

## 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.<sup>1</sup> It can also be difficult to adequately replicate patient geometries and heterogeneities using phantom-based QA methods.<sup>2</sup>

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

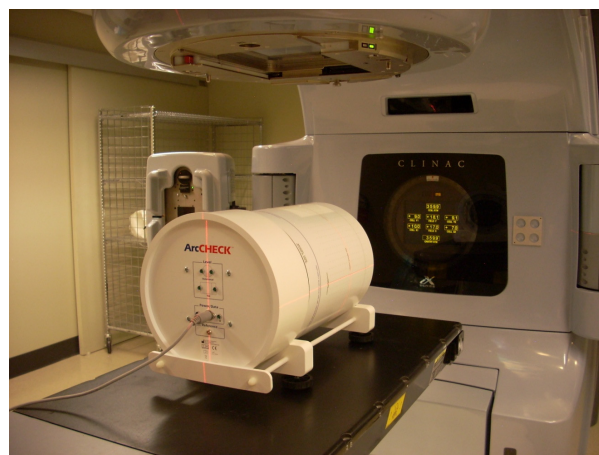
on a linac and greatly reducing the time needed to perform the QA for IMRT plans. *IMSure* (Standard Imaging, Middleton, WI) is one example of treatment plan QA software available commercially. Patient-specific fluence maps generated from the TPS can be imported into *IMSure*, which uses a patented “3-Source 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.<sup>3–5</sup>

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%.<sup>6</sup> 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.<sup>7</sup> 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.<sup>8–10</sup> 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).<sup>11</sup> 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.<sup>12</sup>

*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



**Figure 1.** The *ArcCHECK* (Sun Nuclear Corp.) cylindrical diode array set up for quality assurance measurement on a Varian Medical System's *Trilogy* linear accelerator.

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.<sup>13</sup> The passing gamma criteria of 3%/3 mm of 90% was used.<sup>14</sup>

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 *Eclipse* TPS, the time to set up the *ArcCHECK* phantom, the QA plan delivery time and the postdelivery analysis.

### IMSure QA

Version 3.3 (v3.3) of *IMSure* was used in this study. To perform plan QA using *IMSure*, the *Eclipse* developed plan was exported to the *IMSure* software and an analysis performed. The *IMSure* QA software calculated the number of MUs required for treatment delivery and then compared this value to the MUs estimated by the TPS and provides a difference in the MUs as a percentage value. An in-house threshold of less than 3% difference in MUs as determined by *IMSure* and the TPS is used at FVC to assess if a prostate IMRT plan passes QA. The same 3% threshold was used as the pass/fail criteria for the VMAT plans assessed in this study.

*IMSure* 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	<i>ArcCHECK</i>				<i>IMSure</i>			
	Preparation in <i>Eclipse</i>	Set up of phantom	Planned dose delivery	Postdelivery analysis	Total	Preparation in <i>Eclipse</i>	To run QA	Total
1	9 min 20 sec	15 m	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	3 min 10 sec	30 min 10 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 53 sec	33 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
	<i>ArcCHECK</i> Average: 31 min 31 sec (31.51 min)					<i>IMSure</i> Average: 3 min 27 sec (3.45 min)		

**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	<i>ArcCHECK</i>				<i>IMSure</i>			
	Trilogy		TrueBeam		TPS MUs	<i>IMSure</i> MUs	Percentage difference	Pass/fail
	Gamma value (3%/3 mm)	Pass/fail	Gamma value (3%/3 mm)	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	<i>Fail</i>
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	2.1	Pass
16	98.6	Pass	99.8	Pass	459.1	441.2	3.9	<i>Fail</i>
17	97.6	Pass	98.6	Pass	478.5	453.6	5.2	<i>Fail</i>
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.<sup>15</sup> 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.<sup>15</sup>

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 alluded 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.<sup>15</sup> 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.<sup>6</sup> 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.<sup>16–18</sup> 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.<sup>19</sup> 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  $\pm 10\%$  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*.<sup>20</sup>

The current study was performed using v3.3 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.

## References

- Pawlicki T, Yoo S, Court LE, McMillan SK, Rice RK, Russell JD, et al. Moving from IMRT QA measurements toward independent computer calculations using control charts. *Radiother Oncol* 2008; **89**: 330–7.
- Stern RL, Heaton R, Fraser MW, Goddu SM, Kirby TH, Lam KL, et al. Verification of monitor unit calculations for non-IMRT clinical radiotherapy: report of AAPM Task Group 114. *Med Phys* 2011; **38**: 504–30.
- IMSure. QA Software – Product Home. 2013; [accessed 8 July 2013]. Available from: [http://www.standardimaging.com/product\\_home.php?id=38](http://www.standardimaging.com/product_home.php?id=38).
- Why a Treatment Plan QA Software is Right for Your Facility. 2007; [accessed 8 July 2013]. Available from: [http://www.standardimaging.com/images/File/PDF/pubs/IMSureWhitepaper\\_1297-20.pdf](http://www.standardimaging.com/images/File/PDF/pubs/IMSureWhitepaper_1297-20.pdf).
- Yang Y, Xing L, Li JG, Palta J, Chen Y, Luxton G, et al. Independent dosimetric calculation with inclusion of head scatter and MLC transmission for IMRT. *Med Phys* 2003; **30**: 2937–47.
- Shahine B, Cao F, Ramaseshan R. Quality assurance of IMRT plans using *IMSure* QA software as a substitute for measurement. 2009; [accessed 8 July 2013] Available from: [http://www.standardimaging.com/uploads/publications/IMSure2\\_BShahine\\_AAPM2009poster.pdf](http://www.standardimaging.com/uploads/publications/IMSure2_BShahine_AAPM2009poster.pdf)
- Varian Medical Systems Inc. Varian's new RapidArc Radiotherapy Technology. 2010; [accessed 23 September 2010] Available from: [http://www.varian.com/us/oncology/treatments/treatment\\_techniques/rapidarc/resources.html](http://www.varian.com/us/oncology/treatments/treatment_techniques/rapidarc/resources.html).
- Elith CA, Cao F, Dempsey SE, Findlay N, Warren-Forward H. A Retrospective Planning Analysis Comparing Volumetric-Modulated Arc Therapy (VMAT) to Intensity-Modulated Radiation Therapy (IMRT) for Radiotherapy Treatment of Prostate Cancer. *J Med Imaging Radiat Sci* 2013; **44**: 79–86.
- Elith CA, Dempsey SE, Warren-Forward HM. A retrospective planning analysis comparing intensity modulated radiation therapy (IMRT) to volumetric modulated arc therapy (VMAT) using two optimization algorithms for the treatment of early stage prostate cancer. *J Med Radiat Sci* 2013; **60**: 84–92.
- Elith CA, Dempsey SE, Warren-Forward HM. Comparing four volumetric modulated arc therapy (VMAT) beam arrangements for the treatment of early stage prostate cancer. *J Med Radiat Sci* 2014; **61**: 91–101.
- Benefits Analysis. Sun Nuclear *ArcCHECK* [accessed 8 July 2013]. Available from: <http://www.sunnuclear.com/documents/1220B05102010.pdf>.
- Lin M, Koren S, Veltchev I, Li J, Wang L, Price RA, et al. Measurement comparison and Monte carlo analysis for volumetric-modulated arc therapy (VMAT) delivery verification using the *ArcCHECK* dosimetry system. *J Appl Clin Med Phys* 2013; **14**: 220–33.
- Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. *Med Phys* 1998; **25**: 656–61.
- Ezzell GA, Burmeister JW, Dogan N, LoSasso TJ, Mechalakos JG, Mihailidis D, et al. IMRT commissioning: multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. *Med Phys* 2009; **36**: 5359–73.
- Yoo S, Wu Q, O'Daniel J, Horton J, Yin FF. Comparison of 3D conformal breast radiation treatment plans using the anisotropic analytical algorithm and pencil beam convolution algorithm. *Radiother Oncol* 2012; **103**: 172–7.
- Vassiliev ON, Wareing TA, McGhee J, Failla G, Salehpour MR, Mourtafa F. Validation of a new grid-based Boltzmann equation solver for dose calculation in radiotherapy with photon beams. *Phys Med Biol* 2010; **55**: 581–98.
- Bush K, Gagne IM, Zavgorodni S, Ansbacher W, Beckham W. Dosimetric validation of Acuros XB with Monte Carlo methods for photon dose calculations. *Med Phys* 2011; **38**: 2208–21.
- Fogliata A, Nicolini G, Clivio A, Vanetti E, Mancuso P, Cozzi L. Dosimetric validation of Acuros XB advanced dose calculation algorithm: fundamental characterization in water. *Phys Med Biol* 2011; **38**: 2208–21.
- Rana S, Rogers K, Lee T, Reed D, Biggs C. Dosimetric impact of Acuros XB dose calculation algorithm in prostate cancer treatment using RapidArc. *J Cancer Res Ther* 2013; **9**: 430–5.
- Fan J. Use of *IMSure* for MU Verification on RapidArc Plans. 2009; [accessed 8 July 2013] Available from: [http://www.standardimaging.com/uploads/publications/IMSure3\\_Use\\_of\\_ImSure\\_for\\_MU\\_Verification\\_on\\_RapidArc\\_Plans.pdf](http://www.standardimaging.com/uploads/publications/IMSure3_Use_of_ImSure_for_MU_Verification_on_RapidArc_Plans.pdf)