Jurnal Profesi Medika : Jurnal Kedokteran dan Kesehatan
DOI: https://doi.org/10.33533/jpm.v17i1.5848
Vol 17 No 1 (2023) ISSN 0216-3438 (print); ISSN 2621-1122 (online)

ARTICLE

CURRENT APPROACH OF SMALL FIELD ELECTRON BEAM FOR HEAD AND NECK CASES

Syarifatul Ulya[1]*, Dea Ryangga[2], Wahyu Edy Wibowo[3], Nuruddin Nasution[3], Supriyanto Ardjo Pawiro[4]

[1] Pusat Riset Teknologi Keselamatan, Metrologi, dan Mutu Nuklir, Organisasi Riset Tenaga Nuklir, Badan Riset dan Inovasi Nasional, DKI Jakarta, Indonesia;
[2] Instalasi Radioterapi, Rumah Sakit Pasar Minggu, DKI Jakarta, Indonesia;
[3] Departemen Radioterapi, Rumah Sakit Umum Pusat Nasional Cipto Mangunkusumo, DKI Jakarta, Indonesia
[4] Departemen Fisika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia, Depok, Indonesia;

*Correspondence email : syariflia88@gmail.com

ABSTRACT

Regarding the increasing use of small-field photons in clinical treatment, in this study, we investigate the use of small-field electron beams in clinical treatment. This study aimed to evaluate small-field electron beam dosimetry of the nasopharyngeal, thyroid, and ethmoid sinus carcinoma cases. Dose measurement was done using EBT3 film. In nasopharyngeal cases with a homogenous area and irregular surface, the dose discrepancies for 6 MeV energy were unpredictable except for the 5×5 cm^2 field size. For all energies in 5×5 cm^2 field size, the dose discrepancies were less than 3%. In these cases, we found that a smaller electron beam field will increase the percentage of the dose discrepancy. This is caused by the effect of the lateral scatter disequilibrium in a small field electron beam. For ethmoid sinus cases, dose discrepancy depends on the field size and inhomogeneity of bone and tissue organ. Based on the evaluation of doses on the spinal cord, chiasm, and larynx, it can be seen that these organs received a very small dose. From this result, a small field electron beam is recommended for cases with a homogeneous target. However, in cases with a heterogenous target, further investigation is needed.

Keywords: Electron; Gafchromic; EBT3 film; netOD

АБСТРАКТ

В связи с растущим использованием малопольных фотонов в клиническом лечении, в данном исследовании мы изучаем использование малопольных электронных пучков в клиническом лечении. Целью данного исследования была оценка дозиметрии малопольного электронного пучка в случаях карциномы носоглотки, щитовидной железы и этмоидного синуса. Измерение дозы проводилось с использованием пленки EBT3. В случаях носоглотки с однородной областью и неровной поверхностью расхождения доз для энергии 6 МэВ были непредсказуемыми, за исключением размера поля 5×5 см2. Для всех энергий при размере поля 5×5 см2 расхождения в дозе составляли менее 3%. В этих случаях мы обнаружили, что меньшее поле электронного пучка увеличивает процент расхождения в дозе. Это вызвано эффектом неравновесия бокового рассеяния в электронном пучке с малым полем. В случае с этмоидальным синусом несоответствие дозы зависит от размера поля и неоднородности костной ткани и органа. На основании оценки доз на спинной мозг, хиазму и гортань видно, что эти органы получили очень маленькую дозу. Исходя из этого результата, электронный луч малого поля рекомендуется использовать в случаях с однородной мишенью. Однако в случаях с неоднородной мишенью необходимо дальнейшее исследование.

Ключевые слова: Электрон; гафхром; пленка EBT3; netOD

Submitted: 19 May 2023; Received in revised form: 6 June 2023; Accepted: 13 June 2023; Available online: 15 June 2023; Published regularly: June 2023

INTRODUCTION

Radiotherapy for superficial targets has been using high-energy electron beams for more than 50 years.[1] An electron beam was chosen because it has a uniform distribution of dose, hence the dose falls off with increasing depth sparing the organs in a deeper position.[2]

Currently, small-field techniques in cancer treatment are rapidly developing. The techniques have proven to increase the dose on the cancer target and minimize the dose on the organ at risk (OAR), achieving the therapeutic ratio of radiotherapy. However, a small-field electron beam causes a lack of lateral to scatter equilibrium.[3] Dosimetry accuracy in the verification of small-field electron is one aspect that needs to be developed related to the success of delivering radiotherapy methods[4] which normally use Radiochromic films for dose measurement.[4] One of the films with many advantages and mainly used in radiotherapy is the Gafchromic EBT3 film. The Gafchromic EBT3 film has an equivalent density with tissue, high spatial resolution, and sensitivity.

The implementation of the small field electron beam is commonly used in the treatment of nasopharyngeal, thyroid, and ethmoid sinus cancers. Within undelivered total dose from treatment using photon beam, the purpose of radiotherapy has not yet achieved since the dose in OAR is beyond the tolerance limit around the target.[5] Therefore, this study enquires small field electron beams chosen to increase the dose at the surface target and minimize the dose in the spinal cord and chiasm (OAR). The aim of this study was to evaluate small field electron dosimetry in target volumes and OAR using Gafchromic EBT3 films.

MATERIAL AND METHODS

Irradiation of Gafchromic EBT3 films was performed using an applicator with a 6 × 6 cm² frame size on EBT3 film and 2×2 cm² frame size at maximum depth, measured in a blue water phantom for each field size (Figure 1) with a varied electron beam energy of 6 MeV, 12 MeV, and 15 MeV. Each beam has various dose ranges (0-250 cGy). The calibration of EBT3 film was conducted on d_{max}. The previous study was done by Ulya et al. (2016), that recommended the use of curve calibration for small electron beam using every field size.[6] The variation of each energy electron beam was done using a radiation field of 5 × 5, 3 × 3, 2 × 2, and 1 × 1 cm².

Digitalization was performed using V700 flatbed scanner with 72 dpi in 48 bit RGB. In order to analyze the pixel value readout, Image-J software was used. The red channel was used to analyze since it has the highest netOD. The netOD value was calculated by subtraction the pre-scan OD value from the corresponding post-scan OD value.

Rando phantom was scanned using Toshiba CT Simulator and GE Bright Speed CT Simulator (Figure 2). Image CT was transferred to the Treatment Planning System (TPS) and was delineated by the radiation oncologist to determine the target volume and OAR.

Treatment planning for small-field electron beam on ethmoid sinus, nasopharyngeal, and thyroid cancer volume targets was carried out by medical physicists using the TPS Eclipse 13.6, shown in Figure 3 and TPS Precise Plan Release 2.16 - 28.76. This planning was created with field size variation of 1×1 cm², 2×2 cm², 3×3 cm², and 5×5 cm² for 6, 12, and 15 MeV electron beams.

The planning data result from the TPS Eclipse was sent to the Varian Trilogy Linear Accelerator (LINAC) for the purposes of irradiation using an electron beam and the setup position of which is shown in Figure 4. Treatment planning data from TPS Precise Plan was sent to Synergy Platform LINAC.

Measurements on nasopharyngeal carcinoma volume targets were taken on 270° gantry with 102 cm source-skin-to-distance (SSD), with 1×1 cm², 2×2 cm², 3×3 cm², and 5×5 cm² field sizes. The measurement of OAR dose in the spinal cord was done using EBT3 film with the planar setup. This was carried out to evaluate the range of the electron beam dose in the target and OAR.

DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

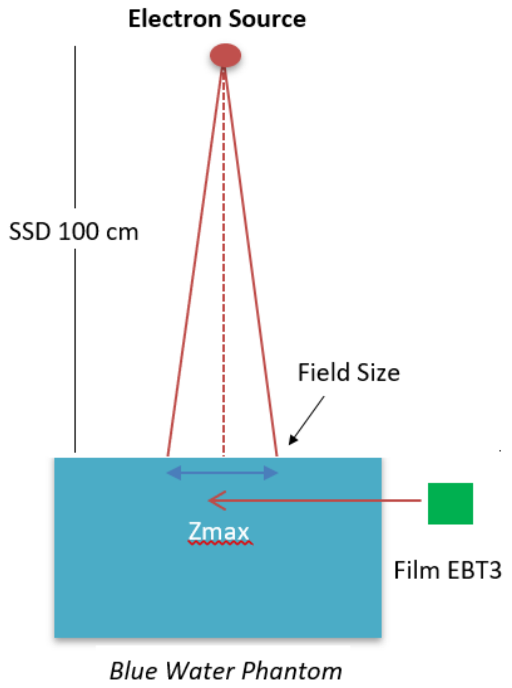


Figure 1. Calibration setup of the EBT3 film using small field electron beam

In the ethmoid sinus volume target, measurement was taken using 100 cm SSD and 0° gantry. In this case, we used EBT3 film with a length of 10 cm to reach the distance of the OAR (chiasm) which is at a depth of 9 cm from the surface. This irradiation technique used an applicator with 6×6 cm² size and varied sizes of electron beam fields such as 1×1 cm², 2×2 cm², 3×3 cm², and 5×5 cm². The radiation image was analyzed using Image-J by drawing a line from the surface to the range of the OAR.

The thyroid volume target was measured using 102 cm SSD and 0° gantry with EBT3 film in a planar setup ranged until the isodose line 70% from the prescribing dose. Another evaluation using the EBT3 was conducted to describe the dose coverage of the larynx as the OAR. For this case, 100 cm SSD cannot be achieved for the nasopharyngeal and thyroid case because of the difference in the irregular shape of the head and neck anatomy.

Evaluation of the therapeutic planning results was done by comparing the dose of TPS Eclipse and Precise with the results of measurements on EBT3 films in each field. This evaluation has been done for 100% isodose of the nasopharyngeal carcinoma and ethmoid sinus cases. However, the clinical electron beam dose evaluation of other isodose in 90%, 80%, and 70 % is needed. The prescription dose in this method used 200 cGy dose prescription in each case. The value of the dose discrepancy can be shown in equation [1].

$$Discrepancy\ (\%) = \frac{D_{measured} - D_{plan}}{D_{plan}}\ x\ 100\%\ [1]$$

with $D_{measure}$ is the dose read on EBT3 and D_{plan} is a dose calculation of TPS Eclipse.

In this method, we evaluated the nasopharynx, thyroid, and ethmoid sinus as a target. Each case has its own unique characteristic. A nasopharyngeal case has a homogeneous density of soft tissue but has an irregular surface and the existence of a vertebra at the depth of 5 cm from the surface. The thyroid case has an inhomogeneous target of soft tissue and air cavity. While ethmoid sinus case has an inhomogeneous density that comes from the soft tissue and bone.

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

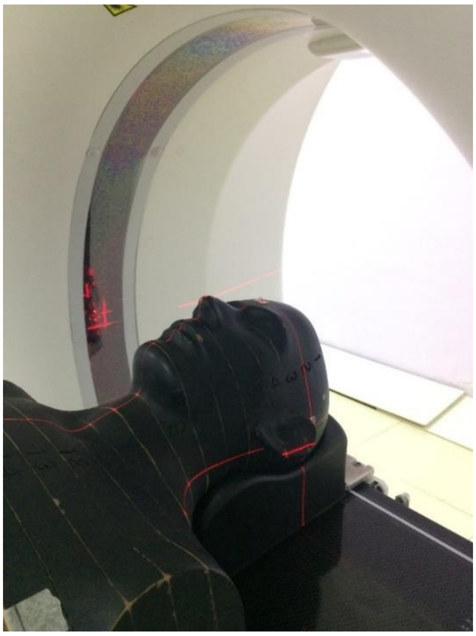
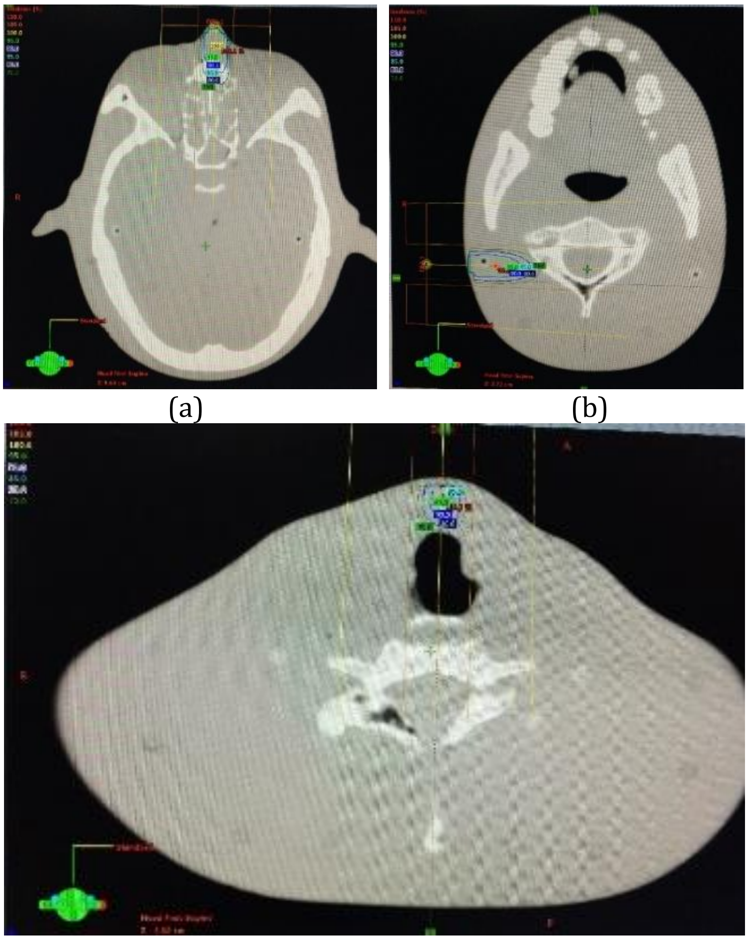


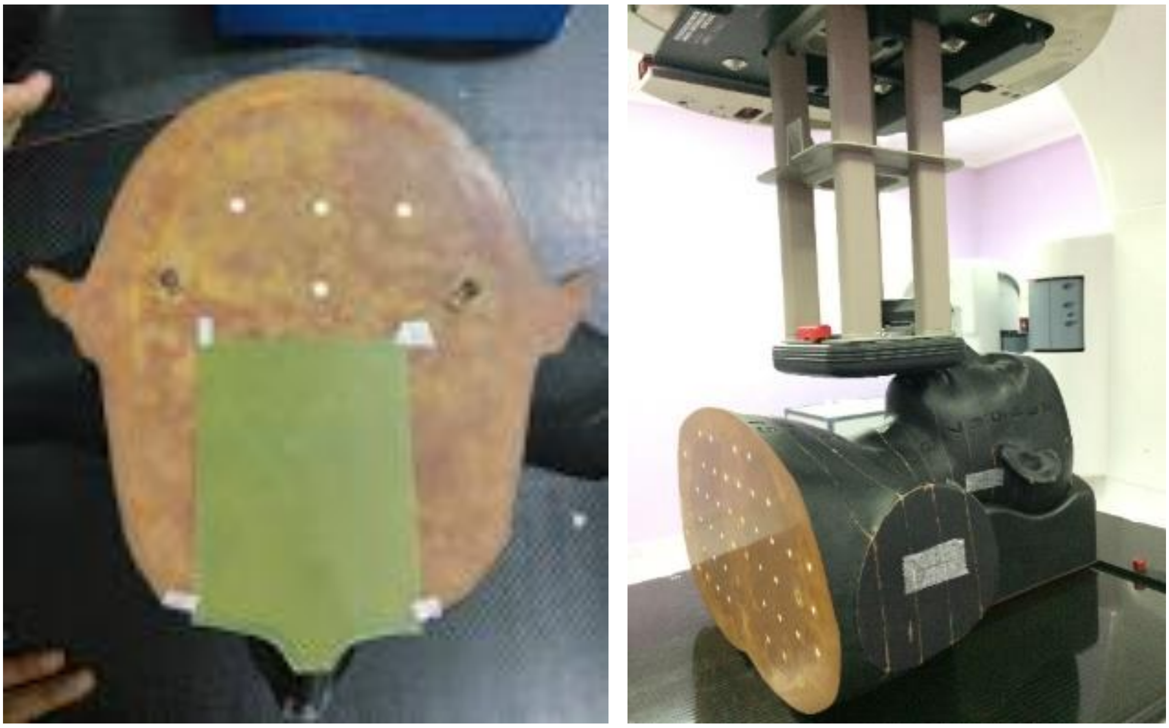
Figure 2. Scanning of Rando Phantom using CT Simulator Toshiba



(a) (b) (c)

Figure 3. Treatment planning of the (a) ethmoid sinus, (b) nasopharyngeal, and (c) thyroid case cancer targets using TPS Eclipse

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)



(a) (b)

Figure 4. (a) EBT3 film setup (b) irradiation of small field electron beam of the ethmoid sinus case

RESULT

The calibration curve for the small field electron beam of the EBT3 film calibration and the netOD value was analyzed on each calibration equation of energy. The plot of the calibration curve was generated using the polynomial equation. The calibration curve of each electron beam field size and each energy is linear, with an R-value close to 1. That means the increase of netOD on the EBT3 film is directly proportional to the dose delivery (Figure 5).

The dose evaluation of small electron fields in the nasopharyngeal carcinoma cases using an electron beam was performed in various field sizes ranging from 5×5 cm^2 to 1×1 cm^2. Each field used variations of electron beam energy of 6, 12, and 15 MeV on the Varian Trilogy and Elekta Platform LINAC. The area chosen for small field technique in nasopharyngeal cases is a homogenous area with an irregular surface, shown in Figure 3b. Figure 6 shows the isodose line 100% in nasopharyngeal carcinoma case. The higher energy of small field electron, the dose discrepancies is more consistent. However, especially for the Varian Trilogy Linac on the 15 MeV, the dose discrepancies are invariable. The dose discrepancies for 6 MeV energy are unpredictable except for 5×5 cm^2 field size**.** This is appropriate according to Aubry et al. (2011).[7] For all energies in 5×5 cm^2 field size, the dose discrepancies were less than 3%.[8] Therefore, the higher the energy, the lower the dose discrepancy will be. Based on the result of the analysis of dose discrepancies between dose measurement with dose calculation on the TPS, we could find that a larger field size of the electron beam would results in a smaller percentage value of the discrepancies (see Figure 6).

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

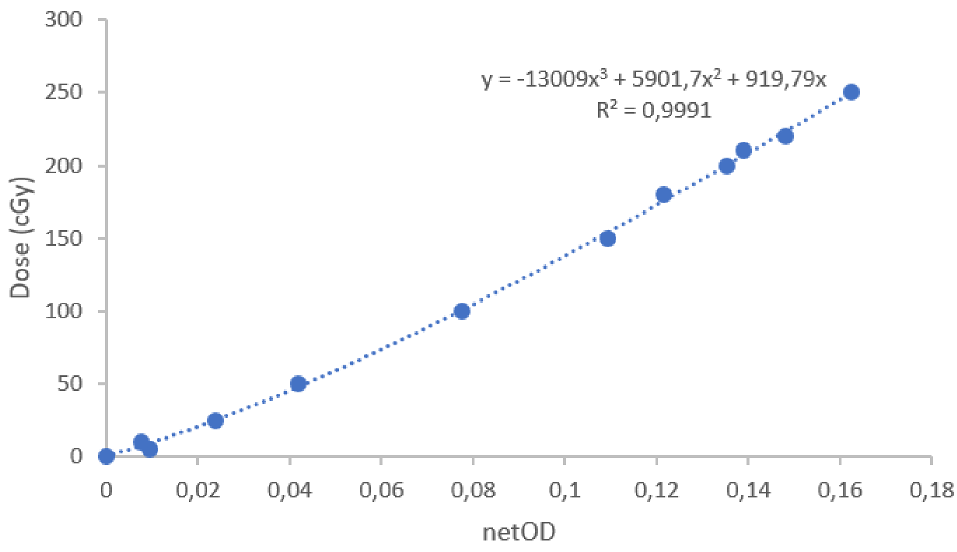


Figure 5. Calibration curve of 12 MeV energy of 1×1 cm² field size

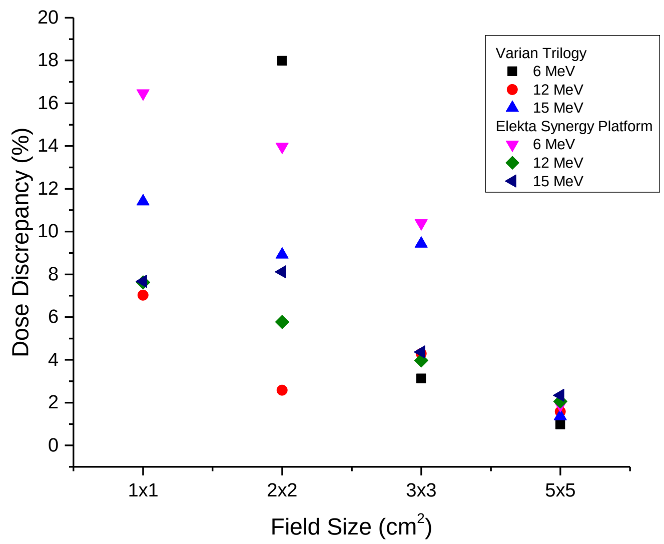


Figure 6. Dose discrepancies evaluation of nasopharyngeal carcinoma in the isodose line 100%

In the ethmoid cases, the 1×1 cm² field size shows a smaller discrepancy, due to the homogeneous area target in this field size. Yet, there is a high discrepancy in 3×3 cm² and 2×2 cm² field size which can be seen in Figure 7, mostly caused by the inhomogeneity of the ethmoid. In these cases, internal factor heterogeneities are noted and such for non-equilibrium side scatter which is caused by lateral discontinuities of the skin surface and internal anatomy. Similarly, these notions are concluded in the research done by Palta et al (1983).[9]

The lower discrepancy is due to a small effect of lateral scatter and lower surface irregularity in 5×5 cm² field size. Meanwhile, in the 3×3 cm² and 2×2 cm² field sizes, the discrepancy value of the dose is greater than the 5×5 cm² field size (Figure 7). High surface irregularity in these fields could explain the high dose discrepancy. In the 1x1 cm² field, the surface irregularity is low while the lateral scatter is high, causing low dose discrepancy.

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

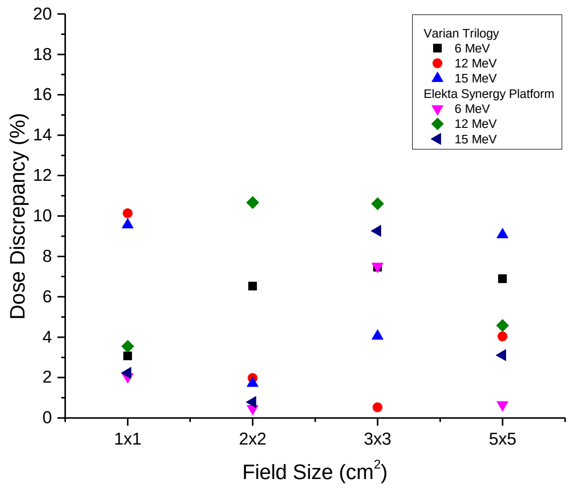


Figure 7. Evaluation of dose discrepancies of ethmoid sinus cancer in the isodose line 100%

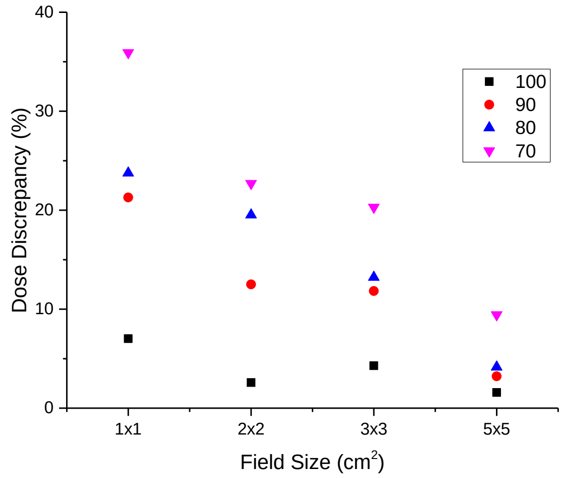


Figure 8. Dose discrepancies of nasopharyngeal case in the 12 MeV with isodoses line 100, 90, 80, 70%

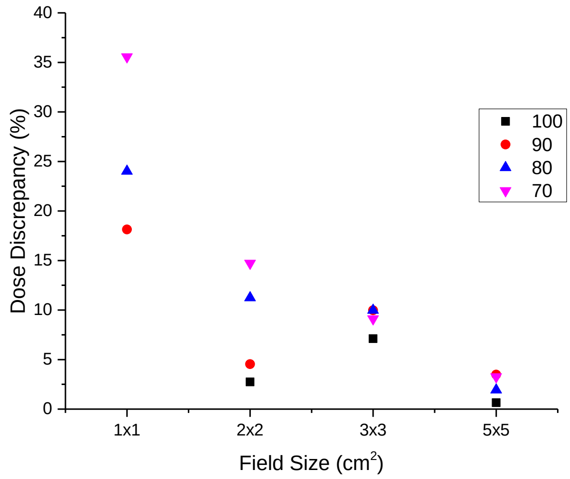


Figure 9. The dose discrepancies of the 6 MeV in the thyroid case with isodoses line 100, 90, 80, 70%

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

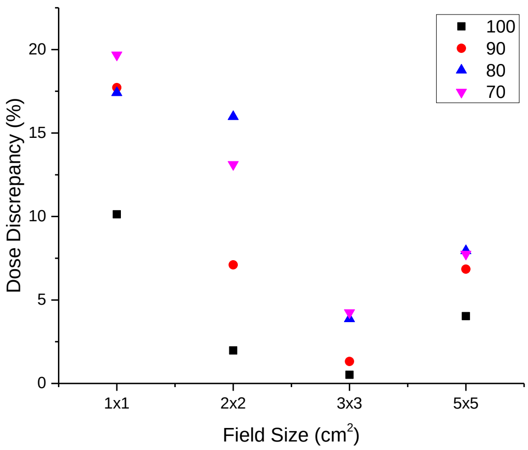


Figure 10. Ethmoid sinus case dose discrepancies in the 12 MeV energy electron with isodoses line 100, 90, 80, 70%

DISCUSSION

From the result of the nasopharyngeal cases using 12 MeV energy, we can see that the greater depth affected the higher dose discrepancies (Figure 8). Increasing depth from the electron beam source has made dose measurement more unpredictable due to the contribution of the electrons scattered from lateral sides surrounding the cavity to the on-axis electron fluence, the energy of which is decreasing.[10] Besides that, other 5×5 cm^2 field size shows that the dose discrepancies are more than tolerance. This is because the small field of the electron has the effect of lateral scatter disequilibrium which causes the output factor of this small field to decrease in dose.[8]

The dose discrepancies of the thyroid cases of the 6 MeV energy are shown in Figure 9. From these results, the smaller the isodose is affected, the higher the dose discrepancies will be. This is because in the 70% isodose, there is an inhomogeneity due to the existence of the air cavity. Inhomogeneity in electron beams is affected by changes in electron scattering, electron beam penetration, and interface effects. [11]

The dose discrepancies of the 12 MeV energy on the ethmoid sinus cases have a small discrepancy in the 100% isodose line. However, the 90, 80, and 70 isodoses have unpredictable dose discrepancies (see Figure 10). These ethmoid sinus cases have an inhomogeneity due to the existence of bone. So, the attenuation from the electron beam is higher. Higher dose discrepancy suggests that the TPS Eclipse calculation have difficulty in predicting the delivered dose in cases with an inhomogeneous target.

Figure 11 shows the dose discrepancies decrease with the decreasing of the electron beam energy and field size, owing to the higher electron energy which has more scatter and constant energy. In carcinoma cases, the area of the target volume is a relatively homogenous soft tissue. There is a small inhomogeneity at the target surface. The nasopharyngeal cases result describes that the depth of the dose influences the uncertainty. In addition, the 6 MeV energy has higher dose discrepancies for the decreasing of measured dose from prescription dose, particularly seen at 70% isodose.

For thyroid cases, 1×1 cm2 field size has the highest dose discrepancies for all electron beam energy, shown in Figure 12. According

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

to Sharma, et al (1984) small field electron beam has a lateral scatter disequilibrium effect that causes the output factor of this small field to decrease in dose.[12] On the other hand, inhomogeneity from the air cavity in the thyroid case made a high discrepancy in the higher electron energy, prominently for 12 MeV and 15 MeV. In these cases, the depth of the air cavity, which is located 1.8 cm from the surface, affected the high dose discrepancies to became higher in deeper isodose and increasing energy.

Figure 13 shows the result of the dose discrepancies of the ethmoid sinus case. The inhomogeneity of the target which is due to the bone existence and surface irregularity contributes to the dose discrepancy. Otherwise, an electron beam field size of more than 2×2 cm^2 has hot areas lateral to the central axis generated by the air-skin interface. Correspondingly a cold area is generated beneath the nose.

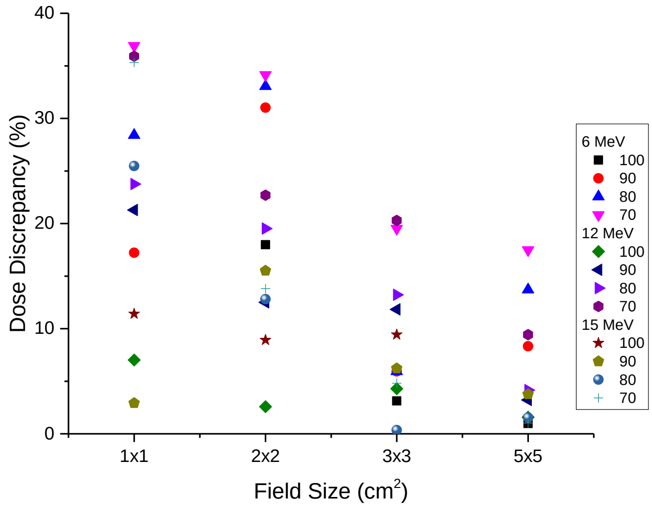


Figure 11. The discrepancies dose of the nasopharyngeal carcinoma case in the 6 MeV, 12 MeV and 15 MeV electron energy of the small field technique

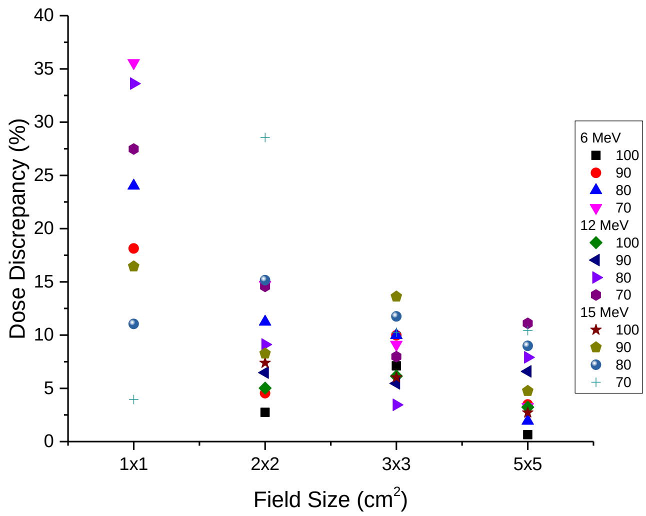


Figure 12. The dose discrepancies of the thyroid case in the 6 MeV, 12 MeV and 15 MeV electron energy of the small field technique

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

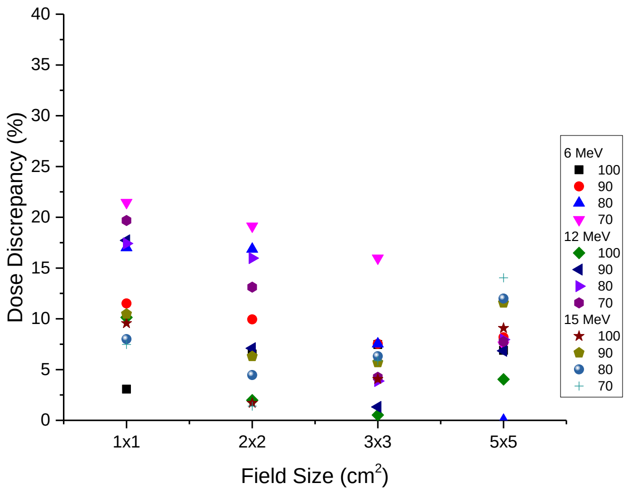


Figure 13. The discrepancies dose of the ethmoid sinus case in the 6 MeV, 12 MeV and 15 MeV electron energy of the small field technique

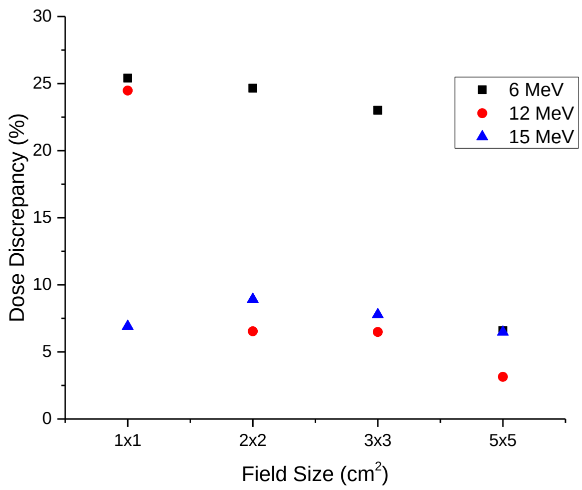


Figure 14. The dose discrepancies of the larynx (OAR) of the thyroid case

The analysis from the nasopharyngeal, thyroid, and ethmoid sinus cases demonstrates the need to continue the investigation of the ability of the TPS algorithm to correct for inhomogeneity, irregularity on the skin surface, and interaction in deeper depth that is less than 80% isodose.

In addition to the dosimetry evaluation of nasopharyngeal carcinoma volume targets, this study also analyzed the value of dose discrepancy in the spinal cord (OAR) located 5.5 cm from the surface. This evaluation used a film of 8 cm in size extending from the irradiated surface to the location of the spinal cord. The electron beam field size varied from 1×1 cm^2 to 5×5 cm^2. The low-energy electron beam and small field produce a dose in the spinal cord and the chiasm receives a small dose because the electron range does not reach the chiasm which is 9 cm from the surface.

This study also evaluated the larynx dose, with a 1.8 cm depth from the surface. It was found that when we used 12 MeV and 15 MeV energy, the dose discrepancy of the larynx was low. However, in evaluation using 6 MeV energy, the dose discrepancy result

 DOI: https://doi.org/10.33533/jpm.v17i1.5848 Vol 17 No : 1 (2023)

was high (Figure 14). Based on these results it can be seen that the use of small electron beams in cancer treatment of nasopharyngeal, ethmoid sinus, and thyroid cases can increase the dose at the target while keeping the OAR safe, except in thyroid cases for 12 MeV, 15 MeV of electron beams.

Currently the research concerning electron beam in radiotherapy that use Very High Energy Electrons (VHEEs) and ultra-high dose rate (FLASH) irradiations are expensively discussed.[13,14] Thus, the characteristic of the small field electron in the high dose rate electron needs to be investigated further.

CONCLUSION

Larger dose discrepancy correlates with smaller field size (lack of lateral scatter disequilibrium), smaller energy, greater depth, and low homogeneity. From this research, we found that the effect of inhomogeneity caused by the air cavity (ethmoid sinus) contributes to higher dose discrepancy far more than the discrepancy caused by the bone.

In the evaluation dose in the spinal cord and chiasm, it can be seen that these organs approximately receive a small dose. However, the larynx receives a high dose of higher energy and field size. It could be concluded from this research that a small field electron beam is recommended for cases with a homogeneous target. In a case with a heterogeneous target, further investigation is needed. In the small field electron with an irregular target surface or in the presence of the inhomogeneous target, more caution is needed in the treatment.

ACKNOWLEDGMENT

This works was supported by National General Hospital Cipto Mangunkusumo, Pasar Minggu Hospital, and Hibah Publikasi Internasional Terindeks Tugas Akhir (PITTA) Universitas Indonesia 2016 with contract number: 2050/UN2.R12/HKP.05.00/2016.

DECLARATIONS

The authors declare no conflict of interest.

REFERENCES

1. Hogstrom KR, Almond PR. Review of electron beam therapy physics. Phys Med Biol 2006;51:455-489.https://doi.org/10.1088/0031-9155/51/13/R25
2. Eeden D Van, Sachse KN, Plessis FCP Du. Practical Dosimetry Considerations for Small MLC-Shaped Electron Fields at 60 cm SSD. J Biomed Phys Eng 2022;12(1):101-108. https://doi.org/10.31661/jbpe.v0i0.2004-1097
3. Sharma SC, Johnson MW, Gossman MS. Practical considerations for electron beam small field size dosimetry. Med Dosim 2005;30(2):104-6. https://doi.org/10.1016/j.meddos.2005.02.001
4. Amin N, Heaton R, Norrlinger B, Islam MK. Small field electron beam dosimetry using MOSFET detector. Jounal of applied clinical medical physics 2011;12(1):50-57. https://doi.org/10.1120/jacmp.v12i1.3267
5. Kam Michael K. M. et al. Intensity-Modulated Radiotherapy in Nasopharyngeal Carcinoma : Dosimetric Advantage Over Conventional Plans and Feasibility of Dose Escalation. Int J Radiat Oncol Biol Phys 2003;56(1):145-157. https://doi.org/10.1016/S0360-3016(03)00075-0
6. Ulya S, Wibowo WE, Nuruddin N, Pawiro SA. Dosimetric Characteristics of EBT3 Gafchromic Film on Small Field Electron. AIP journal 2016;(2016):8-13.https://doi.org/10.1088/1742-6596/851/1/012023
7. Aubry JF, Bouchard H, Bessieres I, Lacroix F. Validation of an elektron Monte Carlo dose calculation algorithm in the presence of heterogeneities using EGSnrc ang radiochromic film measurments. J Appl Clin Med Phys 2011;12(4):13. https://doi.org/10.1120/jacmp.v12i4.3392
8. Gibbons JP, Antolak JA, Followill DS, et al. Monitor unit calculations for external photon and electron beams : Report of the AAPM Therapy Physics Committee Task Group No . 71 Monitor unit calculations for external photon and electron beams : Report of the AAPM Therapy Physics Committee Task Group N. Med Phys 2014;031501(71). https://doi.org/10.1118/1.4864244
9. Hogstrom K R, Mills M D, Meyer J A, J R Palta, Mellenberg D E, Meoz R T, Fields R S. Dosimetric Evaluation of A Pencil-Beam Algorithm For Electrons Employing A Two-Dimensional Heterogeneity Correction. Radiatherapy and Oncology 1983;(November). https://doi.org/10.1016/0360-3016(84)90036-1
10. Zarza-Moreno M, Carreira P, Madureira L, et al. Dosimetric effect by shallow air cavities in high

energy electron beams. Phys Med 2014;30(2):234-41. https://doi.org/10.1016/j.ejmp.2013.07.125
11. Tailor RC, Hanson WF. Tg-25 Clinical Electron-Beam Dosimetry. 2002; https:/doi.org/10.1118/1.1541252
12. Sharma SC, Wilson DL, Jose B. Dosimetry of small fields for Therac 20 electron beams. Med Phys [homepage on the Internet] 1984;11(5):697-702. https://doi.org/10.1118/1.595561
13. Masilela TAM, Delorme R, Prezado Y. Dosimetry and radioprotection evaluations of very high energy electron beams. Sci Rep 2021;11(1). https://doi.org/10.1038/s41598-021-99645-7
14. Martino F Di, Barca P, Barone S, et al. FLASH Radiotherapy with Electrons: Issues Related to the Production, Monitoring, and Dosimetric Characterization of the Beam. Front Phys 2020;8. https://doi.org/10.3389/fphy.2020.570697