RELATIVE OUTPUT FACTOR (ROF) OF GAMMA KNIFE'S MEASUREMENT USING IONIZATION CHAMBER AND GAFCHROMIC FILMS

Pengukuran Faktor Output Relatif Pisau Gamma Menggunakan Ionization Chamber dan Film Gafchromic

Nazaroh[1*], Okky Agassy Firmansyah[1], Assef Firnando Firmansyah[1], Ade Rizky Setiadi[2], Irhas[3], Elia Sudiatmoko[3]

The Center for Safety Technology and Radiation Metrology (CSTRM) –
National Nuclear Energy Agency (NNEA) of Indonesia
Jl. Lebak Bulus Raya No. 49, Jakarta 12440, Indonesia
[2]PT Besindo Medi Prima, Jakarta Indonesia
[3]Rumah Sakit Siloam Lippo Karawaci, Tangerang Indonesia
**e-mail: nazaroh_s@batan.go.id*

Diterima 31 Mei 2021 Direvisi: 23 Juli 2021, Disetujui: 30 November 2021

Abstract

The important things on Leksell Gamma Knife (LGK) is determination of Relative Output Factor (ROF), which is required for beam data collection (BDC) process, as an input value to the Treatment Planning System (TPS). The ROF is also needed to traceability of dosimetry measurements and patient safety. ROF measurements on LGK using PTW PinPoint 3D ionization chamber: 0.016 cm^3, PTW Semiflex: 0.125 cm^3, and Exradin A16: 0.017 cm^3 at collimators 4, 8 and 16 mm. and gafchromic films. ROF values obtained in hospital-A, using PTW PinPoint 3D was: [(1.00 ± 0.002)], [(0.80 ± 0.02]); [(0.42 ± 0.002)]; and using Exradin A16 [(1.00 ± 0]; [(0, 87 ± 0)]; [(0.69 ± 0.0002)]. And using gafchromic films was: [(1.00 ± 0.006]; (0.96 ± 0.005); (0.86 ± 0.06)]; respectively for collimators 4, 8 and 16 mm, and Measurement of ROF in hospital-B using using a PTW PinPoint 3D was: [(1 ± 0); (0.75 ± 0); and (0.33 ± 0)] and using Exradin A16 was: [(1; 0.87; and 0.69)] and gafchromic films was: [(1.00 ± 0.03); (0.98 ± 0.045); and (0.85 ± 0.09)]; The results of ROF's measurement were compared with the ROF values of Novotny, et al (2009) and TPS. The Gafchromic's ROF values were relatively closer than both of them, while the ROF value of ionization. chamber at 4 mm collimators was relatively lower, because measurement in a small field occurs an averaging effect volume and lack of lateral charge particle equilibrium (LCPE).

Keywords: relative output factor; leksell gamma knife; ionization chamber; small field; gafchromic film

Abstrak

Aspek penting pada Pisau Gamma Leksell adalah menentukan Faktor Output Relatif, yang diperlukan untuk proses pengumpulan data berkas sebagai nilai masukan ke TPS.. Penentuan ROF juga dibutuhkan untuk ketertelusuran pengukuran dosimetri dan keselamatan pasien. Telah dilakukan pengukuran ROF pada rumah sakit (RS) yang memiliki LGK menggunakan film gafchromic dan detektor PTW Pinpoint: 3D berukuran 0,016 cm^3, PTW semiflex 0,125 cm^3, dan Exradin A16 0,017 cm^3 pada kolimator 4, 8 dan 16 mm. Diperoleh nilai ROF di RS-A, menggunakan film gafchromic: [(1,00±0,006), (0,96±0,005), (0,86±0,06)] masing-masing untuk kolimator 4, 8 dan 16 mm; menggunakan detektor PTW PinPoint: [(1,00±0,002, (0,80±0,02), (0,42±0,002)]; dan menggunakan detector Exradin A16: [(1,00±0), (0,87±0), (0,69±0,0002)]. Pengukuran ROF pada RS-B menggunakan film gafchromic: [(1,00±0,03), (0,98±0,045), (0,85±0,09)]; menggunakan detektor PinPoint: [(1±0); (0,75±0); (0,33±0)] dan menggunakan Exradin A16: [(1; 0,87; dan 0,69)]. Hasil pengukuran ROF ini dibandingkan dengan nilai ROF Novotny, et. al (2009) dan TPS. Nilai ROF Gafchromic relatif lebih dekat dengan hasil Novotny (2009) dan TPS, sedangkan nilai ROF detektor ionisasi pada kolimator 4 mm relatif rendah, karena pada pengukuran di lapangan kecil terjadi volume averaging effect dan lack of lateral charge particle equilibrium (LCPE).

Kata Kunci: *relative output factor, LGK, detektor ionisasi, lapangan radiasi kecil, film gafchromic*

1. INTRODUCTION

According to reference (Novotny et al. 2010), the Leksell Gamma Knife (LGK) is a method of radiosurgery to cure the tumors in the brain without having to undergo surgery. The gamma-ray used on LGK is Co-60, which can interact and kill cancer cells. The LGK has a high level of precision and accuracy of up to 0.15 mm. The size of the gamma-ray beam varies at each target position. This feature gives the LGK to irradiate tumor targets accurately. LGK-PFX is a generation of LGK introduced by Elekta Instrument, AB, Sweden, in 2006. LGK-PFXF was a continuation of the previous LGK, namely the U, B, C, and 4C LGK models. In 2016, the Elekta Instrument introduced the latest model LGK, the LGK Icon. LGK-PFX has 192 of Co-60 sources. Unlike its predecessor, which has 201 sources. From 192 sources, divided into eight sectors, each installed with 24 of Co-60 sources. The collimator is made of tungsten, which has 16, 8, and 4 mm. 192 Co-60 sources against the center support each collimator.

After obtaining optimal results, radiation was carried out with the help of a unique fixation device placed on the patient's head to be sure that the patient's head does not move during the procedure. The irradiation time depends on tumor volume and planning.

One of the dosimetry parameters on the LGK is the relative output factor (ROF). ROF is the quotient value from measuring the output of a collimator to the largest collimator output value on the LGK (Zeverino, Jaccard, and Patin 2017). LGK-PFX has the largest collimator size, 16 mm, different from its predecessor LGK models U, B, C, and 4C, with the largest collimator size of 18 mm.

ROF measurement is a quality assurance (QA) because ROF has a significant influence on the accuracy of LGK dose (Firmansyah, Assef Firnando,et al., (2016). LGK ROF measurement has several difficulties, including accuracy in positioning the detector on the phantom of the head and the averaging volume effect experienced by the ionization chamber with a small volume. The dosimetry in the LGK is considered in the small field dosimetry category in the IAEA TRS- 483 protocol. Previous authors have carried out the ROF measurements using various types of detectors, including diamond detectors, diode detectors, and films (Hrsak et al. 2014; Klawikowski et al. 2014).

In Indonesia, there were only two LGK-PFX, which were installed in 2012 and 2017 (Firmansyah et al. 2016, 2017; Nazaroh, Firmansyah, and Rajagukguk 2012). The ROF value has never been determined by measurement.

To provide therapy with an accurate dose, the LGK must be measured in terms of output of dose and ROF. This paper describes the first experience for ROF measurements in two LGK-PFX in Indonesia. The measurement was made using the gafchromic film EBT3 and three micro-ionization chambers. The result compared to the value from LGK's TPS and reference Novotny (Novotny et al. 2009).

2. REVIEW

The absolute dose rate of LGK is usually measured only in the largest collimator, i.e., the dose distribution, which shows a relatively large plateau region, in the x-y plane. The dose rate for the smaller collimator helmet calculated according to the following equation:

$$\left(\frac{dD}{dt}\right)_n = \left(\frac{dD}{dt}\right)_{16} .OF_n \qquad (1)$$

$\left(\frac{dD}{dt}\right)$: measured dose rate for collimator 16 mm.

$\left(\frac{dD}{dt}\right)_n$: the dosage rate for collimators 4, 8, and 16 mm.

$(OF)_n$: the output factor that corresponds to the collimator.

Corresponding the output factor, with OF_{16} was 1,000 by definition. The output factor, which was still being discussed, in a 4 mm collimator, shows a 4-11% (with Monte Carlo calculations, analytical calculations, or experimental methods).

According to the IAEA publication TRS-483, one of the dosimetric parameters that must determine on LGK was the relative output factor (ROF). The ROF is the quotient value of the output measurement in a collimator to the value of the largest collimator.

(a)

(b)

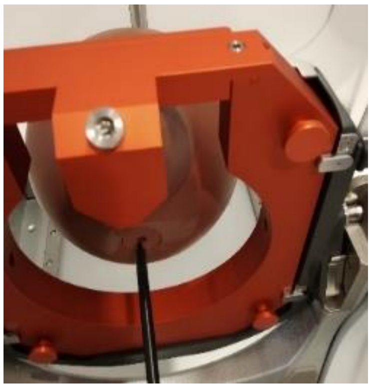
Figure 1 (a) PTW Semiflex, PTW PinPoint 3D and Exradin A16 ionization detectors (b) Scan Results of Gafchromic EBT3

Based on the IAEA TRS 398, the detectors used for measurement must be traceable to the international system (SI) and checked for stability.

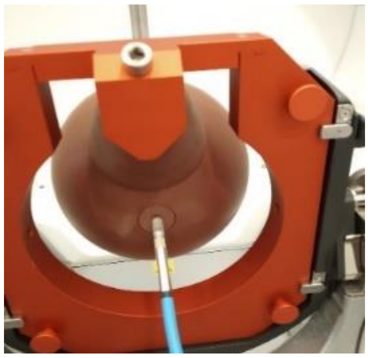
The radiation source used for this study was the LGK-PFX in Hospital A (RS-A) and Hospital B (RS-B). Before the research, the LGK-PFX has been calibrated its output with a reference of 1 MU ≈ 1 cGy.

The ionization chamber for measurement of dosimetry in a small field was a micro-ionization detector, namely PTW Pinpoint 3D ionization chamber 0.016 cm^3, PTW Semiflex 0.125 cm^3 and Exradin A16 0.007 cm^3 ionization chamber (Figure 1a) and EBT3 gafchromic films (Figure 1b). The electrometer used was PTW Unidose Webline. For the measurement of ionization chamber, it conducted five repetition data in each point of dose.

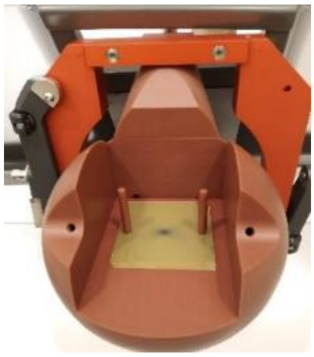
The use of gafchromic EBT3 film has an advantage, especially for the darkness can be negligible when scanning at least 24 hours after irradiation (Li et al. 2017). Few publications show the gafchromic films were advanced dosimetry tools for small field measurement, include the relative output factors (Gonzalez-Lopez, Vera-Sanchez, and Lago-Martin 2015; Morales et al. 2016; Mourya et al. 2018; Ulya et al. 2016)



(a)



(b)



(c)

Figure 2 Setting of ionization chamber: (a) Exradin A16, (b) PTW Semiflex (c) film gafchromic

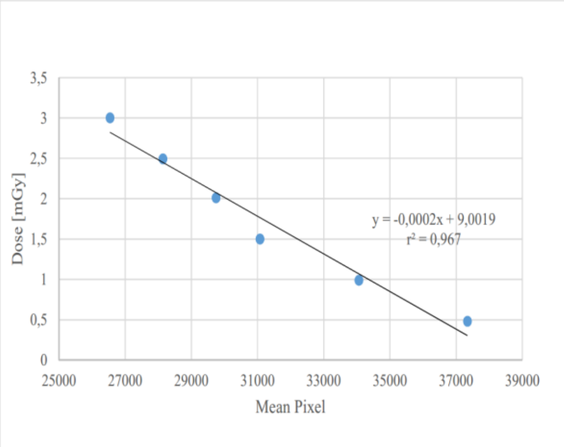
3. METHOD

Before being used for ROF measurements on the LGK-PFX, the PTW PinPoint 3D was checked for stability and repeatability. By the measurement, the PTW Pinpoint 3D ionization chamber stability was below 1% and the repeatability was 0.2% at a confidence level of 67%. In radiotherapy, it was required an accurate dosimeter, a good response to dose and energy, high spatial resolution, and tissue equivalent. Based on the recommendation of AAPM TG 55, the film was the main dosimeter in measuring radiotherapy sources. Currently, one of the Gafchromic films that were often used was the EBT3 Gafchromic film.

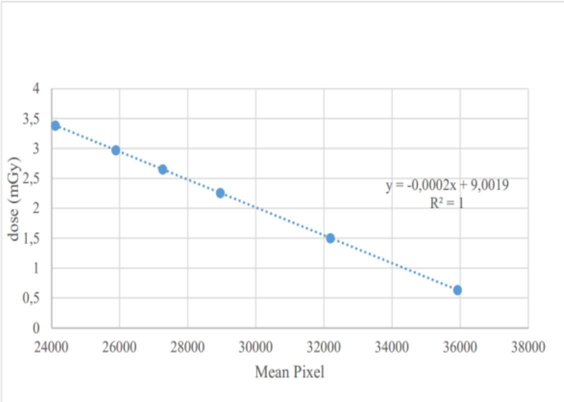
Before using, the response of Gafchromic films were checked by made a calibration curve. For this reason, the film was irradiated with Co-60, with six dose variations, using 72 and 420 dots per inch (dpi), the film was read and produces the number of pixels, so a calibration curve was obtained. The measurement using EBT3 film were conducted three times repetition each dose point.

4. RESULT AND DISCUSSION

The result of the evaluation Gafchromic film as calibration curve was showed in Figure 3a and 3b. For Figure 3a, the relationship between Y vs X-axis is showed has square residual 0.967.



(a)



(b)

Figure 3 Calibration Curve of Gafchromic for (a) 720 dpi and (b) 420 dpi

The evaluation using 420 dpi (Figure 3b), the film was read and produces the number of pixels. The calibration curve was obtained with the relationship between the Y vs X-axis. Y = 0.0002X+9.0019, Y (dose), X (mean pixel), with r2 = 1, r (correlation coefficient). By using 420 dpi (better film resolution) so that the calibration results were better, with a very linear correlation coefficient square residual 1,000.

Using the gafchromic calibration curve, the dose and ROF of the LGK-PFX in RS-A and and RS-B can be determined, for collimators 4, 8, and 16 mm. ROF was calculated using the dose rate for each collimator using the formula ~ (1). The results were presented in Table 1.

The ROF measurements using Gafchromic Films in RS-A and RS-B were quite good with ROF results in RS-A (1; 0.96; and 0.86) and RS-B (1; 0.98; and 0.85). Dose measurements using Gafchromic film on collimators 16, 8 and 4 mm in RS-A have a standard deviation of 6.03%; 0.53%; and 7.24%, and the results of dose measurements using Gafchromic film in RS-B have a standard deviation, respectively of 3.3%; 4.6; and 10.7%. Based on some references, the use of Gafchromic films in radiotherapy dosimetry was the best option especially for small radiation field dosimetry (Gonzalez-Lopez, Antonio, Juan Antonio Vera-Sanchez, and Jose Domingo Lago-Martin,. (2015), (Das, Indra J., George X. Ding, and Anders Ahnesjö, (2008) and Hassani, Hossein, Hassan Ali Nedaie, Mohammad Hassan Zahmatkesh, and Kaveh Shirani (2014).

Table 1 ROF Measurement Results for LGK-PFX.in RS-A and RS-B (using Gafchromic Film**)**

Collimator (mm)	Film Gafchromic			
	RS-A		RS-B	
	Dosis (mGy)	ROF	Dosis (mGy)	ROF
16	4.54 ± 6.0%	1.00	2.93 ± 3.3%	1.00
8	4.35 ± 0.5%	0.96	2.86 ± 4.6%	0.98
4	3.92 ± 7.2%	0.86	2.48 ±10.7%	0.85

In the ROF measurement of the LGK-PFX, three ionization chamber was used: the PTW PinPoint 3D ionization chamber, the Exradin A16 detector, and the PTW semiflex. The ionization chamber was positioned on the head phantom isocenter, then irradiated with a certain dose. Three data were taken in each irradiation. The measurement results were presented in Table 2.

The measurement using PTW PinPoint 3D in RS-A has good agreement with the TPS value, but the ROF results were not good. The measurement using a semiflex ionization at RS-B was a quite good standard deviation, but the results of ROF measurements using a relatively low ionization detector on a 4 mm collimator with a value of 0.33 were measured using a PTW Semiflex detector.

Table 3 presents the results of determining the ROF for collimators 16, 8, and 4 mm using 3 types of detectors, with references Novotny [10] and TPS. The determination of ROF by using gafchromic film the results were quite accurate namely 1; 0.98 and 0.85 compared to TPS and Novotny, but the standard deviation was not good because the data collection was only three times.

From Table 3, it can be concluded that the measurement using the Exradin A16 ionization chamber at an 8 mm collimator has a good agreement compared with the TPS value in terms of a 3% deviation. In comparison, the measurement for a 4 mm collimator was not good, because the deviation is more than 3%.

The measurement result using gafchromic films has been shown a good agreement in both hospitals. It compared to the normalization value at 18 mm for each measurement. Generally, on the radiotherapy dosimetry, the maximum deviation, which acceptable was 3%. Higher than 3% should be re-calibrating and do the adjustment system for the machine. However, for the measurement of relative factor output factor, some references showed a good agreement for 10% (for 8 mm) and 20% (for 4 mm) deviation (Araki et al. 2003; Ma et al. 2009). From those results, the gafchromic result showed below the reference.

Based on several references, the use of gafchromic films in radiotherapy dosimetry is one of the best choice especially for small radiation field dosimetry (Li et al. 2017; Novotny et al. 2009; Zeverino et al. 2017). To ensure the quality of gafcrhomic film result, the scanning was performed in the range 24 hours after irradiation using the Epson Flatbed Scanner. Also, the temperature was set in the range 20 – 24 ^{o}C to maintain the effect of gafchromic film.

The use of a micro ionization chamber for measurement of small field dosimetry was still not able to optimally measure the smallest collimators. The averaging effect and the lack of lateral charged particle equilibrium are the main causes of the non-optimal ionization chamber.

Table 2**.** ROF Measurement Results for LGK-PFX machine using an ionization chamber

Collimator (mm)	RS-A				RS-B	
	PTW PinPoint 3D		Exradin A16		PTW Semiflex	
	M (nC/minute)	ROF	M (nC/minute)	ROF	M (nC/minute)	ROF
16	0.011±0	1.00	0.75±0	1.00	10.95±0	1.00
8	0.008±0	0.75	0.66±0	0.87	8.21±0	0.75
4	0.004±0	0.33	0.52±0	0.69	3.60±0	0.33

Table 3**.** Results of Determination of ROF on LGK in RS-A and in RS-B compared to the TPS and Novotny's result (Novotny et al. 2009)

Col (mm)	RS-A			RS-B		TPS	Novotny (Novotny et al. 2009)
	PTW PinPoint 3D	Exradin A16	Gafchromic	Semiflex	Gafchromic		
16	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	0.80	0.87	0.98	0.75	0.94	0.90	0.92
4	0.42	0.69	0.85	0.33	0.81	0.81	0.81

The average volume effect (volume averaging effect) can occur because the volume of the detector is greater than the radiation field so that the reading of charged particles is uneven in their accumulation. This effect causes the dose reading to be lower than it should be (underestimate dose). For the equilibrium of particles in the lateral direction not achieved has the same impact, namely the accumulative reading of the ionization in the detector cannot be optimal. But, for years there were few publications looking for correction factor to correct the small field detectors (Bouchard et al. 2015; Das, Ding, and Ahnesjö 2008; Hrsak et al. 2014).

Until now, calibration traceability for small field ionization detectors still uses available protocols, the standard 10 cm x 10 cm radiation field or by using the daisy-chaining measurement method(Firmansyah et al. 2020). There is still possible study to conduct for the determination in the small field dosimetry by using the others approach, i.e., the alanine dosimetry (Baffa and Kinoshita 2014) or polymer gel dosimetry (Hassani et al. 2014).

Based on the experiment, the relative output factor can be determined using the ionization chamber with the small volume and Gafchromic films due to their advantage. However, the normally condition in the hospital used the value of relative output factor from TPS system for clinical purpose. The manufacturer already set up the TPS value with simulation in advance while in the commissioning purpose. For the result of determination of relative output factor can be used as verification method for research purpose.

5. CONCLUSION

The ROF measurement on LGK-PFX has been carried out using ionization detector and Gafchromic film. The results of the ROF measurement using the PTW PinPoint 3D on a 4 mm collimator are relatively lower compared to the TPS reference values.

Determination of ROF using Gafchromic Film get relatively no significant difference with the reference value. Gafchromic film on radiotherapy dosimetry is the best choice, especially for small radiation field dosimetry.

ACKNOWLEDGEMENT

The authors would like to thank PTKMR-BATAN, PT Besindo Medi Prima, Jakarta Indonesia, and Siloam Lippo Karawaci Hospital, Tangerang Indonesia for providing facilities and infrastructure as well as permission to carry out ROF measurements on Gamma Knife Machine.

REFERENCES

Araki, Fujio, Tohru Ikegami, Tatsuyo Ishidoya, and Hideo D. Kubo. (2003), “Measurements of Gamma-Knife Helmet Output Factors Using a Radiophotoluminescent G.ass Rod Dosimeter and a Diode Detector.” *Medical Physics* 30(8):1976–81.

Baffa, Oswaldo, and Angela Kinoshita. (2014), “Clinical Applications of Alanine/Electron Spin Resonance Dosimetry.” *Radiation and Environmental Biophysics* 53(2):233–40.

Bhatnagar, Jagdish P., Josef Novotny, Ajay Niranjan, Douglas Kondziolka, John Flickinger, Dade Lunsford, and M. Saiful Huq. (2009), “First Year Experience with Newly Developed Leksell Gamma Knife ® Perfexion ™ Full Text Introduction.” 34–36.

Bouchard, Hugo, Jan Seuntjens, Simon Duane, Québec Hl, and Hugo Palmans, (2015), “Detector Dose Response in Megavoltage Small Photon Beams . I . Theoretical Concepts.” 42(10):6033–47.

Das, Indra J., George X. Ding, and Anders Ahnesjö, (2008). “Small Fields: Nonequilibrium Radiation Dosimetry.” *Medical Physics* 35(1):206–15.

Firmansyah, Assef Firnando, C. Tuti Budiantari, Gatot Wurdiyanto, and Nurman Rajagukuguk. (2016), “Stabilitas Luaran Berkas Radiasi Cobalt 60 Pesawat Pisau Gamma Leksell Perfexion.” Pp. 193–99 in *Seminar Nasional XII SDM Teknologi Nuklir*.

Firmansyah, Assef Firnando, Okky Agassy Firmansyah, Nurman Rajagukuguk, and Dea Ryangga. (2020), “Studi Awal Pengukuran Daisy Chaining Detektor Ionisasi Pada Berkas Foton 6 MV Flattening Filter Free Lapangan Kecil.” *Jurnal Ilmu Fisika (JIF)* 12(1):16–25.

Firmansyah, Assef Firnando, Sri Inang Sunaryati, Nurman Rajagukuguk, and Gatot Wurdiyanto. (2017), “Penentua Dosis Serap Air Berkas Radiasi Co-60 Pesawat Pisau Gamma Leksell Perfexion No. Seri 6428.” Pp. 63–66 in *Seminar Keselamatan Nuklir*.

Gonzalez-Lopez, Antonio, Juan Antonio Vera-Sanchez, and Jose Domingo Lago-Martin,. (2015), “Small Fields Measurements with Radiochromic Films.” *Journal of Medical Physics* 40(2):61–67.

Hassani, Hossein, Hassan Ali Nedaie, Mohammad Hassan Zahmatkesh, and Kaveh Shirani, (2014), “A Dosimetric Study of Small Photon Fields Using Polymer Gel and Gafchromic EBT Films.” *Medical Dosimetry* 39(1):102–7.

Higuchi, Yoshinori, Shinji Matsuda, and Toru Serizawa, (2017), “Gamma Knife Radiosurgery in Movement Disorders: Indications and Limitations.” *Movement Disorders* 32(1):28–35.

Hrsak, Hrvoje, Marija Majer, Timor Grego, Juraj

Bibic, and Zdravko Heinric, (2014), "Correction of Measured Gamma-Knife Output Factors for Angular Dependence of Diode Detectors and PinPoint Ionization Chamber Hrvoje Hr." *Physica Medica* 30(8):914–19.

Klawikowski, Slade J., James N. Yang, John Adamovics, and Geoffrey S. Ibbott, (2014). "PRESAGE 3D Dosimetry Accurately Measures Gamma Knife Output Factors." *Phys. Med. Biol* 59:N211–20.

Li, Yinghui, Lixin Chen, Jinhan Zhu, and Xiaowei Liu, (2017), "The Combination of the Error Correction Methods of Gafchromic EBT3 Film." *PLoS ONE* 12(7):1–17.

Ma, Lijun, Jonas Johansson, Lynn Verhey, Per Kjall, Josef Novotny Jr, and Hakam Nordstrom, (2009), "A Simple and Effective Method for Validation and Measurement of Collimator Output Factors for Leksell Gamma Knife ® Perfexion TM." *Phys. Med. Biol* 54(12):3897–3907.

Morales, Johnny E., Martin Butson, Scott B. Crowe, Robin Hill, and J. V. Trapp, (2016), "An Experimental Extrapolation Technique Using the Gafchromic EBT3 Film for Relative Output Factor Measurements in Small X-Ray Fields." *Medical Physics* 43(8):4687–92.

Mourya, Ankur, Lalit Mohan Aggarwal, Abhijit Mandal, Uday Pratap Shahi, and Chhape Ram, (2018), "An Inexpensive Method of Small Photon Field Dosimetry with EBT3 Radiochromic Film." *Health and Technology* 8(6).

Nazaroh, Assef Firnando Firmansyah, and Nurman Rajagukguk, (2012), "Leksell Gamma Knife (LGK) Perfexion/6121, Pertama Di Indonesia Dan Verifikasi Keluarannya." pada *Pertemuan dan Presentasi Ilmiah Standardisasi (PPIS)*.

Novotny, Josef, Jagdish P. Bhatnagar, Jonas Johansson, and Greg Bednarz. (2010), "Assessment of Variation in Elekta ® Plastic Spherical-Calibration Phantom and Its Impact on the Leksell Gamma Knife ® Calibration." *Medical Physics* 37(9):5066–71.

Novotny, Josef, Jagdish P. Bhatnagar, Mubina A. Quader, Greg Bednarz, L. Dade Lunsford, and M. Saiful Huq, (2009), "Measurement of Relative Output Factors for the 8 and 4 Mm Collimators of Leksell Gamma Knife Perfexion by Film Dosimetry." *Medical Physics* 36(5):1768–74.

Ulya, Syarifatul, Wahyu Edy Wibowo, Nuruddin Nuruddin, and Supriyanto Ardjo Pawiro. (2016), Karakteristik Dosimetri Film Gafchromic Ebt3 Pada Berkas Elektron Dan Foton." *Spektra: Jurnal Fisika Dan Aplikasinya* 1(2):149–56.

Zeverino, Michele, Maud Jaccard, and David Patin, (2017), Commissioning of the Leksell Gamma Knife ® Icon ™." *Medical Physics* 44(February):355–63.