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# Performing a comprehensive radio-physical examination of the leksell gamma knife Icon treatment unit

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ABSTRACT

The Gamma Knife Icon unit is the latest radiosurgery equipment used for non-invasively treating intra-cranial diseases through Stereotactic radiosurgery treatment procedures. Performing radio-physical testing on the new Gamma Knife Icon unit before starting clinical procedures is essential to ensure its functionality. In line with the manufacturer's recommendations and the American Association of Physicists in Medicine (AAPM) formed Task Group 178 (TG-178), we conducted the vital radio physical tests for the newly installed Gamma Knife unit, including precision of beam alignment, measurement of Gamma Knife accuracy, Center Position measurements, off center position measurements, measurement of absorbed dose rate, and Relative Output factor measurement. We used high special resolution External Beam Therapy 3 (EBT3) GafChromic film and small volume ion chambers (Exradin A16, chamber volume 0.007 cc and PTW 0.125 cc) for the above mentioned tests. We also performed the source confirmation test with a 16 mm collimator. Our results are consistent with previous literature values and within international guidelines' acceptable measurement uncertainty tolerance.

**Keywords:** gamma knife, American Association of Physicists in Medicine (AAPM) formed Task Group 178 (TG-178), position measurement, External Beam Therapy 3 (EBT3) gafchromic film, output factor measurement

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## INTRODUCTION

Our hospital uses the Leksell Gamma Knife Icon treatment unit from Elekta in Stockholm, Sweden, to treat intra-cranial diseases non-invasively (Figure 1). The Leksell Gamma Knife (LGK) Icon system has 192 fixed Cobalt-60 sources separated into eight sectors, each sector containing 24 sources. These sectors can move over a tungsten collimation ring system to provide collimations of 4 mm, 8 mm, and 16 mm diameter defined at the machine's Radiological Focus Point (RFP). The Leksell Gamma Knife (LGK) Icon unit employs an automated selection process to position the sectors, guaranteeing that the sources are precisely aligned with the collimating channels for field sizes of 4 mm, 8 mm, and 16 mm. In order to ensure accurate Stereotactic Radiosurgery (SRS) treatment delivery, the unit is equipped with a Cone Beam Computed Tomography (CBCT) image guidance system that is calibrated to utilize the Leksell Coordinate System (LCS) of the LGK Icon. The CBCT imaging enables the determination of any translational or rotational shifts of the patient's skull relative to the reference image, thereby enhancing treatment precision The LGK Icon also has an Intra-Fraction Motion Management (IFMM) system that tracks intra-fractional motions using an Infrared (IR) camera and a reflective marker placed on the patient's nose. Radio-physical testing is essential before starting actual treatment to ensure accurate delivery to patients [1-3]. Few studies have been conducted to calibrate and quality assure the LGK Icon unit using ion chambers, GafChromic EBT3 films, synthetic diamond detectors, and CATPHAN 500 phantom [4-6]. This work focuses on performing the radio physical testing of the LGK ICONTM for clinical use, including confirmation of proper source installation, beam alignment precision, LGK ICON accuracy, absorbed dose rate, and Relative Output Factor (ROF) [7, 8].

## MATERIAL AND METHOD

### Confirmation proper source installation

According to the literature 1 and 2, improper source loading of Co-60 sources has been observed after source exchange. Therefore, the manufacturer recommends that AAPM TG report 178 to perform a test to ensure all sources are loaded in each of the eight sectors of the Gamma Knife ICON unit. In order to determine the dose rate, a 16 mm collimator is utilized for each individual sector while simultaneously obstructing all other sectors. It's important to mention that every sector comprises of

24 sources, and in the event that even one source is absent, the reading will be 4% lower than the nominal value of total machine output. Detection of this discrepancy can be achieved through ionization measurement, which is a straightforward and reliable means of identifying such a situation. For this test, we used an Elekta solid water phantom and a PTW 0.125 ionization chamber coupled with a PTW Unidose electrometer (Figure 2). The water-equivalent phantom is placed at the intersection point of all beam axis in the Gamma Knife. For each sector, the meter reading was taken for one minute. The meter reading is then converted into a dose rate by applying the temperature, pressure correction, and chamber calibration factors. The exact measurement was also taken with all sectors open to measure the dose rate.


**Fig. 1.** Leksell gamma knife ICON treatment unit

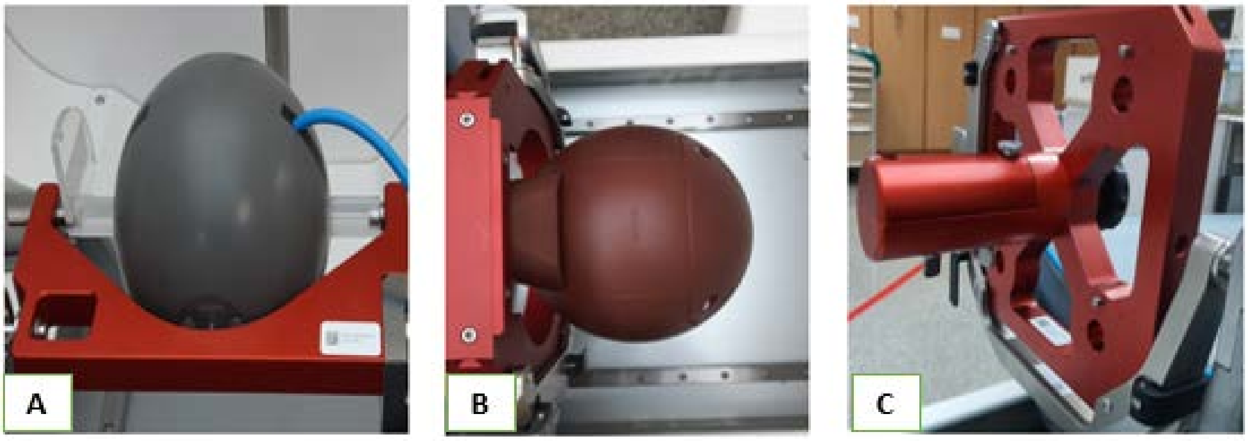


**Fig. 2. A)** Elekta ABS Phantom **B)** Solid Phantom **C)** Film Holder Tool

## The precision of beam alignment

The beam alignment must intersect at a single point in space to ensure accurate gamma-ray beam alignment. They measured by comparing dose profiles with calculated profiles from the Leksell Gamma Plan (LGP) treatment planning system. EBT3 film ensures accuracy for all collimator sizes. The intensity levels in the chefchromic film need to be calibrated to accurately determine the absolute dose (Figure 3). GafChromic EBT3 films were exposed, and image intensity was measured using a flatbed scanner. The intensity profiles were then converted to dose profiles using an image intensity-dose calibration curve. Finally, measured Full Width Half Maximum (FWHM) and penumbra values were compared with TPS-calculated values.

## Measurement of gamma knife accuracy

Achieving accurate radiation treatment requires precise delivery of the radiation dose to a specific area in the stereotactic space to maintain proper dosimetric performance. To ensure accurate radiation treatment, it is important to compare the location of the Radiological Focus Point (RFP) in the radiation field with the calibration centre point of the Patient Positioning System (PPS). These two points should match. In order to verify this, the distance between the RFP and the PPS calibration centre point was measured through film dosimetry during the installation of the Icon unit. For centre position measurements at the (100, 100, 100) position and off-centre measurements at (40, 160, 100), the distance between the RFP and the PPS calibration centre point resulting from all 192 beams of the 4 mm collimator must not exceed 0.4 mm and 0.5 mm respectively. Additionally, for each axial direction (X, Y, and Z), the distance between the RFP and the PPS calibration centre point resulting from all 192 beams of the 4 mm collimator must not exceed 0.3 mm.

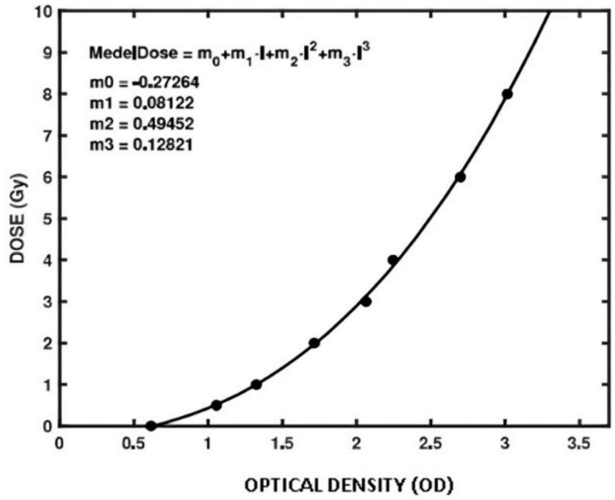


**Fig. 3.** EBT3 film calibration curve

### Center position measurements:

A specialized film holder was used to ensure accurate calibration with precise geometric tolerances (Figure 2). Placed at the centre point of the PPS calibration, a sharp needle in the tool pointed directly towards it. Before exposure, the needle punctured a small piece of radiological film. Six films were exposed in total, with three perpendiculars to the X-Z planes and three rotated 90 degrees to represent the Y-Z planes. The films are scanned by an automatic densitometer at a resolution of 400 dpi and a dynamic range of 48 bits per channel. The resulting intensity profiles included the shift caused by the pierced hole. By measuring the asymmetry of the hole concerning the density distribution at FWHM, the accuracy of the Leksell Gamma Knife ICON unit determined

### Off-center position measurements:

To evaluate the precision of the PPS-coordinate system in a distinct position, we positioned the film holder at the PPS calibration offset location. At positions (40, 160, and 100) with X-low, Y-high, and Z-center, we aligned the sharp needle in the tool with the PPS calibration offset position. The needle punctured a small radiological film in the tool immediately before exposure, and during exposure, the film plane was aligned with the RFP. We obtained four films in total: two with their surface's perpendicular to the symmetry axis of the source distribution (X-Z planes), and two films rotated 90 degrees relative to the first group to represent Y-Z planes. To scan the image intensity profiles in three perpendicular directions, we utilized an automatic densitometer. The flatbed scanner had an image output resolution of 400 dpi and a dynamic range of 48 bits (16 bits per channel). The film images were saved as tiff files in scan (professional mode). The acquired intensity profiles contained the intensity shift caused by the small hole in the films. By measuring the asymmetry of the position of the hole relative to the density distribution at approximately FWHM, we were able to determine the accuracy of the Leksell Gamma Knife ICON unit.

## Measurement of absorbed dose rate

A 0.125 cc thimble ionization chamber (PTW Semiflex) and PTW Unidose electrometer were used to measure the absorbed dose rate. The chamber was positioned at the centre of a 160 mm diameter spherical phantom, which was aligned with its centre at the point in the LGP where all the beam axis intersect. All 192 beams, defined by the 16 mm collimators, irradiated the phantom, which was aligned in the calibration centre point of PPS. The measurement was initiated with a 20-minute irradiation, with a separate timer used for each measurement to avoid small excessive doses that may be absorbed during the transportation of source sectors into their positions. The signal charge was repeatedly measured by integrating the signal over 1 minute, and the collected charge was converted to an absorbed dose following the International Atomic Energy Agency (IAEA) protocol. The standard imaging exradin a 16 ion chamber with a volume of 0.007 cc was used for the exact measurement of the output for the 16 mm collimator. The exradin a 16 chamber was placed in Elekta ABS spherical phantom at the Unit Centre Point (UCP).

## Relative Output Factor measurement (ROF)

As part of the commissioning process, it is necessary to measure the ROF values for LGK collimators and compare them with the ROF values calculated by the Leksell Gamma Plan (LGP) treatment planning software. The ROF, which is defined as the ratio of the dose rate with the 4 mm or 8 mm collimator to the 16 mm collimator, is measured at the centre of the spherical phantom located at the UCP in the LGK ICON.

In this study, we used DR (c) to refer to the dose rate of either 4 mm or 8 mm collimator and DR (16) to denote the dose rate of the 16 mm collimator. The LGP TPS utilized Monte Carlo simulated ROF values of 0.814 and 0.900 for the 4 mm and 8 mm collimators, respectively, which were provided by the manufacturer. Two films were irradiated for each collimator, and the average of the two values was taken. The same films and image intensity-dose calibration curve used for the dose profile FWHM measurements for the 4 mm, 8 mm, and 16 mm collimators were also used for ROF measurement. The ROF values were measured using a Standard Imaging exradin a 16 chamber and a Spherical phantom placed at the UCP, as used in absolute dose measurement. The meter readings of the 4 mm and 8 mm collimators were compared to those of the 16 mm collimator using recommended correction factors to calculate the ratio.

# RESULTS

## Confirmation of proper source installation

In order to verify that all 192 sources in the eight sectors were installed correctly, the dose rate was measured individually in each sector while the other sectors were blocked (Table 1). The total dose rate for all sectors was 3.4371 Gy/min. The dose rate was also measured while all sectors were open, and the absorbed dose rate was 3.433 Gy/min. This resulted in a difference of only 0.11% between the sum of the individual sector dose rates and the machine output.

**Tab. 1.** Independent sector dose rate measurement

| SL. No | Sectors | Dose rate (Gy /min) |
|---|---|---|
| 1 | Sector 1 | 0.431 |
| 2 | Sector 2 | 0.4291 |
| 3 | Sector 3 | 0.4308 |
| 4 | Sector 4 | 0.4294 |
| 5 | Sector 5 | 0.4298 |
| 6 | Sector 6 | 0.429 |
| 7 | Sector 7 | 0.4291 |
| 8 | Sector 8 | 0.4289 |
| Total | | 3.4371 Gy/min |

## Precision of beam alignment

The critical metrics for the dose distribution from figures 4-6 are listed in table 2. These metrics apply to a standard situation where all 192 beams for model ICON are equal and open. The Full Width Half Maximum (FWHM) distance of the normalized dose profile at the 50% dose level and the 80%-20% Penumbra distances along the X, Y, and Z directions were calculated. It is worth noting that the profiles normalized to the centre value of the profile, not the maximum value. FWHM measures the dose profile's width at the 50% dose level, and the total uncertainties in measurements usually within ± 1 mm from the stated values at 50% dose levels. The Penumbra width measures the distance between the position of 80% and the position of 20% in the dose profile normalized to 100% of the dose levels. The nominal penumbra value given is the average nominal value of the Penumbra on both sides of the profile. Typically, the total uncertainties in experimental data for the Penumbra regions are within 2 mm from the stated values, which is typical and expected. Additionally, our dosimetry method has a maximum accepted uncertainty limit within ± 0.5 mm. All experimental dose profiles are within specifications (≤ 1 mm at the 50% isodose level) and agree with the calculated dose profiles.

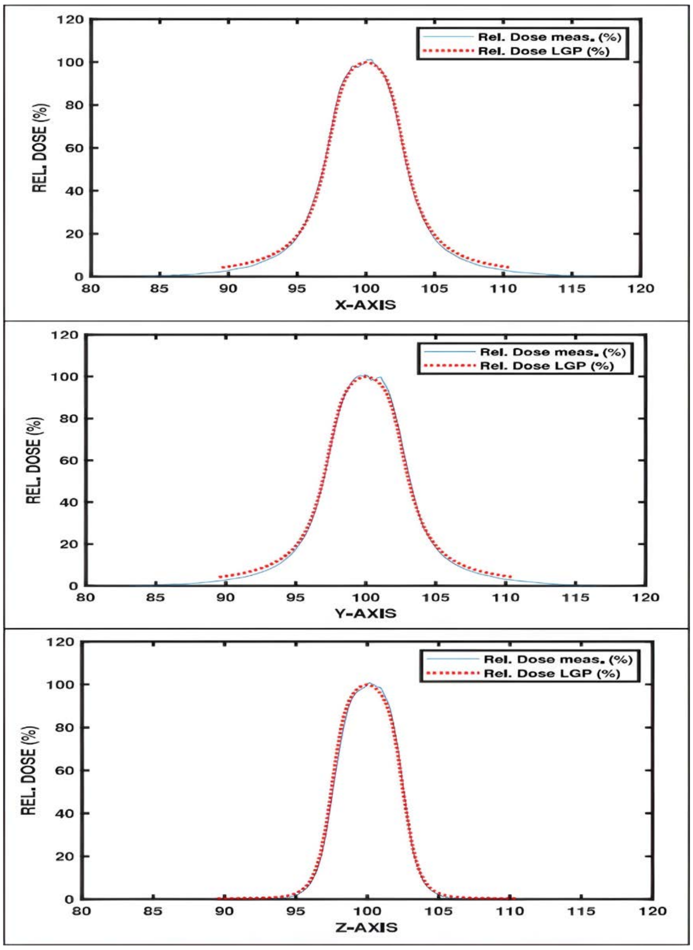


**Fig. 4.** X, Y, and Z -direction dose profiles of the 4 mm collimator

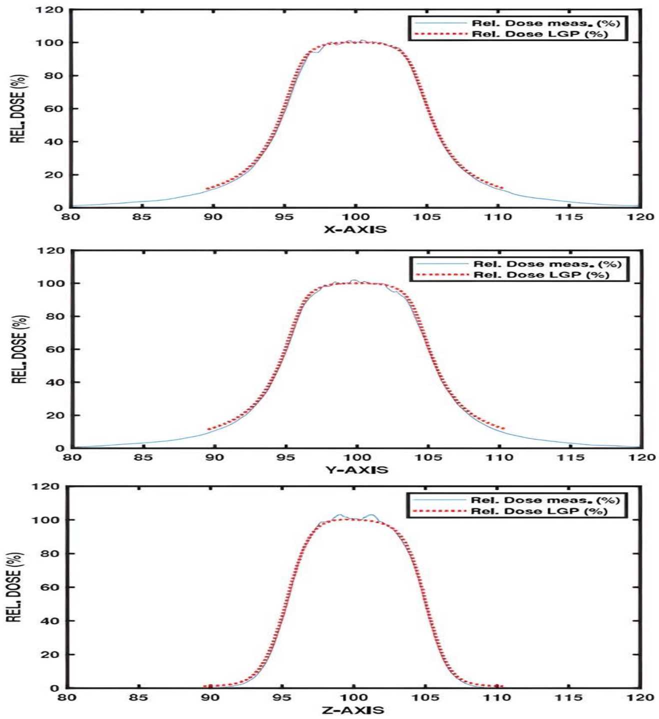


**Fig. 5.** X, Y, and Z -direction dose profiles of the 8 mm collimator

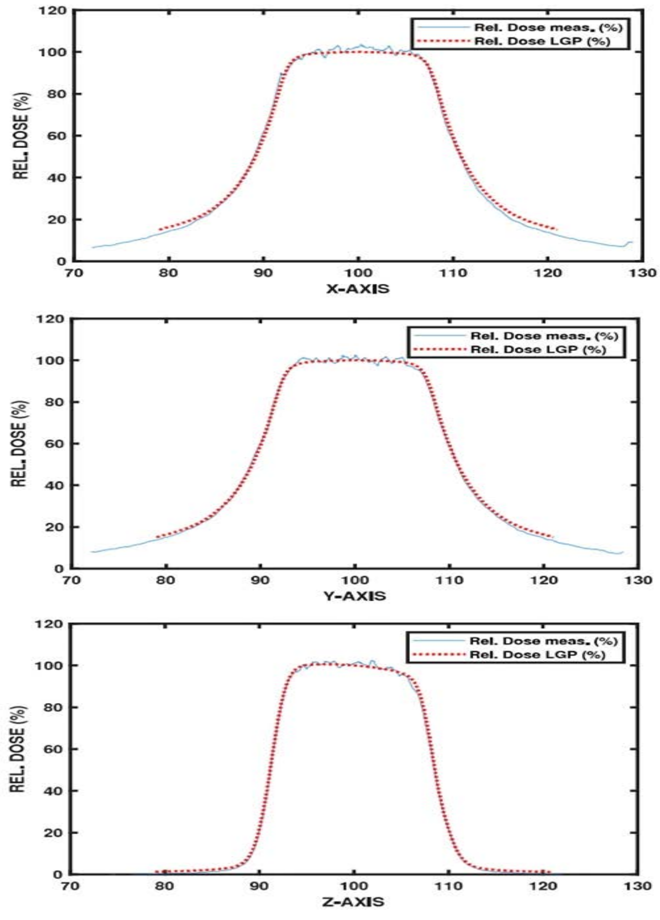


**Fig. 6.** X, Y, and Z -direction dose profiles of the 16 mm collimators

**Tab. 2.** FWHM and Penumbra widths for all three collimators in X, Y, Z direction

| | FWHMLGK (mm) | FWHMLGP (mm) | Diff (mm) | PenumbraLGK (mm) | PenumbraLGP (mm) | Diff (mm) |
|---|---|---|---|---|---|---|
| **4 mm-X** | 6.16 | 6.16 | - | 2.67 | 2.82 | 0.15 |
| **4 mm-Y** | 6.22 | 6.16 | 0.06 | 2.67 | 2.82 | 0.15 |
| **4 mm-Z** | 4.98 | 5.04 | - 0.06 | 1.51 | 1.52 | 0.01 |
| **8 mm-X** | 10.82 | 11.06 | 0.24 | 3.82 | 3.95 | 0.13 |
| **8 mm-Y** | 10.9 | 11.06 | 0.16 | 3.82 | 3.95 | 0.13 |
| **8 mm-Z** | 9.69 | 9.8 | 0.11 | 2.24 | 2.29 | 0.05 |
| **16 mm-X** | 21.81 | 21.75 | - 0.06 | 8.01 | 9.03 | 1.02 |
| **16 mm-Y** | 21.86 | 21.75 | - 0.11 | 8.44 | 9.03 | 0.59 |
| **16 mm-Z** | 17.41 | 17.44 | 0.03 | 2.6 | 2.55 | - 0.05 |

## Measurement of gamma knife accuracy center position measurements

In order to measure the distance between the radiological center and the needle mark, we used figures 7 and 8 measured along the X, Y, and Z axis. We also calculated the distance between the RFP and the PPS calibration center point, which is listed in table 3. Please note that there may be an experimental error of approximately 0.1 mm in these measurements (Figures 9 and 10).

$$\delta = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$$

$$\delta = \sqrt{(0.12)^2 + (0.097)^2 + (-0.18)^2} = 0.24\ mm$$

The measured distance i.e., the accuracy of the Gamma Knife was well within the specifications (0.4 mm).

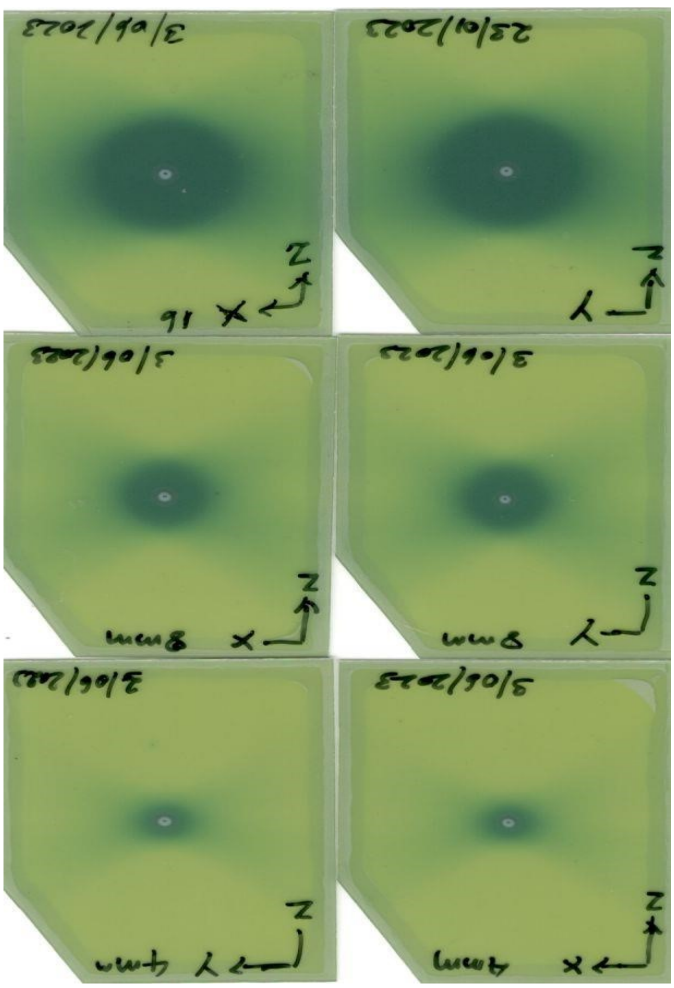

**Fig. 7.** Irradiated EBT3 films for center position measurements for 4 mm, 8 mm and 16 mm collimators respectively

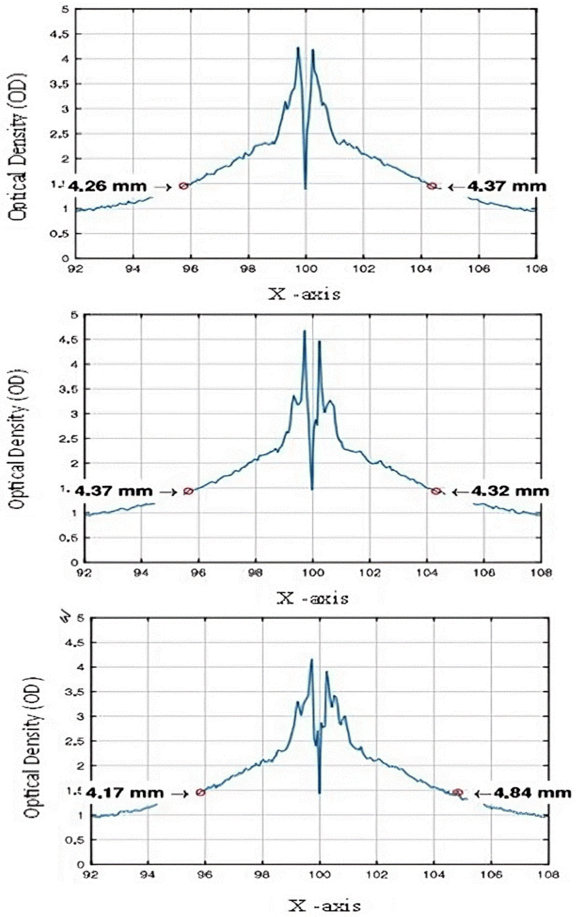


**Fig. 8.** X direction of the 4 mm Collimators Accuracy measurements

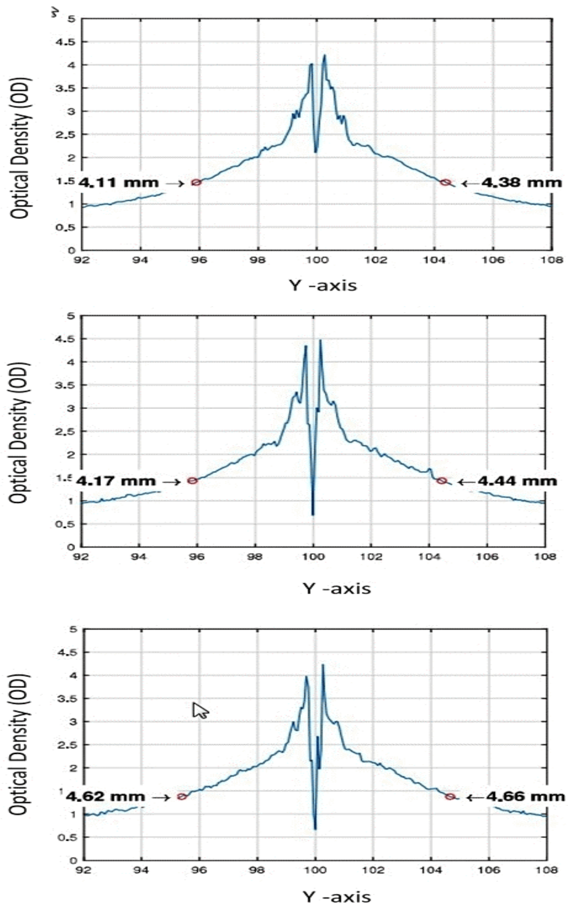


**Fig. 9.** Y direction of the 4 mm Collimators Accuracy measurements

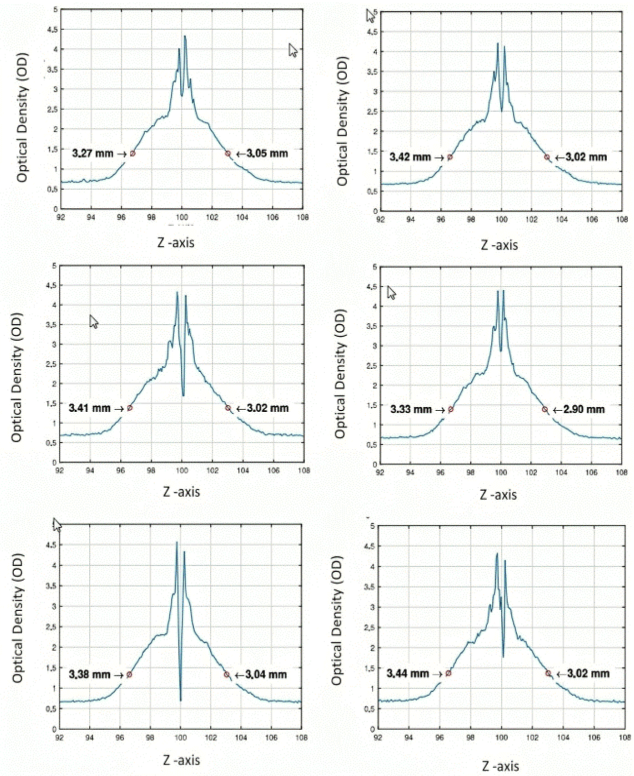


**Fig. 10.** Z direction of the 4 mm Collimators Accuracy measurements

**Tab. 3.** Center position measurements in three main axis (X, Y and Z)

| S.No | Deviation between RFP PPS (ΔX) | Deviation between RFP PPS (ΔY) | Deviation between RFP PPS (ΔZ) |
|---|---|---|---|
| 1 | 0.059 | - | -0.11 |
| 2 | -0.024 | - | -0.2 |
| 3 | 0.33 | - | -0.2 |
| 4 | - | 0.14 | -0.21 |
| 5 | - | 0.13 | -0.17 |
| 6 | - | 0.022 | -0.21 |
| Mean Deviation | 0.12 | 0.097 | -0.18 |

## Off-center position measurements

To determine the distance between the radiological center and the needle mark, measurements were taken from figures 11-13 along the X, Y, and Z axis. The distance between the RFP and the needle mark was also evaluated, and the center point of the PPS calibration off-Z axis was calculated and recorded in table 4. It should be noted that the Z-axis measurements may contain an experimental error of approximately 0.1 mm.

$$\delta = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$$

$$\delta = \sqrt{(0.12)^2 + (0.17)^2 + (-0.16)^2} = 0.26$$

The measured distance i.e., the accuracy of the Gamma Knife at the Leksell coordinate X, Y, Z =40 mm, 160 mm, 100 mm was well within the specifications (0.5 mm).

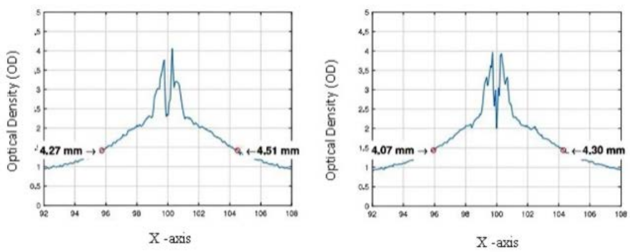


**Fig. 11.** X-direction of the 4 mm Collimator-Off center measurements

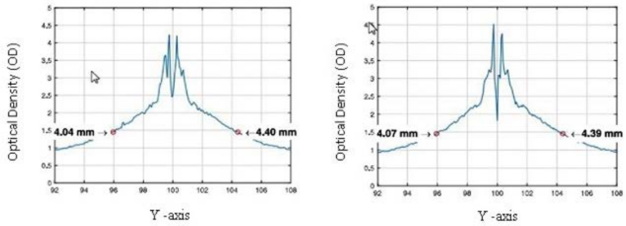


**Fig. 12.** Y-direction of the 4 mm Collimator-Off center measurements

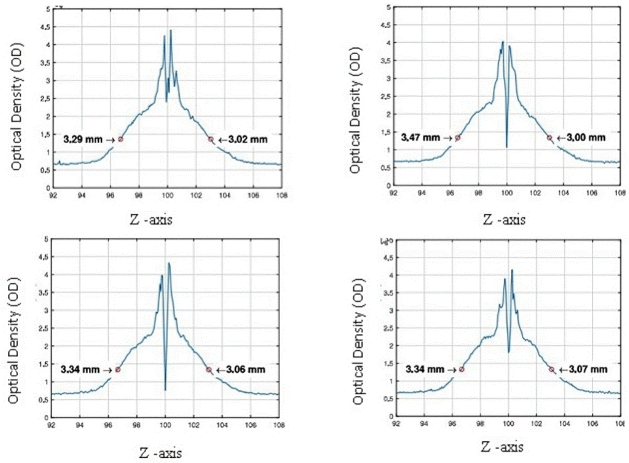


**Fig. 13.** Z-direction of the 4 mm Collimator-Off center measurements

**Tab. 4.** Off center position measurements in three main axis (X, Y and Z)

| S.No | Deviation between RFP & PPS (ΔX) | Deviation between RFP & PPS (ΔY) | Deviation between RFP & PPS (ΔZ) |
|---|---|---|---|
| 1 | 0.12 | - | - 0.13 |
| 2 | 0.12 | - | - 0.24 |
| 3 | - | 0.18 | - 0.14 |
| 4 | - | 0.16 | - 0.13 |
| **Mean Deviation** | 0.12 | 0.17 | - 0.16 |

## Determination of absorbed dose rate

During the stated condition, the average absorbed dose rate was measured to be 3.4333 Gy/min using the PTW Semiflex ion chamber. Additionally, the absorbed dose was measured to be 3.452 Gy/min using the Exradin A16 ion chamber. The difference between the two measurements was only 0.55%, which is well within the measurement uncertainty.

### Relative output factor measurement:

Contains the ROF values for both the Exradin A16 ionization chamber and the EBT3 films. The EBT3 films showed ROF values of 0.879 and 0.788 for 8 mm and 4 mm collimators, respectively. The percentage difference between Monte Carlo-calculated ROFs and EBT3 film ROFs were -2.33% and -3.199% for 8 mm and 4 mm collimators, respectively. The Exradin A16 ion chamber measured ROFs that had a percentage difference of 0.05% and -15.23% compared to Monte Carlo calculated values for 8 mm and 4 mm collimators, respectively (Table 5).

**Tab. 5.** Relative Output Factor (ROF) measurement

| S. No | Collimators | Monte Carlo ROF values | ROF of Exradin A16 chamber | ROF of EBT3 Film |
|---|---|---|---|---|
| 1 | 4 mm | 0.814 | 0.690 (-15.23%) | 0.788 (-3.19%) |
| 2 | 8 mm | 0.9 | 0.9005 (0.05%) | 0.879 (-2.33%) |

## DISCUSSION

This study is the comprehensive and meticulous process for the Radio-physical analysis of the Leksell Gamma Knife ICON unit, which is an important step before initiating the radiosurgery. The process involves using EBT3 films to gauge the measurement accuracy and precision of the LGK Icon unit, while also ensuring the proper installation of Co 60 sources in the Gamma Knife unit. The study evaluated the LGK Icon unit's precision and comparison between the LGP TPS system calculated dose profile and the LGK Icon unit measured dose profiles for all three collimators in the X, Y, and Z coordinates. The study found that all LGK Icon unit-measured dose profiles were in complete agreement with the LGP-calculated dose profiles within ≤ 1 mm at 50% dose levels, indicating high precision. The accuracy of the LGK Icon unit was also tested by measuring the distance between the RFP and PPS calibration center point using EBT3 films [9]. The study concluded that the LGK unit's accuracy was highly satisfactory. Zeverino et al reported the percentage difference of ROF values of -1.5% and -2.1 % between EBT3 films and Monto Carlo calculated values for 8 mm and 4 mm collimators respectively. In our study, the ROFs measured by EBT3 films were found to be lower than Monto Carlo calculated values by the amount of -2.33 % and -3.19 % for 8 mm and 4 mm collimators, respectively [10].

## CONCLUSION

It's essential to perform radio-physical analysis procedures before starting the SRS treatment. Our study highlights the different tests carried out on the LGK Icon unit, ensuring its accuracy and precision. We utilized advanced QA tools such as ABS spherical phantom, solid spherical phantom, and Film test tools to guarantee the highest quality treatments. The EBT3 films have a high spatial resolution, making them ideal for measuring the accuracy and precision of the LGK Icon unit, even with a 4 mm collimator. Our tests also included PTW Semiflex, and exradin a 16 ion chambers, which were also suitable for source confirmation tests and absorbed dose rate measurements. Our results are consistent with previous literature values and within the acceptable tolerance range as outlined by international guidelines.

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