend for each test, so it is possible to monitor the overall behavior of the linacs and know if they need important technical interventions.

Developing an automated, streamlined quality assurance (QA) program is the purpose of many works [14–17]. A QA program is fundamental and mandatory for a correct check of linacs to guarantee a correct execution of clinical treatments and patients safety. In our routine the introduction of Machine Performance Check (MPC), running on the TrueBeam console workstation, had already allowed us to performed many daily tests, all automatically. This work proves the feasibility of implementing of AutoQA for monthly routine Linac QA tests. AutoQA use allows to execute QA tests by substantially speeding up the procedures, obtaining more information and deleting intra- and interpersonal variation.

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