Validation of an Individualized Home-Made Superficial Brachytherapy Mould Applied for Non-Melanoma Skin Cancer

Ramin Jaberi

Tehran University of Medical Sciences

Zahra Siavashpour

Shahid Beheshti University of Medical Sciences School of Nursing and Midwifery

Naser zare akha

Tehran University of Medical Sciences Childrens Hospital

Mohammad Hadi Gholami (✉ hadigholami2@gmail.com)

Department of medical radiation engineering ,science and research branch ,Islamic Azad university

<https://orcid.org/0000-0002-4903-6464>

Fatemeh Jafari

Radiation oncology department, Imam khomeini Hospital Complex,Tehran University of Medical Science ,Tehran. Iran

Mandana Biniyaz

Hamedan University of Medical Science

Research Article

Keywords: HDR-BT, Mold, nonmelanoma skin cancer, Dosimetry

Posted Date: July 9th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-261044/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Purpose: This study was conducted to evaluate the effect of a Brachytherapy (BT) customized mold (Condensation silicone elastomer (Protesil TM)) thickness, on dose distribution pattern in deeper lesions used for nonmelanoma skin cancers (NMSC).

Material and Method: MOSFET TM and GAFCHROMIC TM EBT3 film dosimeters were used for the different thicknesses of a Brachytherapy (BT) customized mold (up to 20 mm), skin dose and dose in different depths were evaluated.

Result: The received dose to the surface is overestimated by TPS. Skin dose can be reduced from 250 to 150% of prescription dose by increasing mold thickness from 5 mm to 20 mm. There was a 7.7% difference in calculated dose by TPS and measured dose by MOSFET. Film dosimetry data was unreliable. There was a good agreement between film dosimetry, MOSFET detector, and TPS results, in the depth of 5mm<.

Conclusion: Any individualized material chosen to use for making the customized surface BT mold should be validated at BT departments. Protasil TM can be selected as feasible material to make any form of superficial molds. For thicker NMSC lesions up to 20 mm using thicker molds up to 20 mm can be. Even for 10 mm lesions, by changing mold thickness from 5 mm to 20 mm, skin dose would reduce. Protasil TM can be used to make an individualized superficial BT mold. By increasing the mold thickness, lesions can be treated without overexposing the skin surface and skin dose reduced by increasing mold thickness. So, superficial BT can be recommended as an appropriate treatment option for NMSC lesions with some consideration.

Introduction

Nonmelanoma skin cancer (NMSC) is the most common malignancy worldwide, and its incidence has an increasing trend following the population gets older [1-3]. The two most frequent kinds of NMSC are known as basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). Although NMSC has a low morbidity and mortality rate, it can significantly affect the patients' quality of life [1].

Among cancer treatment options, including surgery, radiotherapy, photodynamic therapy, and chemotherapy [4], radiation therapy has an important role in managing NMSC [5]. Superficial, ortho/megavoltage x-rays, electron beam irradiation, and radionuclide-based brachytherapy (BT) are such various radiotherapy modalities applied to NMSC. High Dose Rate Brachytherapy (HDR-BT) is a technique that supplies a high dose rate of a low energy x-ray in the tumor area with minimal shielding requirement [6-9]. Because of the widespread availability of HDR-BT, it has become a powerful option for radiotherapy, particularly for clinical cases where surface irregularity, bone proximity, or poor inherent tolerance of surrounding tissues do not allow for suitable dose distribution [10]. Merkel cell lesions, keloids, and

Kaposi sarcoma are the other kinds of skin cancer that HDR brachytherapy can be considered an alternative solution [10].

Due to the dose distribution of EBRT and its commercial applicators, surface mold brachytherapy, in addition to 3D treatment planning based on CT images, emerge as an appropriate option in the treatment planning of organs like the head and neck[11]. Also, shielded cup-shaped applicators are restricted to lesions of less than 3 cm in diameter for both Valencia™ and Leipzig [12]. For larger lesions, catheter flaps such as the Freiburg™ flap, Catheter Flap Set™, H.A.M.™, or individualized routine made molds are widely used [13]. At our institution, to BT of widespread NMSC that cannot surgically be excised or for irregular shaped lesions case, individualized home-made surface mold has been used.

AAPM TG-43 is the most common code of practice used for the most dose calculations in clinical brachytherapy. TG-43 protocol performs to estimating dose distributions in water and is strictly valid for homogeneous water medium and does not consider the actual inhomogeneity around BT source [14,15]. Some new model-based dose calculation algorithms, such as advanced collapsed cone, have been presented to enhancing treatment planning systems (TPS) that can be considered full scatter condition inhomogeneity medium [12]. Nowadays, many treatment planning systems still use TG-43 basic protocols. It has been recently shown that the delivered dose can be up to 15% lower at the prescription depth than that was considered by the TG-43 model for surface mold HDR brachytherapy. This difference increased with the skin lesion size [16]. Consequently, before the commencement of their employment in clinical practice, some dosimetry and quality control examinations should be evaluated and approved for individualized routine-made molds, particularly when just TG-43 based TPSs are presented.

High dose gradient and rapid dose fall-off are the intrinsic characteristics of brachytherapy dose distribution that require particular radiation detectors to provide proper and accurate dose calculations.

The most common radiation detection systems used for dose measurements in brachytherapy are thermoluminescent dosimeters (TLDs), radiochromic film detectors, and metal–oxide semiconductor field-effect transistors (MOSFETs) detectors[17]. TLD and film detectors are inexpensive and commonly accessible in radiotherapy departments, but they are offline, and also their calibration procedure is a vital problem. MOSFETs can be considered credible miniature detectors for online in vivo dosimetry and quality assurance (QA) [18].

This study was conducted to confirm a mold BT procedure in our institute and examine whether the delivered dose to the tissue agrees with TG-43 protocols when a customized mold material is used. So, three main aims were followed; (a) comparing the skin HDR-BT delivered dose to the patient in experimental dosimetry and calculating dose with TPS, (b) investigating for the optimum individualized molds (as the surface applicator) thickness according to different thickness of target lesions which would result in an acceptable dose distribution to the tumor volume, and finally (c) acquisition the maximum lesion thickness that can be treated with the suggested BT mold. MOSFET™ and

GAFCHROMICTM EBT3 film dosimetry as two reliable brachytherapy dosimeters were used to achieve the mentioned aims.

Materials And Methods

Condensation silicone elastomer material with the commercial name Protesil™ (Vannini Dental Industry, Florence, Italy) is used in dentistry as a common material to shape a surface mold. These materials are classified as a group of elastomeric impressions with suitable physical and chemical properties such as biocompatibility, sufficient working time, room temperature working condition, dimensional stability, plasticity, non-toxicity to tissue, and electron density [19].

The TPS measurement was performed based on the dose calculation extensively detailed at AAPM Task Group 43. HDR plus 3 (Eckert & Ziegler BEBIG GmbH, Berlin, Germany) as a brachytherapy TPS, MultiSource™ (Eckert & Ziegler BEBIG GmbH, Berlin, Germany) as HDR-BT afterloader treatment unit and a ⁶⁰Co radioactive source (model: Co0.A86, EZAG BEBIG, Berlin, Germany) as an HDR-BT source, was applied. Dose verification measurements were performed using Gafchromic EBT3 film (Ashland Specialty Ingredients, NJ, USA lot#09071703 and #04171901) and three MOSFET™ detectors to be described in the following section. The feasibility and efficiency of MOSFET detectors were confirmed in real-time in-vivo dosimetry for brachytherapy by previous researchers [20,21].

2-1: Mold construction

Four blocks of mold material were constructed in 5, 10, 15, and 20 mm thickness and 100×100 mm² area by a plastic cast. The mold was removed from the cast after 15 to 20 minutes. Three plastic catheters (Flexible Catheter Single Leader, 1.65 mm diameter, Eckert & Ziegler BEBIG, GmbH, Berlin, Germany) were fixed on top of each mold block via adhesive tape and with 10 mm parallel spacing between the catheters.

2-2: MOSFET calibration

In the current study, the MOSFET dosimeters (Best Medical Canada LTD model TN-502RD-H) with a sensitive volume of less than $4 \times 10^{-5} \text{ mm}^3$ and a physical volume of 4 mm^3 were utilized. The MOSFET Calibration Jig (TN-RD-57-30, Best Medical Canada) was applied to the facile and reproducible placement of the MOSFETs through calibration and measurement. The jig is an accessory of the mobile MOSFET wireless patient dosimetry system (TN-RD-70-W, Best Medical Canada) [22]. MOSFET detectors were placed on the surface of the jig, with the flat surface facing the beam during all the experimental measurements.

PMMA slabs were also used in the calibration step; 10 cm of slabs were located under the detectors for providing the backscatter condition, and 2 cm of slabs were placed on the MOSFET for buildup effect. The calibration was carried out for a field size of $10 \times 10 \text{ cm}^2$ with an SSD of 98 cm (100 cm at the MOSFET plane). The MOSFETs were then irradiated with 100 cGy by a 6 MV photon beam with a mono-

energy medical linear accelerator (Elekta, Compact), and the corresponding readings were tabulated in table1.

MOSFETs were initially positioned in the jig channels, such as all of them were placed into a 100 × 100 mm² central square. The first detector was in the center (red arrow), the second was in the upper right (10 mm to the right and 10 mm up from the center; yellow arrow), and the third one was in the lower left (10 mm to the left and 10 mm down from the center; blue arrow); as illustrated in Figure 1.

2-3: CT set up, and dose calculations

A 64-slice CT scanner (General Electric Medical Systems, USA) was also applied to acquire tomographic imaging to provide data required to be imported to the TPS. CTIs were acquired with 1 mm slice thickness. Metallic x-ray markers were also placed inside the catheters during scanning.

Two configurations of source loading for comparing the TPS data with MOSFET dose calculations were performed. Details of the procedure are briefly explained in the sections below.

2-3-1: The central point of the central BT catheter located just above the central MOSFET detector at the middle of the jig, shown as red MOSFET in Figure 1, was activated. The planning aim was to deliver 3 Gy to 10 mm under the phantom surface, the XZ plane of the central point. Eventually, four treatment plans were performed for four mold thicknesses, with the identical prescribed dose to the same point of interest.

24 set up configurations were created using a combination of 30cm PMMA slabs. The radiation doses were then calculated for 6 points at different depths for four different mold thicknesses. More details of the configurations are shown in Figure 2. At this step, 72 dose points (24 setups × 3 MOSFET) were compared for various mold thicknesses by the MOSFET.

2-3-2: A treatment plan was developed to deliver a 3 Gy radiation dose to all three MOSFETs. Radiation doses into a point located at 10 mm under the skin for different mold thickness were measured using MOSFET detectors. All measurements were repeated three times for all configurations explained at 2-3-1. The processed results were then compared with those calculated by TPS, as explained at 2-3-1.

The Source to Detector Distance (SDD) was defined as follows:

$$SDD = \frac{t_{catheter}}{2} + t_{slab} + t_{mould} + \frac{t_{MOSFET}}{2}$$

Where $t_{catheter}$, t_{mold} , t_{slab} , and t_{MOSFET} are the measured thicknesses of the catheters, the mold, the PMMA slab, and the MOSFET detector, respectively. The SDD was used to calculate the depth of the intended plane in TPS-calculated 3D dose distribution and coinciding with the plane of the MOSFETs and to define the exact position of control points in TPS.

It should be emphasized that to prevent the angular dependency of the MOSFET detector, the direction of entrance radiation to the MOSFET at all of the calculations set up were set to be the same as the calibration condition.

Film dosimetry

A calibration curve was obtained with eight pieces of 2×2 cm² GAFCHROMIC™ EBT3 films, shown in Figure 3, to verify the film response to irradiation with the dose range from 1 to 9 Gy. For calibration curve measurements, buildup conditions and background radiation were also taken into considerations. Film dosimetry was performed for all four mold thicknesses explained at 2-3-1. An EBT3 film (5×10 mm) slice was also positioned under the mold surface.

Results

3-1. Results of MOSFET Calibration

Calibration factors (CF) of MOSFETs were calculated as mentioned in the method. The factors were found to be in the range from 1.00 to 1.05 cGy/mV when MOSFETs were irradiated with a 6 MV photon beam. Table 1 represents the MOSFET results after 1 Gy exposure.

Table 1. Calibration results of MOSFETs

MOSFET	Blue (cGy/mV)	Red	Yellow	Mean ± SD	Blue (cGy/mV)	Red	Yellow	Mean ± SD
	First step				Second step			
1	1.03	1.01	1.05	1.03 ± 0.02	1.04	1.03	1.06	1.04 ± 0.01
2	1.02	1.01	1.03	1.02 ± 0.01	1.03	1.01	1.05	1.03 ± 0.02
3	1.00	1.00	1.01	1.00 ± 0.01	1.01	1.00	1.03	1.01 ± 0.01

3-2. Data achieved for Dose calculation

3-2-1. Results of the first configuration, represented in section 2-3-1, to compare the calculated dose in TPS and MOSFET are shown in Figure 4. In Figure 4 (a) to (d), skin dose reduces approximately from 250% (about 7.5 Gy) to 150% (about 5 Gy) of prescription dose at the red MOSFET. Therefore, by using mold thickness from 5 mm to 20 mm, skin dose reduces significantly.

3-2-2. Results of the second configuration, mentioned in section 2-3-2, through which performed treatment planning were aiming to deliver a 3 Gy to all the three MOSFETs, are presented in Table 2.

Table 2. Comparing MOSFETs measured and TPS calculated doses for the second configuration is represented in section 2-3-2 with 3 Gy photon beam.

Molds		Readings (cGy)				
Thickness	Color	1	2	3	Mean $\pm$ SD	Difference $\pm$ SD
5 mm	Blue	317	314	314	315 $\pm$ 1.7	4.9 $\pm$ 0.5
	Red	307	312	303	307 $\pm$ 4.5	2.5 $\pm$ 1.6
	Yellow	316	323	318	319 $\pm$ 3.6	6.4 $\pm$ 1.2
10 mm	Blue	320	316	321	319 $\pm$ 2.6	6.4 $\pm$ 0.9
	Red	322	319	321	321 $\pm$ 1.5	6.9 $\pm$ 0.6
	Yellow	314	319	317	317 $\pm$ 2.5	5.5 $\pm$ 0.7
15 mm	Blue	310	312	317	313 $\pm$ 3.6	4.2 $\pm$ 1.2
	Red	317	315	316	316 $\pm$ 1.0	5.3 $\pm$ 0.4
	Yellow	324	320	322	322 $\pm$ 2.0	7.4 $\pm$ 0.7
20 mm	Blue	309	317	308	311 $\pm$ 4.9	3.9 $\pm$ 1.7
	Red	310	309	307	309 $\pm$ 1.5	3.0 $\pm$ 0.5
	Yellow	318	314	319	317 $\pm$ 2.6	5.6 $\pm$ 0.9

3-3. Film dosimetry

The calibration curve of the GAFCHROMIC™ EBT3 film was drawn in Figure5.

Figure 6 compares the calculated dose in TPS, GAFCHROMIC™ EBT3 film, and the central red MOSFET.

Discussion

There are many particular, and routinely applicators dedicated to BT of skin in clinical practice, such as Valencia, Leipzig, and even electronic BT applicators verified for NMSC [11]. Despite the fact that their compatibility of applicators to any non-uniformity of skin types is restricted. Application of personalized home-made surface mold is a common approach in brachytherapy [23,13,11,24].

The significant benefit of such modified mold construction is reaching the best shape conformity to the various curvatures of body sites. For instance, Budrukkar *et al.* reported using a dental acrylic mold in HDR-BT for head and neck tumors and concluded that this therapy has excellent organ preservation functions. [23]. We used condensation silicone elastomer material to construct the individualized skin BT mold in our institute.

MOSFET detectors are necessary for the high spatial resolution to provide accurate dosimetry in high dose gradient areas due to their small sensitive volumes, were applied. Moreover, MOSFET dosimeters are online and independent from dose rate. Melchert *et al.* used MOSFET for online in vivo dosimetry during

interstitial brachytherapy of thoracic-wall, head and neck, and breast cases [21]. In another study, Persson et al. applied MOSFET to perform an end-to-end ^{192}Ir quality assurance (QA) procedure. After dose verification measurements, they figured out the stability of MOSFET detectors over time and their good functionality of them for QA in brachytherapy [25].

Due to the previous studies, reaching an unsuccessfully full scatter condition is a fundamental problem in superficial brachytherapy, which leads to systematic uncertainty, about 5%, especially within the first 5 mm of the skin surface [26]. As a result of these facts, the difference in dose recorded by MOSFETs (the red arrow, illustrated in Figure 1) in comparison to the TPS results, in the distance less than 5 mm from the phantom surface, is justifiable.

The TPS and MOSFET output differences were higher for blue and yellow MOSFET detectors in less than or equal to 5 mm in depth. These two MOSFETs were not at the same XY plane (Figure 2), and due to rapid dose fall in small SDD, higher alterations were predictable. After 10 mm for all of the mold thicknesses, the differences between MOSFETs and TPS output were negligible (less than 0.1 Gy). Melchert *et al.* were also concluded that the deviations between TPS results and measured dose were influenced by the proximity of their detectors to the target [21]. Our results are in agreement with their conclusion, particularly for the high dose region that occurred in-depth below 5 mm from the phantom surfaces.

The other noticeable results that can be seen in Figure 4 are at the BT mold with 5 mm thickness, TPS calculated dose was 7.7% higher than the MOSFET detector result (red) at the surface of the phantom. It is concluded that TPS overestimated the dose at the surface by considering mold's material as water based on TPS algorithm (TG-43). This can help us when we are facing patients with unhealed lesions after surgery. Beyond 2 mm from the surface, this difference became insignificant (figure4(a)). This difference cannot be generalized to the thicker molds. By increasing mold thickness, data matching between central MOSFET and TPS outputs was improved.

Through comparing Figure4 (a) to (d), the inverse square law effect was observed. By increasing the mold thickness, the dose per plane in the prescription point (10 mm in this study) became higher. Doses at the 15 and 20 mm in depths were higher when we applied molds with 15 and 20 mm thickness. However, due to the attenuation effect of phantom and mold, by increasing the thickness of mold by more than 20 mm, no more dose escalation was observed.

Table 2 represents the experimental results of all three MOSFETs at the prescription dose. The differences between calculated dose with TPS and peripheral MOSFET detectors are found to be identical with the central MOSFET, as expected. The maximum difference between the MOSFET's data and the TPS outputs was $7.4 \pm 0.7\%$. By considering the results, we can conclude that the sensitivity of the MOSFET to the exposure angle did not influence their reading in the current study.

EBT3 film, due to its near tissue-equivalent characteristic and its independent energy range, is suitable for BT with ^{60}Co source in dose more than 100 cGy[26]. Furthermore, any positional inaccuracy between

source and film causes significant inaccuracy in final achievements. As it is shown in Figure 6, loss of scattering equilibrium or any positional uncertainty leads to a difference up to 35% between calculated dose in film and TPS at the surface of the phantom. Several studies used EBT2 or EBT3 films as a dosimeter in various BT dosimetry procedures [27-30]. Sinnantamby et al. performed a verification study to evaluate the radiation dosimetry in HDR-BT by EBT2 film. They used several film stacks to confirm the AcurosTMBV algorithm and applied this detector to make the quality assurance of cylinder applicators with/without the shield but with a buildup cap of 5 mm or thicker. Gamma analysis of their results demonstrated the reliability of the QA procedure, particularly with 5% and 1 mm [29]. Bassi et al. used EBT3-V3 film for dosimetry assessment of a 3D printable material in surface BT as a mold. Their results were in good agreement with Oncentra[®]Brachy TPS when two films were irradiated at 5 mm and 15 mm distance from their 3D-printed 5 mm slab [27]. However, there is no report for dosimetry data in the distance less than 5 mm near the BT source due to the high dose gradient.

Figure 6 demonstrates the positioning uncertainties are inversely proportional to the SSD, especially for film studies. The relative difference between film data and the TPS results is reduced to 4 % in 20 mm under the skin. On the surface of the phantom, the results of film dosimetry were unreliable. Beyond 5 mm, all the film, MOSFET, and TPS calculated dose are in good agreement with each other.

HDR-BT of NMSC with individualized skin molds cause conformal radiotherapy with high biologically equivalent dose, advanced functional outcomes, and high local control of tumor [24]. However, any BT center must be validating their customized mold material.

Conclusion

Based on the present study results, condensation silicone elastomer material with the commercial name ProtesilTM can be used to make an individualized superficial BT mold. Moreover, the MOSFET detector can be employed as a reliable online dosimeter in NMSC superficial BT and also TPS based on the TG-43 algorithm, overestimate the skin dose through superficial BT. Furthermore, film dosimetry in HDR-BT and contact to the superficial BT mold caused unreliable outputs. By increasing the mold thickness, more than 20 mm in depth, lesions can be treated without overexposing the skin. Skin dose can be reduced from 250% to 150% of prescription dose by increasing in mold thickness from 5 to 20 mm, respectively. Therefore, superficial BT can be used as a treatment option for NMSC lesions that are even thicker than 5 mm, but more than 20 mm in depth.

References

1. Lomas A, Leonardi-Bee J, Bath-Hextall F (2012) A systematic review of the worldwide incidence of nonmelanoma skin cancer. *Br J Dermatol* 166 (5):1069-1080. doi:10.1111/j.1365-2133.2012.10830.x
2. Perera E, Gnaneswaran N, Staines C, Win AK, Sinclair R (2015) Incidence and prevalence of nonmelanoma skin cancer in Australia: A systematic review. *Australas J Dermatol* 56 (4):258-267. doi:10.1111/ajd.12282

3. Veness MJ, Delishaj D, Barnes EA, Bezugly A, Rembielak A (2019) Current Role of Radiotherapy in Non-melanoma Skin Cancer. *Clin Oncol (R Coll Radiol)* 31 (11):749-758. doi:S0936-6555(19)30340-1 [pii] 10.1016/j.clon.2019.08.004
4. Treatments for nonmelanoma skin cancer (Jan 2020) <https://www.cancer.ca/en/cancer-information/cancer-type/skin-non-melanoma/treatment/?region=on>. <https://www.cancer.ca/en/cancer-information/cancer-type/skin-non-melanoma/treatment/?region=on>. Accessed Jan 2020
5. Ouhib Z, Kasper M, Perez Calatayud J, Rodriguez S, Bhatnagar A, Pai S, Strasswimmer J (2015) Aspects of the dosimetry and clinical practice of skin brachytherapy: The American Brachytherapy Society working group report. *Brachytherapy* 14 (6):840-858. doi:S1538-4721(15)00504-8 [pii] 10.1016/j.brachy.2015.06.005
6. Conill C, Sanchez-Reyes A, Molla M, Vilalta A (2004) Brachytherapy with ¹⁹²Ir as treatment of carcinoma of the tarsal structure of the eyelid. *Int J Radiat Oncol Biol Phys* 59 (5):1326-1329. doi:10.1016/j.ijrobp.2004.01.048 S0360301604002202 [pii]
7. Shields JA, Shields CL, Freire JE, Brady LW, Komarnicky L (2003) Plaque radiotherapy for selected orbital malignancies: preliminary observations: the 2002 Montgomery Lecture, part 2. *Ophthalmic Plast Reconstr Surg* 19 (2):91-95. doi:10.1097/01.IOP.0000056020.66654.33 00002341-200303000-00001 [pii]
8. Chan S, Dhadda AS, Swindell R (2007) Single fraction radiotherapy for small superficial carcinoma of the skin. *Clin Oncol (R Coll Radiol)* 19 (4):256-259. doi:S0936-6555(07)00519-5 [pii] 10.1016/j.clon.2007.02.004
9. Kwan W, Wilson D, Moravan V (2004) Radiotherapy for locally advanced basal cell and squamous cell carcinomas of the skin. *Int J Radiat Oncol Biol Phys* 60 (2):406-411. doi:10.1016/j.ijrobp.2004.03.006 S036030160400389X [pii]
10. Halperin EC, Wazer DE, Perez CA, Brady LW (2019) Perez & Brady's principles and practice of radiation oncology
11. Kuncman L, Kozlowski S, Pietraszek A, Pietrzykowska-Kuncman M, Danielska J, Sobotkowski J, Luniewska-Bury J, Fijuth J (2016) Highly conformal CT based surface mold brachytherapy for non-melanoma skin cancers of earlobe and nose. *J Contemp Brachytherapy* 8 (3):195-200. doi:10.5114/jcb.2016.61066
12. Boman EL, Paterson DB, Pearson S, Naidoo N, Johnson C (2018) Dosimetric comparison of surface mold HDR brachytherapy with VMAT. *J Med Radiat Sci* 65 (4):311-318. doi:10.1002/jmrs.301
13. Guinot JL, Rembielak A, Perez-Calatayud J, Rodriguez-Villalba S, Skowronek J, Tagliaferri L, Guix B, Gonzalez-Perez V, Valentini V, Kovacs G (2018) GEC-ESTRO ACROP recommendations in skin brachytherapy. *Radiother Oncol* 126 (3):377-385. doi:S0167-8140(18)30035-5 [pii] 10.1016/j.radonc.2018.01.013
14. Rivard MJ, Coursey BM, DeWerd LA, Hanson WF, Huq MS, Ibbott GS, Mitch MG, Nath R, Williamson JF (2004) Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy

- dose calculations. *Med Phys* 31 (3):633-674. doi:10.1118/1.1646040
15. Beaulieu L, Carlsson Tedgren A, Carrier JF, Davis SD, Mourtada F, Rivard MJ, Thomson RM, Verhaegen F, Wareing TA, Williamson JF (2012) Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: current status and recommendations for clinical implementation. *Med Phys* 39 (10):6208-6236. doi:10.1118/1.4747264
 16. Boman EL, Satherley TWS, Schleich N, Paterson DB, Greig L, Louwe RJW (2017) The validity of Acuros BV and TG-43 for high-dose-rate brachytherapy superficial mold treatments. *Brachytherapy* 16 (6):1280-1288. doi:S1538-4721(17)30451-8 [pii] 10.1016/j.brachy.2017.08.010
 17. Fonseca PG, Luvizotto J, Salles Coelho T, Antunes PCG, Rubo R, Siqueira PTD, Yoriyaz H (2014) BRACHYTHERAPY DOSE MEASUREMENTS IN HETEROGENEOUS TISSUES.176-188
 18. Yu Qi Z (2010) Mosfet dosimetry in HDR brachytherapy and IMRT for nasopharyngeal carcinoma. The University of Wollongong,
 19. PROTESIL NORMAL RIGID VANNINI DENTAL INDUSTRY S.r.l.
http://www.vanninidental.com/certification/instruction_for_use/protesil_normal_rigid.pdf. Accessed Jan 2020
 20. Tuntipumiamorn L, Nakkrasae P, Kongkum S, Dankulchai P (2019) End-to-end test and MOSFET in vivo skin dosimetry for (192)Ir high-dose-rate brachytherapy of chronic psoriasis. *J Contemp Brachytherapy* 11 (4):384-391. doi:10.5114/jcb.2019.86973 37337 [pii]
 21. Melchert C, Soror T, Kovacs G (2018) Quality assurance during interstitial brachytherapy: in vivo dosimetry using MOSFET dosimeters. *J Contemp Brachytherapy* 10 (3):232-237
 22. MOSFET Calibration Jig. (Dec 2019) Best medical Canada.
http://www.bestmedicalcanada.com/pdf/datasheets/mosfet_calibration_jig.pdf. Dec 2019
 23. Budrukkar A, Dasgupta A, Pandit P, Laskar SG, Murthy V, Upreti RR, Gupta T, Dholam K, Agarwal JP (2017) Clinical outcomes with high-dose-rate surface mold brachytherapy for intra-oral and skin malignancies involving head and neck region. *J Contemp Brachytherapy* 9 (3):242-250. doi:10.5114/jcb.2017.66773
 24. Casey S, Awotwi-Pratt J, Bahl G (2019) Surface Mold Brachytherapy for Skin Cancers: The British Columbia Cancer Experience. *Cureus* 11 (12):e6412. doi:10.7759/cureus.6412
 25. Persson M, Nilsson J, Tedgren AC (2017) Experience of using MOSFET detectors for dose verification measurements in an end-to-end 192Ir brachytherapy quality assurance system. *Brachytherapy* 17 (1):227-233. doi:https://doi.org/10.1016/j.brachy.2017.09.005
 26. Oare C, Wilke C, Ehler E, Mathew D, Sterling D, Ferreira C (2019) Dose calibration of Gafchromic EBT3 film for Ir-192 brachytherapy source using 3D-printed PLA and ABS plastics. *3D Print Med* 5 (1):3. doi:10.1186/s41205-019-0040-4
 27. Bassi S, Langan B, Malone C (2019) Dosimetry assessment of patient-specific 3D printable materials for HDR surface brachytherapy. *Phys Med* 67:166-175. doi:10.1016/j.ejmp.2019.10.035
 28. Ayoobian N, Asl AS, Poorbaygi H, Javanshir MR (2016) Gafchromic film dosimetry of a new HDR 192Ir brachytherapy source. *J Appl Clin Med Phys* 17 (2):194-205. doi:10.1120/jacmp.v17i2.6005

29. Sinnatamby M, Nagarajan V, Kanipakam RS, Karunanidhi G, Neelakandan V, Kandasamy S (2018) Verification of Radiation Fluence using Stack Film in HDR Brachytherapy with Heterogeneity Algorithm. Journal of Clinical and Diagnostic Research 12 (11):5-10.
doi:10.7860/JCDR/2018/36733.12258
30. Palmer AL, Nisbet A, Bradley D (2013) Verification of high dose rate brachytherapy dose distributions with EBT3 Gafchromic film quality control techniques. Phys Med Biol 58 (3):497-511.
doi:10.1088/0031-9155/58/3/497

Figures

Figure 1

Schematic illustration of jig and color-coded MOSFETs used for radiation dose measurements.

Figure 2

Set up the configuration for a mold with 5 mm thickness positioned on the top of a 30 cm PMMA slab. Measurements were done at (a) surface, (b) 2 mm, (c) 5 mm, (d) 10 mm, (e) 15 mm, and (f) 20 mm depths (shown in red star) while the dose prescribed to a central point (shown as PP) at a depth of 10 mm.

Figure 3

Constructed molds and setup configuration for film dosimetry. (a,b) BT catheter fixation and molds with different thickness, (c,d) Setup arrangement using water equivalent trays for film dosimetry.

Figure 4

Calculated dose for (a): 5 mm (b): 10mm (c): 15mm (d): 20mm mold thickness during deferent depths from the surface of the phantom.

Figure 5

calibration curve of GAFCHROMICTM EBT3 film.

Figure 6

Comparison between calculated dose in TPS, GAFCHROMICTM EBT3 film, and the central red MOSFET in 4 depths (i.e., 0, 5, 10, and 20 mm) and for four different molds (with 5, 10, 15, and 20 mm).