QUALITY ASSURANCE OF MEDICAL LINEAR ACCELERATOR USING TG-142

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Abstract— **Quality control (QC) is a process that focuses on detecting mistakes, errors, or missed requirements in a medical linear accelerator. AAPM Task Group-142 (TG-142) is a collaborative effort established by the American Association of Physicists in Medicine (AAPM). The primary purpose of TG-142 is to develop and publish guidelines for Quality Assurance (QA) of medical accelerators used in radiotherapy.**

Keywords— **Multi-Leaf Collimator, Quality Assurance, Cone Beam CT, Electronic Portal Imaging Device**

I. INTRODUCTION

Quality Assurance is defined as a process through which the actual performance of the equipment is measured and compared with the existing standard or reference value (baseline value), and actions necessary to keep or regain uniformity with these standards are taken. The primary purpose of TG-142 is to develop and publish guidelines for Quality Assurance (QA) of medical accelerators used in radiotherapy. Quality Assurance is a broad process for preventing quality failures. The QA team is involved in all product development stages, production, testing, packaging, and delivery.

The AAPM TG-40 report, published in 1994, is widely used as reference document that includes recommendations for general quality assurance (QA) tests for medical linear accelerators. Since the publication of TG-40, several new technologies have been developed and are now commonly used in clinical practice. These technologies include Multi-Leaf Collimation (MLC), asymmetric jaws, dynamic and virtual wedges, and electronic portal imaging devices(EPIDs). Image guidance devices such as cone-beam CT(CBCT), static kilovoltage (kV) imaging, and respiratory gating were rarely used in 1994. The purpose of this report is to build upon the recommendations of TG-40 for QA of medical linear accelerators, including the aforementioned technologies (MLC, newer wedge systems, asymmetric jaws, imaging systems, and respiratory systems) and procedures such as SRS, SBRT, TBI, and IMRT. During the development of this report, an investigation of technologies that deliver MLC-based IMRT with simultaneous gantry rotation had just begun, and therefore, QA for these technologies is not included in the report.

The need for TG-142 arose from the recognition that medical accelerators play a crucial role in radiation therapy. Precise and accurate delivery of radiation to target tissues is essential for effective treatment while sparing healthy surrounding tissues. Any errors or malfunctions in medical accelerators can have serious consequences for patients' safety and treatment outcomes. Therefore, AAPM Task Group 142 was convened to create a comprehensive set of guidelines and recommendations for the Quality Assurance of Medical accelerators.

The ultimate goal of AAPM TG-142 is to enhance patient safety and treatment efficacy by establishing standardized QA protocols that medical physicists and radiation therapy teams can follow to ensure the reliable and accurate performance of medical accelerators.

The recommendations of this report are summarized in tables. The first three tables, Table (daily), Table (monthly), and Table (annual). Each table has specific recommendations based on the nature of the treatments delivered on the individual machine. The tables are differentiated into non-IMRT or non-Stereotactic machines, IMRT machines, and IMRT/ stereotactic machines. Three additional tables were created for Dynamic/ Virtual/ Universal wedges (Tables), MLC (Tables), and Imaging (Tables). This task group (TG) considers that all of the tests included in the tables are important for ensuring the equipment is suitable for high-quality and safe radiation treatments. A consistent beam profile is an important quantity for accurate and reproducible dose delivery in radiotherapy. Beam uniformity was addressed in TG-40 with flatness constancy.

The expansion of tests is also justifiable because, since TG-40 and post-IMRT, the selection of available QA tools makes annual testing less burdensome; these tools range from 3D water scanning tanks to large area detector arrays. The proper tools should be chosen by matching the detectors and software to the needs and sensitivity requirements.

This study aimed to perform and analyse a medical linear accelerator's Quality Assurance (QA) test using TG-142. TG-142 aims to ensure the entire radiation therapy process, from imaging to treatment delivery.

II. MATERIALS AND METHOD

The study was performed on the True Beam Varian Medical System (SN-4378) machine with photon energies 6MV, 10MV and 15MV (6FFF, 10FFF), and electron energies 6MeV, 9MeV, 12MeV, 15MeV, 18MeV and 20MeV.

Dosimetry checks for daily QA were performed in the slab phantom, monthly in the water phantom (30×30×30 cm^3), and annually in RFA. Other equipment are ionization chambers, electrometers, dosimetry phantoms, lasers and alignment tools, beam quality analyzers, imaging devices, phantom positioning devices, water tanks, multi-leaf collimator (MLC), radiation detectors and probes, radiation survey meters, software systems, thermometer, barometer, spirit level.

Daily QA Set-up:

Daily QA focuses on quickly verifying the overall functionality and stability of the treatment delivery system. It ensures that the treatment machine is in a suitable condition for patient treatments each day. It helps catch any sudden malfunctions or changes that could impact treatment accuracy. The daily QA typically includes checks on basic parameters such as beam output, beam symmetry, and mechanical stability.

Fig. 1: Set-up for daily QA

Monthly QA Set-up:

Monthly QA comprised gantry, collimator and table (couch) spoke test; Radiation and light field congruence; X-ray output constancy and electron output constancy; and Beam quality index measurement.

Fig. 2: Set-up and images for monthly QA

Annual QA RFA Set-up:

The annual QA measurements include bean quality index, PDD curves, MLC and imaging tests, leaf test, output calibration, beam profile, dose rate – gantry speed test.

NOTE: This QA report is as per the recommendations of AERB Safety Code No. AERB/RF-MED/SC-1(Rev.1) March-2011 and AAPM Report TG-142.

Fig. 2: Set-up and images for annual QA

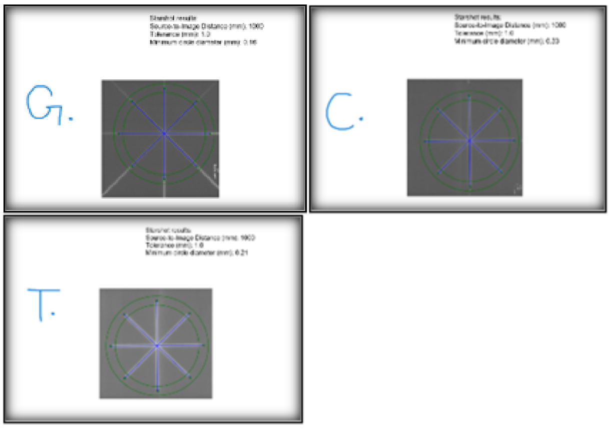
III. RESULTS AND DISCUSSION

Daily output consistency:

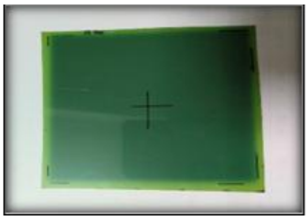
	Energy	MR (nC)	CORR. MR(nC)	DEV (%)
Output Consistency Photons	6 X	17.89	18.01	1.01%
	6 FFF	17.45	17.57	1.27%
	10 X	19.20	19.33	1.20%
	10 FFF	18.64	18.77	1.18%
	15 X	19.67	19.81	1.07%
Output Consistency Electrons	6 E	20.49	20.63	1.13%
	9 E	19.94	20.08	1.41%
	12 E	20.85	20.99	1.30%
	15 E	21.98	22.13	1.28%
	18 E	22.93	23.09	1.09%
	20 E	23.32	23.48	1.25%

Monthly QA:

Gantry, collimator and table (couch) spoke test:



Radiation and light field congruence:



Energy	Optical F.S.	Radiation F.S.	% Difference
6 MV	10×10 cm2	10×10 cm^2	0.0

X-ray and Electron output constancy tests

Energy	Measured Output	Base Line	% Deviation
6 MV	101.62	100cGy/100MU	1.62
10 MV	101.82	100cGy/100MU	1.82
15 MV	101.87	100cGy/100MU	1.87
6 FFF	101.76	100cGy/100MU	1.76
10 FFF	101.56	100cGy/100MU	1.56
6 MeV	100.45	99.10cGy/100MU	1.36
9 MeV	100.62	98.36cGy/100MU	2.29
12 MeV	100.08	98.63cGy/100MU	1.46
15 MeV	100.00	98.56cGy/100MU	1.45
18 MeV	100.02	99.20cGy/100MU	0.87
20 MeV	101.17	99.04cGy/100MU	2.146

Beam Quality Index Measurement:

Energy	6 MV	10 MV	15 MV	6 FFF	10 FFF
Baseline	0.665	0.739	0.763	0.630	0.707
MR@20cm Depth	11.03	13.80	14.88	9.823	12.43
	11.01	13.78	14.88	9.822	12.42
	11.01	13.74	14.86	9.823	12.42
Avg.	11.01	13.77	14.87	9.822	12.42
MR@10cm Depth	16.59	18.68	19.55	15.69	17.68
	16.60	18.66	19.53	15.68	17.66
	16.60	18.67	19.54	15.65	17.67
Avg.	16.59	18.67	19.54	15.67	17.67
TPR20/10	0.663	0.735	0.761	0.626	0.703

Annual QA:

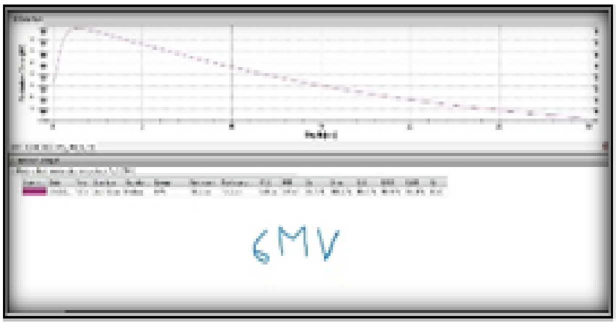
Beam Quality Index

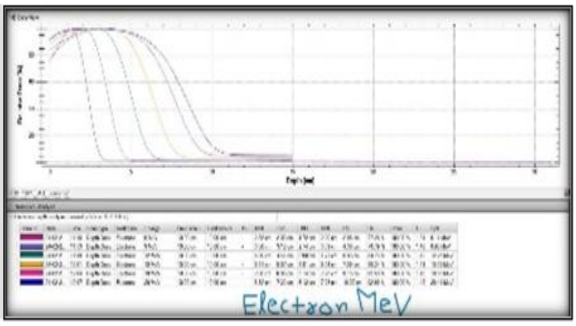
Energy	TPR10 (10cm depth)	TPR20 (20cm depth)	TPR (20/10)	Reference	Tolerance (from baseline)
6 MV	16.83	11.17	0.664	0.665	±1%
10 MV	19.01	14.01	0.736	0.739	± 1%
15 MV	19.54	14.87	0.761	0.763	± 1%
6 FFF	15.673	9.822	0.627	0.630	± 1%
10 FFF	17.67	12.425	0.703	0.707	± 1%

PDD Curves:

Photon PDDs					
Energy	Dmax	D_{10}(cm)	Q index	Reference	Tolerance
6 MV	1.48	66.14 %	0.575	1.6±0.15	± 1mm
10 MV	2.34	73.83 %	0.631	2.4±0.15	± 1mm
15 MV	2.83	76.92 %	0.651	2.9±0.15	± 1mm
6 FFF	1.38	63.14 %	0.547	1.5±0.15	± 1mm
10 FFF	2.23	71.36 %	0.606	2.34±0.15	± 1mm

ELECTRONS Pdds						
Energy	Dmax	R_{50}	Tolerance	R_{90}	R_{80}	Z ref
6MeV	1.29	2.33	± 5 mm	1.72	1.92	1.30
9MeV	2.02	3.56	from	2.74	3.00	2.04
12MeV	2.86	4.99	Base line	3.90	4.26	2.89
15MeV	3.58	6.31		4.91	5.39	3.69
18MeV	2.75	7.60		5.74	6.40	4.46
20MeV	2.74	8.32		6.12	6.92	4.89





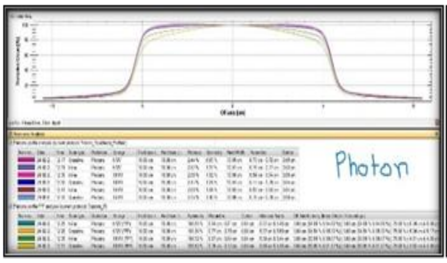
Leaf Speed Test:

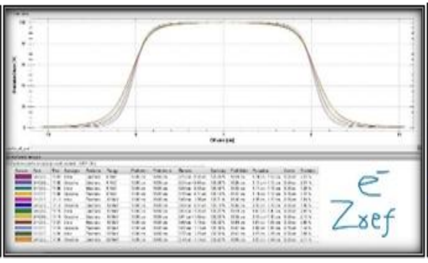
Image Analysis Using (10 cm × 0.5 cm) ROI					
Leaf Speed Test					
Band No.	-4.5 cm	-1.5 cm	1.5 cm	4.5 cm	Threshold
R(ls)	0.171	0.17	0.17	0.17	
R(open)	1.232	1.25	1.25	1.23	
R(corr.)	13.88	13.86	13.86	13.79	
Diff(X)	0.07	0.13	0.18	-0.39	<±3%
Average of Absolute Deviations [Diff.(abs)]				0.19	<1.5%

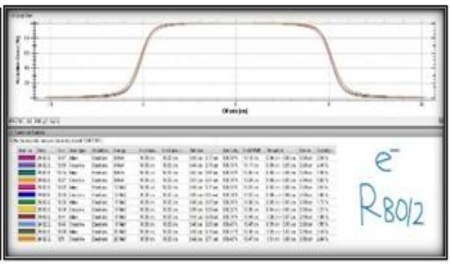
Output Calibration (TRS-398):

Energy	$K_{q\,q_o}$	Kt p	Ks	Kpol	Avg. MR (nC)	PPD at 10 Cm %	Ndw x10^8 Gy/C	O/P Dmax %	% Variation
6 MV	0.996	0.999	1.0	1.0	13.83	66.3	4.82	100.4	0.42
10 MV	0.985	0.999	1.0	1.0	15.53	73.7	4.82	100.3	0.37
15 MV	0.980	0.999	1.0	1.0	16.24	76.8	4.82	100.5	0.51
6 FFF	0.998	0.999	1.0	1.0	13.11	63.2	4.82	100.4	0.45
10 FFF	0.991	0.999	1.0	1.0	14.75	71.2	4.82	100.4	0.41
6 MeV	0.94	1.0	1.0	1.0	11.95	99.8	8.84	99.96	0.04
9 MeV	0.92	1.0	1.0	1.0	12.22	99.9	8.84	100.3	0.31
12 MeV	0.91	1.0	1.0	1.0	12.35	99.9	8.84	99.98	0.02
15 MeV	0.90	1.0	1.0	1.0	12.42	99.6	8.84	99.98	0.02
18 MeV	0.89	1.0	1.0	1.0	12.33	98.1	8.84	99.99	0.01
20 MeV	0.89	1.0	1.0	1.0	12.30	96.9	8.84	100.5	0.55

Beam Profile:







Energy	Separation between IPL & IPR cm	X - 90% cm	X-75% cm	X - 60% cm	Symmetry %	Left Penumbra (cm)	Right Penumbra (cm)
6 FFF (In plane)	10.84	4.04 4.02	5.12 5.12	5.30 5.28	0.91	0.85	0.82
6 FFF (Cross plane)	10.88	4.09 4.09	5.10 5.10	5.32 5.32	0.62	0.78	0.75
10 FFF (In plane)	10.86	3.19 3.16	4.87 4.63	5.21 5.19	0.38	0.87	0.84
10 FFF (Cross plane)	10.82	3.15 3.21	4.87 4.90	5.22 5.23	0.75	0.79	0.77

Dose Rate- Gantry Speed:

Image Analysis Using (10 cm × 0.5 cm) ROI								
Dose Rate- Gantry Speed Test								
Band No.	-6cm	-4cm	-2cm	0.0cm	2cm	4cm	6cm	Threshold
R(dr_gs)	0.60	0.61	0.61	0.61	0.61	0.61	0.60	
R(open)	4.08	4.19	4.19	4.19	4.20	4.20	4.06	
R(corr.)	14.90	14.67	14.70	14.72	14.73	14.7	14.8	
Diff(X)	0.92	-0.62	-0.38	-0.25	-0.22	0.08	0.64	<±3%
Average of Absolute Deviations [Diff.(abs)]							0.45	<1.5%

The results for daily output photon constancy were 1.15±0.11% (mean ±SD), and daily output electron constancy was 1.24±0.13 (mean ±SD). The measured values for monthly output photon consistency were 1.73±0.13% (mean ±SD), and monthly output electron consistency was 1.60±0.53 (mean ±SD). The results for annual output photon consistency were 0.43±0.05% (mean ±SD), and annual output electron consistency was 0.16±0.22 (mean ±SD). The calculated values for Beam Quality Index (TPR20/10) were 0.70±0.05 (mean ±SD) of annual & monthly. MLC leakage test and MLC leaf speed test were calculated as Max 2.91% (Tol: ±5.0%) and average of absolute deviations 0.19% (Threshold: ±1.5%), respectively.

All results are within tolerance limits as per TG-142 protocols. Machine performance data are in the tolerance range.

IV. CONCLUSION

These records show the activities conducted and serve as a reference to follow up on any changes and issues that may affect patient care.

V. ACKNOWLEDGEMENTS

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REFERENCES

1. TG-40, TG-100, TG-142. Eric E. Klein (Washington University, St. Louis, Missouri), Joseph Hanley (Hackensack University Medical Center, Hackensack). TG-142 was constituted by the AAPM-Science Council-Therapy Physics Committee-Quality Assurance and Outcome Improvement Subcommittee.

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