Research Article

Alper Özseven*

Assessment of using electronic portal imaging device for analysing bolus material utilised in radiation therapy

<https://doi.org/10.1515/chem-2022-0126>

received December 9, 2021; accepted January 6, 2022

Abstract: In this study, the feasibility of using electronic portal imaging device (EPID) as an analysing equipment for bolus material was evaluated in terms of its dosimetric parameters. Seven superflab bolus material samples, 4 samples of 0.5 cm (S1–S4) and 3 samples of 1 cm thickness (S5–S7), were analysed and compared with tissue equivalent water phantom, which was selected for reference material. Gamma analysis method was used to evaluate the dose distribution of the boluses. In addition, 487,204 point-dose values of each bolus were compared with the point-doses of corresponding reference material by using Spearman's correlation coefficient analysis. The passing rates varied from 58.3 to 100% for 0.5 cm thick samples, and on the other hand, the passing rates of all the 1 cm thick boluses were 100%. All the correlation coefficient values were above 0.975. The correlation was statistically significant for all the samples ($p < 0.001$). The correlation coefficient of S4 bolus sample was the highest among the 0.5 cm thick bolus samples with a result of 0.989. Likewise, S5 and S6 bolus samples were the highest among the 1 cm thick ones with a result of 0.995. The results indicated that the material planned to be used as bolus can be evaluated with EPID in daily use.

Keywords: bolus, gamma analysis, flat panel detectors, electronic portal imaging device, radiation therapy

1 Introduction

In radiation therapy (RT), high energy photons are extensively used to treat deep seated tumours [1,2]. However, substantial number of superficial lesions and target volumes are also treated in radiotherapy. Megavoltage photon beams, which are widely utilised in RT, release most of their energy at a depth below the surface. This physical matter of fact is called as skin sparing effect and this phenomenon is unwelcomed in the cases where surface doses are necessary [3]. To improve the surface dose distribution and target coverage of superficial tumours, bolus materials that give a sufficient build-up dose in the skin are commonly used.

Several forms of bolus materials are usually utilized in RT and the most well-known type is superflab boluses. Generally, bolus materials are manufactured as tissue equivalent. It is crucial that the bolus material is sufficiently elastic to get the form of surface and be durable to incident radiation throughout the treatment. Moreover, providing complete contact with the irregularly shaped surface is a priority for ideal treatment conditions. The difficulties in the placement of bolus material on top of the skin can cause air gaps resulting in a decrease in dose coverage and homogeneity in the target volume [2,4–6]. In addition, the homogeneity of the material is also important in clinical practice in terms of patient dosimetry. Therefore, the content of bolus material and the distribution of the composing elements are the most determining factors for the tissue equivalence of this substance. The tissue or water equivalence of the bolus material is important for the accuracy of the surface dose distribution. The deviations from the tissue equivalence of bolus affect the build-up zone and lead to under dose regions during RT.

In recent years, a wide range of bolus materials have been manufactured by 3D printers, whose contents can differ and can get the shape of the surface they will be applied. The differences in the production method and

* Corresponding author: Alper Özseven, Department of Radiation Oncology, Faculty of Medicine, Süleyman Demirel University, Isparta, PC: 32260, Turkey, e-mail: alperozseven@sdu.edu.tr
ORCID: Alper Özseven 0000-0001-6128-6426

material content makes it more important to determine the physical properties and dosimetric effect of these materials to be used in clinical practice. Therefore, the dosimetric parameters of these newly-introduced materials were assessed using various measurement methods by the researchers. In contrast to the production methods of bolus material, there is much less information about the dosimetric investigation of it [4–11].

The main aim of this study was to explore the feasibility of using electronic portal imaging device (EPID), which is a flat panel detector mounted on linear accelerator, as an analysing equipment for bolus material in terms of its dosimetric parameters.

2 Materials and methods

2.1 Bolus materials and RW3 slab water-equivalent phantom

Seven superflab bolus material samples, 4 samples of 0.5 cm and 3 samples of 1 cm thickness each, were enrolled in the study. The 0.5 cm thick (S1–S4) and 1 cm thick (S5–S7) boluses had minimum dimensions of 30 cm × 30 cm × 0.5 cm and 30 cm × 30 cm × 1 cm, respectively. 0.5 and 1 cm thick RW3 slab water-equivalent phantoms (PTW Freiburg, Freiburg, Germany) were used as reference material in comparison process with 30 cm × 30 cm dimensions (Figure 1). Boluses were classified into two groups according to their thickness. 0.5 cm thick boluses were compared with 0.5 cm thick RW3 slab phantom (R0.5) as a separate group, while 1 cm thick boluses were compared with 1 cm thick RW3 slab phantom (R1).

2.2 EPID

EPID is a retractable component of linear accelerator used in RT mainly used for portal images taken during patient set up for pre-treatment verification. The acquired images during the set up are matched with the reference image originating from the simulation tomography in treatment planning procedure. Bony structures are principally matched and necessary corrections are applied to the patient's geometry in vertical, longitudinal and lateral directions.

The EPID studied in this article was Varian aS1000, which is an amorphous silicon flat panel detector (Varian Medical Systems, Inc., Palo Alto, CA, USA). Terbium-doped

Figure 1: The typical view of the RW3 slab water-equivalent phantom (upper right) and some of the bolus materials (length of ruler is 30 cm).

gadolinium oxysulphide ($\text{Gd}_2\text{O}_2\text{S:Tb}$) scintillating phosphor screen is used to convert the X-rays into light photons. The sensitive part, also known as the active matrix, of the imager is 30 cm × 40 cm. Each pixel is comprised of a photodiode and a thin film transistor (TFT). The sensitive area consists of 1,024 × 768 pixels and the size of each pixel is 0.38 mm × 0.38 mm at the surface of the detector [12].

2.3 Measurements and evaluation process

Varian DBX linear accelerator (Varian Medical Systems, Palo Alto, California, USA) with fixed source to surface distances of 104.5 and 104 cm were used for 0.5 and 1 cm thick boluses, respectively. EPID was positioned at 105 cm from the X-ray source and each bolus was located on the top of the EPID surface. For each irradiation, 0° gantry angle and 26 cm × 26 cm open field at isocentre were chosen in order to prevent the dramatic dose degradation at the border of the bolus. 6 MV X-rays were used and total of 100 monitor units were delivered for each bolus irradiation (Figure 2).

After acquiring the images, Portal Dosimetry software version 10.0 (Varian Medical Systems, Inc., Palo Alto, CA, USA) was used to analyse the collected dose distribution data (Figure 3).

Figure 2: The experimental set up for the irradiation of bolus materials.

A combination of quantitative and qualitative approaches was used in the data analysis. Gamma analysis method was used to evaluate the dose distribution of boluses. Briefly, gamma analysis method utilizes dose-difference (DD) in percentage (%) and distance-to-agreement (DTA) in millimetres (mm) acceptance criteria to assess the predicted and measured doses in order to make planar dose comparisons. That means, the software system checks the corresponding percentage dose difference for the selected DTA in mm in each pixel. The acceptance region is determined using an ellipse, with area gamma value <1 indicating fulfilment of the criteria. Detailed information about gamma analysis method can be found in literature [13–16]. In this study, 0.5% DD and 0.5 mm DTA (0.5%/0.5 mm), 0.5% DD and 1 mm DTA (0.5%/1 mm), 1% DD and 0.5 mm DTA (1%/0.5 mm) and 1% DD and 1 mm DTA (1%/1 mm) acceptance criteria were used for the comparison of each bolus with the corresponding RW3 slab water-equivalent phantom to evaluate the dose distributions. An area gamma <1 value with 100% indicates the maximum fulfilment of criteria for

Figure 3: The view of Portal Dosimetry software to analyse the tissue or water equivalence of bolus materials (portal dose images of 0.5 cm RW3 slab water-equivalent phantom on the upper left, portal dose images of the compared bolus material on the upper right, blended image of gamma evaluation in upper middle and gamma evaluation result of compared bolus in lower left).

the selected material in terms of dose parameters. The value of area gamma <1 represents the passing rate of the total points for gamma analysis.

In addition to gamma analysis evaluations, the point doses of each bolus in portal images were transferred to SPSS software version 22 (Armonk, NY: IBM Corp., USA) to achieve point-to-point comparison. 487,204 point-dose values of each bolus were compared with the 487,204 point-dose values of RW3 slab water-equivalent phantoms to evaluate the possible correlation in terms of dose distributions.

2.4 Statistical analysis

Statistical analysis was done using the SPSS software version 22. Descriptive statistics were used to evaluate the distribution forms of the collected data. Frequency histograms were plotted for assessing the normal distribution of the sample results. Significances and correlations, amongst boluses and water slab phantoms, were done by Spearman's correlation coefficient analysis. The *p*-value less than 0.05 was considered statistically significant for all statistical analyses.

3 Results and discussion

A total of 7 bolus materials (4 samples of 0.5 cm thick and 3 samples of 1 cm thick) were assessed with EPID. The calculated passing rates of S1, S2, S3 and S4 for 0.5%/0.5 mm criteria were 60.2, 58.3, 65.0 and 99.7%, respectively. When the criteria were selected as 0.5%/1 mm, the passing rates were increased to 68.2, 66.4, 74.3 and 99.9%, respectively. The passing rates were at maximum level for all 0.5 cm thick bolus samples for the

criteria of 1%/0.5 mm and 1%/1 mm. The experimental results on 1 cm thick bolus samples were closer to each other for all 4 sets of criteria. They generated direct results for S5, S6 and S7, yielding minimum dose differences with R1 and the area gamma values were 100% each. The calculated gamma analysis values for all the bolus samples are presented in Table 1.

Furthermore, point-to-point comparison of all the 0.5 cm thick bolus samples and 1 cm thick bolus samples revealed a strong positive correlation with the R0.5 and R1, respectively. All the correlation coefficient values were above 0.975. The correlation was statistically significant for all the samples ($p < 0.001$). The correlation coefficient of S4 bolus sample was the highest among the 0.5 cm thick bolus samples with a result of 0.989, whereas S5 and S6 bolus samples were relatively higher with a result of 0.995. Tables 2 and 3 show the correlation coefficient values of correlation between 0.5 cm thick bolus samples with R0.5 and 1 cm thick bolus samples with R1, respectively.

Area gamma results showed that there was consistency between the S4 bolus sample and R0.5. According to gamma analysis results, the tissue or water-equivalence of the other samples were relatively lower than S4 sample.

The area gamma value obtained at the end of the procedure was affected by the selected acceptance criteria while performing gamma analysis. The gamma analysis software uses a colour code (orange colouring) to

Table 2: Spearman's correlation coefficients and *p* values for 0.5 cm thick bolus samples comparison (*p* values in parenthesis)

R0.5	S1	S2	S3	S4
	0.975** (0.000)	0.978** (0.000)	0.980** (0.000)	0.989** (0.000)

**Denotes that correlation is significant at the 0.01 level (2-tailed).

Table 1: Results of gamma analysis calculated with Portal Dosimetry for the four sets of acceptance criteria

Compared samples	Area gamma < 1				Average gamma			
	0.5%/0.5 mm	0.5%/1 mm	1%/0.5 mm	1%/1 mm	0.5%/0.5 mm	0.5%/1 mm	1%/0.5 mm	1%/1 mm
S1-R0.5	60.2	68.2	100.0	100.0	0.82	0.76	0.42	0.41
S2-R0.5	58.3	66.4	100.0	100.0	0.88	0.81	0.45	0.44
S3-R0.5	65.0	74.3	100.0	100.0	0.81	0.74	0.41	0.40
S4-R0.5	99.7	99.9	100.0	100.0	0.47	0.44	0.23	0.23
S5-R1	100.0	100.0	100.0	100.0	0.15	0.15	0.07	0.07
S6-R1	100.0	100.0	100.0	100.0	0.20	0.20	0.10	0.10
S7-R1	100.0	100.0	100.0	100.0	0.31	0.30	0.16	0.16

Table 3: Spearman’s correlation coefficients and p values for 1 cm thick bolus samples comparisons (p values in parenthesis)

R1	S5	S6	S7
	0.995** (0.000)	0.995** (0.000)	0.994** (0.000)

**Denotes that correlation is significant at the 0.01 level (2-tailed).

illustrate the inconsistency between the compared sample and the reference material. When the acceptance criteria 0.5%/0.5 mm was selected in 0.5 cm thick samples, pixels that do not match with the specified DD and DTA values appeared in orange colour dots in the blended image obtained with gamma analysis (Figure 4). That means, the points exceeding the acceptance criteria are shown in orange colour in the gamma map. On the other hand, these orange indicator points disappeared when evaluation criteria were selected as the rest of the set (Figures 4 and 5). Concisely, these orange patterns denote the regional discrepancies of the corresponding sample with the reference material for the specified DD% and DTA. Unlike 0.5 cm thick bolus samples, the blended view of 1 cm thick samples with R1 were seen spotless in all 4 sets of acceptance criteria (Figure 6).

The average gamma value is another expressive parameter that should be considered. It can be inferred from the results that the lower average gamma value can give an idea about the similarity of a sample to the material being compared. In cases where area gamma values <1 give the same result in all samples, it may be helpful to

consider average gamma to find the best dosimetric match among the samples. To put it more clearly, having smaller average gamma value for a sample is confirming better dose distribution for the compared samples. This inference can be encountered for the 1 cm thick bolus sample comparisons in Table 1. All the passing rates of the gamma analyses generated the same value with a 100% result. In order to determine the most identical sample among these three samples, average gamma parameter can be quite useful. For the whole acceptance criteria, S5 sample noticeably had the lowest average gamma value. Besides, this outcome was supported with the statistical analysis revealing correlation coefficient of S5 and S6 samples to be higher than S7 sample ($p < 0.001$).

Another important finding of this study was the decisiveness of DD over DTA in gamma analyses of the compared materials. Considering 0.5%/1 mm and 1%/0.5 mm acceptance criteria among the 0.5 cm thick bolus sample comparisons, it was understood that the former was more critical than the latter on passing rates (Table 1). That means, the DD parameter was more significant than the DTA in terms of detecting the minor differences in gamma analyses process. It can be stated from the obtained results that increasing the DD and DTA values will directly affect the similarity rate of the materials upward. The main reason of this consequence was the disregarding of the percentage DD within the specified DTA in the gamma analysis. Chaikh et al. reported comparable findings in their study by comparing two different inhomogeneity correction methods of pencil beam convolution algorithm [7].

Figure 4: Blended view of gamma analysis results of the 0.5 cm thick bolus samples and R0.5 for 0.5%/0.5 mm criteria (from upper left to right S1, S2, S3 and S4, respectively).

Figure 5: Blended view of gamma analysis results of the 0.5 cm thick bolus samples and R0.5 for 1%/1 mm criteria (from upper left to right S1, S2, S3 and S4, respectively).

It was stated that altering DTA and keeping the DD constant has no significant effect on the passing rates. In their study, it was stated that varying the acceptance criteria from 3%/1 mm to 3%/3 mm has not led to any change in the passing rate. On the contrary, changing the acceptance criteria from 1%/1 mm to 3%/1 mm has enhanced the passing rate from 86.2 to 99.9%.

The fabrication of bolus material, examination of its internal structure and investigation of the effects of this material on dose distribution in RT have gained momentum in recent years. Burleson et al. studied the patient-specific bolus material manufactured with 3D printer for external beam RT in terms of its effect on dose distribution [8]. They used Gafchromic EBT2 film to check the measured planar dose distribution with the simulated dose calculated in the planning system by selecting 5% DD and 2 mm DTA as the acceptance criteria. The reported passing rates were

86.5 and 89.6% for the two sets of measurements, which were lower than the present study.

Choosing the water equivalent plastic phantom as a reference material for the comparisons is widely reported in literature [3,6,9–11]. Due to the fact that water equivalent plastic phantoms are practical to handle, they are frequently used in experiments related with the bolus studies. Babic et al. investigated specially designed bolus material at different concentrations and then compared them with the plastic water phantom in terms of tissue equivalence by obtaining percentage depth dose (PDD) curves with ion chamber for various electron and photon energies [10]. They showed that the results of the designed bolus were in good agreement with the plastic water ones. Especially, the formed bolus with 1.3 cm exhibited minimum deviation from plastic water measurements at electron energies of 6, 12 and 20 MeV and photon energies of 6 and 15 MV.

Figure 6: Blended view of gamma analysis results of the 1 cm thick bolus samples and R1 for 0.5%/0.5 mm and higher criteria (from left to right S5, S6 and S7, respectively).

Aoyama et al. analysed four different bolus materials by comparing the calculated and obtained PDD curves and absolute dose values at different depths with ion chamber for 6 MV photon energy. They reported that the dose differences for all boluses were within $\pm 5\%$ in the build-up region and $\pm 1.5\%$ beyond the build-up region for PDD values and within $\pm 1.5\%$ for absolute dose values, which were higher than our study [11].

Consequently, the experimental work presented here provides one of the first investigations into how EPID can be used as an analysing equipment for comparing the similarities of materials. It is hoped that this research will contribute to a deeper understanding as an alternative method for material analysis.

4 Conclusion

The results indicated that the material planned to be used as a bolus can be evaluated with EPID in daily use by using gamma analysis. The assessment level of tissue equivalence is totally dependent on the acceptance criteria that the user specified during the testing procedure. The DD value should be specified as low as possible to check the similarity of the test sample with the reference material. Moreover, average gamma value can be an important indicator for materials having the same passing rates. This inference is confirmed with the correlation coefficients for all the samples. Evaluating the dosimetric accuracy of the bolus material, which is an indispensable material for radiotherapy, is critical for treatment precision in clinical practice. Although there are several analysing methods currently available for evaluating the tissue equivalence of bolus material, gamma analysis with portal dosimetry is one of the most functional tools in terms offering the advantage of reduced time to conduct an analysis. This is one of the first study assessing the serviceability of the flat panel technology to investigate the bolus material and further research is needed to assure the accuracy of the findings.

Funding information: No funding to declare.

Author contribution: A.Ö. – conceptualisation, methodology, formal analysis, investigation, supervision, validation, visualization, writing – original draft and writing – review and editing. Author has carefully revised and approved the final version of the manuscript.

Conflict of interest: Author declares no conflict of interest.

Ethical approval: The conducted research is not related to either human or animal use.

Data availability statement: All data generated or analysed during this study are included in this published article.

References

- [1] Khan FM, Gibbons JP. Khan's the physics of radiation therapy. 5th edn. Philadelphia: Lippincott Williams & Wilkins; 2014.
- [2] Kim SW, Shin HJ, Kay CS, Son SH. A customized bolus produced using a 3-dimensional printer for radiotherapy. *PLoS One*. 2014;9(10):e110746. doi: 10.1371/journal.pone.0110746.
- [3] Bilge H, Cakir A, Okutan M, Acar H. Surface dose measurements with GafChromic EBT film for 6 and 18 MV photon beams. *Phys Med*. 2009;25(2):101–4. doi: 10.1016/j.ejmp.2008.05.001.
- [4] Visscher S, Barnett E. Comparison of bolus materials to highly absorbent polypropylene and rayon cloths. *J Med Imaging Radiat Sci*. 2017;48(1):55–60. doi: 10.1016/j.jmir.2016.08.003.
- [5] Dyer BA, Campos DD, Hernandez DD, Wright CL, Perks JR, Lucero SA, et al. Characterization and clinical validation of patient-specific three-dimensional printed tissue-equivalent bolus for radiotherapy of head and neck malignancies involving skin. *Phys Med*. 2020;77:138–45. doi: 10.1016/j.ejmp.2020.08.010.
- [6] Aras S, Tanzer İO, İkizceli T. Dosimetric comparison of superflab and specially prepared bolus materials used in radiotherapy practice. *Eur J Breast Health*. 2020;16(3):167–70. doi: 10.5152/ejbh.2020.5041.
- [7] Chaikh A, Desgranges C, Balosso J. The use of gamma indices with medical imaging as quality assurance tool to validate the dose calculation algorithm in the modern practice of medical physics. *Nucl Med Biomed Imaging*. 2016;1(2):31–4. doi: 10.15761/NMBI.1000112.
- [8] Burleson S, Baker J, Hsia AT, Xu Z. Use of 3D printers to create a patient-specific 3D bolus for external beam therapy. *J Appl Clin Med Phys*. 2015;16(3):5247. doi: 10.1120/jacmp.v16i3.5247.
- [9] Sroka M, Reguła J, Lobodziec W. The influence of the bolus-surface distance on the dose distribution in the build-up region. *Rep Pract Oncol Radiother*. 2010;15(6):161–4. doi: 10.1016/j.rpor.2010.09.003.
- [10] Babic S, Kerr AT, Westerland M, Gooding J, Schreiner LJ. Examination of Jeltrate Plus as a tissue equivalent bolus material. *J Appl Clin Med Phys*. 2002;3(3):170–5. doi: 10.1120/jacmp.v3i3.2560.
- [11] Aoyama T, Uto K, Shimizu H, Ebara M, Kitagawa T, Tachibana H, et al. Physical and dosimetric characterization of thermoset shape memory bolus developed for radiotherapy. *Med Phys*. 2020;47(12):6103–12. doi: 10.1002/mp.14516.
- [12] Vision documentation. Clinac ExactArm type 01 reference guide. Varian Medical Systems; 2003a.

- [13] Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. *Med Phys.* 1998;25(5):656–61. doi: 10.1118/1.598248.
- [14] Bakai A, Alber M, Nüsslin F. A revision of the gamma-evaluation concept for the comparison of dose distributions. *Phys Med Biol.* 2003;48(21):3543–53. doi: 10.1088/0031-9155/48/21/006.
- [15] Low DA, Dempsey JF. Evaluation of the gamma dose distribution comparison method. *Med Phys.* 2003;30(9):2455–64. doi: 10.1118/1.1598711.
- [16] Spezi E, Lewis DG. Gamma histograms for radiotherapy plan evaluation. *Radiother Oncol.* 2006;79(2):224–30. doi: 10.1016/j.radonc.2006.03.020.