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Analyzing the performance of the URT treatment planning system and URT-Linac 506C for flattening filter (FF) and flattening filter free (FFF) photon beams of Monte Carlo algorithm by use of AAPM TG 119 test cases

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▶ ***Original article***

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ABSTRACT

Background: The objective in this study was to create AAPM TG 119 test plans for Intensity-modulated radiation therapy (IMRT), burst mode and volumetric modulated arc therapy (VMAT) in convolution study in order to investigate accuracy of the United Imaging Healthcare's URT treatment planning system (URT-TPS). ***Materials and Methods:*** The plans were delivered to the phantom using the United Imaging Healthcare's URT-Linac 506C. For there treatment mode as IMRT, Burst Mode and VMAT, with two kind of beams as flattening filter (FF) photon beam and flattening filter free (FFF) photon beam, calculated by uRT-TPS Monte Carlo algorithm, the overall accuracy was measured, and analyzed with five test geometries provided in TG 119. The point measurements were measured by a Farmer type ion chamber and fluence measurements were done with film respectively. ***Results:*** For the FF photon beams, the difference between measured point doses and planned doses of static multi-leaf collimator (MLC), dynamic MLC, Burst Mode and VMAT were within±3.92%,±3.26%, ±4.11%and±3.31% respectively. Gamma passing rates of Static IMRT, Dynamic IMRT Burst Mode and VMAT were >93.08%, 90.93%, 90.40% and> 92.00% respectively. For the FFF photon beams, the deviation between measured point doses and planed dose of static MLC, dynamic MLC, Burst Mode and VMAT were within 1.84%, 3.36%, 2.65%and 3.11% respectively. Gamma passing rates of Static IMRT, Dynamic IMRT Burst Mode and VMAT were>92.60%, 94.07%, 93.54% and 94.39% respectively and all confidence limits of the TG 119 report were matched. ***Conclusion:*** Based on this analysis which were performed in accordance with the TG 119 recommendations, it is evident that the URT treatment planning system and URT-Linac 506C have commissioned IMRT and VMAT techniques with adequate accuracy.

Keywords: *TG 119, dosimetric validation, linac 506C, URT_TPS, flattening filter, flattening filter free*

INTRODUCTION

Intensity-modulated radiation therapy (IMRT) has replaced 3-dimensional conformal radiotherapy (3DCRT) because of its capacity to deliver a more conformal dose to the target and to spare normal structures. This helps the oncologist to escalate the dose to the tumor volume. It can improve the cure rate of cancer and better protect the organs at risk. A lot of scholars have reported that Intensity-modulated radiation therapy has an advantage over three-dimensional conformal radiation therapy (3DCRT) [1, 2]. IMRT plans can be delivered by use of a static multi-leaf collimator (SMLC) and a dynamic multi-leaf collimator (DMLC)

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techniques [3]. Volumetric modulated arc therapy (VMAT) was introduced in radiotherapy with additional degrees of freedom to optimize the dose delivery [4]. During delivery of the beam, VMAT varies the MLC aperture shape, dose rate and gantry speed. IMRT and VMAT allow delivery of highly conformal dose distributions to the tumor with reduced dose to surrounding normal tissue structures. These days IMRT and VMAT are very common treatment modalities throughout the world due to their clinical advantages for various anatomical sites [5]. There are several guidelines and protocols for IMRT and VMAT [6–8], however there is some evidence that IMRT and VMAT treatments may not always be as accurate as practitioners believe.

The Radiological Physics Center (RPC) published the results of 250 irradiation of head and neck phantom and showed that 71 of the 250 irradiations did not meet their basic accuracy requirements [9-11]. The American Association of Physicists in Medicine (AAPM) Task Group (TG) 119 states that the Radiological Physics Center findings strongly suggest that IMRT systems may be incorrectly commissioned [12]. The AAPM has therefore published guidelines for IMRT commissioning, specifically Task Group 119 (TG 119) [12, 13]. In order to establish the tolerance limits, AAPM TG 119 defined the test cases and compared the results of multiple institutions.

The TG 119 report baseline is also helpful to gain confidence limits in new modalities like VMAT. Mynapati *et al.* [14] published a scientific paper in the Journal of Applied Medical Physics to apply the AAPM TG 119 benchmark plans for VMAT. Nithya *et al.* [15] analyzed the performance of the planning system with VMAT technology by use of AAPM TG 119 test cases. Sharma *et al.* [16] studied the VMAT commission for Versa HD linear accelerator using AAPM TG 119. In their study following TG 119, IMRT and VMAT plans were created, which looked at the basic capabilities of VMAT technique by plan comparison of VMAT and IMRT plans. After these studies they made the conclusion of practicability of using TG 119 test cases in creating VMAT benchmark plans.

The uRT-linac 506c medical linear accelerator (United imaging HealthCare co., LTD.) is an innovative type of accelerator which combines diagnostic helical CT with high dose rate intensity modulated accelerator to make it capable to perform precise radiotherapy with high resolution CT image, having capability of adaptive radiotherapy, 4D image guided radiotherapy (IGRT) and so on. Since the diagnostic CT machine is sequentially located behind the accelerator, the couch stepping depth is remarkably longer than that of other counterparts, which demands a more rigid, sturdier and steadier couch compared to its peers.

Aim of this study was to validate the commissioning of URT-Linac 506C and URT-TPS dosimetrically using AAPM TG 119 benchmark plans for Static IMRT, Dynamic IMRT Burst Mode and VMAT plans for FF and FFF beams. Because it is still in the stage of clinical test, we hope that we can make a comprehensive assessment of its performance and provide references for later performance improvement. This equipment is the world's first integrated CT -linac. This study also is the first article on this machine

MATERIALS AND METHODS

uRT-linac 506c medical accelerator

The uRT-linac 506c (United imaging HealthCare co., LTD., Shanghai) is a novel linear accelerator which combines diagnostic helical CT with high dose rate intensity modulated accelerator by locating a diagnostic CT behind the gantry sequentially on the same axis (see figure 1). With this design, it would realize high quality image verification, adaptive radiotherapy and on-line CT simulation and treatment, and so on.

AAPM TG 119

For the validation of IMRT/VMAT the phantom with contoured structure set was downloaded from AAPM website (http://www.aapm.org/pubs/tg119/default.asp) and then transferred to the local square phantom of water equivalent slabs (Gammex Solid Water).

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The size of water equivalent slabs was 30cm L, ×30cm W, ×15cm H. We arranged the solid water blocks in different combinations to make sure the ion chamber measurements could be done at any depth in the AAPM TG 119 report. Five structure sets were Created according toTG 119 report cases namely prostate, head-and-neck (H and N), C-shaped and Multi Target. AAPM TG 119 defines the beam arrangement, IMRT goals, and methods for analyzing the dosimetric results. For these test cases, we generated five treatment plans (namely Static IMRT, Dynamic IMRT Burst Mode and VMAT) on URT-Linac 506C with 120 MLC (United Imaging Healthcare) in the URT treatment planning system (clinical trial version), figure 1. Burst Mode is a semi-dynamic VMAT technology of United Imaging Healthcare. And burst mode is new mode, like simple VMAT, when gantry is rotating, MLC is static with beam is on, and only moves when beam is off. This technology divides every 6 degrees into one unit, of which MLC moves during 2 degrees, and the machine does not produce beams.

For prostate and Multi Target cases, seven fields at 50° intervals from the vertical (0°, 50°, 100°, 150°, 310°, 260° and 210°) and one full arc (179° to 181° with a collimator angle 30°) were chosen for IMRT and VMAT plans respectively. For head-and-neck and C-shaped tests, nine fields at 40° intervals from the vertical (0°, 40°, 80°, 120°, 160°, 320°, 280°, 240° and 200°) for IMRT and two complimentary full arcs were used for VMAT. For all VMAT plans we maintained the collimator angle at ±30° while for IMRT plans 0° collimator angle was applied throughout.

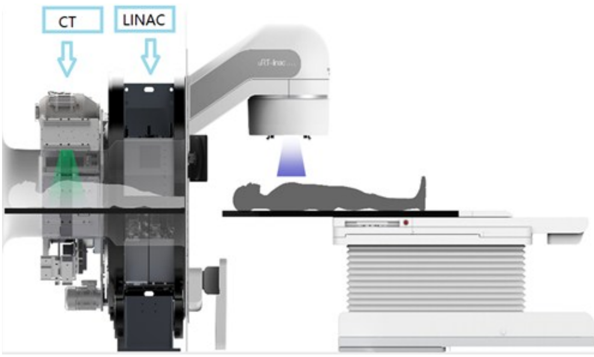

Figure 1. The linear accelerator of United Imaging Healthcare's CT linac URT-Linac 506C.

Point dose measurement

According to the AAPM TG 119, the IMRT and VMAT plans were moved to the solid water phantom and the 0.125cc ionization chamber (PTW TM31010) was used to measure the point dose. When measuring the point dose, the location of the ionization chamber must be considered, because the changes in the submillimeter level may significantly change the results.

The point dose measured by the ionization chamber is compared with the point dose calculated by the treatment plan system. According to the equation 1, in the target area, the results of measurement error should be with 4.5%, in the Organs at Risk (OAR), the results of measurement error should be within 4.7%,

$$discrepancy = \frac{D_{measured} - D_{calculated}}{D_{prescribed}} \times 100\% \quad (1)$$

Where, $D_{measured}$ (cGy), $D_{calculated}$ (cGy) and $D_{prescribed}$ (cGy) are the measured, calculated, and prescribed doses, respectively.

Fluence measurement

GAFCHROMIC TM EBT3-1417 Films and EPSON Expression 11000XL Scanner and IBA OmniPro I"mRT 1.7 software (IBA Dosimetry Germany) were used for the gamma evaluation of the composite dose distribution of the individual plans (both IMRT and VMAT) at different dose planes as specified in the AAPM TG 119 report.

Calibration films were irradiated for each photon energy with a seven 5×5 cm^2 square MU ranging from 0 to 1000 MU (0MU, 50MU, 100MU, 200MU, 400MU, 800MU, 1000MU,). The sampled optical density values of each color channel were then paired with the calculated dose values to establish the calibration curve through a cubic polynomial least squares fitting. The wait time from irradiation to scanning was approximately 24 hrs for postirradiation coloration. An Epson Expression 10000XL document flatbed scanner (Seiko Epson Corp, Nagano, Japan) with Epson Scansoftware was used to scan the films. Each film was scanned in the center of the scanner bed to allow for better scanner response uniformity. The films were

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scanned in transmission mode for better scanning stability with settings of 75 dot-per-inch and 48 bit RGB mode (16 bits per color channel). Images were exported in tagged image file format (TIFF) for analysis and image processing filters were disabled.

When scanned the films using EpsonTM expression 10000XL scanner, we kept all the films in the same direction. The scanned films were evaluated using OminiPro IMRT software using the gamma criteria of 3 % dose difference and 3 mm DTA.

Statistical analysis

Statistical analyses were processed with SPSS® Statistics 19.0 software (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). If p-values<0.05, it was considered statistically significant.

RESULTS

Statistics for primary set planning results across all five planners are presented in table 1-3. Each planner, in this study, had unique selections of planning parameters, but all plans followed the major guidelines, such as beam angles, isocenter point, dose per fraction, etc., as specified in TG 119. Because the TPS in this paper is only a clinical trial version, its performance is not yet finalized, so it is difficult to complete the C shape (hard) in the test.

Treatment plan statistics

Figure 2 shows the test structures of these CT's superimposed upon a set of water-equivalent slab phantom. TG 119 problem set consists of five structure sets namely test Prostate, Multi Target, Head-and-neck (H and N), C-shaped (easy) and C-shaped (hard). All plan results for SMLC, DMLC, Burst Mode & VMAT plans achieved the planning goals except the D10 parameter of C-shaped (hard).

Planning results

All treatment planning results for Multi target, Prostate, Head and Neck, C shape Easy and C shape Hard are listed in the tables 1. The C shape (Hard) core D10 dose was similar to the mean value (1630) from the nine institutes, however still could not achieve the goal (<1000) set by TG 119 protocol, just like the other nine institutes. Meanwhile, all other parameters have been achieved following TG119 protocol in our clinic.

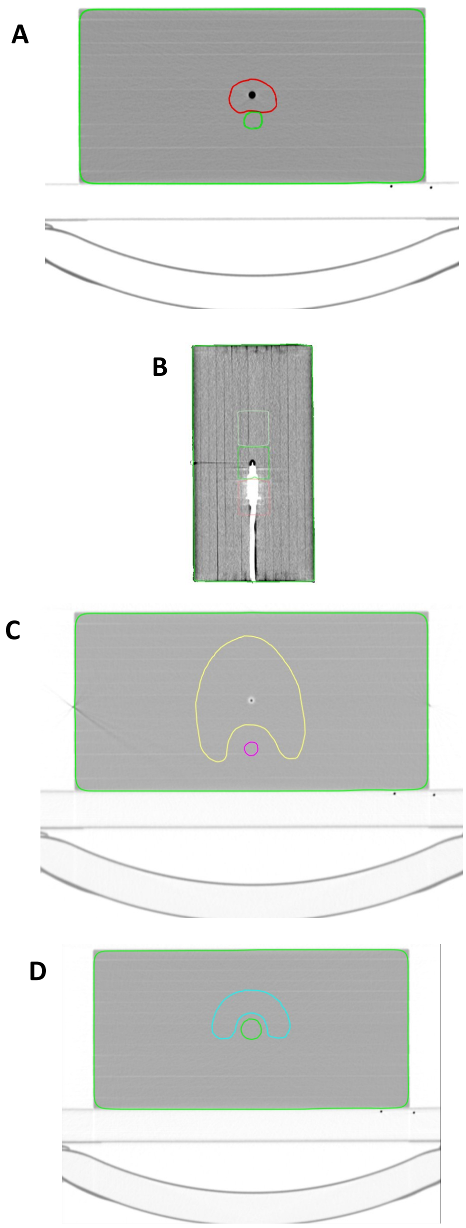

Figure 2. The test structures of Prostate **(A)**, Multi Target **(B)**, Head-and-neck **(C)** and C-shaped **(D)**.

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Table 1. Treatment plan statistics with results for SMLC, DMLC, Burst Mode and uArc plans of FF and FFF mode.

Case	*Location*	Parameter	Goal (cGy)	FF				FFF			
				SMLC (cGy)	DMLC (cGy)	Burst Mode (cGy)	VMAT (cGy)	SMLC (cGy)	DMLC (cGy)	Burst Mode (cGy)	VMAT (cGy)
Multi Target case	Center	D99	>5000	5003.14	5000.33	5017.16	5001.87	5001.98	5001.265	5003.76	5000.46
		D10	<5300	5253.13	5233.63	5277.52	5293.43	5268.93	5296.41	5298.52	5276.10
	Superior	D99	>2500	2678.07	2593.72	2686.58	2649.02	2550.42	2558.45	2616.00	2609.19
		D10	<3500	3301.66	3460.72	3487.07	3404.66	3363.84	3429.43	3432.70	3395.30
	Inferior	D99	>1250	1465.11	1535.37	1420.04	1295.67	1404.23	1534.31	1390.59	1321.55
		D10	<2500	2270.35	2363.88	2303.06	2195.67	2259.27	2368.46	2275.22	1983.44
Prostate case	PTV	D95	>7560	7663.12	7638.90	7591.68	7913.41	7562.09	7575.00	7562.35	7562.11
		D5	<8300	8138.12	8244.84	8265.68	8235.60	8187.29	7919.84	7888.15	8003.23
	Rectum	D30	<7000	6366.55	6173.16	6496.17	6699.07	6618.70	6392.57	6344.57	6552.58
		D10	<7500	7430.71	7360.99	7238.75	7361.03	7264.77	7475.23	7219.67	7133.85
	Bladder	D30	<7000	5020.51	4083.54	4700.18	3838.80	4064.14	4076.30	4038.55	4071.89
		D10	<7500	6978.53	5901.38	6551.25	5774.49	5921.57	5790.29	5759.94	5869.32
Head-and-neck case	PTV	D90	>5000	5032.91	5025.01	5100.05	5100.04	5029.94	5052.79	5126.43	5003.93
		D99	>4650	4792.39	4747.27	4762.67	4808.88	4652.20	4708.39	4699.13	4826.49
		D20	<5500	5466.11	5490.39	5487.27	5442.50	5484.44	5463.00	5378.54	5322.92
	Cord	Max	<4000	3895.89	3964.23	3934.44	3963.14	3948.47	3854.04	3990.32	3790.03
	Left Parotid	D50	<2000	1631.92	1599.67	1639.88	1651.26	1754.19	1891.17	1762.68	1963.75
	Right Parotid	D50	<2000	1666.21	1542.89	1682.53	1613.1	1829.11	1964.93	1723.58	1988.09
C-shaped case(easy)	PTV	D95	>5000	5029.05	5009.67	5020.18	5019.78	5009.63	5009.50	5029.48	5036.20
		D10	<5500	5462.80	5384.87	5473.46	5448.27	5442.14	5421.28	5399.81	5453.21
	Core	D10	<2500	2267.49	2053.70	2071.77	2325.57	2237.11	2385.16	2491.39	2348.44
C-shaped case(hard)	PTV	D95	>5000	5032.14	5014.58	5006.92	5011.48	5005.52	5004.33	5016.32	5014.78
		D10	<5500	5487.51	5489.29	5487.29	5491.28	5452.94	5448.84	5459.52	5473.95
	Core	D10	<1000	1435.98	1658.82	1749.67	1628.93	1743.78	1628.87	1687.37	1487.23

The point dosimetry measurement results for different test cases

High and low dose point measurement (inside the target) results are summarized in table 2. For the SMLC plan, all the prostate, head -and-neck (H and N), C-shaped (easy and hard) and Multi Target of FF and FFF plans achieved the planning goals. Measured point doses of high and low dose regions of SMLC were within 3.92% and 1.84% corresponding to the CL of 0.051 and 0.038 respectively. For the DMLC plan, all cases achieved the planning goals. Measured point doses of high and low dose regions of FF and FFF DMLC plans were within 3.26% and 4.18% corresponding to the CL of 0.044 and 0.045 respectively. For the Burst Mode plan, all cases achieved the planning goals. Measured point doses of high and low dose regions of FF and FFF DMLC plans were within 4.11% and 2.65% corresponding to the CL of 0.065 and 0.046 respectively. For the VMAT plan, all cases achieved the planning goals. Measured point doses of high and low dose regions of FF and FFF DMLC plans were within 3.96% and 3.11% corresponding to the CL of 0.064 and 0.046 respectively.

Gamma analysis

Gamma analysis was done for 3% dose difference and 3 mm distance to agreement. For the FF photo beams and FFF photo beams, the mean percentage of gamma passing with 3%/3 mm passing criteria were higher than 90.93%. The CL of FF and FFF photo beams were below 6.300, which however recommended in TG 119 was 12.4.

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Table 2. Point Dosimetry Results in High and Low Dose Regions of SMLC, DMLC, Burst Mode and uArc of FF and FFF mode.

Case	Location	FF				FFF			
		SMLC	DMLC	Burst Mode	uArc	SMLC	DMLC	Burst Mode	uArc
Multitarget	Isocenter	-0.22%	0.27%	-0.96%	-1.64%	-0.73%	1.02%	-1.41%	2.10%
Multitarget	4 cm superior to isocenter	-0.41%	-0.41%	-0.49%	-1.90%	-0.61%	2.39%	-0.48%	-0.73%
Multitarget	4 cm inferior to isocenter	-0.81%	0.18%	1.95%	-1.66%	-1.04%	1.56%	0.08%	-1.15%
Prostate	Isocenter	-2.58%	-0.03%	-0.06%	0.73%	-1.00%	1.79%	-0.50%	0.54%
Prostate	2.5 cm posterior to isocenter	-2.34%	1.28%	-2.30%	-3.69%	-1.84%	3.23%	0.90%	0.31%
Head neck	Isocenter	-3.92%	-1.93%	-0.49%	-2.37%	0.93%	1.41%	-2.27%	-1.17%
Head neck	4 cm posterior to isocenter	-3.46%	1.29%	-1.55%	-0.56%	1.28%	4.18%	0.55%	1.54%
C-shaped case (easy)	Isocenter	2.37%	3.26%	-2.90%	3.31%	1.63%	3.10%	1.47%	1.09%
C-shaped case (easy)	2.5 cm anterior to isocenter	1.93%	1.90%	-4.11%	-0.96%	0.57%	3.36%	1.37%	3.11%
C-shaped case (hard)	Isocenter	2.34%	2.74%	1.98%	-2.29%	1.35%	-1.45%	2.59%	2.13%
C-shaped case (hard)	2.5 cm anterior to isocenter	1.94%	1.83%	3.00%	2.56%	1.82%	2.28%	2.65%	2.93%
Mean		-0.47%	0.94%	-0.54%	-0.77%	0.21%	2.08%	0.45%	0.97%
Standard deviation		0.024	0.015	0.022	0.022	0.013	0.015	0.016	0.015
Confidence limit = |Mean|± 1.96*σ		0.051	0.044	0.065	0.064	0.038	0.045	0.046	0.046

Table 3. Gamma Analysis (3%/3mm) Results of SMLC, DMLC, Burst Mode and uArc of FF and FFF mode.

		FF				FFF			
Case	Location	SMLC	DMLC	Burst	uArc	SMLC	DMLC	Burst	uArc
Multitarget	Isocenter	96.45%	90.93%	92.46%	97.63%	92.78%	98.53%	98.12%	98.66%
Prostate	Isocenter	92.61%	95.86%	94.09%	93.28%	97.64%	94.07%	99.64%	97.67%
Head neck	Isocenter	95.75%	93.98%	95.27%	92.00%	95.77%	98.90%	96.62%	98.34%
Head neck	4 cm posterior to isocenter	95.77%	91.97%	94.50%	96.60%	99.02%	98.93%	99.11%	96.60%
C-shaped case (easy)	Isocenter	93.08%	94.51%	90.40%	96.64%	94.41%	99.43%	96.50%	98.85%
C-shaped case (easy)	2.5 cm anterior to isocenter	98.24%	91.92%	93.58%	97.47%	92.60%	94.11%	93.54%	97.76%
C-shaped case (hard)	Isocenter	93.43%	94.25%	97.57%	95.45%	94.29%	96.73%	98.03%	96.47%
C-shaped case (hard)	2.5 cm anterior to isocenter	95.38%	96.49%	96.72%	95.28%	95.38%	96.52%	94.39%	94.39%
Mean		95.09%	93.74%	94.32%	95.54%	95.24%	97.15%	96.99%	97.34%
Standard deviation		0.019	0.020	0.023	0.020	0.022	0.022	0.022	0.015
CL= | 100-mean | + 1.96σ		4.949	6.300	5.721	4.496	4.808	2.890	3.049	2.686

DISCUSSION

The planning results for the different test cases shown in table 1 indicate that our clinic has met the dose goals specified in TG 119. We also provide a ratio between our planning results and the benchmark values of TG 119. Different DX (D5, D10, D20, D30, D95, and D99) of IMRT and VMAT plans are comparable to AAPM TG 119 plans.

Our results were similar to Kadam A *et al.*'s data, [17] and all of us tested single energy (IMRT, 6 MV). All criteria meet or even exceed the requirements of TG 119. The C shape (Hard) core D10 dose was similar to the mean value (1630) from the nine institutes, however still

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could not achieve the goal (<1000) set by TG 119 protocol, just like the other nine institutes, which were same with Zhang *et al.* [13]. Meanwhile, all other parameters have been achieved following TG119 protocol in our clinic.

It is necessary to evaluate the accuracy of the IMRT and VMAT system before performing clinical treatment [18, 19]. TG 119 test suite is helpful in evaluating commission of planning and delivery. We set CL as a benchmark for commission and QA for IMRT and VMAT system with different energy beams and the results help us gain confidence in the accuracy of the treatment. Based on these measurements above and the following analysis of the results, it is obvious that the CLs obtained in our institute are superior to the benchmark recommended by the TG 119. The mean CLs for this accelerator ranged from 0.038 to 0.065 which sMLC, Burst Mode and VMAT for FF were less than what the TG119 recommended (CLs of 4.7 %) low dose region. Meanwhile, all other parameters have been achieved following TG119 protocol in our clinic. For the FF photo beams and FFF photo beams, the mean percentage of gamma passing with 3%/3 mm passing criteria were higher than 90.93%. The CL of FF and FFF photo beams were below 6.300, Kadam A. *et al.* [17], Zhang *et al.* [13] and Kaviarasu *et al.* [19] obtained the same result as ours, which the recommended in TG 119 was 12.4. While our γ passing rates for test cases were lower than those in studies of Zhang *et al.* [13] Our results were similar to Kadam and Sharma's data,[17] and all of us tested single technology and single energy (IMRT, 6 MV). Kaviarasu *et al.* [18] reported results similar to ours.

In addition, the planning depends on the experience of the planners to some extent. TG 119 has been presented as a practical tool to evaluate the quality of an IMRT system as a part of the commissioning process. Although its results cannot pinpoint the source of the error, the CL of TG 119 is expected to help physicists determine whether the system can be applied for clinical practice [20].

In this paper, we study the domestic accelerator that was still in the clinical trial stage. This article can make a comprehensive assessment of its performance and provide some guidance for the improvement of performance. As for the TPS in this paper was only a clinical trial version, its performance was not yet at its final state, so it was difficult to implement the C shape module (hard) in the test, but otherwise the cases have met the TG 119 report. The TG 119 report provided the optimization results of 10 hospitals using commercial TPS. Some hospital showed that PTV D95 was (5011±16.5) cGy, D10 was (5702±220) cGy, Core D10 was (1630±307) cGy. From the above average value, 3 goals cannot meet TG 119 report. Therefore, it can be seen that the setting of the test condition itself is stricter and more difficult to be met. For all plans, the planning results matched TG 119 planning results. The deviation of measured point doses of Static IMRT, Dynamic IMRT Burst Mode and VMAT and planned doses were within 4.11%. Measured film dosimetry gamma passing rates of Static IMRT, Dynamic IMRT Burst Mode and VMAT were >90.93%.

CONCLUSION

Based on this analysis which were performed in line with the TG 119 recommendations, it is evident that the URT treatment planning system and URT-Linac 506C have commissioned Static IMRT, Dynamic IMRT Burst Mode and VMAT techniques with adequate accuracy.

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