The quality assurance of volumetric modulated arc therapy (VMAT) plans for early stage prostate cancer: a technical note

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Abstract
As radiation therapy transitions from intensity modulated radiation therapy (IMRT) to volumetric modulated arc therapy (VMAT) it is important to consider the quality assurance (QA) of VMAT plans in light of what has previously been learned and developed in IMRT QA. This technical note assesses if IMRT based plan QA software, which has reduced the need in IMRT for phantom dose measurements on the linear accelerator, can be incorporated into VMAT QA processes. Twenty prostate cases were retrospectively planned using VMAT with one arc to deliver a prescription of 74 Gy in 37 fractions. A plan QA was performed using both IMSure (version 3.3), a software-based IMRT QA program, and ArcCHECK (version 6.2.3.5713), a phantom-based VMAT QA tool. Outcomes assessed included the time needed to perform the QA of both the IMSure and ArcCHECK QA methods, and agreement between planned dose and QA measured dose. On average per case, the ArcCHECK technique needed 31.5 min to perform the VMAT plan QA, while IMSure required 3.5 min to perform the same QA. All 20 cases passed dosimetric QA using ArcCHECK. However, using IMSure, three cases failed dosimetric QA using the departments existing IMRT QA criteria. This research has demonstrated that the IMRT QA software IMSure may be incorporated into the QA of VMAT plans, however the criteria to assess the dosimetry of the VMAT plans may need to be different to that for IMRT cases. The implication of this research for radiation therapists is to be critically aware of the differences between the plan QA requirements and methods for IMRT and those required for VMAT.

Introduction
In terms of dosimetry, intensity modulated radiation therapy (IMRT) treatments utilising a linear accelerator (linac) with dynamic multi-leaf collimators (MLCs) are extremely complex and require patient-specific quality assurance (QA) be performed to ensure the dose predicted to be delivered by the treatment planning system (TPS) is the actual dose being delivered to the patient at the treatment unit. Typically, IMRT patient-specific QA is performed on a linac using a phantom and a dose-measuring device to measure the absolute dose in the phantom as well as the relative planar dose distribution. This method of plan IMRT QA requires time on a linac to perform the physical measurement of dose delivered and increases the after hours workload for medical physicists. 1 It can also be difficult to adequately replicate patient geometries and heterogeneities using phantom-based QA methods. 2

Treatment plan QA software is now available which can act as an independent plan evaluation and dosimetry check removing the need to perform a dose measurement

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on a linac and greatly reducing the time needed to perform the QA for IMRT plans. IMSure (Standard Imaging, Middleton, WI) is one example of treatment plan QA software available commercially. Patient-specific fluence maps generated from the TPS can be imported into IMSure, which uses a patented “3-Source Model” algorithm developed at Stanford University that considers dose from primary and scattered photon sources, to produce dose calculations and monitor units (MUs) calculations allowing for patient-specific QA plan comparison to be completed.3–5

Previous research at the Fraser Valley Centre (FVC) of the British Columbia Cancer Agency (BCCA) demonstrated that for a five-field IMRT treatment of prostate cancer, the IMSure software point dose calculations showed agreement with the Eclipse (Varian Medical Systems, Palo Alto, CA) TPS to within 1%.6 This research established that the IMSure software can be a reliable tool for prostate IMRT QA. As such, IMSure is routinely used to QA the plans for five-field IMRT treatments of prostate cancers at FVC.

FVC has recently upgraded its linacs to be capable of delivering volumetric modulated arc therapy (VMAT) treatment using Varian Medical Systems, RapidArc. VMAT treatments further increase treatment and dosimetric complexity by utilising dynamic MLCs in combination with variable dose rates and variable gantry speeds to generate IMRT quality dose distributions in a single optimised arc around the patient.7 Research by the authors has demonstrated that VMAT is a realistic option for early stage prostate cases at FVC, however, prior to implementation the centre needs to establish a system of QA for its VMAT plans.8–10 The increased complexity of VMAT planning and treatment dictates that patient-specific QA is required to ensure accurate dose delivery.

FVC purchased ArcCHECK (Sun Nuclear Corp., Melbourne, FL) specifically for the purpose of performing patient-specific plan QA for VMAT dose distributions. ArcCHECK uses a cylindrical diode array that ensures an orthogonal beam-to-diode configuration for all angles (Fig. 1).11 For a coplanar treatment delivery, the ArcCHECK system accumulates and records the dose in two areas of the dose distribution, one for the diodes close to the beam source and the other for the diodes measuring the beam exiting the phantom. Therefore, the ArcCHECK measured peripheral dose is the sum of the entrance and exits doses which is then compared to the dose calculated by the TPS.12

ArcCHECK QA of VMAT plans, much like the earlier phantom based methods of IMRT QA, requires physical measurements be performed on a linac. This can be time consuming for the physicist performing the measurement, and if not performed after clinical hours may utilise time on a linac that could otherwise be used for patient treatment. If a treatment plan QA software, such as IMSure, could be used instead, less time and departmental resource would be needed to QA a VMAT plan.

The study presented here assesses if the plan IMRT QA software IMSure, which has largely replaced phantom-based QA at FVC, can be used for the QA of VMAT plans for the treatment of early stage prostate cancer. IMSure will be benchmarked against ArcCHECK which is the current accepted standard of performing QA for VMAT plans at FVC. The QA tools have been compared in terms of the time required to perform patient-specific VMAT QA, and plan quality and/or dose delivered.

**Methods**

Approval for this study was provided by the University of Newcastle, Australia, Human Research Ethics Committee (approval number: H-2011-0073) and the British Columbia Cancer Agency, Canada, Research Ethics Board (approval number: H11-00108).

The study used de-identified CT data sets from 20 patients that had been previously treated at FVC with IMRT to the prostate only. The original CT data sets were obtained on a Phillips Brilliance Big Bore scanner using 2 mm slices with the patient in a supine position. All planning was done using v10.0 (PRO10.0.28) of Varian Medical Systems Eclipse planning software (which includes RapidArc). A VMAT plan was retrospectively produced for each data set that delivered a prescribed dose of 7400 cGy in 37 fractions to a planning target volume (PTV) that include the prostate plus a margin of
10 mm in all directions (6 mm posteriorly if fiducial markers were implanted). The VMAT plan utilised a single counterclockwise arc from 179° to 181°. The collimator was set to 45° in all cases. VMAT calculations utilised the anisotropic analytical algorithm (AAA) with heterogeneity correction on and a 2.5 mm calculation grid. Of note, cases 1–10 were planned for treatment on a Varian TrueBeam linac and cases 11–20 were planned for treatment on a Varian Trilogy linac. Both the Trilogy and TrueBeam units are equipped with a Millennium MLC incorporating 120 leaves.

**ArcCHECK QA**

ArcCHECK is the current standard of VMAT planning QA at FVC. Plan QA using ArcCHECK was performed in this study to set a standard for IMSure QA to be compared against. The ArcCHECK measurement was performed by running the VMAT treatment on a linac with the ArcCHECK QA tool in place. The measured data were then transferred to the SNC Patient software (version 6.2.3.5713, Sun Nuclear Corp.) which analyses the measured data against the treatment plan imported from the TPS. The differences between the two dose distributions are evaluated using the gamma method that takes into account two parameters for every point analysed in the distribution; a dose value difference and a distance to agreement. The passing gamma criteria of 3%/3 mm of 90% was used.

In this study, plan QA using ArcCHECK was performed for all 20 cases on the Trilogy linac and all 20 cases on the TrueBeam unit. Measured results were recorded as pass or fail. The time needed to perform the QA for 20 cases was also measured and recorded (10 cases on the Trilogy linac and 10 cases on the TrueBeam unit). The time measured included; preparation time in the QA plan delivery time and the postdelivery analysis. ArcCHECK QA was performed for all 20 cases and recorded as pass or fail. The time needed to perform the QA for each of the 20 cases was measured and recorded. The time measured included the time needed to run a QA in the IMSure program as well as the time required to prepare the treatment plan for QA in the TPS (including; the time to open each case in Eclipse, copy the treatment plan and export the copied plan into IMSure).

**IMSure versus ArcCHECK**

The IMSure plan QA software and ArcCHECK QA tool were compared using ArcCHECK as the accepted standard of VMAT plan QA. The efficacy of the techniques was examined by comparing the QA pass/fail results. The time needed to perform IMSure and ArcCHECK QA was measured as described above and the average time required compared. Statistical analysis was not performed on the average time difference.

For IMSure QA, a plan is considered to pass QA if the number of MUs calculated in the TPS and the QA software differed by less than 3%. Using the ArcCHECK system, a plan was considered to pass QA if the gamma analysis of 3%/3 mm is greater than 90%.

**Results**

The average time per case needed to perform the IMSure and ArcCHECK QA is presented in Table 1. On average, the VMAT QA took 3.5 min using the IMSure plan QA software, and 31.5 min using the ArcCHECK system. A significant portion of the time needed to perform ArcCHECK QA was the time to set up the QA phantom which took 15 min per case.

The dosimetric QA results using ArcCHECK and IMSure are presented in Table 2. All 20 cases passed plan QA using ArcCHECK irrespective of whether the QA was planned and/or treated on a Varian Trilogy or TrueBeam linac. Of the 20 cases, 3 failed QA (cases 4, 16–17) using IMSure, that is, the difference in the number of MUs as determined by IMSure was greater than 3% of the TPS calculated MUs for these three cases. Two of the failed distributions (cases 16 and 17) were planned for the Trilogy unit, while the other (case 4) was planned for the TrueBeam linac.

**Discussion**

The average time needed to perform a plan QA using the IMSure software was substantially reduced compared to the ArcCHECK system. In this sense, IMSure holds an advantage over ArcCHECK for efficiency. This result was expected as it is appreciated that performing a physical
### Table 1. Measured time to perform QA using ArcCHECK and IMSure (in minutes [min] and seconds [sec]).

| Case number | ArcCHECK | IMSure | IMSure Average: 3 min 27 sec (3.45 min) |
|-------------|----------|--------|----------------------------------------|
|             | Preparation in Eclipse | Set up of phantom | Planed dose delivery | Postdelivery analysis | Total | Preparation in Eclipse | To run QA | Total |
| 1           | 9 min 20 sec | 15 min | 2 min 47 sec | 3 min 47 sec | 30 min 54 sec | 2 min 22 sec | 1 min 49 sec | 4 min 11 sec |
| 2           | 7 min 55 sec | 15 min | 6 min 05 sec | 2 min 53 sec | 33 min 39 sec | 2 min 14 sec | 1 min 52 sec | 4 min 06 sec |
| 3           | 9 min 41 sec | 15 min | 6 min 05 sec | 2 min 43 sec | 30 min 39 sec | 2 min 11 sec | 50 sec | 3 min 01 sec |
| 4           | 7 min 51 sec | 15 min | 5 min 05 sec | 2 min 43 sec | 30 min 39 sec | 2 min 08 sec | 1 min 20 sec | 3 min 28 sec |
| 5           | 8 min 45 sec | 15 min | 5 min 26 sec | 3 min 09 sec | 32 min 20 sec | 2 min 14 sec | 1 min 25 sec | 3 min 39 sec |
| 6           | 8 min 27 sec | 15 min | 5 min 43 sec | 2 min 49 sec | 31 min 59 sec | 2 min 20 sec | 1 min 28 sec | 3 min 48 sec |
| 7           | 8 min 28 sec | 15 min | 6 min 18 sec | 3 min 05 sec | 32 min 51 sec | 2 min 08 sec | 1 min 17 sec | 3 min 25 sec |
| 8           | 8 min 33 sec | 15 min | 4 min 50 sec | 2 min 51 sec | 31 min 14 sec | 2 min 06 sec | 1 min 11 sec | 3 min 17 sec |
| 9           | 8 min 43 sec | 15 min | 4 min 47 sec | 2 min 43 sec | 31 min 13 sec | 2 min 07 sec | 1 min 09 sec | 3 min 16 sec |
| 10          | 8 min 56 sec | 15 min | 5 min 29 sec | 3 min 07 sec | 32 min 32 sec | 2 min 18 sec | 1 min 03 sec | 3 min 21 sec |
| 11          | 6 min 41 sec | 15 min | 5 min 10 sec | 2 min 49 sec | 29 min 40 sec | 2 min 10 sec | 1 min 21 sec | 3 min 31 sec |
| 12          | 7 min 25 sec | 15 min | 5 min 34 sec | 2 min 45 sec | 30 min 44 sec | 2 min 10 sec | 50 sec | 3 min 00 sec |
| 13          | 8 min 22 sec | 15 min | 4 min 50 sec | 3 min 12 sec | 31 min 24 sec | 1 min 58 sec | 1 min 00 sec | 2 min 58 sec |
| 14          | 9 min 20 sec | 15 min | 5 min 50 sec | 3 min 39 sec | 33 min 49 sec | 2 min 06 sec | 1 min 35 sec | 3 min 41 sec |
| 15          | 8 min 27 sec | 15 min | 3 min 58 sec | 3 min 06 sec | 30 min 31 sec | 2 min 04 sec | 53 sec | 2 min 57 sec |
| 16          | 7 min 51 sec | 15 min | 4 min 50 sec | 3 min 02 sec | 30 min 43 sec | 2 min 40 sec | 50 sec | 3 min 30 sec |
| 17          | 8 min 27 sec | 15 min | 5 min 45 sec | 3 min 29 sec | 32 min 41 sec | 2 min 46 sec | 1 min 24 sec | 4 min 10 sec |
| 18          | 8 min 43 sec | 15 min | 4 min 42 sec | 3 min 17 sec | 31 min 42 sec | 2 min 21 sec | 45 sec | 3 min 06 sec |
| 19          | 6 min 41 sec | 15 min | 5 min 44 sec | 3 min 05 sec | 30 min 30 sec | 2 min 15 sec | 1 min 02 sec | 3 min 17 sec |
| 20          | 7 min 25 sec | 15 min | 5 min 38 sec | 2 min 53 sec | 30 min 56 sec | 2 min 31 sec | 50 sec | 3 min 21 sec |

### Table 2. The pass/fail results for the ArcCHECK and IMSure methods for the quality assurance (QA) of volumetric modulated arc therapy (VMAT) treatments of early stage prostate cancer.

| Case number | ArcCHECK | IMSure | IMSure Average: 3 min 27 sec (3.45 min) |
|-------------|----------|--------|----------------------------------------|
|             | Gamma value (3%/3 mm) | Gamma value (3%/3 mm) | TPS MUs | IMSure MUs | Percentage difference | Pass/fail |
| 1           | 99.7 Pass | 99.3 Pass | 466.7 | 453.2 | 2.9 Pass |
| 2           | 98.8 Pass | 98.5 Pass | 457.6 | 451.5 | 1.3 Pass |
| 3           | 97.8 Pass | 99.5 Pass | 461.4 | 465.1 | -0.8 Pass |
| 4           | 97.9 Pass | 98.7 Pass | 456.4 | 451.6 | 1.1 Pass |
| 5           | 98.4 Pass | 98.8 Pass | 441.9 | 422.5 | 4.4 Fail |
| 6           | 98.4 Pass | 99.3 Pass | 498.3 | 492 | 1.3 Pass |
| 7           | 99.3 Pass | 98.9 Pass | 440.4 | 440.2 | 0 Pass |
| 8           | 98.8 Pass | 97.7 Pass | 414.3 | 413 | 0.3 Pass |
| 9           | 99.0 Pass | 98.2 Pass | 442.8 | 436.5 | 1.4 Pass |
| 10          | 99.0 Pass | 99.0 Pass | 525.3 | 528.2 | -0.6 Pass |
| 11          | 97.7 Pass | 98.8 Pass | 419.3 | 416.3 | -0.7 Pass |
| 12          | 99.1 Pass | 98.8 Pass | 454 | 451.3 | -0.3 Pass |
| 13          | 98.2 Pass | 99.5 Pass | 449.4 | 442.7 | 1.5 Pass |
| 14          | 99.5 Pass | 100 Pass | 428.2 | 419.3 | 2.1 Pass |
| 15          | 99.0 Pass | 99.4 Pass | 453.1 | 443.4 | 1.2 Pass |
| 16          | 98.6 Pass | 99.8 Pass | 459.1 | 441.2 | 3.9 Fail |
| 17          | 97.6 Pass | 98.6 Pass | 478.5 | 453.6 | 5.2 Fail |
| 18          | 98.9 Pass | 98.3 Pass | 468.1 | 468.1 | 0 Pass |
| 19          | 97.7 Pass | 99.5 Pass | 519.5 | 526.1 | -1.3 Pass |
| 20          | 98.9 Pass | 99.1 Pass | 476.8 | 478.5 | -0.4 Pass |

Failed cases are presented in italics.
dose measurement on a linac using ArcCHECK requires time to set up the QA phantom and time to run the treatment beams. In this study, it was measured that 15 min was required to set up the ArcCHECK QA phantom. If the QA of multiple plans could be coordinated so that the QA phantom only needed to be set up one time for more than one case, the overall efficiency of QA using ArcCHECK would be improved.

All 20 cases in this study passed plan QA using the ArcCHECK system irrespective of whether the QA was planned and/or treated on a Varian Trilogy or TrueBeam linac. Three cases failed QA using IMSure, that is, the difference in the number of MUs as determined by IMSure was greater than 3% of the TPS calculated MUs for these 3 cases. As all cases passed QA using ArcCHECK, the departmental standard for VMAT QA, the three cases that failed QA using IMSure may be considered false fails. Initial interpretation of this result may be that the planning software IMSure is not consistently accurate for VMAT cases using the existing 3% action level and should not be used as a replacement for the phantom-based ArcCHECK.

The reason for the three false fail cases reported using IMSure is uncertain. As cases failed on both the Trilogy and TrueBeam machines it is unlikely the linac type was the cause of the reported false fail cases. It is possible the false fails could be attributed to the calculation algorithm being used by the TPS. A study by Yoo et al., reported using IMSure as an independent MU verification of breast cases calculated in the Eclipse TPS (version 8.6) using either AAA or the pencil beam convolution (PBC) algorithm. Their study demonstrated that IMSure had significantly higher agreement with the PBC algorithm than with AAA. They attributed this to the IMSure calculation including phantom scatter for the heterogeneity correction based on a simplified one-dimensional path length correction similar to how PBC handles the heterogeneity correction. Yoo et al., also used a 3% action level for their IMSure MU verification which was considered adequate when using PBC, but would result in a large number of false fail cases when using the AAA algorithm. They recommend using a 5% action level threshold when using the AAA algorithm.

The AAA algorithm was used in the current study. If the 5% action level recommended by Yoo et al., was applied to the IMSure QA in the current study, only one case would have been reported as a false fail. A reasonable approach to incorporating IMSure into routine QA of prostate VMAT plans at FVC would be to change the IMSure action level to 5%. If IMSure reports a difference in MUs of greater than 5% compared to the TPS, a measurement on a linac using ArcCHECK could be performed to confirm dose delivery. If this approach was used for the 20 cases in this study, 1 of the 20 cases (5%) would have required a physical measurement using ArcCHECK. The benefits of this approach would be twofold. Firstly, the efficiency of IMSure would reduce the workload for the medical physicists. Secondly, fewer QA measurements will need to be performed on a linac further reducing the workload for the medical physicists and potentially increasing the availability of the linac for patient treatment.

As eluded to by Yoo et al., as well as in this study, the action level set when using the plan QA software IMSure may be dependent on the calculation algorithm being utilised by the TPS. In the previous research at FVC which demonstrated agreement between IMSure and the Eclipse TPS point dose calculations to within 1% for a five-field IMRT treatment of prostate cancer, the PBC algorithm was used. The current research utilises the AAA algorithm and a 5% action level is recommended when using IMSure to QA VMAT plans for prostate cases. It is likely the 5% action level for IMSure will need to be reconsidered if using a calculation algorithm other than AAA. For example, most recently Varian Medical Systems has introduced the advanced dose calculation algorithm Acuros XB (AXB) into the Eclipse TPS. AXB is considered to be similar to classic Monte Carlo methods for accurate modelling of dose deposition in heterogeneous media. A validation study by Rana et al., demonstrated that AXB can perform dose computation comparable to AAA in single arc VMAT treatment of prostate cancer. Importantly, Rana et al., reported that utilising either AXB or AAA resulted in some dose-point differences throughout the plans which would translate to different MUs depending on which calculation algorithm was being used. Therefore, if IMSure was to be used to QA VMAT plans calculated in the TPS using the AXB algorithm, the 5% action level will need to be reconsidered.

An alternative approach to incorporate IMSure into the plan QA process was suggested by Fan (2009). Their recommendation is to use IMSure as an additional safeguard against any gross errors before a VMAT plan is approved for treatment. They recommend using a tolerance of ±10% for IMSure validation of VMAT plans to verify the MUs calculated in the TPS. Importantly, in this process the software validation is not meant to replace the measurement based QA using either film dosimetry or detector arrays such as ArcCHECK.

The current study was performed using v3.4 of IMSure. Of note, version 3.4 of IMSure is now commercially available which is promoted to have additional features increasing the accuracy of its modelling to VMAT plans. It is reasonable to expect that in the future more treatment plan QA software products will become available which will continue to have increased accuracy potentially eliminating the need to perform dose measurement based QA on a linac.
Conclusion

This study aimed to investigate if the plan QA software IMSure could be used to perform the QA of VMAT treatments for early stage prostate cancer. It has been demonstrated here that IMRT plan QA process cannot just be adopted into a VMAT plan QA process, and that VMAT-specific QA criteria are recommended. Importantly, the action level criteria set will be influenced by factors including the calculation algorithm being used by the TPS. The implication of this research for radiation therapists is to be critically aware of the differences between the plan QA requirements and methods for IMRT and those required for VMAT.

Conflict of Interest

The authors declare no conflict of interest.

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