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Verification of Gamma Knife Output Dose Conformity with Treatment Planning System in Terms of Red, Green, and Blue Channels

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ABSTRACT

The calibration method using Gafchromic EBT-3 film is employed to verify the conformity of the Gamma Knife output dose compared to the Treatment Planning System (TPS). The films undergo exposure to doses of 5, 10, 15, 20, and 25 Gy on a phantom, followed by data processing and analysis using ImageJ, MatLab, and Microsoft Excel software. Assessment of the red, green, and blue channels is carried out to evaluate their sensitivity and conformity with the TPS doses. The film calibration curve shows that the red channel has the highest sensitivity among the other two channels, as indicated by the corresponding increase between dose and net Optical Density (OD). Calculation of the gamma index using Dose Difference (DD) and Distance to Agreement (DTA) values at 3% and 2.4 mm were used to determine the conformity of the film dose with TPS using the Gamma Passing Rate (GPR). The red, green, and blue channels obtained GPR values of 98.96%, 98.61%, and 98.27%, respectively. This result validates that the red channel achieved the highest percentage of conformity between film and TPS doses. However, the GPR values of the three channels have no significant difference. It is concluded that the red, green, and blue channels have a high percentage of conformity between the film dose and the TPS dose.

1. Introduction

The medical field is experiencing developments with much research focusing on the most efficient approaches for cancer or tumor treatment. Surgery and chemotherapy are often used in the treatment of cancer and tumors. But as time goes on, cancer or tumor treatment can utilize radiation, taking advantage of the heightened sensitivity of tumor or cancer cells to radiation compared to healthy cells in the body. According to Regulation of the Head of BAPETEN Number 3 of 2013, radiotherapy treatments involve the use of encased radioactive substances or ionizing radiation generators to kill cancer cells without surgery [1].

Brain cancer or tumor is one of the diseases that have a high mortality rate in Indonesia. According to the Global Cancer Observatory, there were 5,738 new cases of brain cancer with a mortality rate of 5,259 cases, and 20,134 cases in the last five years [2]. Brain cancer affects the patient's motor skills, causing seizures, loss of balance, and limb paralysis. A tumor can cause speech difficulties, memory loss, concentration, and vision/hearing problems [3]. Therefore, brain cancers and tumors cannot be neglected even if they are benign.

Gamma Knife Radiosurgery is an alternative method for treating small-sized brain tumors or cancers without surgery. The use of Gamma knife is efficient for managing brain tumors, treatment of cancer metastasis, and addressing conditions like arteriovenous malformation, trigeminal neuralgia, and epilepsy [4]. The Gamma Knife system uses high-dose radiation from multiple angles with a small collimator to target the lesion while minimizing exposure to nearby organs. This modality was commonly used as an alternative treatment for patients unsuitable for surgical procedures [5]. This study used gamma knife perfexion radiosurgery, as shown in Fig. 1.

Fig. 1: Gamma Knife Radiosurgery

The Gamma Knife software system for regulating radiation dose is the Leksell Gamma Plan (LGP). This system is used to maximize radiation in damaging cancerous tissue while preventing excessive radiation to healthy organs. As the gamma knife uses a high radiation dose, it is necessary to ensure that the dose emitted is in accordance with the Treatment

Planning System (TPS). The film calibration method can be used to validate that the quality of the gamma knife works well to provide optimal treatment for patients. Films are used to capture the radiation emitted by the modality and compare it to the dose set in the treatment planning system [6].

EBT3 films are involved in the development of brain tumor treatment and are used for measuring radiation dose in stereotactic radiosurgery (SRS), such as on a gamma knife. The film has a high spatial resolution (minimum 25 μm), low energy dependence, and near-tissue equivalent, which makes it an effective tool for SRS dose measurement [7]. The results of this study confirmed that the radiation emitted by the modality was in agreement with the prescribed TPS. Some previous studies have used radiochromic film dosimetry for IMRT, SBRT, and brachytherapy. This study is one that specifically examines the conformity of Gamma Knife Radiotherapy, using the Gamma Knife Perfexion, ABS phantoms, and radiochromic films.

2. Methods

This research was conducted directly using the gamma knife modality. As shown in Fig. 2, The phantom used was a 16 cm diameter Elekta ABS phantom, made from Acrylonitrile Butadiene material synthesized through the polymerization of acrylonitrile and styrene with polybutadiene. The composition of ABS consists of 15%–35% acrylonitrile, 5%–30% butadiene, and 40%–60% styrene [8]. The EBT3 gafchromic film was used in this study to capture the exposed radiation, in accordance with the procedure in reference [9]. The film was cut into small pieces of 30 x 30 mm^2 as shown in Fig. 3. The film was placed into the phantom, which was positioned on the device to ensure it received radiation optimally. The Treatment Planning System was conducted using the Leksell Gamma Plan, using radiation doses ranging from 5 to 25 Gy. Subsequently, the film underwent scanning using an Epson V700 scanner.

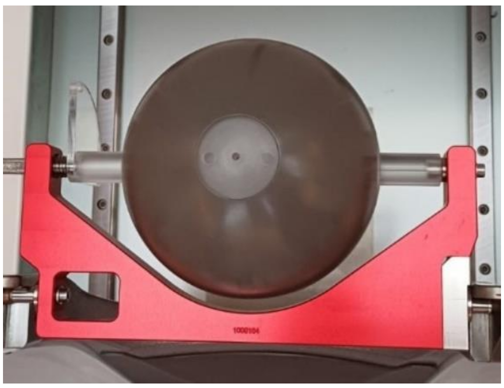


Fig. 2: ABS Phantom Elekta

The data acquisition utilized Image-J software, by using a circular Region of Interest (ROI) with a diameter of 10 pixels and a square of 200 x 200 pixels. The data processing was carried out using MatLab and Microsoft Excel programs to extract the radiation dose value from the film and compare it with the corresponding value from the TPS.

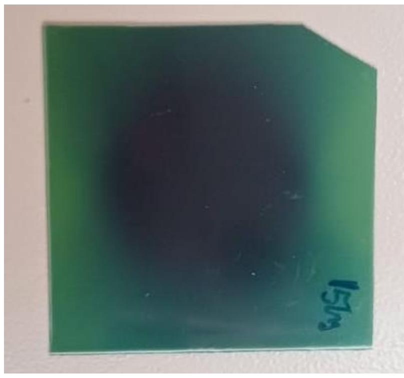


Fig. 3: EBT3 Galchromic Film

The film's pixel values at each dose level (0, 5, 10, 15, 20, and 25 Gy) were obtained from the scanned images using Image-J, following to calculate net Optical Density (netOD) using the following formula [10]:

$$O_D = \log\left(\frac{P_{v-unexp}}{P_{v-exp}}\right) \tag{1}$$

where O_D is the netOD measured in our study, $P_{v\text{-}unexp}$ and $P_{v\text{-}exp}$ represent the average pixel value on the radiation-exposed film and non-exposed film, respectively. The netOD values obtained for each dose was used to create a third-order polynomial curve, then these values were input into the curve equation to determine the dose on the film using the following formula [11]:

$$D(O_D) = Ax^3 + Bx^2 + Cx + D \tag{2}$$

where $D(O_D)$ means dose that measured in this study. The values of A, B, C, and D were derived from the equation on the polynomial curve, while the value of x are the netOD that was obtained from Eq. 1. Point doses in the Treatment Planning System (TPS) are extracted from DICOM data using MatLab, and this software is also used to calculate the gamma index of the TPS and film doses, with DD and DTA set at 3% and 2.4 mm, respectively [12]. The gamma index equation is as follows [13]:

$$\Gamma(\mathrm{D},\mathrm{d}) = \sqrt{\left(\frac{(D_{mea}-D_{ref})^2}{\Delta D^2}\right) + \left(\frac{d_{mea}{}^2}{\Delta d^2}\right)} \tag{3}$$

D_{mea} represents the measured dose, D_{ref} retrieved the reference dose, ΔD represents the dose tolerance as a percentage of the maximum reference dose, d_{mea} retrieved the distance between the measured dose point and the reference dose point (in mm), and Δd represents the spatial tolerance (in mm). The gamma index was obtained by comparing the TPS with each channel, this result will be used to calculate the Gamma Passing Rate (GPR). GPR represents the amount of dose distribution at measurement points that satisfies the tolerance criteria.

The Gamma Passing Rate Equation 4 is as follows:

$$\rho_{GPR} = \frac{N(\Gamma<1)}{N} \times 100\% \tag{4}$$

The number of points with Γ<1 represents the number of points in the measured dose distribution for which the gamma index value obtained is less than 1. These values indicate that they correspond to a reference dose distribution that fulfills the specified criteria. The total number of points represents the total number of points evaluated in the measured dose distribution.

The research commences by measuring pixel values using Image-J. A 10-pixel Region of Interest (ROI) is positioned at the image's center, with three repetitions conducted for each dose value and film channel measurement. The average result of the three measurements is used to calculate the netOD value for each dose and channel, which results in a third-order polynomial curve that is crucial for film dose calculation.

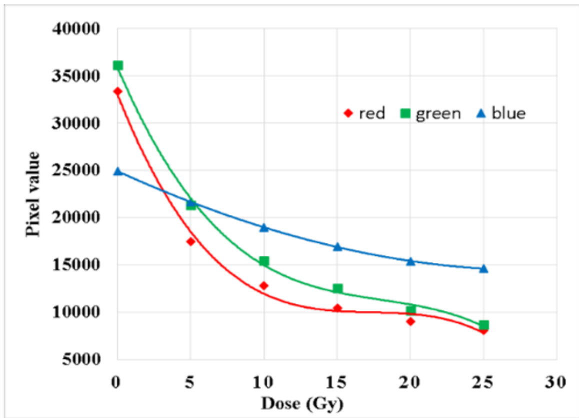
3. Result and Discussion

Table 1 shows the average pixel and netOD values for the variation of TPS dose values for red, green, and blue channels. Figure 4 displays the relationship curve of pixel value and netOD as a function of TPS dose value.

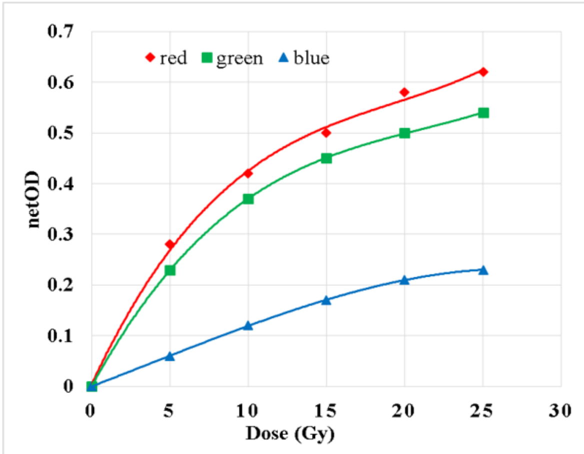
Table 1: Average Intensity and NetOD of Red, Green, and Blue Channels

TPS Dose (Gy)	Red		Green		Blue	
	Pixel Value	***Net OD***	***Pixel Value***	***Net OD***	***Pixel Value***	***Net OD***
0	33341	0	36.087	0	24.896	0
5	17447	0.28	21.301	0.23	21.651	0.06
10	12810	0.42	15.462	0.37	18.923	0.12
15	10449	0.50	12.508	0.45	16.944	0.17
20	9031	0.58	10.134	0.50	15.354	0.21
25	8055	0.62	8.697	0.54	14.603	0.23

The film calibration curve above (a) shows that the red channel curve is steeper compared to the other two channels. The calculated pixel value decreases in the J-image when the emitted dose becomes higher and blackens the movie. Some previous studies on dosimetric film scanners using ImageJ software by Abdullah et al. [14] and Casolaro [15] are in accordance with these results, which show that the pixel value obtained will decrease as the dose given increases. Then, fig. 4 (b) shows that the red channel curve is flatter than green and blue curve. This result in accordance with a previous study by Ning [16] that shows the sensitivity of the red channel was the highest compared other two channels. According to Fig. 4(b), the sensitivity of the red channel is highest at low doses. However, at doses above 10 Gy, the sensitivity of the green channel becomes similar to that of the red channel. The blue channel has the lowest sensitivity in all dose regions. As the radiation dose increases, the netOD on the red channel curve also increases accordingly. This indicates that the red channel has the highest sensitivity to radiation.



(a)



(b)

Fig. 4: Film Calibration Curve of Red, Green, and Blue Channel: (a) Pixel Value to Dose, (b) NetOD to Dose

The film equation calculations for each channel are determined through a third-order polynomial curve. To determine the dose, input the netOD values into the x variable in the equation corresponding to each channel. This yields the dose values on the film, allowing comparison with the TPS doses in the 10 Gy film, the three channels were separated using a 200 x 200 pixel ROI that was saved as text data. Pixel values obtained in the text data and used in calculating the dose values at the film points. MatLab was used to obtain the TPS dose distribution image, followed by observing the conformity of the dose distribution on the movie with the TPS.

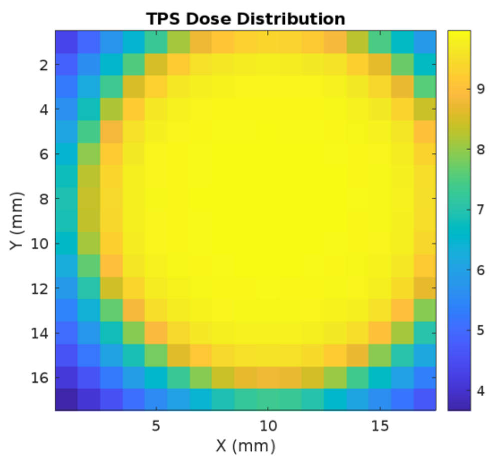


Fig. 5: TPS Dose Distribution

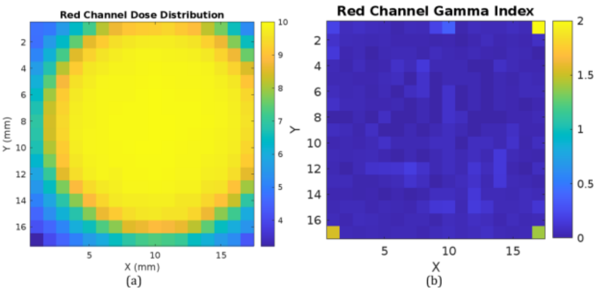


Fig. 6: (a Dose Distribution and (b) Gamma Index Value on Red Channel)

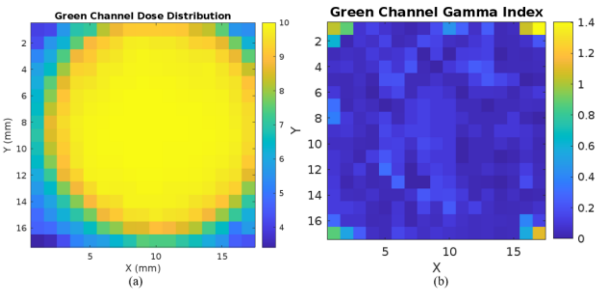


Fig. 7: (a) Dose Distribution and (b) Gamma Index Value on Green Channel

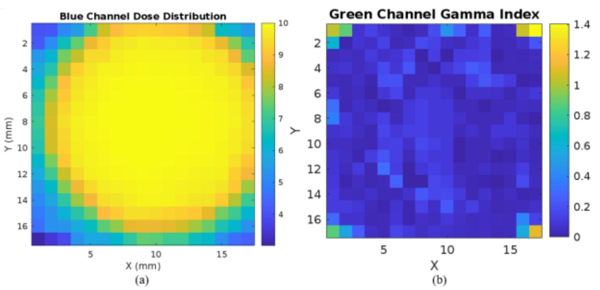


Fig. 8: (a) Dose Distribution and (b) Gamma Index Value on Blue Channel

According to the dose distribution and gamma index values depicted in Figures 6-8, all three channels have high doses in their exposure field areas (shown in shades of orange to yellow) and low gamma index values (shown in dark blue and light blue). These values indicate that the exposure field area has a dose distribution that corresponds to the TPS dose.

The yellowish-green color at the edge of the review point represents that the gamma index value is greater than 1. In the red channel, 3 review points have a gamma index greater than 1, while 4 points in the green channel, and 5 points in the blue channel. These points are located about 7 to 9 mm from the isocenter, so the received dose is very small. As a result, the dividing factor in the calculation becomes very small, yielding a large gamma index value.

Figure 5 shows the dose distribution of TPS with the highest dose values ranging from 8 to more than 9 Gy represented in orange to yellow colors, indicating the exposure field. Lower doses ranging from 5 Gy to less than 8 Gy are shown in light blue to green on the TPS. The lowest doses of less than 5 Gy are shown in dark blue, found at the edge of the radiation field reviewed.

The gamma passing rate value is obtained by inputting the gamma index value in Microsoft Excel and doing the calculation. The maximum gamma index value that indicates conformity between TPS and film dose values is 1. If the gamma index value is less than 1, the dose at that point is considered a conformity between film and TPS. The Gamma Passing Rate was calculated as the percentage of gamma index values from all measurement points that are below 1.

Calculations on the gamma passing rate using a DD of 3% and a DTA of 2.4 mm obtained results on the red, green, and blue channels of 98.96%, 98.61%, and 98.27%, respectively. These values were obtained to ensure the conformity between the dose received by the film and the TPS. The expected gamma passing rate value of the measured points should be 95% so that it is within the csonfidence interval. The conformity of the radiation dose output to the settings in the TPS is determined by the gamma passing rate value getting closer to 100%. Based on the Gamma Passing Rate outcome, it has been determined that there is no significant difference in the values of the three channels. This indicates high conformity of the dose values received by the film with the reference dose in the Treatment Planning System (TPS) for all three channels - red, green, and blue.

Radiochromic film dosimetry studies using the gamma index were conducted for IMRT, giving results exceeding 95% with the 3%/3 mm criterion [10]. In SRS and SBRT studies, the average overall test result was 95% for the 3%/1 mm criterion [16]. The previous study corroborated the results of this study which obtained a value of more than 98%, ensuring that this study got a higher value of conformity. This study will help further research on the conformity of gamma knife radiation with TPS, especially about gamma knife perfexion and the use of ABS phantoms.

4. Conclusions

The red channel has the highest sensitivity level among the other two channels based on the calibration curve obtained. This is indicated by the corresponding increase between the radiation dose and the netOD attained by the film. The gamma passing rate value is obtained by using the index value of the measurement point in each channel, followed by observation of the conformity of the film dose with the TPS. The DD (dose difference) value determined is 3% and the DTA (Distance to Agreement) value is 2.4 mm in the calculation of the Gamma Passing rate value.

High gamma passing rates of 98.96%, 98.61%, and 98.27% for red, green, and blue channels were obtained. This indicates that the red channel achieves the highest percentage and conformity between the film dose and TPS compared to the other two channels. However, the gamma passing rate values obtained for the three channels are not significantly different, so it can be concluded that the three channels (red, green, and blue) show high conformity between film dose and TPS. This study proves that film calibration can aid in verifying the output of the gamma knife device against its designated Treatment Planning System (TPS), ensuring the safety of radiation output for patients and its alignment with the TPS.

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