CHAPTER 6

DOSIMETRIC EVALUATION OF FOUR PRETREATMENT VERIFICATION DEVICES FOR LUNG AND SPINAL SBRT

This chapter deals with the comparison of the four different pretreatment verification tools for stereotactic body radiotherapy (SBRT) plans. These SBRT plans were generated on an anthropomorphic RANDO man phantom using volumetric modulated arc therapy (VMAT) techniques and a 6-MV flattening filter free (FFF) photon beam. The percentage global and local gamma passing rates were used to analyse the pretreatment quality assurance results. In the following sections, an introduction to the topic, methodology, results, and conclusion have been discussed.

6.1 INTRODUCTION

Stereotactic body radiotherapy (SBRT) using volumetric modulated arc therapy (VMAT) based on a flattening filter free (FFF) photon beam can deliver highly conformal dose distributions with improved monitor unit (MU) efficiency and shorter treatment time (Dobler et al., 2016; Huang et al., 2019; Kim et al., 2017; Nalichowski et al., 2017). VMAT is more challenging than conventional therapy because a number of parameters are varied during VMAT delivery. These parameters include the shape and orientation of the multi leaf collimator (MLC) aperture, the rotation speed of the gantry, and the dose rate. Due to the complexities of VMAT delivery, dose distribution verification (usually in 2D) quality assurance (QA) must always be performed prior to treatment (Hodapp et al., 2012; Ezzell et al., 2009). This is called patient-specific QA or pretreatment verification QA, and it is required to determine the difference between treatment planning systems (TPS) calculated and measured dose distributions.

In the past, an ionising chamber or film dosimetry was used for pretreatment verification QA. This method has been used by a number of radiotherapy facilities because it is relatively quick, simple, and accurate for measuring all beams. However, the use of modern patient-specific QA tools has become standard practise for routine pretreatment verification of intensity modulated radiotherapy (IMRT) and VMAT treatment plans in recent years, replacing older methods like point dose measurements and film dosimetry (Bedford et al., 2009; Chaswal et al., 2014; Hussein et al., 2013; Liang et al., 2016; Jin et al., 2015). Recent two-dimensional array systems, such as diode or ion chamber arrays, have been developed specifically for pretreatment verification QA. A Portal Dosimetry system that uses an amorphous silicon electronic

portal imaging device (aSi EPID) is also a very simple method for obtaining dose information from the verification plan (Bakhtiari et al., 2011; Clemente et al., 2014; Bailey et al., 2012). PerFRACTION is an automated, web-based, and comprehensive patient QA software that was developed by Sun Nuclear (Sait et al., 2019). It makes use of EPID images and log files for pretreatment quality assurance. These modern devices measure and evaluate the 2D dose distribution through gamma analysis.

In general, the gamma evaluation method is used to validate the actual dose distribution that will be delivered to the patient during VMAT and IMRT. This method compares the TPS calculated 2D dose distribution with the measured 2D dose distribution from each pretreatment verification tool (Low et al., 2011; Low et al., 1998). Even though there is no universal agreement, QA results are generally considered satisfactory when the gamma passing rate is over 95% and a tolerance of dose difference (DD) of 3% and a distance to agreement (DTA) of 3 mm are used as criteria (Miften et al., 2018; Ezzell et al., 2009; Nelms et al., 2007; Howell et al., 2008). However, the passing rates are dependent on the pretreatment verification tool used. It is therefore the responsibility of institutions to set an acceptance level for each tool rather than using a gamma passing rate of over 95% as the acceptance level for all tools. The current emphasis on pretreatment QA for advanced treatment techniques necessitates the development of patient-specific guidelines for each verification tool.

The study aimed to compare four different pretreatment verification tools, namely MapCHECK 3, ArcCHECK, Portal dosimetry, and PerFRACTION, for lung and spinal SBRT plans using FFF-based VMAT. The correlations between these pretreatment verification tools are used to establish appropriate tolerance levels for each.

6.2 MATERIALS AND METHODS

Pretreatment verification was performed for fifty six SBRT plans, whose treatment regions corresponded to lung and spine cancer. These SBRT plans were generated on an anthropomorphic RANDO man phantom using FFF-based VMAT techniques. SBRT planning was carried out using a 6-MV FFF photon beam with a high dose rate of 1400 MU/min from a True Beam linear accelerator (LINAC, Varian Medical Systems, Inc., Palo Alto, CA, USA) equipped with Millennium 120 MLCs. The

Eclipse treatment planning system version 13.6 (Varian Medical System, Palo Alto, CA) and the Acuros XB algorithm with a 2.5 mm calculation grid size were used to calculate patient plans. The computed tomography (CT) images of the phantom were used for contouring and treatment planning. The lung, spinal cord, and other organs were contoured in the CT image of the phantom to reflect the average size of organs reported in the previous literature (Dwivedi et al., 2021). The pretreatment verification QA of all VMAT plans was created on MapCHECK 3, ArcCHECK, and EPID. These QA plans were then exported to the LINAC for pretreatment verification. The experimental setup of various pretreatment verification tools are shown in the Figure 6.1.

6.2.1 MapCHECK 3

MapCHECK 3 (Sun Nuclear, Melbourne, FL, USA) is made up of 1527 SunPoint 2 diode detectors. These detectors are evenly distributed across the array, which has an active field size of 26 cm x 32 cm and a detector spacing of 7.07 mm. Each detector has an active detector area of 0.23 mm^2 and an active detector volume of 0.007 mm^3. The device has a water equivalent phantom called MapPHAN, which provides the detector plane with a 5 cm water equivalent build-up (Lee and Kim, 2021; Altaf et al., 2018). Each VMAT verification plan was delivered on MapCHECK 3 to obtain a measured dose distribution. The TPS calculated dose distribution of each verification plan was transferred to the SNC patient software (Version 6.4.1., Sun Nuclear, Melbourne, FL, USA) for analysis and comparison. The gamma analysis was performed to compare the calculated and measured dose distributions.

6.2.2 ArcCHECK

ArcCHECK (Sun Nuclear, Melbourne, FL, USA) phantom is made up of a helical detector grid with 1,386 SunPoint diode detectors (Chaswal et al., 2014; Lee and Kim et al., 2021). These detectors are embedded into the helical array, which has a diameter and length of 21 cm each with detector spacing of 1 cm. The phantom has a physical detector depth of 2.9 cm with an inherent buildup and backscatter of 3.3g/cm^2. The ArcCheck phantom was calibrated as per manufacturer's guidelines.

The VMAT arcs of each verification plan were delivered on the ArcCheck phantom as planned to obtain measured dose distribution. The calculated dose distributions were exported from the Eclipse TPS and imported into the SNC patient software (Version 6.4.1., Sun Nuclear, Melbourne, FL, USA) for analysis and comparison. The gamma analysis was carried out to evaluate the accuracy of the TPS predicted and observed dose distributions.

6.2.3 Portal Dosimetry

The Portal Dosimetry system (version 13.6, Varian Medical System, Palo Alto, CA) consists of three main components: (1) the portal dose image prediction (PDIP) algorithm in the Eclipse TPS, (2) EPID, and (3) portal dosimetry analysis software in the TPS. The verification plans were generated using PDIP, imaged with EPID, and analysed utilizing portal dosimetry software. The verification QA of VMAT plans was done with the a-Si 1200 EPID mounted on the TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA, USA), which is made up of arrays of light-sensitive amorphous silicon photodiodes arranged in an active detector area of 40 x 40 cm2 with 1190 x 1190 pixel arrays and a resolution of 0.336 mm. This recently upgraded Varian EPID from a-Si 1000 to a-Si 1200 is fully compatible with high dose rate FFF beams without saturation at any distance between the source and the detector (Mhatre et al., 2018; Miri et al., 2016). These EPID acquired images were analysed using portal dosimetry software.

6.2.4 PerFRACTION

PerFRACTION (Sun Nuclear, Melbourne, FL, USA) is a phantom-less pretreatment quality assurance system developed to provide online and near real-time verification of the radiation dose given to a patient during clinical treatment. It calculates dose using either EPID or log file information, or both. PerFRACTION can do both pretreatment verification QA (called "Fraction 0") and in-vivo transit dosimetry (called "Fraction n") using point and 2D analysis with EPID images and 3D analysis with log files and cone beam CT (photon beams only, not electrons). For verification

of VMAT plans, the DICOM data was transferred to the PerFRACTION server so that it could actively retrieve any LINAC image and log files corresponding to the radiotherapy plan. The PerFRACTION system automatically collects, calculates, and analyses data in the background (Sait et al., 2019). In this study, only the pretreatment verification QA, or "fraction 0," was compared and analysed using gamma analysis.

6.2.5 Evaluation

A percentage gamma passing rate of multiple arcs was used to compare the TPS doses with measured doses for the pretreatment QA analysis. Global and local gamma passing rates using various gamma criteria (DD/DTA), which were 3%/3 mm, 3%/2 mm, 2%/3 mm, 2%/2 mm, and 1%/1 mm, were calculated with the absolute doses using MapCHECK 3, ArcCHECK, Portal Dosimetry, and PerFRACTION software. These analyses included 5% and 10% dose thresholds for all devices. The significance of the differences among the four different pretreatment verification tools was analysed using a two-tailed paired t-test for all criteria.

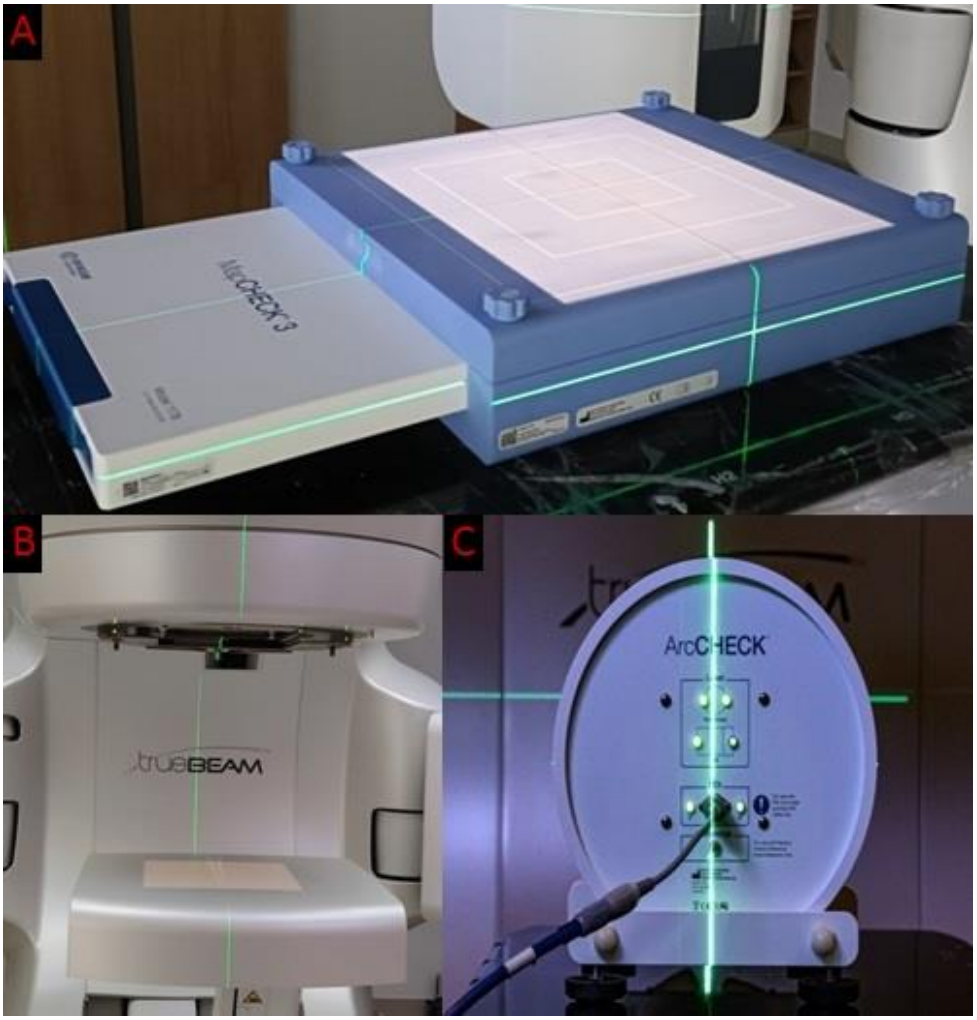

Figure 6.1 Experimental setup of various pretreatment verification tools (A) MapCHECK 3, (B) Electronic portal imaging device (EPID), and (C) ArcCHECK

6.3 RESULTS

The doses calculated by TPS and the doses measured by the four dosimetric tools were compared using the gamma index method. The mean values of the both global and local percentage gamma passing rate and their standard deviation (SD) for all gamma criteria (10% threshold dose) of lung, spine, and combined (both lung and spine) VMAT plans using four pretreatment QA tools are shown in Tables 6.1, 6.2, and 6.3, respectively. The same results using 5% threshold dose criteria are presented in Tables 6.4, 6.5, and 6.6, respectively. The statistical comparison of the both global and local gamma passing rates among four pretreatment QA tools is shown in Table

6.7 and 8. An example of gamma evaluation results for VMAT pretreatment QA using MapCHECK 3, ArcCHECK, EPID, and PerFRACTION is shown in Figure 6.2.

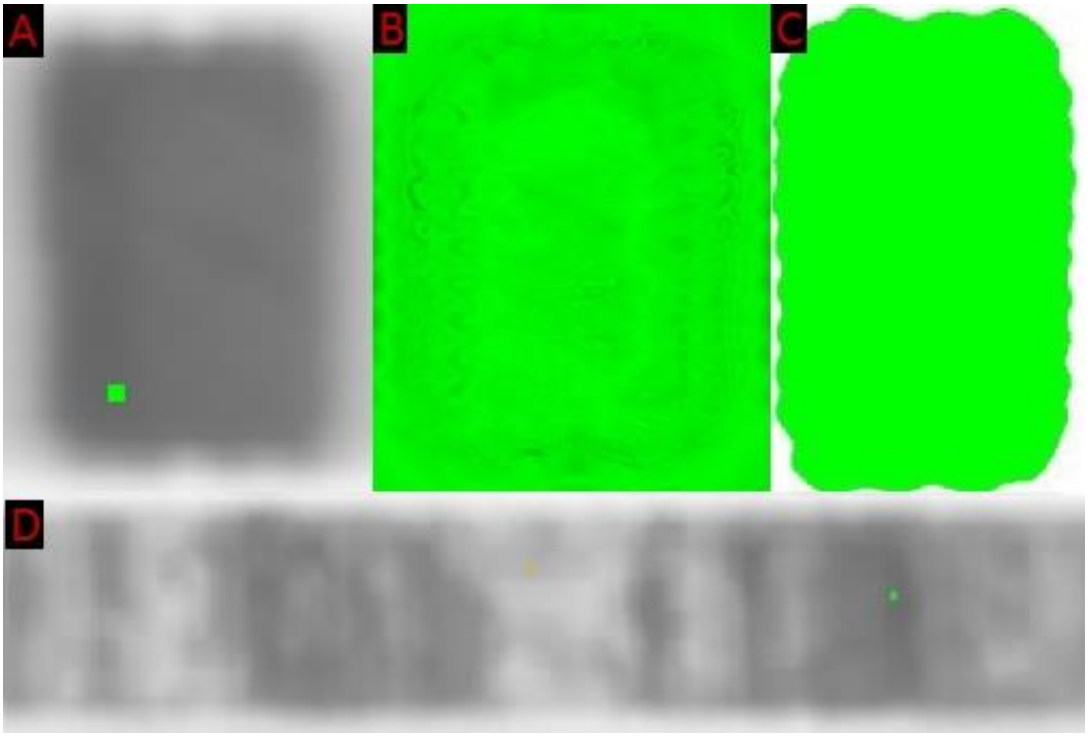

Figure 6.2 Two dimensional (2D) images of the gamma passing rate based on gamma evaluation for various pretreatment verification tools (A) MapCHECK 3, (B) Portal Dosimetry, (C) PerFRACTION, (D) ArcCHECK.

Table 6.1 The mean percentage gamma passing rates of lung VMAT plans using a 10% dose threshold for four different pretreatment QA tools

Parameters	MapCHECK 3		ArcCHECK		Portal Dosimetry		PerFRACTION	
	Global	Local	Global	Local	Global	Local	Global	Local
3%/3mm	100.00 ± 0.00	83.84 ± 11.29	100.00 ± 0.00	88.25 ± 4.46	100.00 ± 0.00	99.95 ± 0.09	100.00 ± 0.00	99.99 ± 0.04
3%/2mm	99.95 ± 0.14	72.34 ± 10.71	99.85 ± 0.18	79.34 ± 7.54	100.00 ± 0.00	99.81 ± 0.26	99.79 ± 0.33	99.66 ± 0.38
2%/3mm	99.89 ± 0.32	80.26 ± 12.39	99.82 ± 0.26	85.62 ± 6.68	100.00 ± 0.00	99.81 ± 0.22	99.74 ± 0.43	99.63 ± 0.83
2%/2mm	99.38 ± 0.72	68.44 ± 12.24	99.12 ± 0.87	75.42 ± 8.83	100.00 ± 0.00	99.44 ± 0.51	98.91 ± 1.26	98.41 ± 1.79
1%/1mm	85.75 ± 6.52	46.64 ± 11.27	85.45 ± 7.21	60.52 ± 10.36	97.63 ± 0.91	85.98 ± 3.69	85.13 ± 10.87	82.81 ± 11.17

Table 6.2 The mean percentage gamma passing rates of spinal VMAT plans using a 10% dose threshold for four different pretreatment QA tools

Parameters	MapCHECK 3		ArcCHECK		Portal Dosimetry		PerFRACTION	
	Global	Local	Global	Local	Global	Local	Global	Local
3%/3mm	96.98 ± 3.93	92.79 ± 6.07	96.66 ± 2.58	94.56 ± 4.22	100.00 ± 0.00	98.55 ± 0.62	97.39 ± 5.41	96.81 ± 5.94
3%/2mm	95.90 ± 4.80	88.37 ± 6.46	95.74 ± 3.95	91.82 ± 4.86	99.94 ± 0.12	97.56 ± 1.03	96.95 ± 5.83	96.38 ± 6.49
2%/3mm	95.73 ± 5.35	90.35 ± 6.28	95.36 ± 3.89	92.14 ± 4.64	99.98 ± 0.04	98.03 ± 0.79	85.27 ± 15.67	83.93 ± 16.73
2%/2mm	94.18 ± 6.34	84.42 ± 6.75	94.29 ± 4.77	89.22 ± 5.42	99.89 ± 0.17	96.59 ± 1.24	81.99 ± 17.91	80.08 ± 19.36
1%/1mm	81.93 ± 7.97	57.19 ± 7.25	82.47 ± 7.96	71.46 ± 8.68	96.36 ± 2.25	84.71 ± 4.23	49.16 ± 29.52	48.29 ± 29.33

Table 6.3 The mean percentage gamma passing rates of combined VMAT plans using a 10% dose threshold for four different pretreatment QA tools

Parameters	MapCHECK 3		ArcCHECK		Portal Dosimetry		PerFRACTION	
	Global	Local	Global	Local	Global	Local	Global	Local
3%/3mm	97.94 ± 3.52	89.93 ± 8.94	97.65 ± 2.24	90.46 ± 6.28	100.00 ± 0.00	99.02 ± 0.84	98.39 ± 4.37	98.02 ± 4.85
3%/2mm	97.20 ± 4.37	83.24 ± 10.93	96.98 ± 3.35	85.46 ± 8.62	99.96 ± 0.10	98.31 ± 1.37	98.03 ± 4.71	97.63 ± 5.27
2%/3mm	97.06 ± 4.80	87.12 ± 9.70	96.62 ± 3.28	89.14 ± 8.54	99.98 ± 0.04	98.62 ± 1.08	90.78 ± 13.96	89.91 ± 14.97
2%/2mm	95.84 ± 5.75	79.30 ± 11.49	95.48 ± 4.21	84.56 ± 10.62	99.93 ± 0.15	97.54 ± 1.72	88.43 ± 16.05	87.06 ± 17.39
1%/1mm	83.15 ± 7.62	53.82 ± 9.87	83.64 ± 7.58	65.95 ± 11.02	96.78 ± 1.98	85.13 ± 4.03	62.86 ± 29.52	61.44 ± 29.03

Table 6.4 The mean percentage gamma passing rates of lung VMAT plans using a 5% dose threshold for four different pretreatment QA tools

Parameters	MapCHECK 3		ArcCHECK		Portal Dosimetry		PerFRACTION	
	Global	Local	Global	Local	Global	Local	Global	Local
3%/3mm	100.00 ± 0.00	78.63 ± 12.02	100.00 ± 0.00	82.47 ± 6.85	100.00 ± 0.00	99.95 ± 0.09	100.00 ± 0.00	99.99 ± 0.04
3%/2mm	99.96 ± 0.11	67.49 ± 13.27	99.90 ± 0.15	73.34 ± 8.26	100.00 ± 0.00	99.81 ± 0.23	99.79 ± 0.33	99.67 ± 0.37
2%/3mm	99.90 ± 0.28	74.06 ± 11.13	99.87 ± 0.22	77.81 ± 7.95	100.00 ± 0.00	99.85 ± 0.17	99.74 ± 0.43	99.63 ± 0.83
2%/2mm	99.55 ± 0.56	62.23 ± 11.72	99.28 ± 0.68	69.28 ± 10.38	100.00 ± 0.00	99.49 ± 0.42	98.91 ± 1.26	98.43 ± 1.80
1%/1mm	90.93 ± 4.24	40.54 ± 9.24	91.22 ± 4.16	54.21 ± 12.42	97.84 ± 0.79	85.48 ± 3.85	85.21 ± 10.94	84.24 ± 11.37

Table 6.5 The mean percentage gamma passing rates of spinal VMAT plans using a 5% dose threshold for four different pretreatment QA tools

Parameters	MapCHECK 3		ArcCHECK		Portal Dosimetry		PerFRACTION	
	Global	Local	Global	Local	Global	Local	Global	Local
3%/3mm	98.04 ± 2.50	91.75 ± 4.54	98.44 ± 1.87	92.95 ± 3.26	100.00 ± 0.00	98.58 ± 0.55	97.39 ± 5.41	96.81 ± 5.94
3%/2mm	97.33 ± 3.07	87.58 ± 5.15	97.43 ± 2.76	89.92 ± 4.56	99.96 ± 0.09	97.54 ± 0.88	96.95 ± 5.84	96.38 ± 6.48
2%/3mm	97.23 ± 3.39	89.68 ± 4.74	97.51 ± 2.46	90.68 ± 4.38	99.98 ± 0.04	97.87 ± 0.74	85.27 ± 15.66	83.93 ± 16.74
2%/2mm	96.22 ± 4.02	84.08 ± 5.48	96.77 ± 3.47	87.24 ± 4.87	99.90 ± 0.16	96.28 ± 1.14	81.98 ± 17.90	80.10 ± 19.39
1%/1mm	88.09 ± 5.16	59.16 ± 5.08	89.16 ± 4.38	67.25 ± 5.78	96.69 ± 2.04	83.46 ± 3.96	49.21 ± 29.55	48.26 ± 29.31

Table 6.6 The mean percentage gamma passing rates of combined VMAT plans using a 5% dose threshold for four different pretreatment QA tools

Parameters	MapCHECK 3		ArcCHECK		Portal Dosimetry		PerFRACTION	
	Global	Local	Global	Local	Global	Local	Global	Local
3%/3mm	98.66 ± 2.24	87.55 ± 9.74	98.84 ± 1.56	88.42 ± 7.05	100.00 ± 0.00	99.03 ± 0.80	98.39 ± 4.37	98.02 ± 4.85
3%/2mm	98.17 ± 2.80	81.15 ± 12.67	98.32 ± 2.48	83.26 ± 11.16	99.98 ± 0.07	98.30 ± 1.31	98.03 ± 4.71	97.63 ± 5.27
2%/3mm	98.08 ± 3.05	84.68 ± 10.31	98.46 ± 2.32	85.74 ± 9.68	99.99 ± 0.03	98.53 ± 1.13	90.79 ± 13.96	89.91 ± 14.97
2%/2mm	97.28 ± 3.66	77.08 ± 12.97	97.92 ± 3.15	81.68 ± 11.32	99.93 ± 0.14	97.35 ± 1.81	88.43 ± 16.05	87.07 ± 17.39
1%/1mm	89.00 ± 4.98	53.20 ± 10.99	90.36 ± 4.21	62.54 ± 11.85	97.07 ± 1.79	84.13 ± 3.96	62.90 ± 29.56	61.99 ± 29.50

Table 6.7 Statistical comparison of the global gamma passing rates among four pretreatment QA tools

		p-value									
Threshold Dose	Criteria / VMAT Plans	MapCHECK 3 vs. ArcCHECK					MapCHECK 3 vs. Portal Dosimetry				
		3%/ 3mm	3%/ 2mm	2%/ 3mm	2%/ 2mm	1%/ 1mm	3%/ 3mm	3%/ 2mm	2%/ 3mm	2%/ 2mm	1%/ 1mm
10%	Lung	1.000	0.556	0.474	0.168	0.224	1.000	0.351	0.351	0.154	0.001
	Spinal	0.572	0.526	0.625	0.265	0.135	0.012	0.007	0.010	0.004	0.000
	Combined	0.432	0.412	0.572	0.218	0.256	0.014	0.008	0.011	0.003	0.000
5%	Lung	1.000	0.462	0.468	0.226	0.232	1.000	0.351	0.351	0.156	0.002
	Spinal	0.578	0.472	0.482	0.453	0.116	0.010	0.006	0.009	0.004	0.000
	Combined	0.686	0.468	0.256	0.274	0.156	0.012	0.007	0.009	0.003	0.000
		MapCHECK 3 vs. PerFRACTION					ArcCHECK vs. Portal Dosimetry				
10%	Lung	1.000	0.178	0.466	0.450	0.902	1.000	0.431	0.452	0.114	0.001
	Spinal	0.771	0.529	0.005	0.003	0.000	0.018	0.010	0.012	0.003	0.000
	Combined	0.767	0.556	0.006	0.004	0.000	0.009	0.005	0.008	0.002	0.000
5%	Lung	1.000	0.150	0.429	0.270	0.000	1.000	0.412	0.435	0.126	0.002
	Spinal	0.670	0.845	0.003	0.002	0.000	0.040	0.008	0.011	0.006	0.000
	Combined	0.665	0.795	0.004	0.002	0.000	0.046	0.009	0.012	0.008	0.000
		ArcCHECK vs. PerFRACTION					Portal Dosimetry vs. PerFRACTION				
10%	Lung	1.000	0.254	0.442	0.436	0.776	1.000	0.109	0.128	0.045	0.017
	Spinal	0.786	0.624	0.003	0.003	0.000	0.065	0.050	0.002	0.001	0.000
	Combined	0.534	0.412	0.004	0.002	0.000	0.066	0.043	0.002	0.001	0.000
5%	Lung	1.000	0.168	0.286	0.284	0.000	1.000	0.109	0.134	0.045	0.016
	Spinal	0.452	0.656	0.004	0.003	0.000	0.065	0.049	0.002	0.001	0.000
	Combined	0.476	0.584	0.006	0.003	0.000	0.066	0.042	0.002	0.001	0.000

Table 6.8 Statistical comparison of the local gamma passing rates among four pretreatment QA tools

		p-value									
Threshold Dose	Criteria / VMAT Plans	MapCHECK 3 vs. ArcCHECK					MapCHECK 3 vs. Portal Dosimetry				
		3%/ 3mm	3%/ 2mm	2%/ 3mm	2%/ 2mm	1%/ 1mm	3%/ 3mm	3%/ 2mm	2%/ 3mm	2%/ 2mm	1%/ 1mm
10%	Lung	0.009	0.006	0.003	0.002	0.000	0.005	0.000	0.003	0.000	0.000
	Spinal	0.486	0.248	0.282	0.016	0.000	0.003	0.000	0.000	0.000	0.000
	Combined	0.272	0.132	0.168	0.008	0.000	0.000	0.000	0.000	0.000	0.000
5%	Lung	0.016	0.008	0.012	0.009	0.000	0.001	0.000	0.000	0.000	0.000
	Spinal	0.532	0.116	0.452	0.024	0.000	0.000	0.000	0.000	0.000	0.000
	Combined	0.658	0.264	0.436	0.018	0.000	0.000	0.000	0.000	0.000	0.000
		MapCHECK 3 vs. PerFRACTION					ArcCHECK vs. Portal Dosimetry				
10%	Lung	0.005	0.000	0.004	0.000	0.000	0.006	0.003	0.004	0.000	0.000
	Spinal	0.070	0.004	0.148	0.443	0.294	0.005	0.002	0.003	0.000	0.000
	Combined	0.001	0.000	0.468	0.102	0.239	0.004	0.003	0.002	0.000	0.000
5%	Lung	0.002	0.000	0.000	0.000	0.000	0.003	0.002	0.000	0.000	0.000
	Spinal	0.009	0.001	0.209	0.536	0.240	0.000	0.000	0.000	0.000	0.000
	Combined	0.000	0.000	0.207	0.055	0.217	0.000	0.000	0.000	0.000	0.000
		ArcCHECK vs. PerFRACTION					Portal Dosimetry vs. PerFRACTION				
10%	Lung	0.012	0.000	0.016	0.000	0.000	0.351	0.222	0.577	0.179	0.539
	Spinal	0.085	0.015	0.009	0.005	0.000	0.281	0.535	0.004	0.003	0.000
	Combined	0.002	0.000	0.518	0.168	0.292	0.283	0.497	0.005	0.003	0.000
5%	Lung	0.004	0.000	0.000	0.000	0.000	0.351	0.222	0.493	0.159	0.806
	Spinal	0.012	0.003	0.276	0.434	0.283	0.268	0.537	0.004	0.004	0.000
	Combined	0.000	0.000	0.189	0.236	0.426	0.270	0.499	0.005	0.004	0.001

6.3.1 Global gamma passing rate

All of the lung, spinal, and combined VMAT plans that were measured by four different pretreatment QA devices had a global mean gamma passing rate using 3%/3 mm of 97.39% to 100% for the 5% dose threshold and 96.66% to 100% for the 10% dose threshold. When gamma criteria were lowered to 3%/2 mm, 2%/3 mm, and 2%/2 mm, all four devices had an average gamma passing rate of more than 95%. The only exception was PerFRACTION for spinal and combined VMAT plans, which had a passing rate of 85.27% to 90.79% and 81.98% to 88.43% when gamma criteria were reduced to 2%/3 mm and 2%/2 mm, respectively. For 1%/1 mm, only Portal Dosimetry had a mean gamma passing rate of greater than 95%, while ArcCHECK, MapCHECK 3, and PerFRACTION had a mean gamma of 82.47% to 92.36%, 81.93% to 90.93%, and 49.16% to 85.21%, respectively.

When 3%/3 mm was chosen, the gamma passing rate did not differ significantly ($p > 0.05$) between the four pretreatment QA devices, except when portal dosimetry was compared to ArcCHECK and MapCHECK 3 ($p < 0.05$). When the gamma criteria were reduced to 3%/2 mm, 2%/3 mm, 2%/2 mm, and 1%/1 mm, the results showed that the four devices were statistically different ($p < 0.05$) in most cases, with the exception of the comparison between MapCHECK 3 and ArcCHECK ($p > 0.05$).

6.3.2 Local gamma passing rate

The local mean gamma pass rate for all VMAT plans measured by Portal Dosimetry and PerFRACTION ranged from 96.28% to 99.99% when 3%/3 mm, 3%/2 mm, 2%/3 mm, and 2%/2 mm were used, while ArcCHECK and MapCHECK 3 had a passing rate of 69.28% to 94.56% and 62.23% to 92.79%, respectively. However, spinal and combined VMAT plans for only PerFRACTION showed passing rates of 80.08% to 89.91% when 2%/3 mm and 2%/2 mm were applied. When comparing gamma pass rates for 1%/1 mm, only portal dosimetry had a gamma between 82.81% and 85.98% for all VMAT plans except PerFRACTION for lung VMAT plans, while ArcCHECK, MapCHECK 3, and PerFRACTION all had gammas of 54.21% to 71.46%, 40.54% to 59.16%, and 48.26% to 61.99%, respectively.

Mostly, there were significant differences ($p < 0.05$) in the local gamma passing rate among the four pretreatment verification tools for all gamma criteria (5% and 10% threshold dose). However, when 3%/3 mm and 3%/2 mm were used, no significant differences ($p > 0.05$) in the local gamma passing rate were found between ArcCHECK and MapCHECK 3, or between Portal Dosimetry and perfraction, except between ArcCHECK and MapCHECK 3 for lung VMAT plans ($p < 0.05$).

6.4 DISCUSSION

The aim of this study is to validate the VMAT plans using various pretreatment verification tools and compare the results. In a clinical setting, the 3%/3 mm gamma analysis metric is often used for pretreatment QA of VMAT plans (Miften et al., 2018; Ezzell et al., 2009). In this study, we looked at more stringent gamma tolerances of less than 3%/3 mm for all four pretreatment verification tools. The global gamma passing rates for the 3%/3 mm, 3%/2 mm, 2%/3 mm, and 2%/2 mm criteria (5% and 10% dose threshold) were greater than 95% when using four different pretreatment verification tools. The same was true for the local gamma passing rates, but only with Portal Dosimetry and PerFRACTION. When the global and local gamma criteria were lowered to 1%/1 mm, the results showed that only Portal Dosimetry had a passing rate of more than 95% for the global criteria. There was also discussion about implementing stricter gamma tolerances in some of the earlier studies (Park et al., 2016; Li et al., 2012; Nelms et al., 2012).

When compared to other pretreatment verification tools, the Portal Dosimetry had the highest global and local gamma pass rates. When it comes to global gamma passing rates that meet the 3%/3 mm criterion, only comparisons between Portal Dosimetry and ArcCHECK or MapCHECK 3 were statistically different ($p < 0.05$). On the other hand, the results of the local gamma passing rate showed that the four pretreatment QA devices were statistically different ($p < 0.05$) in most cases. However, the Portal Dosimetry and PerFRACTION showed identical results for the 3%/3 mm criterion, and the same is true between ArcCHECK and MapCHECK 3. The global and local gamma passing rates showed good agreement between the 5% and 10% dose thresholds for all four pretreatment verification tools. However, the local gamma passing rates for lung SBRT plans with a 10% dose threshold were much

higher than those with a 5% dose threshold when measured using MapCHECK 3 and ArcCHECK.

The study found that EPID-based Portal Dosimetry showed better gamma passing rates overall and especially at 1%/1 mm than the diode-based MapCHECK 3 and ArcCHECK, which mainly due to the MLC tongue-and-groove effect. This effect causes under-dose between two adjacent leaf pairs and can reduce the gamma passing rate because diode detectors are aligned with MLC inter-leaf gaps and also because the diode detector responds differently to scattered radiation for field sizes other than those used for calibration (Jin et al., 2014; Deng et al., 2001; Olch et al., 2012). In addition, the detector density in these two diode-based verification tools is lower than in an EPID-based verification tool. However, the diode-based verification tools showed a better global gamma rate in comparison to PerFRACTION when the gamma criteria were reduced to 2%/3 mm, 2%/2 mm, and 1%/1 mm.

The point dose verification with ion chambers was within 3.5% of the dose predicted by the TPS (Mijnheer et al., 1987). As a result of developments in treatment planning and delivery methods, pretreatment verification has been the topic of extensive investigation. Several verification approaches were investigated for VMAT plan verification. This comparison of gamma indices for ArcCHECK, MapCHECK 3, PerFRACTION, and Portal Dosimetry showed differences in dose distribution while using these various verification tools to perform QA on the same VMAT plan. Even when using the same verification tool, the results for each measurement of the same arc differed slightly. This was caused by a combination of factors, including mechanical sag and detector response. The Portal Dosimetry system that makes use of EPID offers a very straightforward approach, in addition to the fact that it possesses a high degree of resolution (Atlaf et al., 2018; Mhatre et al., 2018; Miri et al., 2016). It was a relatively more effective tool in comparison to the other three verification tools for VMAT plans, and it produced gamma passing rates that were clinically acceptable even when lower gamma criteria were applied.

6.5 CONCLUSIONS

Within the scope of this study, analysis and comparison of four different pretreatment verification tools for VMAT plans has been performed. The verification tools all produced comparable results for the global gamma passing rate when the 3%/3 mm

criterion was applied. On the other hand, when it came to the local gamma passing rate, only Portal Dosimetry and PerFRACTION had similar results. When lower gamma criteria were applied, it was found that Portal Dosimetry was more effective than other verification tools. This was because gamma passing rates were still within clinically acceptable ranges. The findings suggest that setting the same limit for all of these tools is less accurate than selecting an acceptable gamma passing rate based on the correlation between various pretreatment verification tools.

OVERALL CONCLUSION

The current research work was carried out in order to investigate the appropriate detectors for small field dosimetry; the optimised methods of treatment planning techniques for lung and spinal SBRT; and the suitability of pretreatment dose verification tools for a 6 MV FFF photon beam.

In the present investigation, the characteristic parameters of small-fields of 6 MV FFF photon were measured using an SNC125c, PinPoint, EBT3, TLD-100, and EDGE. The study found that the PinPoint, EBT3, TLD-100, and EDGE appear to be the detectors of choice for small field output factor measurement of a 6 MV FFF beam; however, the PinPoint should be used carefully for the smallest field size (0.6 cm × 0.6 cm), as it requires a correction that is slightly higher than 10%. The EDGE must be calibrated against the ion chamber when used for the output factor measurement. EDGE and EBT3 are optimal for measuring beam profile. The EBT3, PinPoint, and EDGE can be selected for the percentage depth dose measurement. The EBT3 appears suitable for surface dose estimation, whereas measurements obtained from ionization chambers and diodes require an appropriate correction factor for the over-response of surface doses. In summary, this study describes the detector suitable for the measurement of a particular dosimetric parameter of a 6 MV FFF small photon beam.

The results of this study suggest that all three treatment techniques, i.e., FFF-VMAT, FFF-IMRT, and FFF-3DCRT were able to deliver conformal SBRT plans while meeting the RTOG dose constraints. On the other hand, based on the comparison of dosimetric indices, such as CI, D2cm, HI, and HDV, FFF-VMAT provides a superior treatment plan to FFF-IMRT and FFF-3DCRT in the treatment of peripheral and central lung PTVs. Dosimetric indices, such as R50% and GI, were improved for FFF-3DCRT compared with those of FFF-VMAT. It is also clear that despite the requirement for higher MUs in the FFF-VMAT plans compared to FFF-3DCRT, the treatment delivery time is much shorter because of the superior gantry speed of the VMAT technique. The study suggests that the treatment dose calculated using Acuros XB is more accurate than that of AAA in a heterogeneous medium, such as the lung.

In the present study, we have investigated the feasibility of both DI and MI VMAT techniques for non-contiguous spinal SBRT. All four beam arrangements

tested were capable of delivering treatment plans that met the RTOG 0631 dose constraints. However, certain beam arrangements performed better than others depending on the tumor shapes, locations, and treatment goals. According to the findings of the study, DI has higher plan quality than MI for treating non-contiguous spine SBRT, achieving adequate tumor coverage, comparable delivery accuracy, better homogeneity, and a lower dose to the spinal cord. 4-Arcs DI had the sharpest dose falloff and achieved the lowest overall spinal cord doses at the expense of twice the treatment time as 2Arcs-MI. These findings could help in deciding which beam arrangements for VMAT are optimal for treating non-contiguous spine tumors.

Within the scope of this study, analysis and comparison of four different pretreatment verification tools for VMAT plans has been performed. The verification tools all produced comparable results for the global gamma passing rate when the 3%/3 mm criterion was applied. On the other hand, when it came to the local gamma passing rate, only Portal Dosimetry and PerFRACTION had similar results. When lower gamma criteria were applied, it was found that Portal Dosimetry was more effective than other verification tools. This was because gamma passing rates were still within clinically acceptable ranges. The findings suggest that setting the same limit for all of these tools is less accurate than selecting an acceptable gamma passing rate based on the correlation between various pretreatment verification tools.

In summary, the outcome of these studies provided some insight about the selection of appropriate detector to be used for dosimetry of small FFF photon field, the optimized method of the treatment planning of SBRT treatment plans and appropriateness of dose verification procedures in FFF photon beam.

FUTURE SCOPE

Future research studied on this topic using higher energy FFF beams (greater than 6 MV FFF) and a different set of detectors may be useful in the development of guidelines for selecting a detector suitable for measuring a specific dosimetric parameter at those energies. In addition to this, we have chosen an anthropomorphic phantom over real patient CT datasets because, this allowed for a highly consistent set of tumors for SBRT planning. Future studies with higher energy FFF beams using current treatment planning methodology may provide some improved results for lung and spinal SBRT. In the future, other commercially available pretreatment devices for FFF beam-based SBRT can be investigated, which will improve the appropriateness of dose verification procedures in FFF photon beam.