RESEARCH ARTICLE

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Determination of Collimator Helmet Factors for Leksell Gamma Knife 4C Unit Using GAF Chromic EBT3 Film and ImageJ Software

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Abstract

Background: Measurement of Collimator helmet factors (CHF) is an important quality assurance procedure to be performed on Leksell Gamma Knife unit at regular interval to make sure that the interchangeable collimator helmet fit into the source channels without any positional inaccuracy which leads to major treatment error. The primary aim of this study is to measure the CHFs for Elekta Leksell Gamma knife 4C helmets using GafChromic EBT3 film and Image J software. **Methods:** GafChromic EBT3 film, EPSON expression 10000 XL scanner and Image J analysis software was used for this study. The calibration curve of GafChromic EBT3 film was generated with known dose values for 14 mm collimator helmet using ImageJ software. The collimator helmet factor (CHF) for 4mm, 8mm and 14 mm collimator helmets were measured by normalizing dose rates of 4mm, 8mm and 14 mm to the dose rate of 18 mm collimator helmet using the previously generated calibration curve. The measured CHF was compared to Elekta reference value and previously published mean values. **Results:** The measured CHFs were 0.896, 0.958, and 0.986 for 4mm, 8mm and 14mm collimators respectively. The percentage difference obtained was 1.7 %, 0.21 %, 0.1 % between measured values and reference values. **Conclusion:** The measurement of CHFs in LGK 4C unit using GafChromic EBT3 film and ImageJ software is a reliable method to verify the manufacturer quoted CHFs in routine quality assurance procedures.

Keywords: Gamma knife Collimator factor- GAF chromic EBT3 film Dosimetry- ImageJ Software- Gamma Knife

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Introduction

Stereotactic radiosurgery (SRS) is a useful treatment option for benign lesions of the brain such as arteriovenous malformations (AVMs), meningiomas, and acoustic neuromas and also to treat many malignant tumors such as brain metastases. It has also been used to treat functional disorders like trigeminal neuralgia and movement disorders. It uses the combination of SRS apparatus and narrow multiple beams for single fraction delivery through non-coplanar isocentric techniques. It involves three-dimensional imaging to localize the lesion and delivering treatment that focuses the dose in the target volume and spares as much as possible the normal brain. A high degree of dose conformity is a main feature of SRS. The Leksell Gamma-Knife (LGK) is widely used as a standard SRS device for treatment of intracranial lesions. The Gamma knife delivers radiation to a target lesion in the brain by simultaneous irradiation with a large number of isocentric gamma-ray beams (Khan, 2014). The Leksell Gamma Knife (Elekta Instruments) model 4C contains 201 60Co sources with a common focus point aiming dose to be delivered only to the treatment area. It has fixed primary collimation for each of Co60 sources and interchangeable four secondary collimators also called as collimator helmets each comprises of 201 apertures which align with primary collimation source channels. The apertures associated with each collimator helmet are identical and result in a full width at half maximum for a single beam profile of 4, 8, 14, and 18mm for the 4, 8, 14, and 18mm helmets, respectively (Kurjewicz et al., 2007). Dosimetry of small fields as used in SRS is challenging because of a possible absence of charged particle equilibrium. The detector used for dosimetry must be of a sufficiently small size so as not to perturb the electron fluence. SRS requires careful commissioning and rigorous Quality Assurance procedures. An overall accuracy of ±1 mm in the coverage of the intended target volume is a commonly accepted standard for the SRS procedures. Measurement of output factor (OF) or Collimator helmet factor (CHF) is significant procedure in dosimetry of SRS. The active volume of the detector relative to the field size

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and absence of charged particle equilibrium makes it complex. However the detector size must be as small as possible compared to the field size. For ultra-small fields (diameter of 10mm or less), film is the most appropriate detector for CHF measurements. Because of their high spatial resolution which is of supreme importance in such measurements. However, they should be properly calibrated against standard dosimetry system. Although the standard CHFs were provided by Elekta, they should be validated at the time of commissioning and at regular intervals thereafter, as recommended by TG42 to make sure that the correct positioning of collimator helmets with radiation isocenter. (AAPM Task Group 42, 1995). The values of CHF used in the treatment planning computer (Leksell Gamma Plan) can be adjusted if required. However, discrepancies from the preset values should be carefully investigated since they may indicate that the collimators in the helmet are not properly aligned with the primary collimation. The CHFs are validated by comparing the relative measured dose rates at isocenter for each helmet to the preset values in the planning computer. In our institute, the Leksell Gamma-Knife 4C model is installed by Elekta Instrument AB, Sweden having four helmets of size 4mm, 8mm, 14mm and 18mm. Importantly, the 4mm helmet (Figure 1) is routinely used for the treatment of trigeminal neuralgia to maximum doses of 80–90Gy with single fraction and presence of small uncertainty in the 4mm CHF will introduce equally large uncertainty in the absolute dose delivered to the target that may affect the clinical outcome. However, experimental determination of the CHF is known for its difficult task (Mack et al., 2002). Therefore, investigations of CHFs for all helmets especially 4mm helmet output factor is extremely important in the dosimetry and for the treatment. Typically, each end user determines the CHFs for its own gamma knife unit. Also, accuracy of the effect due to integration of detector response, measurement techniques, and sensitivity of the detectors and scanner type (Tsai et al., 2003). Najafi et al., (2017) studied the use of EBT3 GafChromic films for dosimetry of SRS and suggested that the EBT3 film can be calibrated in LGK unit itself to measure the unknown dose in LGK unit. Yusof et al., (2017) studied the characteristics of the high energy photons and electrons using GafChromic films and analyzed using the Image J software. They indicated the suitability of Image J as an alternative tool for dosimetry of high energy photons and electrons. Mack et al., (2002) used various detectors for the measurements of Relative Output factors (ROF) of LGK model B. They showed very good agreement between measured and manufacturer's recommended ROF values. The primary aim of this study is to measure the CHFs for Leksell Gamma knife 4C model collimator helmets (18mm, 14mm, 8mm and 4mm) using GafChromic EBT3 film and Image J software and validate the manufacturer specified reference CHF values.

Materials and Methods

The materials used for this study was GafChromic EBT3 films, a guillotine paper cutter, EPSON expression 10000 XL and Image J analysis software. Guillotine paper cutter was used to cut the film precisely to minimize the damage to the edges of the film strips. Scanning of the film was done using an Epson 10000 XL flatbed document scanner and analysis was done with ImageJ film analysis software. GafChromic EBT3 films used to generate the calibration curves and test the accuracy of the calibration were from the same manufactured lot films.

GAF Chromic EBT3 film properties

GafChromic EBT3 films are high spatial resolution dosimeters it changes the structural characteristics of their crystalline sensitive element when exposed to ionizing radiations. The interaction of ionizing radiation with the film produces a polymerization process in the monomers of the sensitive element. In this study GAF Chromic EBT3 is used for the measurement of absorbed doses of ionizing radiation. It is particularly suited for high-energy photons. The dynamic range of this film is designed for best performance in the dose range from 0.2 to 10Gy, making it suitable for many applications in radiotherapy. The structure of EBT3 film is shown in Figure 2. The film is comprised of an active layer, nominally 28µm thick, sandwiched between two 125µm matte-polyester substrates. The active layer contains the active component, a marker dye, stabilizers and other components giving the film its near energy independent response. The thickness of the active layer will vary slightly between different production lots.

Generation of Calibration curve

To obtain the calibration curve, five GAF Chromic EBT3 films were cut to the size of 4cm x 4 cm and orientation of each film was marked. Then the five films were placed in the groove of the film holder. The film holder is inserted into the ELEKTA provided 160mm diameter ABS (Acrylonitrile Butadiene Styrene) spherical phantom. Then the phantom was positioned in the isocentre (Focal point) of the LGK unit in the X-Y plane. (Figure 3 and Figure 4). The irradiation time of all five films were calculated for the known dose values ranging from 0.5 Gy to 6 Gy for a 14 mm collimator helmet at isocenter. All the films were irradiated in LGK 4 C unit with 14 mm helmet. The mean grey scale value was measured at the center for all irradiated film and four more readings were taken within the Region of Interest (ROI) was set at 2mm x 2mm from the center using Image J software. The mean values of grey scale value from irradiated film were recorded. The unexposed film from the same lot was used to measure the background grey scale value. The grey scale value was obtained by subtracting the background grey scale value from the average grey scale value for each irradiated film. Flatbed color scanner EPSON EXPRESSION 10000 XL (Epson America, Inc., Long Beach, CA) was used in transmission mode to scan films and measure the red color components of the GAF Chromic EBT3 films. The response of the film was maximized by using the scan data from the red color channel. All GAF Chromic EBT3 films in our study were read 24hrs after their exposure to assure uniform full post exposure density growth. Film response to the dose for each film were read on EPSON EXPRESSION

(10000 XL) scanner with 300 dpi resolution. Individual film samples were always placed exactly at the same scanning position to exclude the setup error in scanner response over scan field. Particular attention was devoted to maintain the orientation of the GAF Chromic EBT3 film samples in the scanner. All five scanned images were saved as Tiff format. All analysis for this study was done using red color channel data. The mean Grey values was measured for all five films and entered into the ImageJ software in table format with associated known dose values. The calibration curve have been created for Known dose verses measured grey scale values using 2nd Order polynomial fit available in ImageJ software. Figure 5 denotes the calibration curve of EBT3 Film with 14 mm helmet.

Measurement of Collimator helmet Factors

The CHF for a LGK system is defined as the dose rate delivered by a particular collimator helmet (4mm , 8 mm and 14 mm) divided by the dose rate delivered by the reference 18 mm collimator helmet. The CHFs for the 4 mm, 8 mm and 14 mm collimator helmets are relative to the collimator helmet factor for 18 mm at isocenter or unit focal point.

CHFi = (DR) i / (DR) 18mm

i = 4mm , 8mm and 14mm helmets, where CHFi is the collimator helmet factors for the 4mm, 8mm and 14 mm helmets , DRi is the dose rate for the 14 mm, 8 mm, or 4 mm. DR18mm is the measured dose rate for 18mm helmet. The CHF measurements were carried out using the ELEKTA spherical ABS dosimetry phantom similar to the measurement of calibration curve. In order to measure the CHFs, a series of 4 cm x 4 cm in size GafChromic EBT3 films were irradiated to with each of the four-collimator sizes (18, 14, 8 and 4 mm). The experimental films for each collimator were marked individually and placed in the groove of film holder. The film holder was mounted inside the spherical water equivalent phantom with a diameter of 160 mm, and positioned centrally at the focal point (x=100 mm, y=100 mm, z=100 mm) in the direction of the x-z plane. All the films were irradiated with uniform treatment time of 2 minutes. The measurements were carried out after 24 hours for film polymerization. The films were scanned using EPSON EXPRESSION (10000 XL) scanner with 300 dpi resolution. All the films were scanned in same orientation as done with calibration to avoid any uncertainty in scanning orientation. All film images were saved in tiff format. Before measuring the dose rate of individual film the calibration curve values generated previously need to be loaded in image J software. After loading the calibration curve values, the dose rate was measured at the center for all irradiated films for 4mm, 8mm, 14mm and 18mm helmets and four more readings were taken within the Region of Interest (ROI) was set at 2mm x 2mm from the center. The same measurements were carried out with another three set of films and the mean dose rate value at the center was obtained for each collimator helmets. The mean dose rate value of each collimator helmets were normalized to the mean dose rate value of 18 mm collimator helmet to obtain the CHFs for all four collimator helmets. Since the 18mm dose rate value were normalized to 18 mm value itself the helmet factor for 18mm is equal to 1.000.

Results

The measured CHFs and Elekta reference CHFs are tabulated along with mean CHFs published by Mack et al., (2002) values (Table 1). The measured CHFs were 0.896, 0.958, and 0.986 for 4mm, 8mm and 14mm collimators respectively. The 4mm collimator was having 1.7 % difference with ELEKTA reference value compared with -1.8% differences was observed with published value. For 8mm collimator helmet, the measured value had a difference of 0.21 %, whereas the published mean value had -0.62 % difference with Elekta reference values. The difference of 0.1 % was noted between the measured and reference values and 0.2 % difference of obtained with published value and reference value. This value is in good agreement with the Elekta specified helmet factors as well as Mack et al., (2002) published values. Figure 6 illustrates the comparison of collimator helmet factors.

Figure 1. 4mm Helmet of Gamma Knife Treatment Unit

Table 1. Elekta Reference, Measured and Published Values of Gamma Knife Helmet Factors for 4, 8, 14 and 18mm Collimator Helmets

S.no	Helmet Size	Reference helmet factor by Elekta	Measured helmet factor ± std deviation	Mean values of helmet factors ± std deviation (Mack et al)	Percentage of deviation between Measured value and Elekta reference values	Percentage of deviation between Mean values and Elekta reference values
1	4mm	0.881	0.896 ±0.020	0.865±0.020	1.70%	-1.80%
2	8mm	0.956	0.958±0.016	0.950 ±0.005	0.21%	-0.62%
3	14mm	0.985	0.986±0.013	0.983±0.008	0.10%	0.20%
4	18mm	1	1	1	-	-

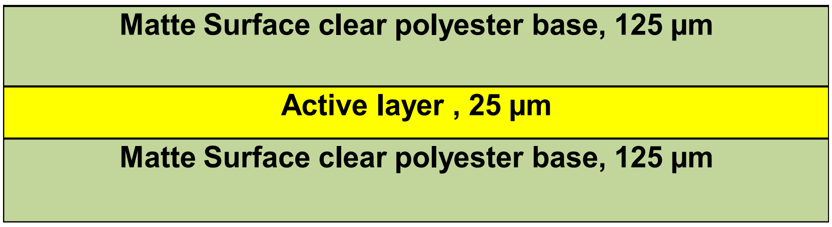

Figure 2. Structure of GAF Chromic EBT3 Dosimetry Film

Figure 3. ABS Phantom Settings in Leksell Gamma Knife 4C Treatment Unit

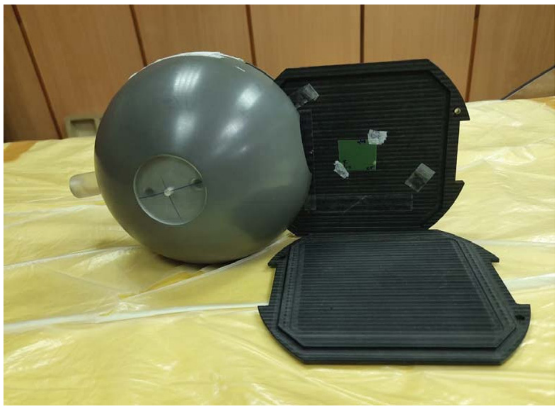

Figure 4. Elekta ABS 160mm Phantom with GAFChromic EBT3 Film Inserts

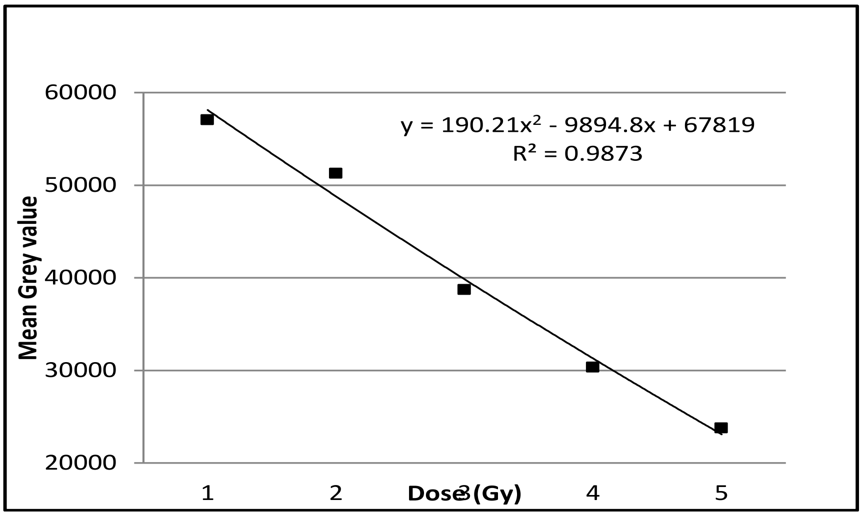

Figure 5. Calibration curve of GAFChromic EBT3 Film with 14mm Helmet

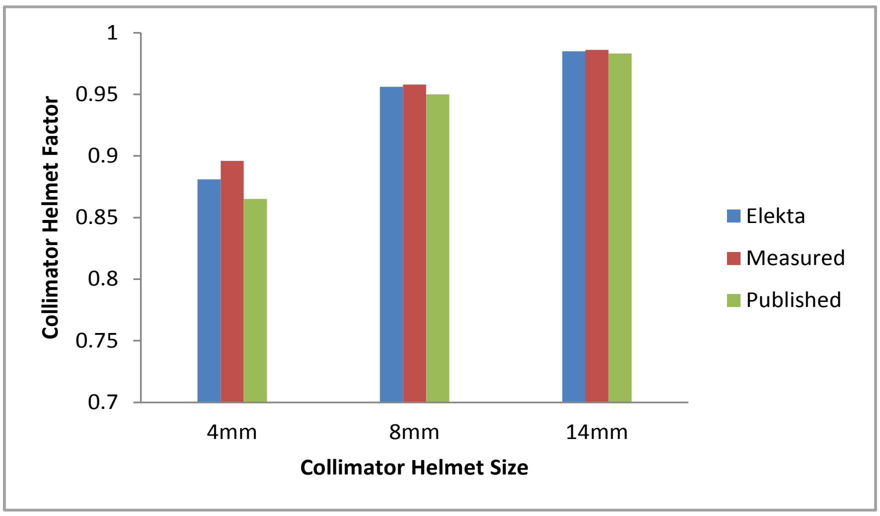

Figure 6. Comparison of Collimator Helmet Factors of Elekta, Measured and Published Values

Discussion

The collimator helmet factor for 4mm, 8mm, 14 mm and 18 mm were performed on LGK 4C using GafChromic EBT 3 film and ImageJ film analysis software. Our results were in good agreement with the ELEKTA, manufacturer reference value as well as published value by Mack et al (2002). Novotny et al (2009) measured the relative output factors of 4 mm and 8 mm collimators of Gamma Knife Perfexion model using KODAK EDR2, GafChromic EBT 2 and GafChromic MD-V2-55 films. In their study, GafChromic EBT and GafChromic MD-V2-55 films were shown good agreement with ELEKTA, manufacturer values, but there was large discrepancies were obtained while using KODAK EDR2 films. In our study we used the GafChromic EBT3 film and analyzed with ImageJ software free available in public domain. The main advantage with EBT3 film dosimetry was the minimal positional inaccuracy compared to the small size detectors as the size of the film used was 4 cm x 4 cm, comfortably fits into the film holder of ABS phantom. Also, it doesn't need any angular correction factor as like other diode detectors. The common assumption with the film dosimetry is lengthy processing time as it needs to be calibrated before the actual measurement. But with the use of GafChromic EBT3 films, the processing time was minimized as it doesn't need any post processing after irradiation. Once the calibration curve generated, the Image J software creates the calibration table and that can be used for future measurement as far as we use the film from the same lot. We need not to create calibration curve for each and every measurement. Hence it reduces the measurement time. We evaluated the feasibility of reliable CHF measurements in the Leksell Gamma Knife 4 C model for all available collimator helmets using GafChromic EBT 3 film and Image J software. Acceptable calibration and analysis of EBT3 film with Image J software result in realistic values. Based on our measurement results, we therefore conclude that using EBT3 film and Image J software is more reliable method because it showed a good agreement with the manufacturer as well as published values for four collimator helmet sizes. However, the limitation of implementing film dosimetry in the measurement of collimator output factor is that it requires proper calibration of films for better outcome of results.

Author Contribution Statement

First Author: Natesan Ponnusamy - involved in study design, data collection, data analysis and manuscript preparation. Second Author (Corresponding author): Dr. Senthil Manikandan Palaniappan –involved in study design, data collection, data analysis and manuscript preparation. Third Author: Dr. Muthuvinayagam – involved in study design, data analysis. Fourth Author: Dr. K.M. Ganesh – involved in study design, data analysis. Fifth Author: Dr. Malla Bhasker Rao - – involved in study design, data analysis.

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Ethical Permission

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How the ethical issue was handled

This is only dosimetry study and does not involve any patient data. So ethical committee approval is not necessary

Conflict of Interest

None.

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