


Factor I0 Expedience of Monthly Linac Quality Assurance via an Ion Chamber Array and Automation Scripts

Technology in Cancer Research & Treatment
Volume 18: 1-10
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DOI: 10.1177/1533033819876897
journals.sagepub.com/home/tct


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Abstract

Purpose: While critical for safe and accurate radiotherapy, monthly quality assurance of medical linear accelerators is time-consuming and takes physics resources away from other valuable tasks. The previous methods at our institution required 5 hours to perform the mechanical and dosimetric monthly linear accelerator quality assurance tests. An improved workflow was developed to perform these tests with higher accuracy, with fewer error pathways, in significantly less time. **Methods:** A commercial ion chamber array (IC profiler, Sun Nuclear, Melbourne, Florida) is combined with automation scripts to consolidate monthly linear accelerator QA. The array was used to measure output, flatness, symmetry, jaw positions, gated dose constancy, energy constancy, collimator walkout, crosshair centering, and dosimetric leaf gap constancy. Treatment plans were combined with automation scripts that interface with Sun Nuclear's graphical user interface. This workflow was implemented on a standard Varian clinac, with no special adaptations, and can be easily applied to other C-arm linear accelerators. **Results:** These methods enable, in 30 minutes, measurement and analysis of 20 of the 26 dosimetric and mechanical monthly tests recommended by TG-142. This method also reduces uncertainties in the measured beam profile constancy, beam energy constancy, field size, and jaw position tests, compared to our previous methods. One drawback is the increased uncertainty associated with output constancy. Output differences between IC profiler and farmer chamber in plastic water measurements over a 6-month period, across 4 machines, were found to have a 0.3% standard deviation for photons and a 0.5% standard deviation for electrons, which is sufficient for verifying output accuracy according to TG-142 guidelines. To minimize error pathways, automation scripts which apply the required settings, as well as check the exported data file integrity were employed. **Conclusions:** The equipment, procedure, and scripts used here reduce the time burden of routine quality assurance tests and in most instances improve precision over our previous methods.

Keywords

quality assurance, IC profiler, linac QA, monthly QA, automation

Abbreviations

DLG, dosimetric leaf gap; MLC, multileaf collimator; PDD, percent depth dose; QA, quality assurance; SDD, source to detector distance; SSD, source to surface distance; TPS, treatment planning system

Received: December 28, 2018; Revised: July 18, 2019; Accepted: August 13, 2019.

Introduction

Quality assurance (QA) of radiotherapy linear accelerators (linacs), with current single farmer chamber methods, is time-consuming and labor-intensive. Various efforts are underway to better prioritize and streamline crucial QA tasks.¹⁻³ In several cases, automation of QA requires digital linacs or custom equipment.⁴ Here we investigate the improvements

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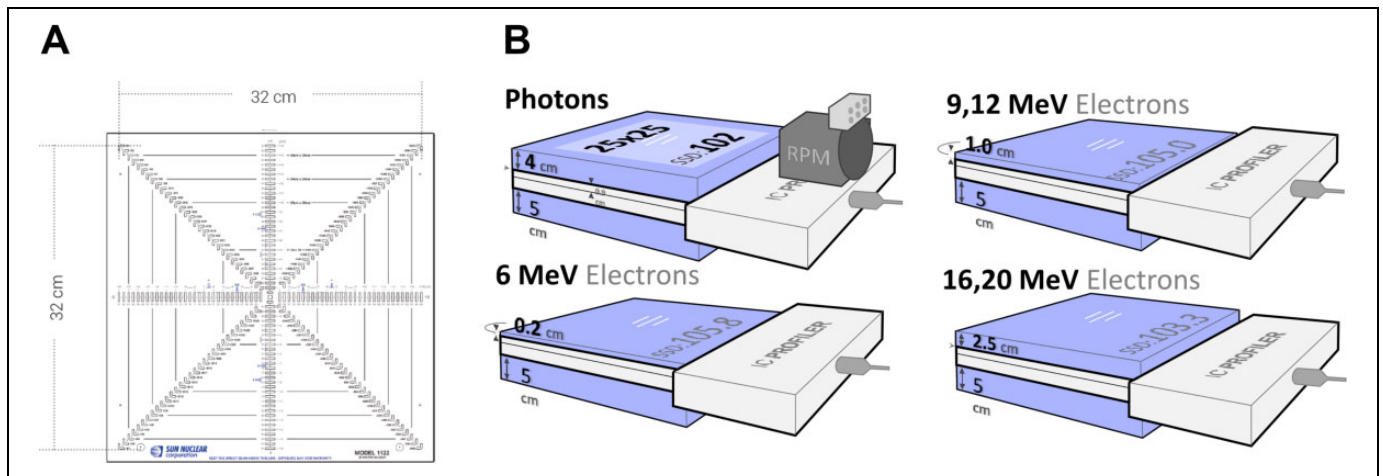


Figure 1. A, Ion chamber array layout of IC profiler. B, Schematic monthly QA example setup conditions of detector surface at SDD: 106 cm with varying thickness solid water on top and additional 5 cm solid water underneath. SDD indicates source to detector distance; QA, quality assurance.

possible with a commercially available ion chamber array detector that can be clinically implemented on any C-arm linac.

Although automated machine performance measurement routines such as Varian's Machine Performance Check exist, these are often limited to newer generation linacs, do not use ion chamber detectors, or are not independent of the linac manufacturer.⁵ In this work, ion chamber array methods were chosen *instead of* diode arrays and semiconductor-based imagers, as the dose-response of ion chambers is normally less susceptible to radiation damage. This stability makes them well suited to monthly QA dose-constancy applications. One disadvantage of ion chamber arrays is that the spatial resolution is limited to several millimeters, which makes them suboptimal for fine positioning measurements, such as those required for multileaf collimator (MLC) QA.

Excluding MLC and imaging tests, which are not considered here, 26 tests are needed each month for compliance with task group report TG-142 recommendations.⁶ For modern linacs with 10 photon and electron beam energies (eg, Varian True Beam, Elekta Versa HD), performing these tests with a standard electrometer and ion chamber requires manual entry of at least 300 to 600 digits. For example, a single energy test requires several repeats of measurements each with 5 digits, which need to be transcribed into software. To improve efficiency and reduce errors, we have implemented an ion chamber array combined with automation scripts to streamline the monthly QA process. In our clinic, these methods reduced the time needed for monthly dosimetric and mechanical tests from 5 hours down to 30 minutes, per linac, per month (a video demonstration of the monthly QA delivery can be viewed online).⁷ The new workflow also reduces error rates by minimizing manual data entry, as well as through automated checks. Ion chamber array-based methods for collimator walkout and asymmetric jaw positions and laser alignment measurements are also introduced. In this article, key calibration findings and the clinical workflow are presented. Also provided are examples of automation scripts and worksheets.

Methods

Quality Assurance Procedure and Delivery

In this study, an IC profiler ion chamber array manufactured by Sun Nuclear (Melbourne, Florida) was used. The IC profiler consists of 251 parallel plate ion chambers, each 2.9 mm wide and spaced 5 mm apart. The chambers are arranged in double-cross pattern such that inline, crossline, and diagonal profiles can be obtained simultaneously.

For monthly QA photon measurements, a 25×25 cm² square field measurement provides output, flatness, symmetry, and jaw position information. These are then repeated with gating. For the gating test, a Varian real-time position management motion phantom was placed on the edge of the IC profiler, and then the ratio of doses from gated and ungated fields was analyzed, for both amplitude and phase gating modes. A 20×20 cm² enhanced dynamic wedge field was used to provide a wedge factor constancy measurement. The wedge angle can also be analyzed if desired. For electron measurements, the 25×25 cm² applicator and square cutout were used to measure output, flatness, and symmetry.

The IC profiler is first aligned to the crosshair. Radiation versus crosshair is measured by delivering radiation with gantry and collimator angles at 0°. The IC profiler reports the position of each radiation beam edge (X_1 , X_2 , Y_1 , and Y_2) against its own center. This allows for independent checks of each jaw position, as well as field size and centering information.

The conditions used for the photon tests were source to surface distance (SSD): 102 cm, depth: 4.9 cm, field size: 25×25 cm², and 100 MU (Figure 1). The unusual SSD of 102 cm was a compromise to allow a single electronic gain setting on the IC profiler for all measurements, while maintaining a single source to detector distance (SDD). The 4.9 cm depth is a result of the inherent 0.9 cm buildup and 4 cm additional solid water. The monthly QA electron measurement conditions were SSD:

103.3 to 105.8 cm (constant SDD), depth: 1.1 to 3.4 cm, field size: $25 \times 25 \text{ cm}^2$, and 200 MU (Figure 1). Three electron depths were chosen so as not to deviate too far from the TG-51 recommended d_{ref} depth, or the $R_{85}/2$ depths for electron flatness and symmetry acceptance tests ($d_{\text{ref}} = 1.3, 2.0, 2.9, 3.9, 4.9 \text{ cm}$, $R_{85}/2 = 1.0, 1.4, 2, 2.7, 3.3 \text{ cm}$ for 6, 9, 12, 16, 20 MeV electron energies, from recent annual QA). Although some time could be saved by making all electron measurements at a single depth, the relationship between monthly QA results, machine acceptance tests, and TG-51 measurements would become less clear. For example, a 2% deviation in the percent depth dose (PDD) at depth A will look like a 2% output change, while the output and PDD at the TG-51 depth (d_{ref}) may both have zero deviation. This would become difficult to disentangle when setting a single baseline for machines that are matched at d_{ref} . The single 200 MU delivery was chosen for the electron fields as this was found to be more consistent between machines than multiple lower MU measurements. For example, it was observed that on linacs with abnormally slow dose rate ramp up, the IC profiler reported approximately 1% lower dose for a 100 MU delivery, compared to a farmer chamber measurement. This difference reduced with the increasing MUs and is assumed to be caused by differences in the triggering threshold between the IC profiler (not adjustable) and the electrometer. The solutions were (1) to tune the linacs to make the ramp-up times consistent and (2) use 200 MU or greater for electron measurements, to reduce the maximum triggering errors to below 0.5%.

Since the array is at a source to detector surface distance, $\text{SDD} = 106 \text{ cm}$ in our setup, the positioning data outputted by the profiler software was corrected using:

$$x_{\text{corr}} = (100/\text{SDD}) \cdot x_{\text{meas}} \quad (1)$$

where x_{corr} and x_{meas} are the corrected and raw measured distances, respectively. Note this is not 106.9 cm as the Profiler software already corrects internally for the 0.9 cm difference between the source to profiler surface and SDDs.

The Sun Nuclear profiler software (version 3.4.2) provides several metrics that are used for the monthly QA tests discussed in this article, namely, central axis dose, flatness and symmetry, beam center, field size, radiation versus light field, PDD_{10} , (PDD at 10 cm depth) and R_{50} (depth where dose is 50%). For each metric, sensitivity to small deviations, repeatability, and stability were tested. Results were compared with the previous monthly QA methods which are approved by our departmental QA committee.

After measurement, data are exported in batches using the profiler export function. This creates a text file of all the open measurements. In our clinical workflow, this export file is read with an automation script to extract the key data for input into an analysis spreadsheet and clinical database. The exported data are then automatically checked to confirm the settings were as expected. To characterize the noise in the central axis output measurements, repeats were made using the monthly

QA setup without any setup changes (see Output Repeatability and Stability Section).

IC Profiler Calibration

The IC profiler detector procedures are detailed in the device's manual; here we only give detail on clinically relevant dependencies and where we deviate from the manual. The IC profiler calibration is separated into 2 independent steps: (1) array calibration and (2) dose calibration. The array calibration corrects for the relative response of each ion chamber, and the dose calibration is essentially a single charge to dose conversion factor which uses a calibration factor applied to the central detector.

The absolute dose calibration was performed by setting up the IC profiler with 10 cm build up (9.1 cm additional buildup) and a SSD of 100 cm. A $10 \times 10 \text{ cm}^2$ field was used to deliver dose to the array and absolute dose calibration was calculated using:

$$D_{\text{deliv}} = \text{MU} \cdot P_{\text{daily}} \cdot \text{PDD}/100 \quad (2)$$

where D_{deliv} is the calculated delivered dose, MU is the number of delivered monitor units, PDD is the percent depth dose of the delivered beam, taken from annual QA measurements or Varian golden beam data, at 10 cm depth, for a $10 \times 10 \text{ cm}^2$ field size, and P_{daily} is the cGy/MU at the depth of maximum dose, as measured using a TG-51 setup in solid water immediately prior to IC profiler dose calibration. The PDD of the additional solid water is verified to be within 1% of that of liquid water by comparison of water tank, and solid-water TG-51 measurements with the same equipment. Dose baselines were then set for each energy by comparing results to TG-51 measurements. Note that all IC profiler dose measurements are automatically corrected using internal temperature and pressure sensors, and the standard P_{TP} correction as specified in TG-51.

Field Size Dependence

The array calibration was found to have some field size dependence, such that the array calibration for the full $32 \times 32 \text{ cm}^2$ array produces imperfect results for measurements at smaller field sizes. For the Varian definitions of flatness and symmetry, which compare pairs of points, this field size dependence causes measured flatness and symmetry increases of 0.5% to 1%, that is, when calibrated to large field sizes flatness and symmetry increases compared with an ideal calibration or water tank data (Figure 2). To obtain improved profiles, we calibrated the array at photon field sizes 2 cm larger than the desired measurements (eg, $27 \times 27 \text{ cm}^2$ for $25 \times 25 \text{ cm}^2$ measurements). The +2 cm was to ensure the detectors in the tails were well-calibrated. Electron fields were calibrated using the same size applicator as the measurements. Compared to using a large generic open field calibration, these procedures significantly improved the agreement of the measured beam profiles with treatment planning system (TPS) and water tank data.

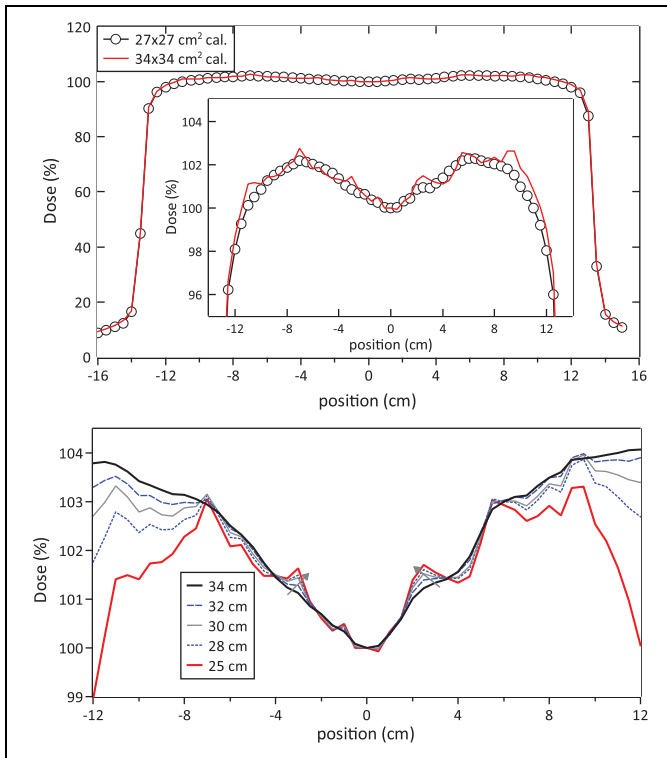


Figure 2. Top, Comparison of a measured 6 MV inline photon profile for a $25 \times 25 \text{ cm}^2$ field with 2 different array calibrations: Red lines are the calibration at $34 \times 34 \text{ cm}^2$, the black lines with circles are the $27 \times 27 \text{ cm}^2$ calibration. Inset, Close-up of the same data, the measurement with the $34 \times 34 \text{ cm}^2$ calibration contains significantly more error. Bottom, Several field sizes all with the $34 \times 34 \text{ cm}^2$ calibration. The arrows indicate the increasing erroneous structure as field size gets further away from the calibration field size. Crossline profiles (not shown) showed the exact same behavior.

Backscatter Dependence

It was confirmed that the in-built backscatter of 2.3 g/cm^2 was not sufficient to make the measurements independent of the detector placement on the treatment couch. The proximity of metal bars inside the couch was found to affect proximal detectors by up to 2%. To investigate this backscatter effect, measurements were made with increasing thicknesses of solidwater backscatter. For each backscatter thickness, central axis dose measurements were made with and without a brass bar beneath the detector. This test showed that for 6 and 15 MV photons, 4 to 5 cm additional solid water backscatter was sufficient to reduce the effects of metal objects beneath the detector to below 0.2% (see Supplemental information for further detail).

PDD and Energy Dependence

Percent depth dose measurements were made to verify the in-built buildup material effective thickness. For photons, the comparison to farmer chamber measurements (shifted to the effective depth) and Varian Golden beam PDD data (also shifted $0.6 \cdot r_{\text{cav}}$) agreed with the 0.9 cm inherent buildup specified by Sun Nuclear. For electrons, however, the effective

thickness of the inherent buildup material was found to be 1.2 cm, that is, PDI results were shifted 0.3 cm compared to Golden beam data and farmer chamber measurements (where golden beam data and farmer depths were both shifted to the effective point of measurement by $-0.5 \cdot r_{\text{cav}}$).

Quad Wedge Calibration

The IC profiler electron quad wedge measurements provide energy determination. For electrons, these were initially calibrated to a single linac's water tank R_{50} data. The quad wedges use a varying thickness of buildup material along the diagonal profiles, this generates a sloped profile from which energy is calculated via energy versus slope calibration curve. The 4 sides of the wedge help eliminate any effects from asymmetry. To minimize errors from different water tank setups, particularly the water surface determination, a single average shift, $<0.5 \text{ mm}$, from the difference between water tank and IC profiler R_{50} measurements, averaged over all electron energies and all linacs, was applied to the IC profiler quad wedge calibration. Using this single corrected IC profiler calibration allows direct comparison between linacs, with the same baseline, while maintaining good overall agreement with water tank measurements.

Mechanical Tests

By measuring the field edges and beam centers with couch and collimator motions, the positioning accuracy, reproducibility, and rotational walkout of the axes can be measured with 0.1 mm precision (see Mechanical Tests section). To test the collimator walkout, measurements of 20 MU were made with the profiler at different collimator angles. The walkout metric, $\text{Walk}_{\text{coll}}$, is calculated from the centering values $C_{x,\theta}$ and $C_{y,\theta}$, which are the distances off-center as calculated by the Profiler software for measurements with collimator angle θ using:

$$\text{Walk}_{\text{coll}} = \max |(C_{x,\theta}^2 + C_{y,\theta}^2)^{1/2} - C_{\text{AV}}| \quad (3)$$

where \max indicates that the maximum difference out of all the θ angles is taken, and $C_{\text{AV}} = \sum_{\theta} (C_{x,\theta}^2 + C_{y,\theta}^2)^{1/2} / n$ is the average deviation between the IC profiler center (crosshair) and the radiation field (n is the number of θ angles used). The collimator zero (radiation vs crosshair distance) value may also be chosen instead of C_{AV} . This test is fast to deliver, the radiation field is tested directly, and it is more quantitative than visual inspection of the light field (see Beam Energy Measurements—Quad Wedge Versus Annual QA Water Tank Data section).

To verify laser alignment, markers with 1 mm spaced lines were added to the side of the IC profiler. On placement of these markers, the vertical alignment was verified using a front pointer and a digital level, a second check was made using the gantry cross-hair at 90° and 270° gantry angles. Deviation of laser lines from these marks is then measured monthly by visual inspection. This negates the need for additional phantoms to perform laser

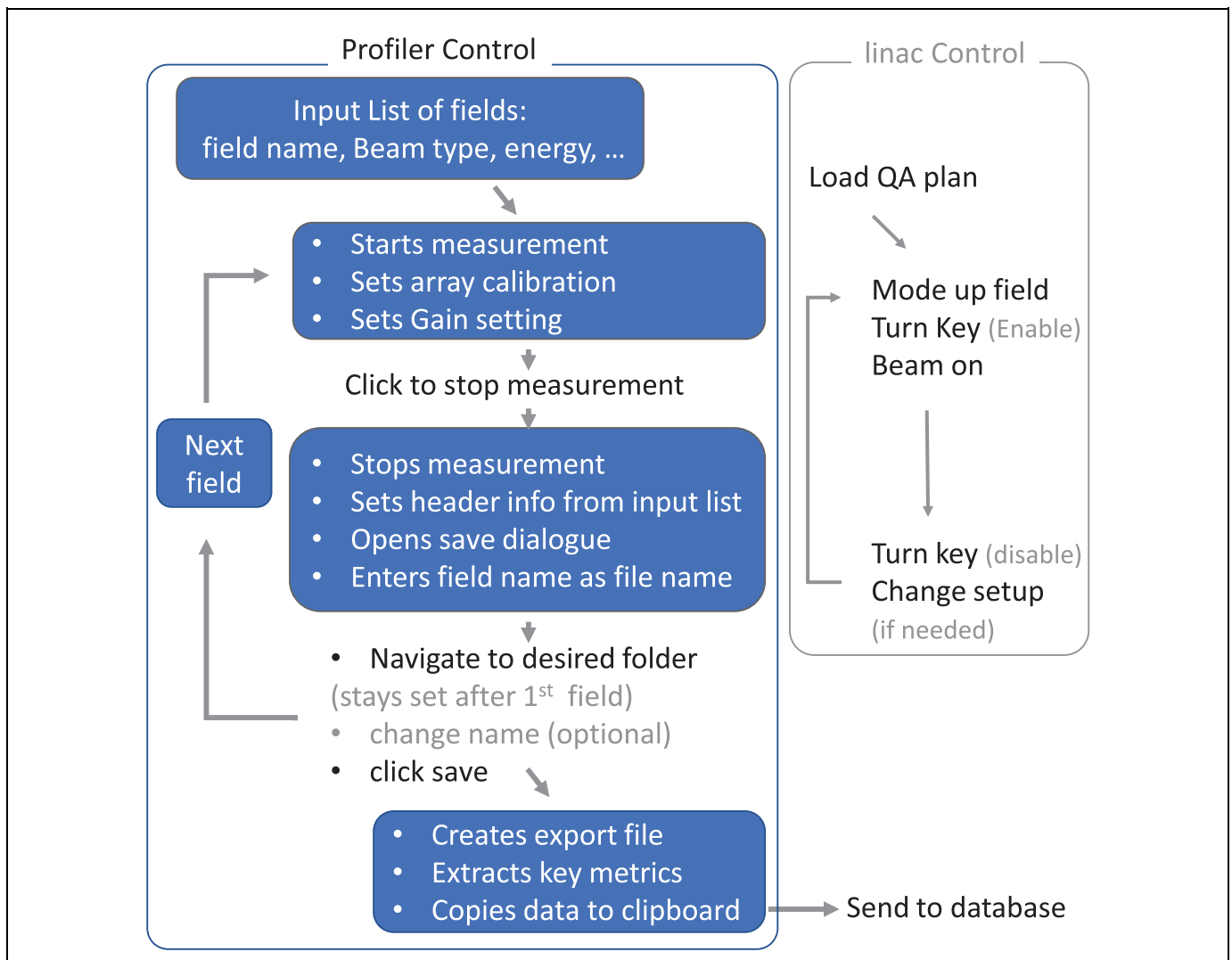


Figure 3. Flow chart of automation script. Blue boxes indicate automated steps. Black text indicates manual user input or confirmation steps.

alignment tests. Some care should be taken when placing the IC profiler on “tennis-racket” couch surfaces since its center of mass is toward the electronics, it can sit unlevel on the couch. To aid alignment, multi-level Shims were designed and 3-dimensional printed (see Supplemental information).

Automation Scripts

Currently, Sun Nuclear’s profiler software (version 3.4.2) does not contain any native method for automation. Yet for IC profiler results to be correct, 10 to 15 settings need to be set for each measurement (gain, array calibration, dose calibration, SSD, field size, etc). This opens many error pathways and requires repetitive user input. To minimize these error pathways, as well as to expedite monthly QA, automation scripts were written in the autohotkey language.⁸ These scripts apply all the desired calibration, field size, energy, alignment, wedge type, CAX correction, SSD, and other settings corresponding to the monthly QA setup and delivery sequence. Error pathways and software

setting dependencies are discussed further in the Discussion section. Figure 3 shows a basic flow chart of the automation program. With this script, most radiation fields require only 1 click to stop the measurement and a second click to save it. Multiple error checking conditions are also implemented in the automation script. This automation allows the effort to be focused on running the linac, checking data as it is measured, and changing the in-room setup as needed. A video of the monthly QA process (at 8× speed) can be viewed online.⁷

Results

Output Repeatability and Stability

To characterize the noise in the central axis output measurements, repeats were made without any setup changes. For measurements at 6X and 6E using our monthly QA conditions (QA Procedure and Delivery section), with 200 MU deliveries, the standard deviations were found to be less than 0.1%. Deliveries

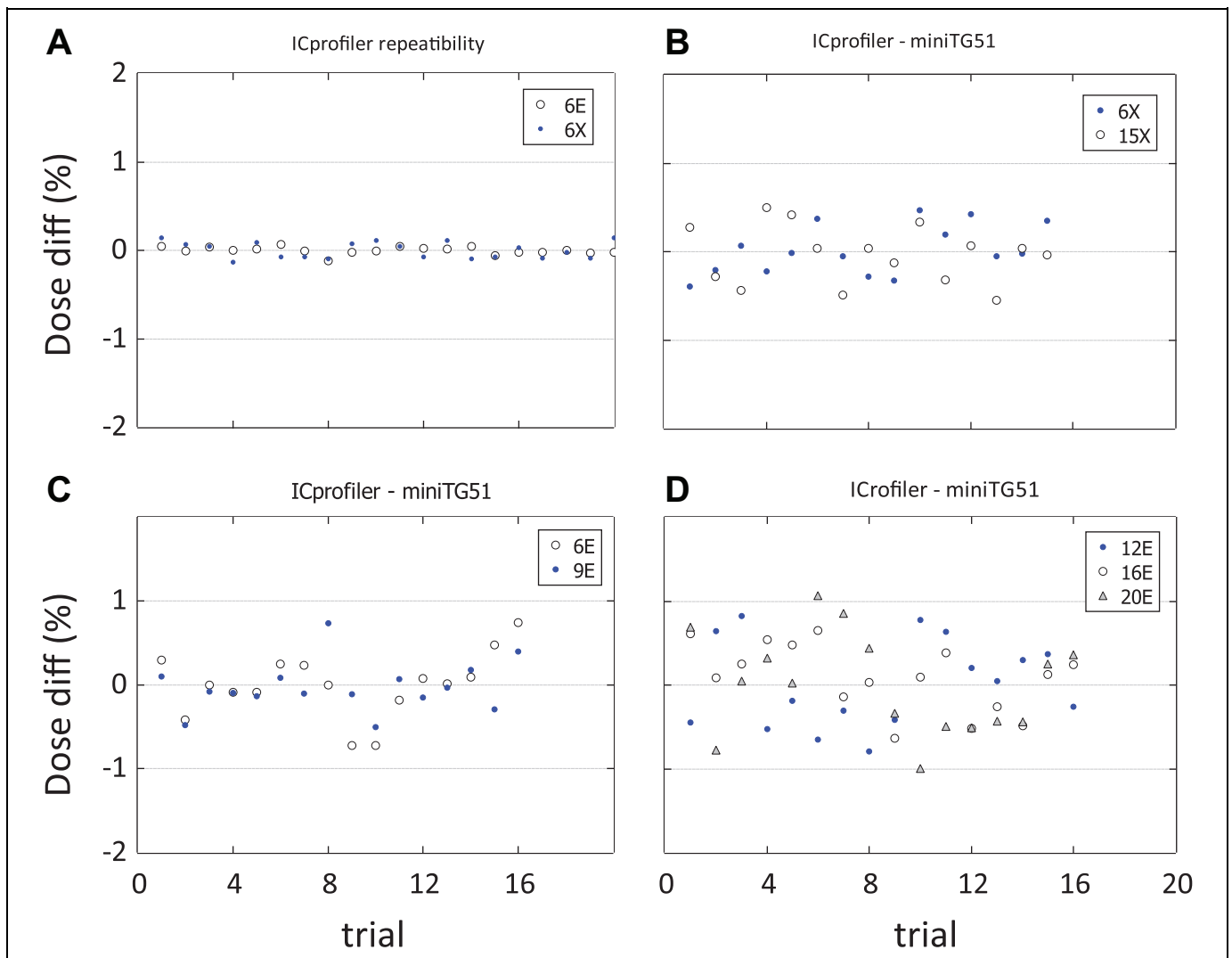


Figure 4. Central axis dose measurements from the IC profiler. A, Difference of repeated central axis measurements from their average value (same day, no setup changes). This has standard deviations of 0.05% (6E) and 0.1% (6X). B–D, Differences of measured IC profiler output constancy and farmer chamber output over 6 months, on 4 different linacs using (see Methods section for setup detail). Each data point is corrected for machine output as measured by a TG51 protocol in solid water. The results were collected for 6 months.

of 99, 100, and 101 MU each produced measured deviations of 1.0% relative (100 MU was chosen for this test because it was performed before the 200 MU protocol was established). For monthly QA, a single-dose calibration in the profiler software was used and baselines were set for machine output relative to a TG51 setup in solid water. The ratio of IC profiler and farmer chamber outputs was taken on 5 machines over 6 months to establish the stability of the IC profiler (Figure 4). These ratios showed significant noise as errors from the ion chamber measurements, multiple setups, and machine differences are all included. The standard deviation of IC profiler–farmer chamber differences was 0.3% for 6X and 15X. For electron energies 6 to 20 MeV, the standard deviations were 0.3% to 0.5%. The 20-MeV electron energy mode showed more significant deviations due to slight energy and dose rate differences between the linacs tested.

Flatness and Symmetry Constancy Results

IC profiler measured beam profiles were compared with those calculated with our treatment planning system (Eclipse, AAA and eMC algorithms). For these TPS calculations, the IC profiler was scanned by computed tomography. Examples for a 6X, 15X, 6E, and 20E, fields are shown in Figure 5 for the monthly QA measurement conditions (eg, for photons SSD: 102 cm, depth: 4.9 cm, field size: $25 \times 25 \text{ cm}^2$). The decision to compare to TPS data and not measured water tank data was made because the TPS comparison is also able to catch any errors that may be present in the TPS. During commissioning of the IC profiler, beam profile measurements were made at the same depth, field size, and SSD as annual water tank measurements with the IC profiler. Agreement within 0.5% was found when the device is also calibrated for those conditions.

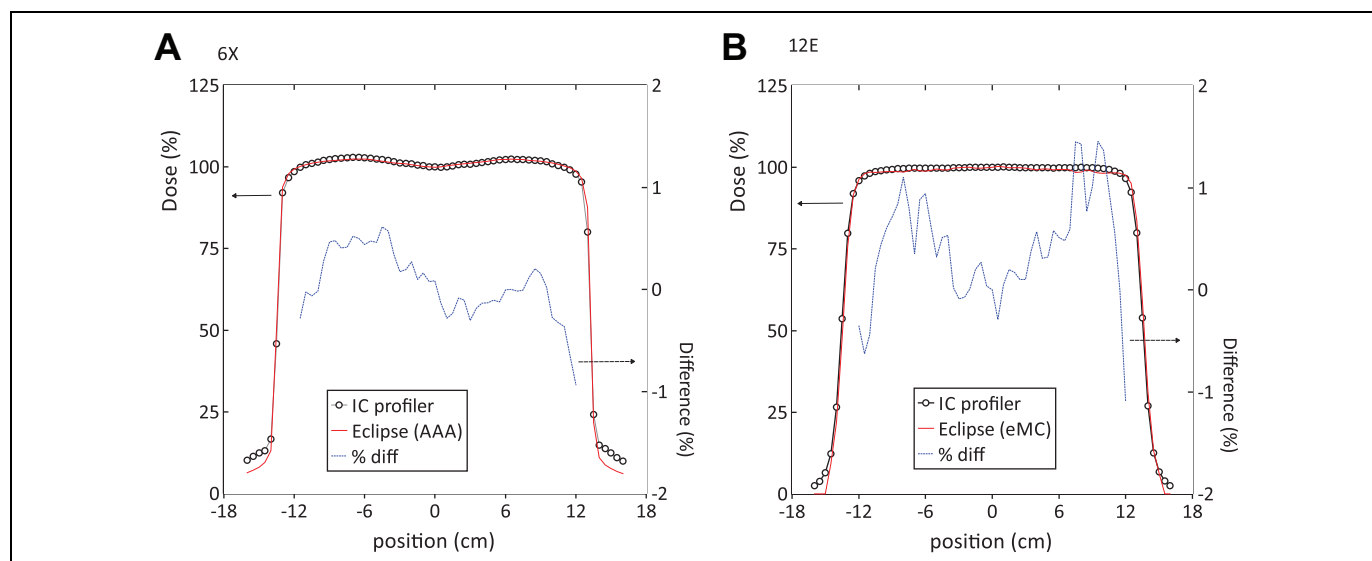


Figure 5. Beam profile measurements compared to the treatment planning system. A) 6MV X-ray field $25 \times 25 \text{ cm}^2$ field at SSD: 102 and depth 5 cm. B) 12 MeV electron field with $25 \times 25 \text{ cm}^2$ applicator cone, SSD 105 cm, depth 1.9 cm. The noise in the difference is dominated by the random uncertainty of the eclipse eMC (electron Monte Carlo) calculation. SSD indicates source to detector distance.

Beam Energy Measurements—Quad Wedge Versus Annual QA Water Tank Data

As explained in Methods section (Quad Wedge Calibration section) to correct for water surface uncertainty in annual QA R_{50} measurements, the calibration was shift-corrected to average out the deviation between linacs. The electron energy quad wedge results are shown in Table 1 for 2 linacs. As an indicator of sensitivity, differences between linacs, in the range of 0.2 to 2 mm in R_{50} , measured in a water tank, were reliably reproduced by the quad wedge energy measurement method (Table 1). The shift correction was not required for photon energy measurements, as a single calibration was sufficient to accurately reproduce water tank results across all our linacs. An alternative way to determine photon energy using the ion chamber array is to analyze the diagonal flatness, this has the advantage that it does not require the quad wedge buildup plate.⁹

Mechanical Tests

The absolute distance of the collimator walkout compared with collimator zero angles is plotted in Figure 6. Previously, visual inspection against 1 mm graph paper provided measurements with $\pm 0.5 \text{ mm}$ uncertainty. Couch walkout may also be performed using essentially the same procedure.

MLC Leaf Gap Constancy

Although the higher resolution of portal imagers (and film) make them better suited than ion chamber arrays for most MLC-based QA tests, one MLC test that was implemented with the ion chamber array was a sliding leaf gap. This takes a subset

Table 1. Water Tank (Blue Phantom, IBA) and IC profiler R_{50} Measurements for 2 Linacs With Differing R_{50} , Demonstrating the $\sim 0.2 \text{ mm}$ Sensitivity of IC Profiler Method.

	Linac A		Linac B	
	Water	IC Profiler	Water	IC Profiler
6E	2.36	2.31	2.29	2.29
9E	3.60	3.65	3.53	3.52
12E	5.04	5.06	4.95	4.93
16E	6.77	6.79	6.59	6.63
20E	8.48	8.50	8.25	8.30

of the Varian dosimetric leaf gap (DLG) fields, delivered on to the IC profiler array to assess the DLG constancy. From this, the constancy of the dose through a small gap in the MLCs is measured monthly with minimal physics work (Figure 7).

This is the central axis dose measured from a 4 mm gap scanned over a 12 cm range on the IC profiler ion chamber array. The measurement contains approximately 3% measurement noise due to the low dose (approximately 7 cGy) seen by the central detectors.

Discussion and Conclusions

The small 0.1% standard deviation for 100 MU central axis measurements makes the IC profiler suitable for absolute output measurement. Using the streamlined monthly QA procedure presented here, which has different depths and field sizes than TG51, the IC profiler versus farmer chamber output differences have up to 0.5% standard deviation for all energies over a period of 6 months. This is significantly less than the TG-142 requirement of 2%, allowing for its use as a decision tool, while beam

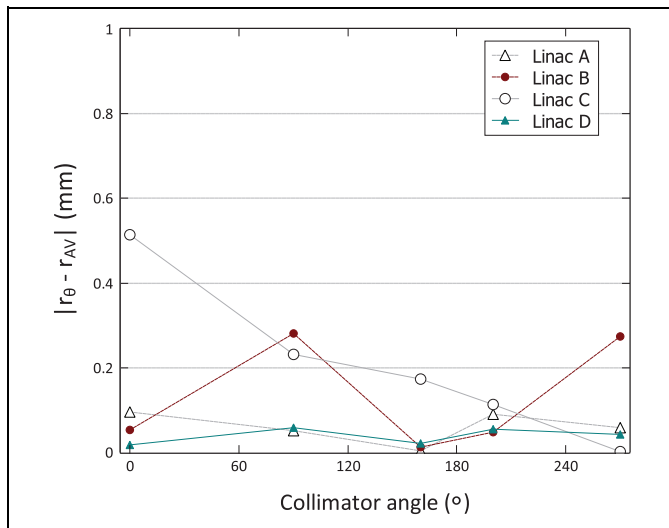


Figure 6. Collimator walkout measured by IC profiler on 4 different linacs.

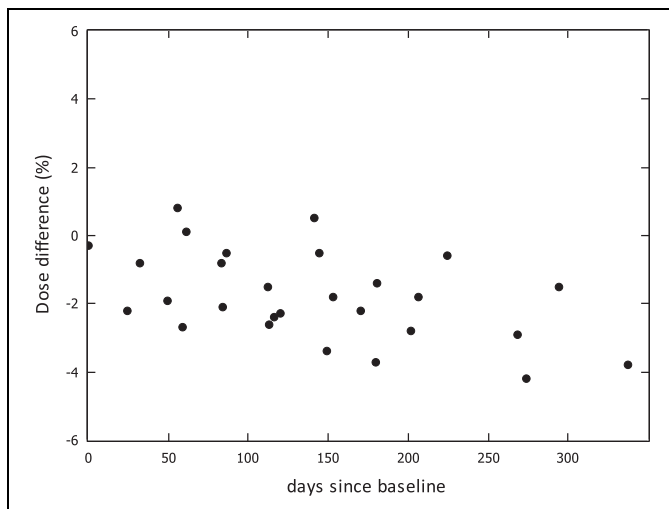


Figure 7. Dose difference to baseline for sliding leaf gap test. Results from 4 machines of the same type over 1 year.

output adjustments continue to be made using a farmer chamber in a water tank or with solid water. Since a single output measurement may have up to 1% deviation to farmer chamber results, we chose to investigate any measured deviations greater than 1% with a farmer type ion chamber, in order to remain within the 2% recommendations of TG-142 and MPPG 8a.

The repeatability of the other metrics (beam center, field size, flatness, and symmetry relative to the jaws) was all found to be $<0.1\%$ or <0.2 mm at the conditions used. Although the detectors are each a few millimeters in size, the chambers are sensitive to small changes in dose value. Hence, the system is sensitive to very small shifts as long as they produce significant dose changes in one or more chambers. We find this to correspond to centering at the 0.1 mm level using 6D couch motions.

For flatness and symmetry, photon flatness values agree closely with TPS calculations (Figure 5). The TPS photon

flatness values were chosen as baselines. For electron flatness baselines, the TPS was not sufficiently accurate, as each linac varied slightly (deviation to TPS 0%-1.5%). Instead, electron flatness baselines were generated by averaging IC profiler measurements over 4 machines of the same type for each energy. This averaged electron flatness baseline was also verified against recent water tank and commissioning data for those machines. Symmetry baselines were chosen to be 1% such that the failing value is 2% absolute symmetry (the Varian specification). In the low dose (edge of field) areas plotted in Figure 5, the IC profiler reports higher dose than the TPS curves. While it does not directly affect monthly QA measurements, this is a known issue with the TPS under-reporting out of field dose; measurements are often 50% higher than TPS predictions outside the field.¹⁰

Field size and beam center measurements used for walkout and jaw position checks are found to be approximately 5 to 10 times more precise than visual inspection of the light field, which were previously used for TG142⁶ “crosshair centering” tests, “Jaw position indicator” tests. Radiation versus crosshair measurements at collimator angle zero show <0.5 mm deviation, which is comparable to our measurements made using the Sun Nuclear FC2 phantom. The IC profiler may also be setup to the light field edges, and then radiation/light field coincidence can be measured. We note, however, that the MPPG 8a guideline is to only measure light field to radiation coincidence after service.³ Automation of these checks is also 2 to 5 times faster than manual measurements, or independent setups, which required several additional trips into the linac vault. For example, this IC profiler setup replaces a dosimetry measurement setup, a laser phantom, a flatness and symmetry setup, and a walkout/jaw position measurement setup. It is still useful to visually check the jaws at one field size to verify the straightness angle of the jaws. While vertical positioning of the profiler is set manually using optical distance indicator or front pointers, the automated field size checks provide a way of catching gross SDD errors greater than 1 cm.

One concern in switching to an array detector with complex “black box” software is that the multiple software options open up many error pathways. To better understand these software error pathways, the software dependencies of all the metrics used was investigated and summarized in Table 2. The check mark indicates that the setting in the left column affects in some way the numerical output of the metric listed in the top row. Where there is no check mark, no changes in the metric were observed when the software setting was varied.

Additional settings that are found to have no significant effect on the metrics used include the following: symmetry (plot setting), on graph point analysis (plot setting), penumbra top/bottom, intensity cutoff, base intensity point, wedge type, and wedge angle. Some of these affect the penumbra and wedge angle metrics which are not used. The following header settings are also found to have no significant effect on data output: Dose (MU), Rate (MU/min), Buildup, Alignment, Gantry Angle, Collimator angle, and tray mount.

Table 2. Metrics Used in Monthly QA Analysis and Their Dependencies (Profiler Version 3.4.2).^a

Software Setting	Metrics Affected					
	CAX Dose	Flat and Symm	PDD ₁₀ and R ₅₀	Field Size	Beam Center	Rad. Versus Light
General settings						
Dose calibration	✓					
Gain setting	✓					
Temp, pressure calibration	✓					
Array calibration		✓	✓	✓	✓	✓
Project to 100 cm		✓	✓	✓	✓	✓
Quad wedge calibrations			✓			
Analysis settings						
Field region (flat/symm)		✓				
Flat/symm analysis type		✓				
CAX correct		✓				✓
Penumbra interpolation				✓	✓	✓
File header settings						
SSD ^b		✓	✓	✓	✓	✓
Beam type			✓			
Beam energy			✓			
Collimator positions						✓

^aAbbreviations: PDD₁₀, percent depth dose at 10 cm depth; QA, quality assurance; R₅₀, depth where dose is 50%; SSD, source to detector distance; symm, symmetry; Temp, temperature.

^bSSD setting only affects the data when project to 100 cm is enabled. Other settings may affect unused metrics such as wedge angle and penumbra. Software version Profiler v3.4.2.

The 0.5% to 1% effect of field size on the array calibration is most likely due to changes in the scattered radiation from structures inside the detector. Similar field size dependencies, for example, are seen on MV image panels, where backscatter contributions from objects behind the detector change with field size.¹¹

Stability of the detector has been assessed over a 6-month period. Longer durations are needed to further assess stability. Quality assurance of the IC profiler device itself is also critical. Currently, in our clinic, absolute dose results are compared to farmer chamber measurements on at least 1 linac each month. This frequency may be reduced as stability is established. As a minimum for QA of the profiler, we would suggest cross-calibration of the IC-profiler dose against an accredited dosimetry calibration laboratory calibrated chamber every 6 months, comparison to water-tank measured profile and PDD results annually, as well as an annual check of the temperature and pressure calibration. Our automation scripts also perform QA checks upon the data acquisition and analysis software settings. Tuning dose output based on the IC profiler is currently not considered adequate. Our array recalibration is performed every 6 months and has been performed twice with minimal changes between recalibrations.

Previous important work in automating linac QA procedures includes using the in-built portal imager electronic portal imaging device (EPID).¹² Such tests are well suited for MLC and mechanical tests (jaw positions, collimator walkouts, etc.) but are less appropriate than ion chamber arrays for dosimetry measurements (output, dose rate constancy, gated dose, etc). While MLC positioning tests may be performed with ion chamber

arrays, we believe the higher resolution of the portal imager makes them better suited for this task. Several simple ion chamber array devices (with 4-10 chambers) are used for daily linac QA.^{13,14} Although useful, such devices typically obtain profile constancy from a few points only. Another approach to streamlining QA is to incorporate multiple measurement devices, such as optically stimulated luminescence detectors (OSLDs) and film into advanced solid water phantoms¹⁵; these devices, however, lack the instant readout convenience of an electronic system. Compared with the radioluminescent QA phantoms of Jenkins *et al.*,⁴ the present work has the advantages of being applicable to older (nondigital) linacs, and the ion chamber array provides more reliable flatness, symmetry, and dose measurements than current radioluminescent film dosimetry systems. Radioluminescent phantoms, radiochromic film, and MV imagers can provide higher accuracy positioning information than the IC profiler array, which makes them well suited to mechanical QA and MLC QA.

In summary, the IC profiler array detector has been investigated for use as a monthly QA device. Twenty of the 26 TG-142 monthly dosimetric and mechanical QA tests have been performed using it over a 6-month period and compared with previous methods. The combination of the ion chamber array and automation scripts has allowed a 10-fold decrease in the time needed for these monthly QA tests. Output is found to have some variability <0.5% compared with farmer chamber measurements. Electron R₅₀ and photon quad wedge energy measurements are found to have higher precision and better agreement with water tank data than previous methods and allow for direct comparison across multiple machines. While

our clinic uses the Sun Nuclear IC profiler, we are not affiliated with them in any way, other manufacturers and devices are perfectly appropriate for the same efficiency improvements. This work is in line with current efforts to simplify the many QA tasks required for accurate and safe radiation therapy delivery, while providing similar if not better precision. Valuable QA time is thus freed up which can be used in other parts of the clinic.



Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

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