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Technical Note

VMAT monthly QA using two techniques: 2D ion chamber array with an isocentric gantry mount and an in vivo dosimetric device attached to gantry

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Abstract

Purpose: Varian RapidArc is a volumetric modulated arc therapy (VMAT) that obtains a conformal dose around the desired structure by employing variable gantry speed, dose rate and dynamic multileaf collimator (DMLC) speed as the gantry rotates about machine isocenter. This study is meant to build upon previous research by Ling et al. by completing the tests with an in vivo dosimetric device attached to the linac gantry and a 2D ionisation chamber array with an isocentric gantry mount.

Materials and methods: Two PTW detectors, seven29 array with gantry mount and DAVID, were attached to the linear accelerator gantry, allowing each device to remain perpendicular to the beam at all gantry angles. Three tests for RapidArc evaluation were performed on these devices including: dose rate and gantry speed variation, DMLC speed and dose rate variation and DMLC position accuracy. The reproducibility of the arc data was also reported.

Results: A picket fence plan varying dose rates (111 to 600 MU/minute) and gantry speeds (5·5 to 4·3°/second) was delivered consisting of seven sections of different combinations. These measurements were compared with static gantry, open field measurements and found to be within 2·39% for the DAVID device and 0·84% for the seven29. A four-section picket fence of varying DMLC speeds (0·46, 0·92, 1·84 and 2·76 cm/second) was similarly evaluated and found to be within 1·99% and 3·66% for the DAVID and seven29, respectively. For DMLC position accuracy, a picket fence arc plan was compared with a static picket fence and found to agree within 0.38% and 2.91%. Reproducibility for these three RapidArc plans was found to be within 0·30% and 2·70% for the DAVID and seven29.

Conclusion: The DAVID and seven29 detectors were able to perform the RapidArc quality assurance tests efficiently and accurately and the results were reproducible. Periodic verification of DMLC movement, dose rate variation and gantry speed variation relating to RapidArc delivery can be completed in a timelier manner using this equipment.

Keywords: DAVID; RapidArc QA; seven29; VMAT

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INTRODUCTION

Intensity modulated radiation therapy (IMRT) was transformed in 1995 with the proposal of intensity modulated arc therapy by Yu et al.[1] and the subsequent developments in optimisation that would lead to clinical implementation.[2–4] In 2008, Otto et al.[5] introduced volumetric modulated arc therapy (VMAT) necessitating just one gantry rotation and reducing treatment times. VMAT is a method of delivering radiation as the gantry rotates around the patient and is aimed at creating the most conformal treatment to the target tissue.[1,5–7] The advent of this technology, however, provides new variables and complications that can arise and must therefore be tested to ensure the best quality treatments for patients. In contrast to previous uses of IMRT, VMAT adds the complexity of synchronising the dose rate and gantry rotation while the multileaf collimator (MLC) is moving. These are important features that must be thoroughly tested for machines that will deliver VMAT patient treatments. Currently, many institutions are familiar with dynamic MLC commissioning and quality assurance for IMRT[8–11] but this must be expanded upon in order to implement VMAT in the clinic.

Ling et al. and Bedford et al. have proposed several procedures to test the VMAT capabilities.[12,13] Both of these authors have demonstrated that VMAT quality assurance (QA) tests can be performed using film measurements. However, film measurements can be time-consuming and may require developing and calibration before analysing. Electronic portal imaging devices (EPIDs) have also been used to perform VMAT QA,[14] but these devices and their accompanying software may not be available in all clinics and camera-based EPIDs may not provide images for quantitative analysis. This study aims to streamline these tests for VMAT using two electronic devices: (a) PTW seven29 2D-ARRAY and (b) PTW DAVID (PTW, Freiburg, Germany) in vivo dosimetric device. By using either of these devices, arc therapy can be thoroughly tested while minimising the time it takes to do so as compared with previous film studies. This work aims to provide information about using these devices for the purpose of RapidArc QA.

MATERIALS AND METHODS

Equipment

PTW DAVID

The DAVID system (PTW) is a transmission-type detector array positioned in the accessory holder of the linac treatment head as seen in Figure 1.[11] At this 'upstream' position with regard to the patient's surface, it provides a set of survey values derived from the MLC-generated photon fluence, thereby serving for the permanent in vivo verification of the IMRT application. The system consists of a flat, vented multi-wire transmission-type ionisation chamber, constructed from transparent materials in order to minimise the interference with the light field of the treatment head. No metals, except the thin detection wires, are used for the in-field part of the device. The DAVID detector has wireless connection with its software.

The multi-wire chamber is placed in the upper slot of the accessory holder, close to the cross-hair reticule. Each of the parallel wires is positioned exactly in the projection of the midline of a MLC leaf pair, so that the signal from each wire is proportional to the line integral of the ionisation density over its length and thereby to the opening width of the associated leaf pair. The sum of all wire signals is a measure of the total radiant energy administered to the patient.

PTW seven29

The PTW seven29 2D-ARRAY is composed of 729 vented parallel plate ion chambers arranged

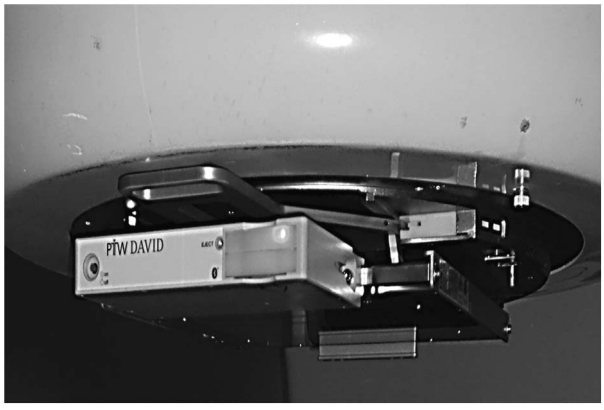

Figure 1. DAVID mounted on the gantry head.

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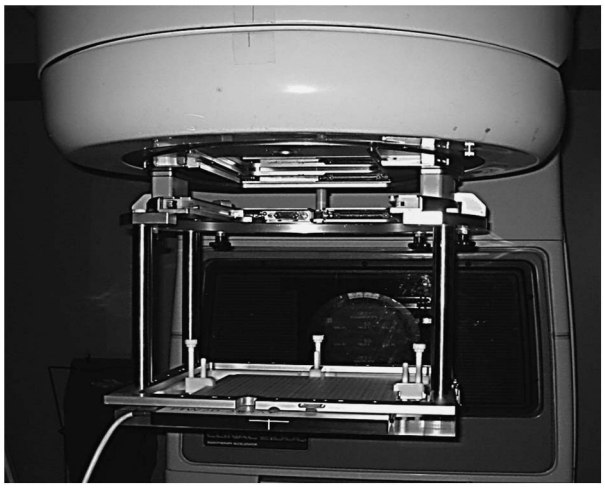

Figure 2. Seven29 array mounted on the gantry with isocentric mounting device.

in a $27 \times 27\,cm^2$ array detector. The detector array was used in conjunction with an isocentric gantry mount, in order to remove directional dependence, on the linear accelerator as shown in Figure 2. The isocentric mount is attached to the gantry head and is designed to keep the seven29 device at the machine isocenter, perpendicular to the beam at all angles.

The PTW seven29 is controlled by the VeriSoft software. It is through VeriSoft that measurements are recorded and analyzed. VeriSoft allows the comparison of two matrices, one being the reference and one being the target. The output can be the dose difference, distance to agreement, gamma index analysis, profile comparison, isodose comparison, etc.

RapidArc QA tests

The first part of this study was to perform three tests for RapidArc evaluation on each device including: dose rate and gantry speed variation, dynamic multileaf collimator (DMLC) speed and dose rate variation and DMLC position accuracy. These tests were performed as described in the 2008 paper by Ling et al.[13] using the RapidArc QA plans that are provided by Varian:

(1) The first test was to evaluate the machine performance as it rotates in an arc while varying the dose rate and gantry speed. A RapidArc pattern was delivered consisting of seven strips, which deliver equal dose while the dose rate varied from 111 to 600 MU/minute and the gantry speeds of 5·5 to 4·3°/second.[13] This RapidArc delivery is compared with an open field one with gantry static at the upright position and the field size is set to the same jaw settings as the RapidArc field size.

(2) The second test examines the accuracy of the delivery of RapidArc while varying DMLC speed and the dose rate. A similar field as in the previous test is delivered, measured and compared against an open field delivery of the same jaw settings. This RapidArc field has four stripes that deliver the same dose at DMLC speeds of 0·46, 0·92, 1·84 and 2·76 cm/second.[13]

(3) The final test was to validate the DMLC position accuracy during arc beam delivery. During this test, a RapidArc picket fence plan is delivered. The results are compared against a picket fence measurement with a stationary gantry.

Metrics for evaluation

In order to analyze the data from the three RapidArc QA tests, percent differences were calculated between the RapidArc measurement and the corresponding static gantry measurements. Equation (1) describes how the percent differences were calculated:

$$\%\mathrm{Diff} = \left(\frac{\mathrm{Static}_{\mathrm{measurement}} - \mathrm{Arc}_{\mathrm{measurement}}}{\mathrm{Static}_{\mathrm{measurment}}}\right) 100\% \quad (1)$$

Reproducibility

The second part of this study was to determine the reproducibility of the RapidArc picket fence deliveries using the seven29 array and DAVID. Each of the three picket fence arc plans was measured five times on different days for comparison. The first delivery was taken to be the reference measurement and each of the four subsequent measurements was compared with the reference for evaluation. Percent differences between the reference measurement and each of the four reproducibility measurements were calculated for comparison.

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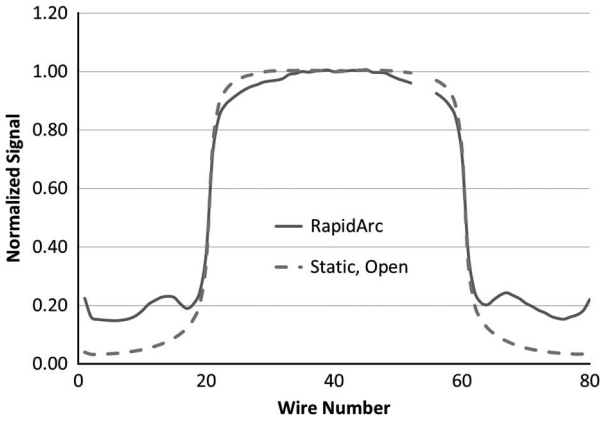

Figure 3. Dose rate and gantry speed variation signals compared with static, open field signals.
Note: Wires 53–55 excluded due to equipment damage in this area.

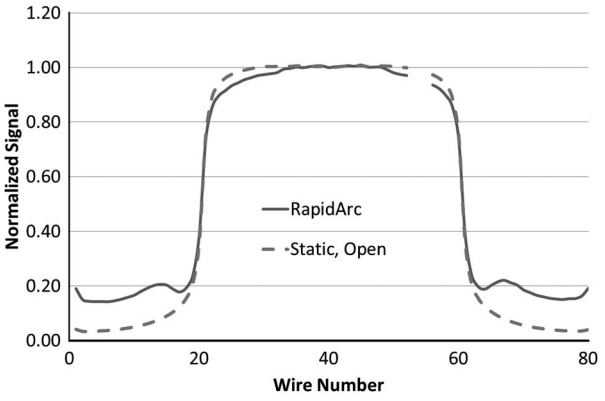

Figure 4. DMLC speed and dose rate variation signals compared with static, open field signals.
Abbreviation: DMLC, dynamic multileaf collimator.

RESULTS

DAVID

For each of the tests (1)–(3), the electric signal from each of the 80 DAVID wires was obtained and these values were compared with the signal values from the corresponding, static gantry measurements. Each of the measurements was normalised to the maximum in order to eliminate any output dependencies between measurements:

(1) Figure 3 shows an example plot of the electric signal for the gantry speed and dose rate variation picket fence measurement and the open field measurement. The profiles have been normalised to their respective maximum values to account for any differences in output of the radiation beam. The profile shows the normalised electrical signal that was measured for each wire of the DAVID. For all signals in the open area of the beam, the percent difference was calculated wire by wire for the RapidArc plan and the open field, static gantry measurement. The average percent difference for the five arc deliveries was found to be: 2·39%, 2·23%, 2·34%, 2·30% and 2·32%, respectively. The percent difference in reproducibility from the reference delivery to each of the four subsequent measurements was within 0·19%. As also observed by Ling et al. was the discrepancies in the comparison between the arc and static fields outside the penumbra and is believed to be due to the increased scatter that occurs during the arc delivery of the seven strips of varying gantry speed and dose rate.[13]

(2) Figure 4 shows an example of a DMLC speed and dose rate variation plan and the corresponding open field, static gantry measurement similar to that from Figure 3. Once again both profiles were normalised to their respective maximum signal values and that value is what is plotted in the figure for comparison. Percent differences between the rotating and static measurements were once again calculated for each of the wire signals in the open area of the beam, excluding the areas outside the penumbra of each beam. The average percent difference for the five RapidArc deliveries was measured as: 1·99%, 1·86%, 1·99%, 1·87% and 1·93%, respectively. The reproducibility of the arc deliveries was found to be within 0·16%.

(3) Figure 5 is an example of a normalised RapidArc and static gantry picket fence measurement plot to validate DMLC positioning as previously described. The percent differences between the five RapidArc deliveries and the static gantry delivery were found to be: 0·34%, 0·39%, 0·31%, 0·37% and 0·37%, respectively. The reproducibility was calculated to be within 0·30%.

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Seven29

The central, horizontal profile from each measurement was obtained from the data files retrieved from the VeriSoft (PTW, Freiburg, Germany) software as seen in the screenshot in Figure 6.

Because the seven29 has a $27 \times 27\,cm^2$ field size, the 27 central ionisation chamber dose values were used for comparison. Each profile was normalised in order to eliminate any output dependencies between measurements:

(1) Figure 7 shows an example of a gantry speed and dose rate variation plan measurement as well as the open field measurement.

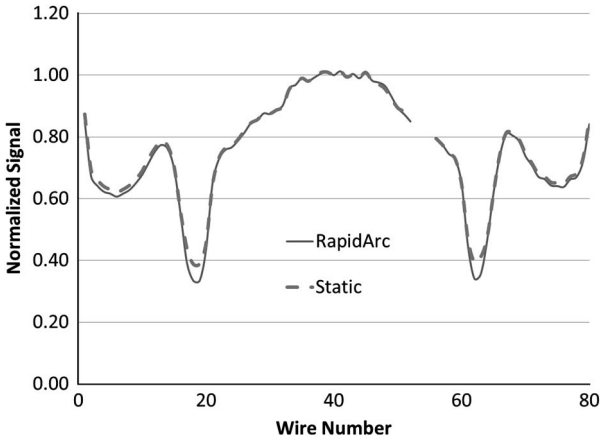

Figure 5. DMLC position accuracy signals compared with static signals.
Abbreviation: DMLC, dynamic multileaf collimator.

The arc delivery has a wavy appearance due to the picket fence pattern that is tested and the resolution of the ionisation chambers of the seven29 device. The profiles have been normalised to the maximum measured ion chamber value to account for differences in beam output. Percent differences, between static and rotating gantry measurements, were calculated for seven points, corresponding to each picket fence location, which is indicated as peaks in the arc profile, with the ion chamber values located in the open field of the beam. The average percent differences that were calculated for each of the 5 RapidArc deliveries for these seven points were: 0·72%, 0·83%, 0·82%, 0·79% and 0·84%, respectively. The percent differences in reproducibility were found to be within 0·57%.

(2) Figure 8 shows an example of a dose rate and DMLC speed variation plan measurement as well as the open field measurement. The profiles were normalised to the average ion chamber reading in order to compare the two deliveries. Percent differences were calculated point by point for the chamber values located in the open field of the beam. An average percent difference was then calculated for each of the 5 RapidArc deliveries compared with the open field measurement and found to be: 2·93%, 3·01%, 3·32%, 2·45% and 3·66%, respectively. Percent differences

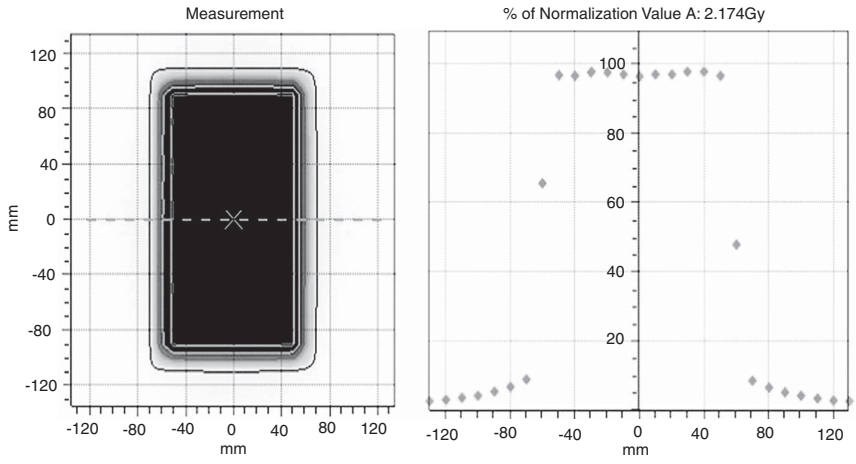

Figure 6. Example VeriSoft screenshots of a horizontal profile of an open field delivered using the PTW seven29.

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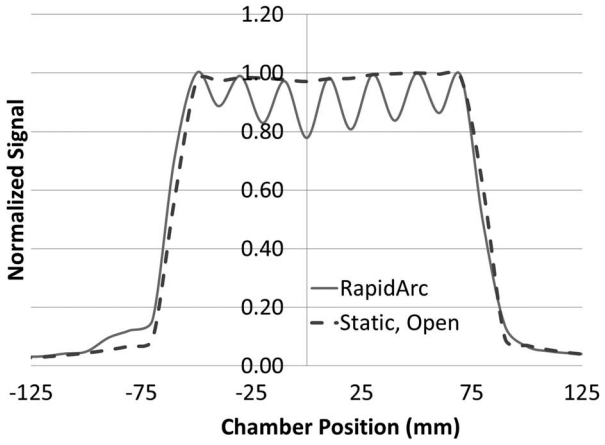

Figure 7. Dose rate and gantry speed variation profile compared with static, open field profile.

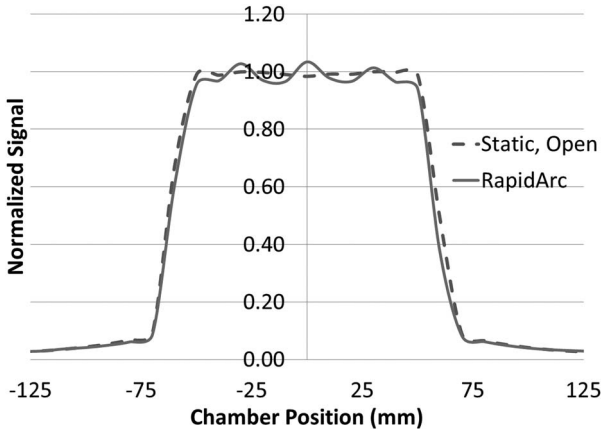

Figure 8. DMLC speed and dose rate variation profile compared with static, open field profile.
Abbreviation: DMLC, dynamic multileaf collimator.

were also calculated for reproducibility as described previously and the average for each session was found to be <1·78%.

(3) Figure 9 shows an example of a DMLC accuracy plan measurement as well as the static measurement that was taken. Percent differences were calculated on the basis of the full width at half maximum values for the arc and static picket fence deliveries. The average percent difference was then calculated for each of the 5 RapidArc deliveries compared with the open field measurement and found to be: 1·80%, 1·77%, 1·85%, 1·82% and 1·76%, respectively. Reproducibility averages were found to be within 2·7%.

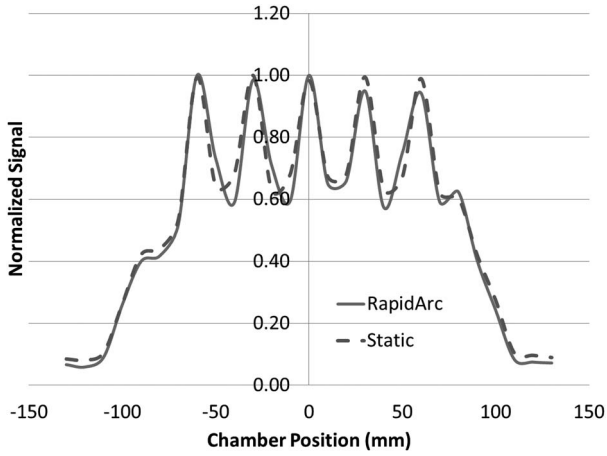

Figure 9. DMLC position accuracy profile compared with static gantry profile.
Abbreviation: DMLC, dynamic multileaf collimator.

DISCUSSION

Figures 3–5 depict an area of the DAVID array in which the signal is not displayed. During routine use of the device, the detector was damaged and these wires (53–55) no longer have an accurate response. Because of these inaccuracies, the data for these wires have been omitted in the figures as well as in the calculations and analysis for the DAVID testing.

As compared with film and EPID-based VMAT QA, the seven29 and DAVID also was able to perform the three tests for: dose rate and gantry speed variation, dose rate and DMLC speed variation and DMLC position accuracy. Previously published results for these tests using film[13] have noted an average of 0·7% deviation for dose rate and gantry speed tests, 0·4% deviation for DMLC leaf speed tests and deviations <2·5 mm for DMLC position accuracy tests. Similarly, the results for EPID[14] show deviations <1·75% for dose rate and gantry speed, mean deviations ranging from −0·73% to 0·41% for DMLC speed variation, and no visible deviations in the picket fence with regard to DMLC position accuracy. Comparing the results obtained in this study, the seven29 and DAVID had slightly higher mean deviations for the VMAT QA tests, however, given the limitations on resolution of these devices as compared with those used in the previous

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research discussed, results are still within acceptable limits.

Time is also an important factor to consider when deciding on a method for VMAT QA. Film measurements can be time-consuming and therefore clinically inefficient. Using the devices discussed in this study, these three RapidArc tests can be performed in a timely and efficient manner as compared with using film. A total of six fields, three arcs and their corresponding open, stationary fields, are delivered without the interruption of going into the treatment room to remove the exposed film and place a new one. During our study, the measurements could be completed in 10 minutes or less and the analysis could be done immediately after the measurements were taken and completed within 30 minutes. The time would be comparable for EPID-based solutions for these tests, however, as was mentioned in the introduction, these devices as well as their software are not always available, and camera-based EPIDs may not have the capability of performing quantitative analysis.

CONCLUSION

The DAVID detector was able to measure the RapidArc QA plans accurately and was found to produce reproducible data. Testing the main three elements of variation for RapidArc delivery is a necessary component of VMAT evaluation and this device allows for a time-efficient method of doing so.

The seven29 detector was able to perform the RapidArc QA tests efficiently and accurately and the results were reproducible. Periodic verification of DMLC movement, dose rate variation and gantry speed variation relating to RapidArc delivery can be completed in a timelier manner using this equipment.

Acknowledgements

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