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Thomas Sajeev[1, 2], Mohamed M. Mustafa[2],
Sanjay S. Supe[3]

Dosimetrical evaluation of Leksell Gamma Knife 4C radiosurgery unit

[1] Department of Neurosurgery, National Institute of Mental Health and Neuro Sciences (Deemed University), Bangalore, India
[2] Department of Physics, University of Calicut, Kozhikode Kerala, India
[3] Department of Radiation Physics, Kidwai Memorial Institute of Oncology, Banaglore, India
e-mail: sajeevmthomas@gmail.com

A number of experiments was performed using standard protocols, in order to evaluate the dosimetric accuracy of Leksell Gamma Knife 4C unit. Verification of the beam alignment has been performed for all collimators using solid plastic head phantom and Gafchromic™ type MD-55 films. The study showed a good agreement of Leksell Gammaplan calculated dose profiles with experimentally determined profiles in all three axes. Isocentric accuracy is verified using a specially machined cylindrical aluminium film holder tool made with very narrow geometric tolerances aligned between trunnions of 4 mm collimator. Considering all uncertainties in all three dimensions, the estimated accuracy of the unit was 0.1 mm. Dose rate at the centre point of the unit has been determined according to the IAEA, TRS-398 protocol, using Unidose-E (PTW-Freiburg, Germany) with a 0.125 cc ion chamber, over a period of 6 years. The study showed that the Leksell Gamma Knife 4C unit is excellent radiosurgical equipment with high accuracy and precision, which makes it possible to deliver larger doses of radiation, within the limits defined by national and international guidelines, applicable for stereotactic radiosurgery procedures.

Key Words: Gamma knife, radiosurgery, dosimetry, Leksell, stereotactic, accuracy.

Introduction

One of the most innovative radiation therapy techniques, developed during the last 50 years is stereotactic radiosurgery, a term coined by neurosurgeon Lars Leksell to refer to surgery using radiation rather than the more common and invasive surgical tools [1,7].

Gamma Knife unit has 201 Co-60 gamma ray beams converging at the unit centre point (UCP) with accuracy of 0.3 mm. In the static source models of Leksell Gamma Knife equipment (Figure 1), gamma ray beams are collimated into narrow beams with a set of interchangeable collimators of different sizes (4 mm, 8 mm, 14 mm, 18 mm). Mechanical precision and electronic complexity of the treatment delivery unit requires the implementation of adherence to the on-going quality assurance program [2, 4, 7]. The patient fixed with a stereotactic head frame is positioned at the treatment isocentre by means of an Automatic Positioning System (APS) or trunnion for delivery of radiation treatment.

Figure 1. Leksell Gamma Knife 4C Radiosurgery Unit

The aim of this experiment was to evaluate the dosimetric accuracy and stability of Leksell Gamma Knife 4C Radio surgery unit.

Methods

In this study, a detailed evaluation of Gamma Knife unit was performed. Verification of the beam alignment was performed for all collimators (4 mm, 8 mm, 14 mm, 18 mm) along X-axis, Y-axis and Z-axis, using a solid plastic phantom with cassettes. The isocentric accuracy of the unit was verified using a special cylindrical aluminium film holder tool. The dose rate at the isocenter of the unit was measured and evaluated over a period of 6 years after installation.

Verification of precision of the beam alignment

The size and shape of the solid plastic phantom simulates the head of an adult human. In the measurements of the absorbed doses of Co-60 radiation, the material can be considered as water equivalent. The phantom is divided into two half spheres, between which a cassette can be inserted. Two half-spheres and the cassettes are held together by plastic pieces. The phantom can be aligned in the helmet by means of trunnions, according to the axis passing through the plastic pieces,

The spherical phantom was aligned in Gamma Knife, using the trunnions (Figure-2), with the phantom centre at the unit centre point (X-coordinate -100, Y-100, Z-100), where all beam axes intersect.

Figure 2. Experimental set up for verification of precision of the beam alignment with 14 mm collimator

Two films (GafchromicTM type MD-55) were used to prepare eight equal sized squares of 5”×5“ which were exposed in each of the four helmets (4 mm, 8 mm, 14 mm, 18 mm). The films were irradiated (100 Gy) in perpendicular planes in the spherical phantom with appropriate marks of the orientation of the films. The correct orientation of the taped film was ensured by indicating the stereotactic axis at the periphery of the film.

Film calibration was done by exposing two films consecutively in the polystyrene spherical phantom by means of 18 mm collimator helmet in X-Y plane (Figure-3). The doses delivered to the films were 30 Gy and 120 Gy, respectively.

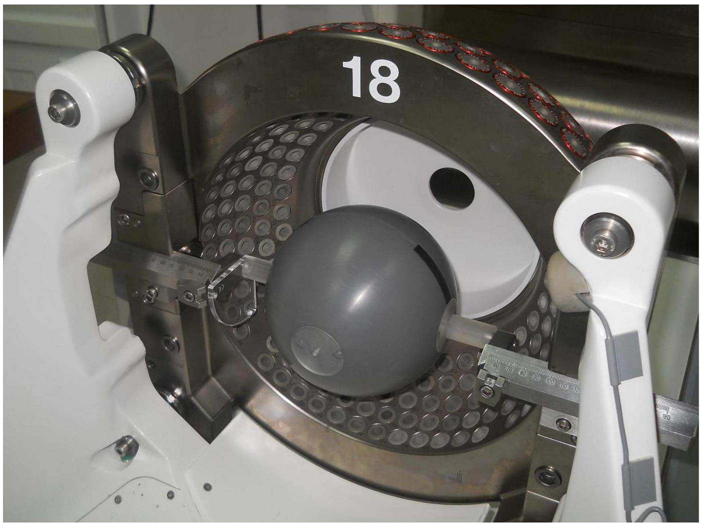

Figure 3. Positioning of Spherical Phantom with cassettes at the unit centre point of Leksell Gamma Knife 4C using trunnions

The experimental data for the optical density - dose calibration curve was obtained irradiating films with different doses using the 18 mm collimator. A third order polynomial has been fitted to the experimental data. The polynomial was used to convert optical density to absorbed dose (Figure 4).

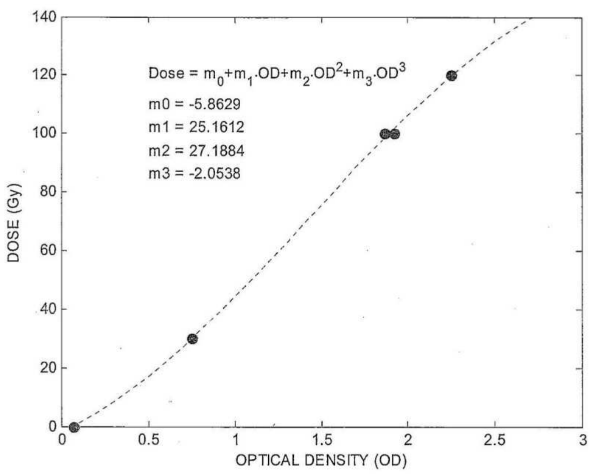

Figure 4. Dose calibration curve

The optical density was measured along the three axes (X, Y and Z) of the stereotactic frame, by means of an automatic densitometer. The densitometer had a laser light source and its geometrical resolution was selected to 50 μm or 100 μm. The dynamic range of the densitometer is chosen to be 12 bits. The measured density profiles were converted to the dose profiles by means of an optical density dose calibration curve.

Verification of the isocentric accuracy

A precisely machined cylindrical aluminium film holder tool (Figure 5), made with very narrow geometric tolerances is aligned between the trunnions of the 4mm collimator helmet.

Figure 5. Cylindrical film holder tool

When both trunnions are set to 100.00, the tip of the sharp spring loaded needle, located in the tool, points exactly towards the UCP, provided the couch is in treatment position. Just prior to exposure, the film is pierced by the tip of the needle. During the exposure, the film plane coincides with the UCP. Two films are consecutively exposed - one with its surface oriented perpendicularly, relatively to the symmetry axis of the source distribution. The second film is rotated by 90° with respect to the first film (Figure 6).

Figure 6. Experimental set up for verification of the isocentric accuracy of Leksell Gamma Knife 4C

Optical density profiles are scanned by means of an automatic densitometer in three mutually perpendicular directions. The geometrical resolution of the densitometer has been set to 50 μm and the dynamic range was set to 12 bits. The density profiles thus obtained include the shift in density caused by the small hole pierced in to the films. By measuring the asymmetry of the position of the hole in relation to the density distribution at approximately FWHM, the isocentric accuracy of the Gamma Knife is determined.

Determination of the absorbed dose rate

The dose rate was measured with a small thimble chamber placed at the centre of a spherical polystyrene phantom of 160 mm in diameter. The phantom was aligned using trunnions (at the coordinate of X=100, Y=100, Z=100) with its centre at the unit centre point in Gamma Knife, where all beam axis intersect (Figure-7). The phantom was irradiated by all 201 beams defined by the 18 mm collimator helmet. Atmospheric pressure and temperature inside the chamber were measured and recorded after and before irradiation of the chamber. The irradiation was performed by setting the unit timer to 25 minutes and was initiated by pressing the 'start' button of PTW-Unidose E.

Figure 7. Positioning of the 0.125 cc ion chamber inside the spherical dosimetric phantom at the unit centre point with 18 mm collimator

The centre of the chamber was placed at the centre of the phantom .The charge was measured repeatedly by integrating the signal over a period of 1 minute in Unidose-E. The collected charge was converted to the absorbed dose in accordance with the IAEA TRS-398 protocol.

The output of the Leksell Gammaknife 4C has been measured and observed over a period of 6 years and was represented graphically.

Results

Verification of precision of the beam alignment

The study showed good agreement between the measured dose profile and calculated with Leksell Gamma plan, along X-axis, Y-axis and Z-axis(Figures 8-11).

18 mm collimator:

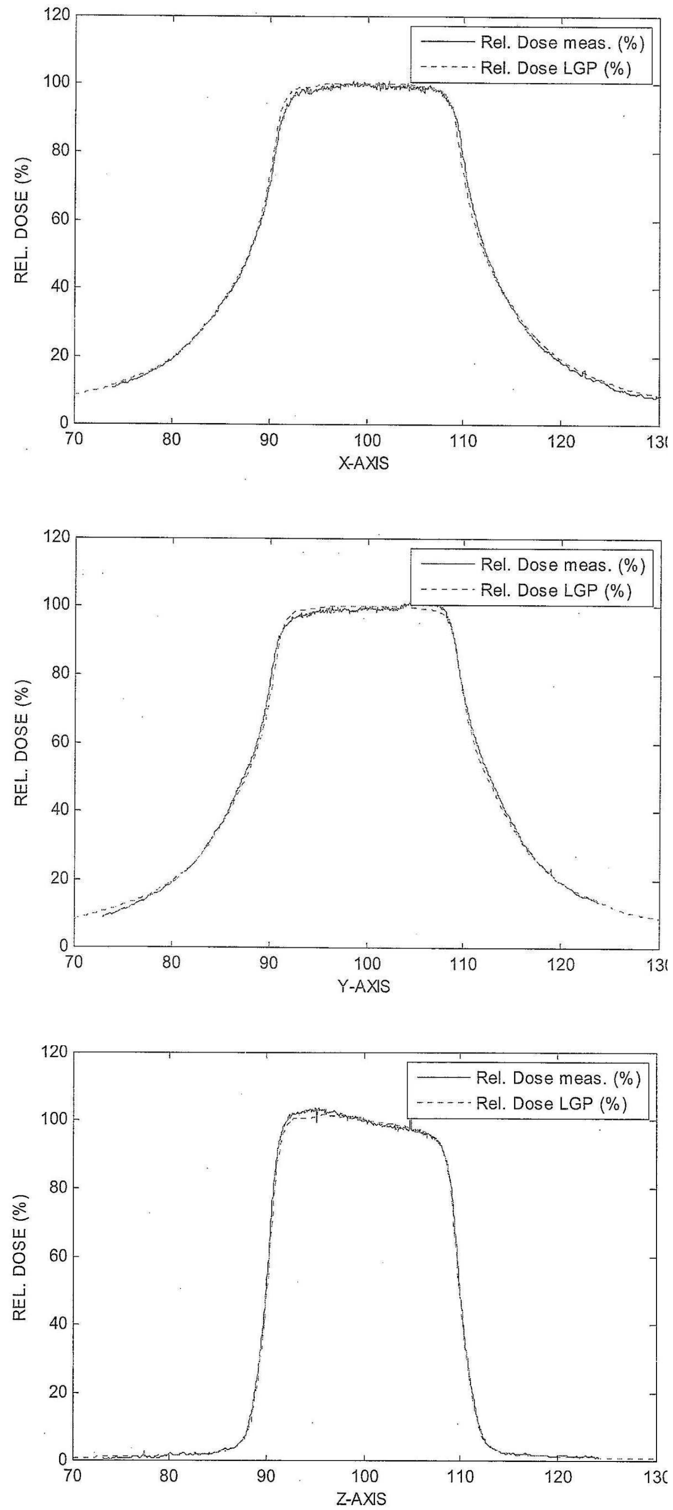

Figure 8. Measured and calculated (LGP) dose for 18 mm collimator, along X-Axis (upper plot), Y-Axis (middle plot) and Z-Axis (bottom plot)

14 mm collimator:

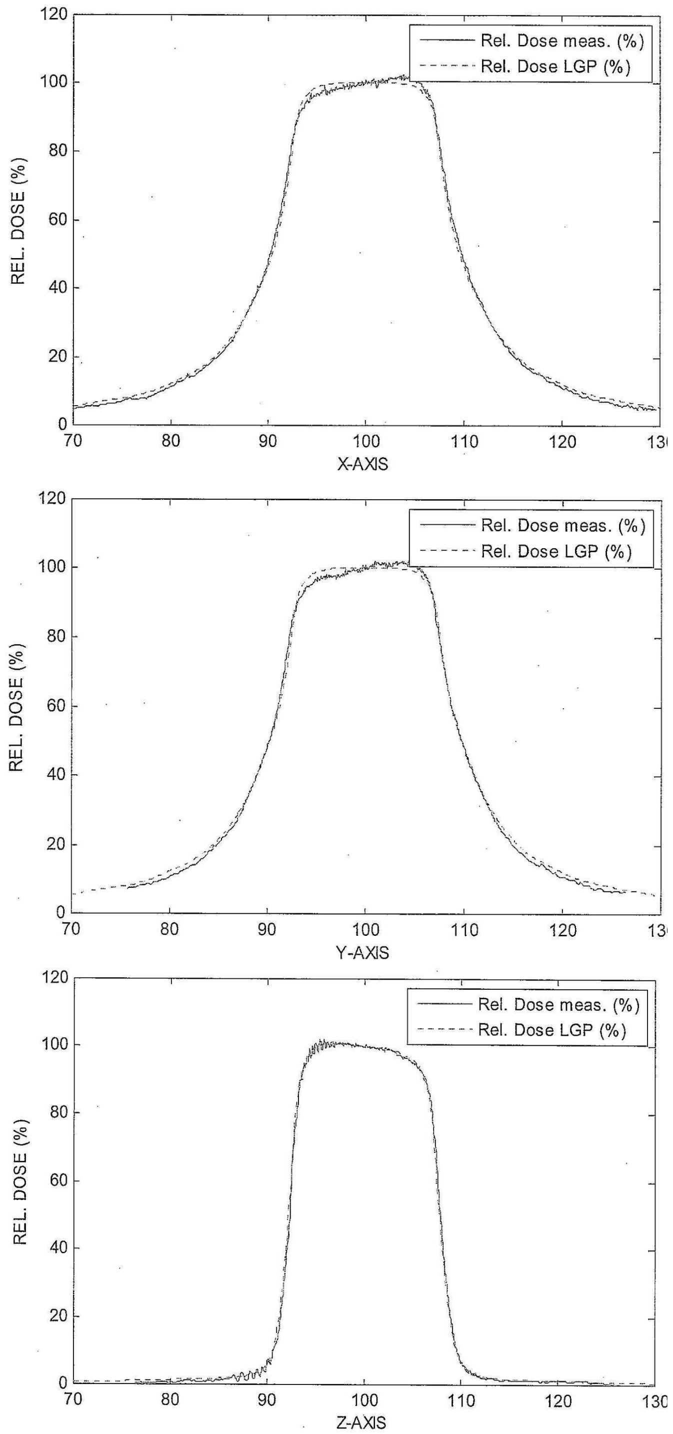

Figure 9. Measured and calculated (LGP) dose for 14 mm collimator, along X-Axis (upper plot), Y-Axis (middle plot) and Z-Axis (bottom plot)

8 mm collimator

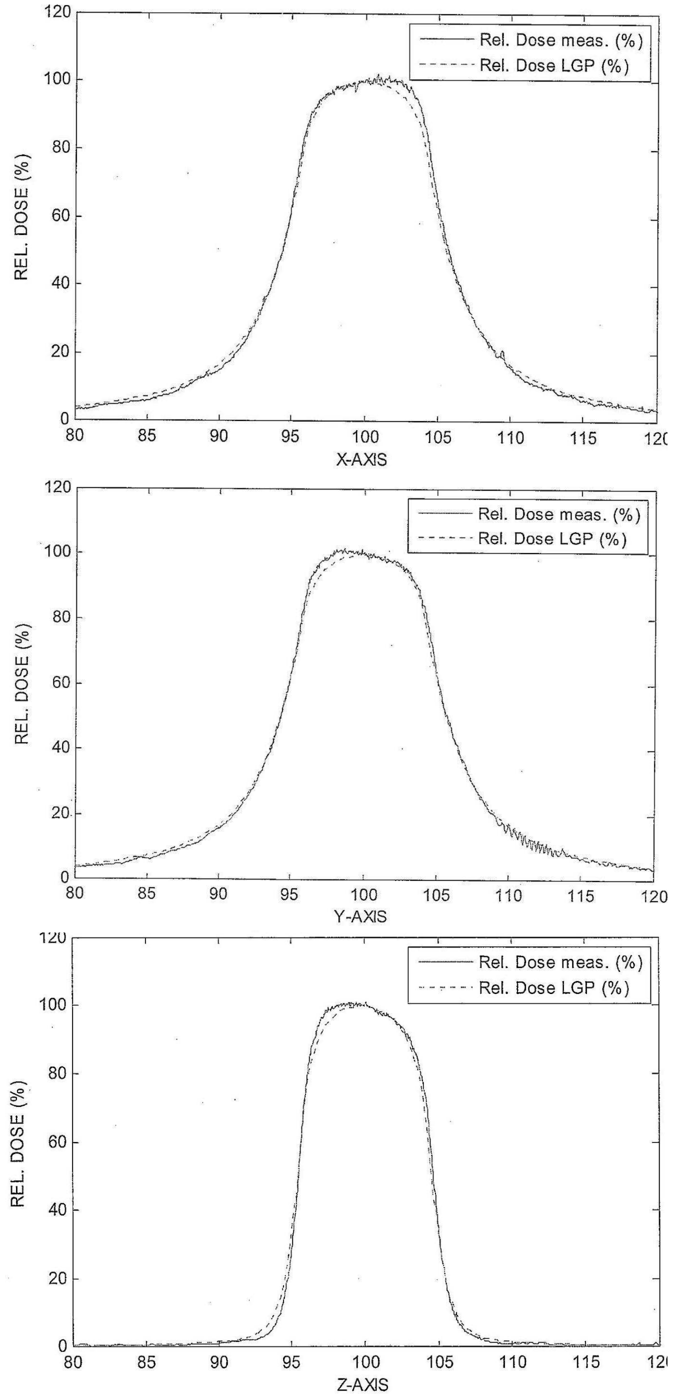

Figure 10. Measured and calculated (LGP) dose for 8 mm collimator, along X-Axis (upper plot), Y-Axis (middle plot) and Z-Axis (bottom plot)

4 mm collimator

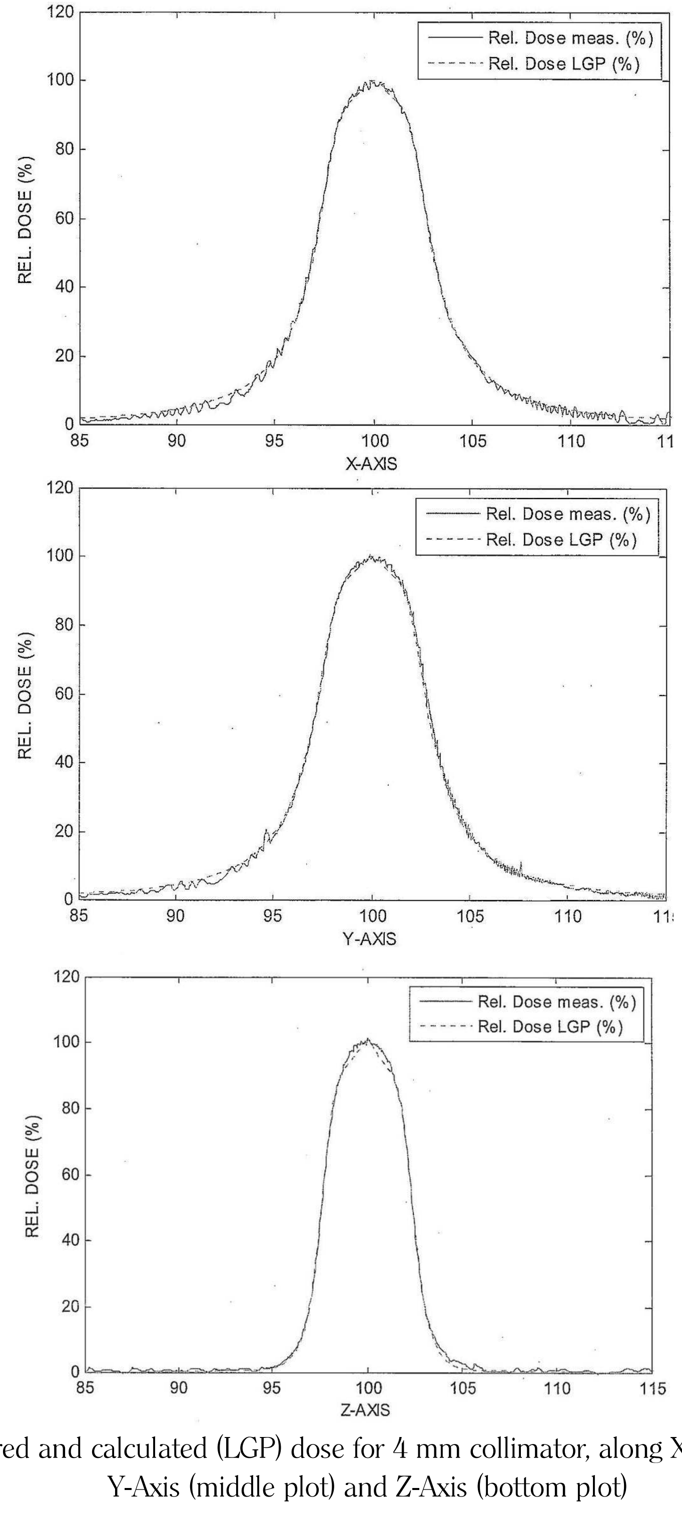

Figure 11. Measured and calculated (LGP) dose for 4 mm collimator, along X-Axis (upper plot), Y-Axis (middle plot) and Z-Axis (bottom plot)

Verification of the isocentric accuracy

This study showed good agreement between geometrical isocentre and radiation isocentre in all three directions for 4 mm collimator (Figure-12).

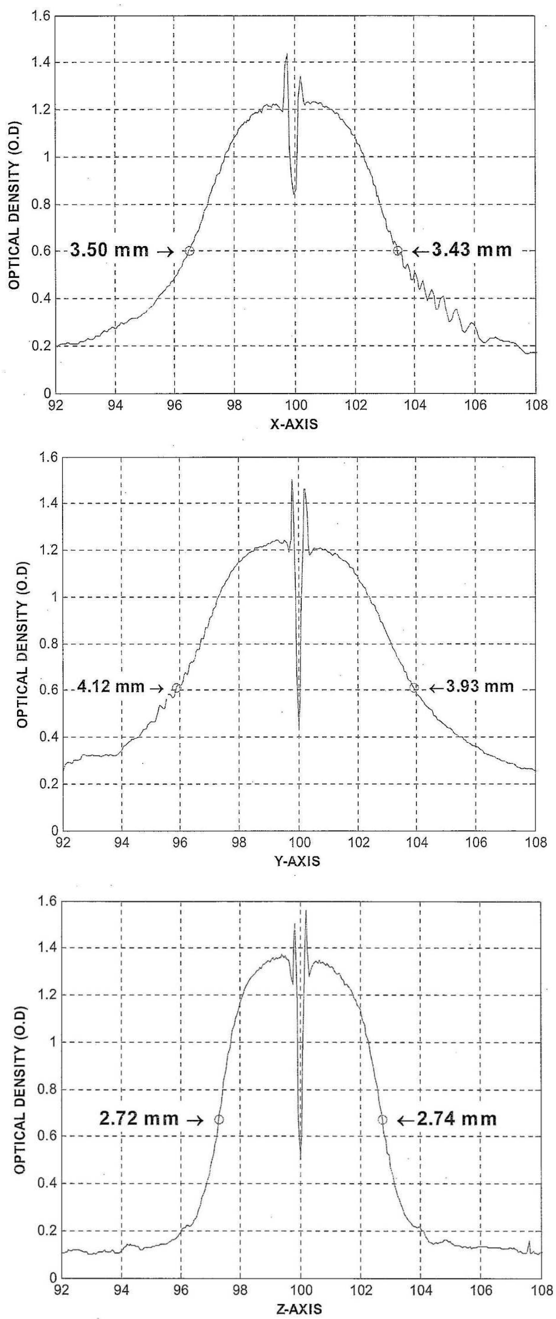

Figure 12. Position of the pin hole at FWHM along X-direction (upper plot) Y-direction (middle plot) and Z-direction (bottom plot)

The distance (delta) between radiological centre and the needle mark is measured along the three main axes (X, Y and Z). The distance between the radiological centre and the mechanical centre is then calculated. The measure includes an experimental error:

$$\delta = \sqrt{\Delta^2_x + \Delta^2_y + \Delta^2}$$

$$\delta = \sqrt{0.035^2 + 0.095^2 + 0.010^2} = 0.10 \text{ mm} .$$

Resulting accuracy of Gamma Knife is equal 0.10 mm

Determination of the absorbed dose rate

Dose rates were measured for a period of 6 years and their values are tabulated (Table 1) and represented graphically (Figure 13).

Table 1. Dose rates measurement in the period of 6 years.

Date of Measurement	Dose Rate(Gy/Min)
02-02-2006	3.275
20-12-2006	2.940
14-01-2008	2.597
31-12-2008	2.265
30-12-2009	1.993
28-12-2010	1.727
26-11-2011	1.547

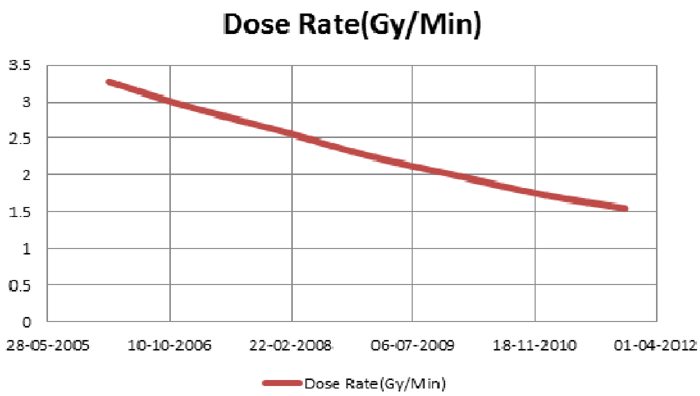

Figure 13. Consistency in measured dose rates in 6 years.

Discussion

Verification of precision of the beam alignment

Precision in the dose delivery of Gamma Knife in space is much dependent on the precision of the beam alignment with the collimator system. Due to the existence of very high radiation gradient in the field to be measured, film dosimetry with radiochromic films was used. This is due to high spatial resolution and low energy dependence of the Gafchromic films. All experimental dose profiles agree with the calculated dose profiles within specifications ($\leq$ 1mm at 50% isodose levels). In gamma Knife treatment, a high dose region at isocentre with steep dose gradient of 30% per mm is used [7] for the treatment, where the precision of the beam alignment is critical in defining the outcome of radiosurgery. The experimental results showing the precision $\leq$ 0.1 mm ensures the dose delivery within 5 % of the acceptable limits [2, 3, 4] for external beam radiation treatments. This experiment gives enough confidence for dose delivery using all four collimators (4 mm, 8 mm, 14 mm, 18 mm) in Leksel Gamma Knife 4C.

Verification of the isocentric accuracy

This evaluation has been carried out with a special cylindrical aluminium tool, supplied by Elekta Instrument AB with provision for keeping films in different orientations. The difference between the tip of the needle and the centre of the profile (FWHM) represents the geometrical distance between the radiological isocentre and mechanical isocentre. Radiation beams from all sources collimated to narrow beams meet at radiological centre of the unit and forms a sphere with a common focus at the centre of the unit. A beam axis is defined as the line between the centre of a radiation source and mechanically determined point, cantered in the treatment unit. In the ideal situation all the 201 lines must meet at the centre of the sphere cantered at the unit centre point. The deviation in alignment between the axes is critical as it affects the combined spatial dose distribution from all beams. This is why the tolerance is defined for the most critical situation (4 mm collimator).

The trunnions of the helmet provide mechanical means to accurately align a predetermined point with in the coordinate system of the frame to the UCP. The uncertainty in target alignment to the UCP introduced by the trunnion is of systematic nature and for the critical situation. The distance between the centre of the sphere and mechanical isocentre of the unit is 0.1 mm which indicates the accuracy of the unit in delivering the radiation dose. This is important because it affects the combined spatial dose distribution from all beams.

The analysis shows better accuracy along z- axis compared to x- axis and y-axis with maximum deviation along y- axis. This may be due to geometrical distribution of radiation sources around the collimator and geometry of the collimator. In the most critical situation, which is 4mm helmet collimator, the shown accuracy ensure the required precision of the equipment in delivering treatment.

Determination of dose rate / dose calibration

Since there are no national and international specifications which deal specifically with the dosimetry in connection with the narrow beams used in radiosurgery, International Atomic Energy Agency(IAEA) technical report series No.398 (2) was used for absorbed dose determination for photon beams.

The output measurement result showed consistency in the output of Gamma Knife unit over a period of 6 years. Gamma knife unit has 201 Co-60 sources converging at the centre of the unit (Unit Centre Point) with accuracy of 0.1 mm. The measurement performed with 18 mm collimator helmet, using the spherical phantom, indicated the dosimetrical stability of the unit in delivering a significantly higher dose at the isocentre.

Conclusion

The study confirmed the dosimetrical accuracy of Leksell Gamma Knife 4C unit in terms of stable dose rate, beam alignment and isocentric dose delivery. The equipment can be used for delivering larger radiation doses in high dose gradient with in the specifications of dosimetric protocols and guidelines used in stereotactic radiosurgery procedures

References

[1]. Andrew Wu, Linder G, Maitz A.H, Kalend A.M., Lunsford L.D, Flickinger, Bloomer W.D, "Physics of gamma knife approach on convergent beams in stereotactic Radiosurgey" Int J. Radiation oncology biology physics,Vol-18(4),941-949,1990.

[2]. IAEA "An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water" IAEA Technical Reports, Series No. 398

[3]. AAPM Report 54 “Stereotactic Radiosurgery” Report of Task Group-42, Radiation Therapy Committee, June 95

[4]. American College of Radiology-American Society for Radiation Oncology, “Practise guidelines for performance of stereotactic Radiosurgery, Revised” 2011,1-9

[5]. L.Walton, C.K. Bomford, D. Ramsden ”The scheffield stereotactic radiosurgery unit: physical characteristics and principles of operation” The British Journal of Radiology, September,1987,897-905.

[6]. Mack A, Scheib SG, Major J, Gianolini S, Pazmandi G, Feist H, Czempiel H, Kreiner HJ, Precision dosimetry for narrow photon beams used in radiosurgery-determination of Gamma Knife output factors, Medical Physics 2002, September 29(9), 2080-2089.

[7]. Stanley H. Benedict, Frank J Bova, Brenda Clark, et al, ”Anniversary paper: the role of medical physicists in developing stereotactic radiosurgery” Medical Physics.35(9),September 2008.