CYBERKNIFE QUALITY ASSURANCE USING TG-135

S.P. Sharma[1], A. Kaur[1], S.M. Pelgade[1], A. Parikh[2]

[1] Gujarat Cancer and Research Institute, Department of Medical Physics, Ahmedabad, India
[2] Gujarat Cancer and Research Institute, Department of Radiation Oncologist, Ahmedabad, India

Abstract— **This research paper introduces the CyberKnife system, robotic radiosurgery device used to treat non-invasive (no surgery), small size tumors with high accuracy. This study also focuses on importance of Quality Assurance (QA) in maintaining the system's accuracy and safety during targeting and treating tumors. In this study daily, monthly, annually quality assurance tests were performed under the guideline of American Association of Physicist in Medical Task Group 135 (AAPM TG-135) at our Gujarat Cancer and Research Institute (GCRI). All the QA tests were within the acceptable tolerance limit. In daily QA, output constancy was measured using Birdcage phantom assembled with an ionization chamber. Additionally, all safety checks, including door interlock, emergency stop function etc. were performed and were fully operational/working. AQA test was performed using AQA phantom and EBT-films to verify robot path calibration. In monthly QA, dose output, beam shape consistency and beam symmetry were evaluated, using RFA with 60mm FIX collimator and compared with the commissioning values. E2E test was performed using a 6D skull phantom and EBT-films to verify entire system from imaging to delivery of treatment. Coincidence of imaging and radiation isocenter was performed using Isopost system. Annual QA was performed using RFA with diode for beam profiles and PDD. Output consistency was measured using 0.6cc chamber. All the results were within the given tolerance limit. According to TG-135 guideline all QA results were carefully recorded in both hardcopy and softcopy formats to ensure easy access for further inspection or in case of emergencies. The implementation of TG-135 highlights the importance of regular quality assurance in delivering safe, accurate and effective dose for treatment.**

Keywords— **CyberKnife Quality Assurance, TG-135, E2E, AQA, Ouptut.**

I. INTRODUCTION

The CyberKnife system represents a paradigm shift in delivering stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT) [1,2]. Unlike conventional LINACs, CyberKnife uses a compact linear accelerator mounted on a robotic arm, enabling non-isocentric, non-coplanar beam delivery. This demands rigorous and unique QA procedures as recommended in the AAPM Task Group 135 report [3]

The CyberKnife system was developed in the early 1990s by Dr. John R. Adler at Stanford University. The first installation was at Stanford in 1994 [1,4]. Later on in 2001, Accuray became a legally registered corporation to develop, market and sell the CyberKnife system. In 1999 it got FDA approval and in 2001 it was allowed to treat tumors in head & neck, body [2]

The CyberKnife system is an advanced robotic system [2,5,6] used to deliver very accurate radiation therapy to treat tumors with the help of synchrony to monitor tumors if in motion. CyberKnife which can target tumor accurately less than a millimeter. It can deliver radiation dose to patients from almost any direction, making any angle. CyberKnife treatment procedure is painless, no blood loss and it is completely frameless [1,7,8,9]. Tumors with a volume < 60cc are only treated by CyberKnife [9], a limitation of this system with long treatment time [10].

However, following TG- 135, quality assurance is crucial to make sure that CyberKnife system treatments are effective and safe for patients. TG-135 gives detailed guidelines for QA [3], including specific needs for CyberKnife. This guideline covers various asserts of QA from commissioning and acceptance testing to daily quality checks and ongoing performance monitoring. The QA process for CyberKnife begins with equipment commissioning, through testing and calibration. By collaborating CyberKnife with TG-135, the main goal is to provide practical advice to help physicist and healthcare workers to build trust in CyberKnife unit and in its treatment techniques, making sure of not only to provide accuracy but also meet the highest standards for patients and workers safety and care. Documentation is an integral part of the QA process providing a record of QA activities.

Factors for Beam Parameters

Temperature and Pressure Correction factor [5]: $K_{T,P}$ This is not necessary that at the time of QA, temperature and pressure will be same as at the time of chamber calibration.

$$K_{T,P} = \frac{(273.15+T)}{(273.15+T0)} \times \frac{P0}{P}; \qquad (1)$$

T= measured temperature, P= measure pressure
T_0= reference temperature, P_0= reference pressured T_0= 20^0C, P_0= 1013.25 mbar

So, the correction factor is applied to convert the cavity air mass to the reference conditions.

Electrometer Correction factor [5]: K_{elec}

When ionization chamber and electrometer are calibrated together its calibration factor is 1.

$$K_{elec} = 1 \qquad (2)$$

When ionization chamber and the electrometer are calibrated separately, a calibration factor for each is given by the calibration laboratory, which is close to unity.

Polarity effect correction factor [5]: K_{pol}

Polarity effect varies with beam quality and other conditions such as cable position. Corrects chamber's response for possible polarity effects.

$$K_{pol} = \frac{(|M+|+|M-|)}{2\times(M+)} \qquad (3)$$

Ion Recombination correction factor [5]: K_s

The incomplete collection of charge in an ionization chamber cavity due to the recombination of ions this correction factor is used.

$$K_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 \qquad (4)$$

Correction for the radiation quality of the beam [5]: $K_{Q,Q0}$

The factor $K_{Q,Q0}$ corrects for the effect of the difference between the reference beam quality Q_0 and the actual user quality Q.

It is defined as the ratio, at the qualities Q and Q_0, of the calibration factor in terms of absorbed dose to water of the ionization chamber.

The dosimeter reading: M_Q

It is corrected to the reference values of influence qualities, other than beam quality, for which the calibration factor is valid.

$$M_{corr.} = M_1 \times K_{TP} \times K_{pol} \times K_s \qquad (5)$$

$D_{W,\,ref}$: Is the absorbed dose to water at the reference point of measurement in a beam - of quality Q. [5]

$$D_{W,\,ref} = M_{Corr.} \times N_{D,\,W,\,Q0} \times K_{Q,Q0} \qquad (6)$$

$N_{D,\,W,\,Q0}$: Is the chamber calibration factor in terms of absorbed dose to water in the reference beam of quality Qo. $K_{Q,Q0}$: Is the factor that corrects for the effects of the difference between the reference beam quality Qo and the user quality Q.

MQ is the fully corrected chamber reading. [5]

Output:
Measure dose delivers per MU

$$\text{Output \%} = M_Q \times N_{D,\,W} \times K_{Q,\,Q0} \times K_{T,\,P} \times K_{elec} \times K_s \times K_{pol} \times \frac{1}{PDD} \times 100 \qquad (7)$$

$$Variation\ \% = \frac{(Measured\ value - Actual\ value)}{Actual\ value} \times 100 \qquad (8)$$

Focal Spot Size

The area of target in the x-ray detector within which the electrons are absorbed and x-rays are generated is called focal spot or area. If the focal spot is small, the penumbra will be lesser, picture sharpness will be good but heat removal will be difficult. While if spot is large, heat will be removed quickly, penumbra will be larger, picture sharpness will be bad.

FFF (Flatting Filter Free)

FFF beam has a shape of downfall [11, 12] which reduce surrounding dose and improve treatment outcome. Whereas FF beam provides uniform dose distribution to the target volume but due to uniform beam surrounding tissues get excess dose and risk of side effect, shown in Figure.1.

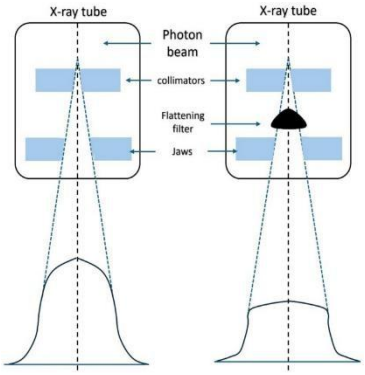

Figure 1: FFF & FF

Flatness

Flatness tells us how uniform [5] (even) the radiation beam is in the central region of the treatment field shown in figure wasted.2. Flatness is measured within a region bounded by 80% of the field width. i.e. If the dose at one part of the center is 100%, and another point is 105%, then it's not completely flat. Photon beam: ±3%.

Symmetry:

Symmetry tells that dose on left and right [5] side or top and bottom side of the beam should have equal dose distribution. Shown in Figure 2. The profile plot may be folded at the field center and the two halves of the profiles compared. In the reference region, the dose should not differ more than 2% at any pair of points situated symmetrically with respect to the central ray. i.e. If on one side it shows 100% dose then the other side should be between 98% to 102%. Photon beam: ±2%

Penumbra

Shows shapes dose falloff [5] from the edge of 80% - 20% isodose line. In a general sense, this is the region, at the edge of a radiation beam, over which the dose rate changes rapidly as a function of distance from the beam axis. The dose at the field edge is approximately 50% of the dose at the center of the field. Photon: ~5–7 mm.

Percentage Depth Dose

Which shows how dose changes with depth/changes along the **central axis** of the beam. We compare the dose at any given depth to a **standard/reference point** dose usually at $\mathbf{D_{max}}$ or **10 cm depth**. Percentage Depth Dose is the ratio [5] of absorbed dose at any depth to the absorbed dose at a fixed reference depth.

$$PDD\% = \frac{D20}{D10} \qquad (9)$$

Inline: Direction of beam profile along gantry rotation i.e. from head to foot which is Y-axis. Shown in Figure 2

Crossline: Direction of beam profile perpendicular to inline i.e. from left to right which is X-axis Shown in Figure.2.

TPR: Measure beam quality i.e. energy. Tissue Phantom Ratio is the ratio [5] of absorbed dose at given depth to the absorbed dose at fixed reference depth. The Cyberknife's reference depth is 1.5cm

$$\mathbf{TPR_{20/10}} = \frac{Avg.\ 20cm}{Avg.\ 10cm} \qquad (10)$$

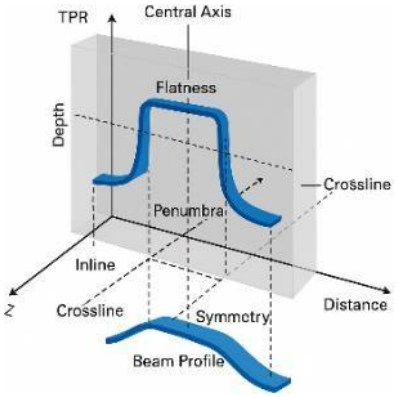

Fig. 2: Beam Profile

II. MATERIALS AND METHODS

This study of Quality Assurance was performed on CyberKnife System at GCRI. The Treatment room contains treatment robot M6 Cyberknife® unit with 6MV (FFF) energy. Robotic arm: 6-axis. Imaging: Orthogonal kV X-rays - Tracking: Fiducial, Xsight Spine, Synchrony respiratory tracking.

Daily QA

Machine should be warmed-up after 4 – 5 hours if not in use. In our institute X-ray tube warm-up is processed because it minimizes target (anode) cracking due to thermal shock. Linac warm-up to stabilize dose rate & RF components before output. All safety interlocks were performed as mentioned in Table 1. Output constancy is performed by using Birdcage and SNC 0.6cc Farmer ion chamber with build-up cap assembling with Linac. Output was calculated using all the given correction factors using Eq 8. Output Constancy on daily basis was within tolerance ±3%. Laser Alignment test was performed. It checks laser intensity, which was ≥ to 80% with respect to baseline. AQA test was performed using AQA phantom, Graf chromic films were inserted properly. Phantom was allied with green laser and was exposed by matching with fiducials. Later analyses with AQA software and result of Radial error (distance between imagine center & target center) was within tolerance less than 1mm from baseline.

Table 1: Daily QA Table

Name of Test	Tolerance	Result
Dosimetry		
Output Check	3%	0.44 %
Dose Rate	939 Mu/min	934 Mu/min
Safety Interlock		
Collimator Interlock	W/NW	W
Beam ON/OFF Indicator	W/NW	W
High Voltage ON	W/NW	W
Dorr Interlock	W/NW	W
Audio/Visual Monitor	W/NW	W
LMOS	W/NW	W
EMO	W/NW	W
Interrupt Button	W/NW	W
Robot Perch position deviation from baseline	2 mm	No Deviation
Laser Alignment Check	Within 80% of Baseline	Off Set: 0.02mm Measured Value: 1819
Temp./Press. /Humidity	19.3℃ /1004.9mbar /55.6%	

Monthly QA

All Monthly QA which are performed at our Institute are mentioned in Table 2 with equipment and setup.

Annual QA

In annual QA, all the QA were performed by both FIXED and IRIS collimators. Output & TPR20/10. are performed by same procedure as in monthly using Eq. 10. Flatness, Symmetry, Penumbra were performed at 10 cm depth & 1.5 cm depth with both collimators. PDD was also measured from beam profiles using Eq.9. E2E was performed for synchrony and all tracking modes. It is performed to check the entire system of cyberknife from imaging to beam delivering. Radiation survey was performed using Fluke Survey meter & dose rate was 1000 MU/min, with 60 mm FIXED collimator. All the steps of QA setup were followed by ESSENTIAL GUIDE given by Accuray Company. All the monthly & daily QA were also performed in annually QA.

Table 2: Monthly QA Table

Name of Test	Equipment's Setup	Tolerance /Result
1. Beam Parameter		
a. Output Check	SAD: 80cm, FIX 60 mm Collimator. SNC 0.6cc Ion Chamber, Sun Nuclear RFA, K_{TP}, Kpol, Kele, K_{QQ0}	Result was within 2%
b. TPR20/10	SAD: 80cm, FIX 60 mm Collimator. SNC 0.6cc Ion Chamber, Sun Nuclear RFA.	Result was within 2%
c. Beam Profile / PDD	SNC Diode, SUN Nuclear RRFA with 80cm SAD	Profile results within tolerance Flatness < 120% Symmetry < 104% Penumbra: 60 mm – 8 mm 40 mm – 4.5 mm 10 mm – 3.5 mm
2. E2E	6D Skull phantom, Radio chromic films. Used for tracking methods: Skull, Spine, Fiducial, Synchrony	For static within tolerance < 0.95 mm & for motion tracking < 1.50 mm
3. Laser & Radiation Congruence	30mm collimator, Laser QA tool, Radio chromic film, ImageJ Software.	<0.5 mm
4. Imaging Alignment	Isopost attached with camera stand in floor, kVp, mA, ms	±1 mm from Baseline

III. RESULTS

All the QA which was performed at our institute were within the tolerance limit as per TG-135. All the results are mentioned in Table 3.

Table 3: Results table and tolerance

Name of Test	Results
Output a. Daily b. Monthly c. Annually	 < ±3 % < ±2 % < ±1 %
TPR20/10 a. Monthly b. Annually	 < ±2 %
Beam Profile	Profile results with-in tolerance Flatness < 120% Symmetry <104% Penumbra: 60 mm – 8 mm 40 mm-4.5 mm 10 mm-3.5 mm
E2E	For static with in tolerance < 0.95 mm & for motion tracking < 1.50 mm
Laser & Radiation Congruence	< 0.5 mm
Imaging Alignment	±1 mm from Baseline
Safety Interlocks a) LMO b) Door Interlock c) Emergency Switch d) EMO	All are working

IV. CONCLUSION

TG-135 provides a structured approach to CyberKnife QA ensuring both mechanical and dosimetry fidelity. However, certain limitations include complex setup and time-intensive annual QA tests. Software tools and automation (e.g., MultiPlan/Precision QA tools) can enhance QA throughput. Regular QA as per TG-135 is essential for safe and effective CyberKnife treatments. GCRI's implementation of TG-135 demonstrates clinical feasibility and robustness, forming a benchmark for similar installations.

REFERENCES

1. Adler JR (1997) The CyberKnife: A frameless robotic system for radiosurgery. Stereotact Funct Neurosurg 69(1–4):124–128.
2. Kilby W, Dooley JR, Kuduvalli G, Sayeh S, Maurer CR (2010) The CyberKnife® robotic radiosurgery system in 2010. Technol Cancer Res Treat 9(5):433–452.
3. AAPM Task Group 135 Report (2009) Quality assurance for robotic radiosurgery. Med Phys 36(12):5315–5327.
4. ICRU Report 91 (2017) Prescribing, recording, and reporting of stereotactic treatments with small photon beams. J ICRU 17(1):1–39.
5. Khan FM, Gibbons JP (2014) The Physics of Radiation Therapy. 5th ed. Lippincott Williams & Wilkins, Philadelphia.
6. Accuray Inc. (2020) CyberKnife® M6 System: Quality Assurance User Manual. Sunnyvale, CA.
7. Hall EJ, Giaccia AJ (2012) Radiobiology for the Radiologist. 7th ed. Lippincott Williams & Wilkins, Philadelphia.
8. ICRU Report 91 Commentary (2017) Updates on SRS/SBRT Clinical Applications. J ICRU 17(1):40–50.
9. Sahgal A, Larson DA, Chang EL (2009) Stereotactic body radiosurgery for spinal metastases: a critical review. Cancer 115(6):1420– 1431.
10. Hoogeman MS, Nuyttens JJ, Levendag PC, Heijmen BJ (2009) Clinical accuracy of the respiratory tracking system of the CyberKnife: assessment by analysis of log files. Int J Radiat Oncol Biol Phys 74(1):297– 303.
11. Vassiliev ON, Titt U, Pönisch F, Kry SF, Mohan R, Gillin MT (2006) Dosimetric properties of photon beams from a flattening filter-free clinical accelerator. Med Phys 33(4):820–827.
12. Accuray Inc. (2021) Precision® QA Software Overview. Sunnyvale, CA.

Contacts of the corresponding author:

Author: Sonal P. Sharma
Institute: Gujarat Cancer and Research Institute
City: Ahmedabad
Country: India
Email: sonalsharma12420@gmail.com