QUALITY ASSURANCE CHECKS FOR KV X-RAY SOURCES AND DETECTORS USED IN CYBERKNIFE

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Abstract— **This current work aims to present the performance evaluation procedures implemented at our department for the Quality Assurance of kV X-ray sources and detectors of the Cyberknife M6 system. The performance of the target locating system was evaluated in terms of the mechanical and radiation accuracy of both cameras and detectors. AAPM Report 74 is used to perform QA tests, including filtration, kVp accuracy, mA station exposure linearity, exposure reproducibility, and focal spot size. A multimeter device is used to check the above parameters. Image position reproducibility is verified with the help of Isopost, Bad pixel statistics and leakage measurement of X-ray sources are also performed. The kVp accuracy is within ±5 kVp. The variation in mA station exposure linearity is < 0.1. The variation in exposure reproducibility is ≤ 0.05. The minimum filtration of the X-ray tube is also within the tolerance limit. The Imager position reproducibility is (0.0, 0.0) (Tolerance: ±1 mm). The leakage measurement is not more than 114 mR in 1 hour. The study concludes that the imaging system in Cyberknife is safe for both patients and staff.**

Keywords— **Quality Assurance, Isopost, Bad pixel, SNR, CNR, Gain stability.**

I. INTRODUCTION

In Stereotactic Radiosurgery (SRS) and Stereotactic Body Radiation Therapy (SBRT), single or multiple fractions of a high radiation dose are delivered to a well-defined small target. SRS has become an important treatment modality in the management of a wide variety of intracranial and extracranial lesions, offering the possibility of a significant reduction in dose to critical healthy tissues with substantial benefits to patients. The CyberKnife SRS system is a frameless radiosurgery device that combines image guidance with robotic technology, aiming at the delivery of highly conformal dose distributions to intracranial and extracranial lesions with a standard uncertainty of < 1 mm.

The facility where the study was performed has a Cyberknife M6 machine with a standard couch and G4 on floor imagers, which contains a-Si detector. The X-ray sources are a conventional rotating anode tube. It has 2.5 mm of Al added filtration on the window side. The X-ray generators supplying high voltage power operate at 37.5 kW at peak power output and can deliver X-rays with technique factors of 40-125 kV, 40-300 mA, and 1-500 ms. The QA principles and procedures described in AAPM Reports No. 14, Part 3 (Ref 23), and No. 74 of Task Group 12 (Ref 24) can be applied. TG-135 is also used for the QA tests.

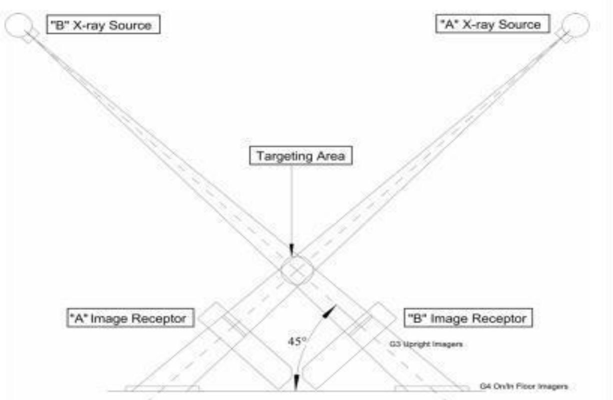

Figure 1: The Geometry of an image-guided X-ray system. This view has the head of the couch looking toward the patient

II. MATERIALS AND MEDTHODS

In this study, QA tests were performed for different parameters for kV X-ray tubes. The tests performed are filtration, kVp Accuracy, mA station exposure linearity, exposure reproducibility, focal spot size, imager position reproducibility, and bad pixel statistics. For the measurement, solid-state detector and the multimeter were used (Figures 2 – 7). For imager position reproducibility and bad pixel statistics, Field Service Engineer was contacted. In the radiation test SID was set to 100 cm.

Figure 2: Solid State Detector

Figure 3: RaySafe Multimeter

III. RESULTS

Results of the study are presented in Tables 1 – 12.

kVp Accuracy

Tolerance: ± 5 kVp

Table 1: For X-ray tube A

Applied kVp	Applied mAs	Measured kVp	Average
60	20	59.82	59.9
	32	60.14	
	40	59.75	
70	20	69.96	71.37
	32	72.69	
	40	71.45	
90	20	93.27	93.11
	32	92.82	
	40	93.25	

Table 2: For X-ray tube B

Applied kVp	Applied mAs	Measured kVp	Average
60	20	55.95	58.58
	32	59.97	
	40	59.82	
70	20	70.41	70.26
	32	70.04	
	40	70.33	
90	20	93.65	93.76
	32	93.75	
	40	93.88	

Filtration

Minimum filtration of the X-ray tube is:
1.5 mm of Al for kV ≤ 70
2.0 mm of Al for 70 ≤ kV ≤ 100
2.5 mm of Al for kV > 100

Table 3: For X-ray tube A

Applied kVp	Measured value
110	3.5 mm of Al

Table 4: For X-ray tube B

Applied kVp	Measured value
110	3.7 mm of Al

mA Station Exposure Linearity

Table 5: For X-ray tube A

Applied kVp	Applied mA	Measured mGy	Average mGy	mGy/mA
90	50	0.286	0.29033	0.005807
		0.294		
		0.291		
	100	0.529	0.526	0.00526
		0.521		
		0.528		

CoL: 0.04

Table 6: For X-ray tube B

Applied kVp	Applied mA	Measured mGy	Average mGy	mGy/mA
90	50	0.265	0.269	0.00538
		0.269		
		0.273		
	100	0.52	0.51633	0.0051633
		0.512		
		0.517		

CoL: 0.02

Exposure Reproducibility

Tolerance: 0.1

Table 7: For X-ray tube A

Applied kVp		60	50
Applied mAs		70	50
Radiation Output (mAs)	1	0.111	0.15
	2	0.109	0.157
	3	0.117	0.149
	4	0.121	0.152
	5	0.113	0.159
Average		0.114	0.153
CoV		0.042	0.029

Table 8: For X-ray tube B

Applied kVp		60	70
Applied mAs		50	50
Radiation Output (mAs)	1	0.104	0.161
	2	0.107	0.162
	3	0.105	0.162
	4	0.108	0.168
	5	0.107	0.165
Average		0.106	0.164
CoV		0.015	0.018

Focal Spot Size

Tolerance: +0.5f for f < 0.8 mm
+0.4f for 0.8 < f < 1.5 mm
+0.3f for f > 1.5 mm

Table 9: For X-ray tube A

Focus	Stated value (mm × mm)	Measured value (mm × mm)
Small	0.6 × 0.6	0.6 × 0.6
Large	1.2 × 1.2	1.2 ×1.2

Table 10: For X-ray tube B

Focus	Stated value (mm × mm)	Measured value (mm × mm)
Small	0.6 × 0.6	0.6 × 0.6
Large	1.2 × 1.2	1.2 ×1.2

Imager Position: (Tol: ± 1 mm) Reproducibility

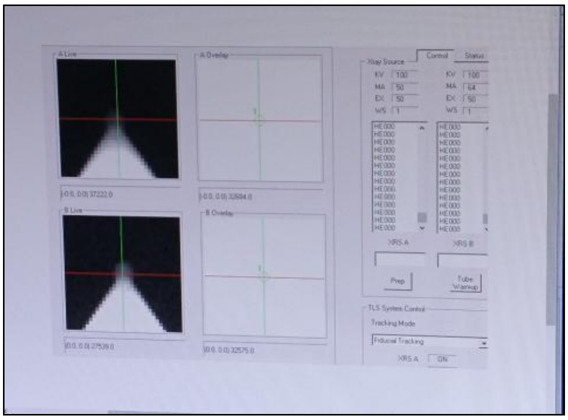

Figure 4: For X-ray tube A

Co-ordinates: (0.0,0.0)

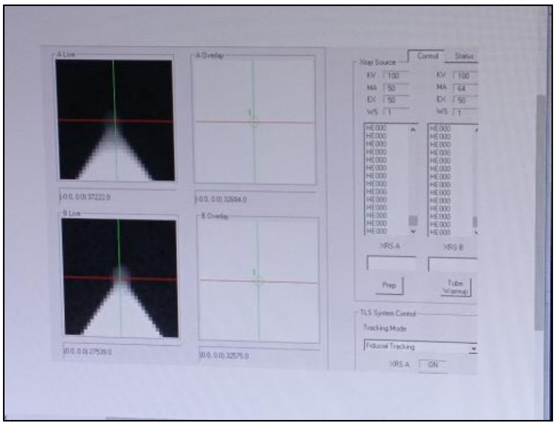

Figure 5: For X-ray tube B

Co-ordinates: (0.0,0.0)

Bad Pixel Statistics

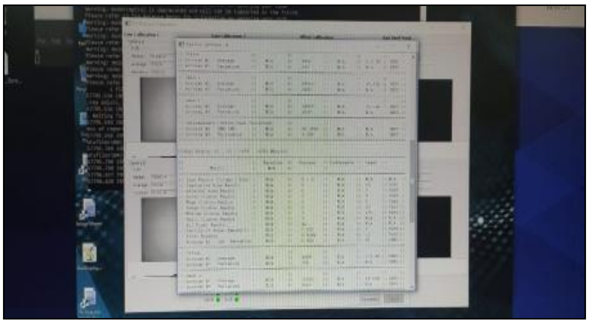

Figure 6: For X-ray tube A

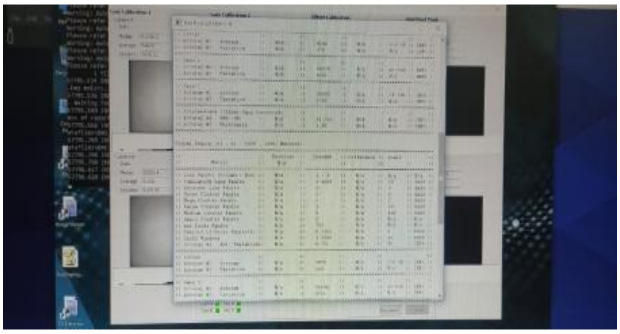

Figure 7: For X-ray tube B

Leakage measurement

Table 11: For X-ray tube A

Location	Exposure level (mR/hr)					Result
	Left	Right	Front	Back	Top	
Tube	1.3	1.9	1.0	1.0	1.0	Pass

Table 12: For X-ray tube B

Location	Exposure level (mR/hr)					Result
	Left	Right	Front	Back	Top	
Tube	1.6	1.6	1.0	1.7	1.0	Pass

Since the Cyberknife machine is used for stereotactic treatment of intracranial and extracranial lesions with higher doses per fraction, with the intent to achieve ablation. To achieve this goal, intrafraction imaging plays an important role. For this purpose, images of the initial patient set up and during treatment can also be taken at short intervals with the help of in-room imaging system. But due to mechanical or radiation errors, there are chances to get inferior quality images, which can result in excessive dose to the patient and will affect the patient's treatment. To resolve this problem, we should perform QA for the kV X- ray tube on a regular basis. For Quality Assurance, we can follow the TG-135 recommendations.

The energy of the X-ray tube depends on the applied kVp. As we increase the kVp, the energy will also increase. The energy is directly proportional to kVp. mA controls the tube current of the X-ray tube. If we want more X-rays, we can increase the mA. By changing the mA, we can control the quantity of X-rays. So, we can increase mA to get more contrast because a larger no of X-rays will pass through the body.

The variation in kVp Accuracy, mA station linearity, and exposure reproducibility can lead to unnecessary extra exposure to the patient, or it can affect the image quality. The variation in filtration can allow more soft X-rays or increase the mA loading in the X-ray tube, which can decrease the life of the X-ray tube. The QA for filtration should also be performed periodically because the surface of the filter can be rough due to the penetration of X-rays a number of times.

The size of the tube focal spot is inversely related to the spatial resolution. So, the spatial resolution will be degraded if the focal spot is too large. The image sharpness will degrade. And if the focal spot is too small, the temperature of the focal spot may increase rapidly, and it will affect the lifetime of the x-ray tube. Also, it will lead to an increase in exposure time that results in patient motion and motion blur.

IV. CONCLUSION

If the system's Quality assurance is conducted routinely, it will result in optimum quality images with lower radiation dose. The Quality Assurance for the imaging system was conducted as per the established protocols. All the Quality Assurance parameters were found to be well within tolerance. The kVp accuracy is within ±5 kVp. The variation in mA station exposure linearity is also within ±5%. The variation in exposure reproducibility is <0.10. The variation in imager position reproducibility is also less than 1 mm. The variation of Bad pixel statistics and tube leakage is also under the tolerance limit. So, it can be concluded that the imaging system in Cyberknife is safe to use for both patients and the staff.

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