Original paper

Film based verification of calculation algorithms used for brachytherapy planning-getting ready for upcoming challenges of MBDCA

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Abstract

Purpose: Well-known defect of TG-43 based algorithms used in brachytherapy is a lack of information about interaction cross-sections, which are determined not only by electron density but also by atomic number. TG-186 recommendations with using of MBDCA (model-based dose calculation algorithm), accurate tissues segmentation, and the structure's elemental composition continue to create difficulties in brachytherapy dosimetry. For the clinical use of new algorithms, it is necessary to introduce reliable and repeatable methods of treatment planning systems (TPS) verification. The aim of this study is the verification of calculation algorithm used in TPS for shielded vaginal applicators as well as developing verification procedures for current and further use, based on the film dosimetry method.

Material and methods: Calibration data was collected by separately irradiating 14 sheets of Gafchromic® EBT films with the doses from 0.25 Gy to 8.0 Gy using HDR ^{192}Ir source. Standard vaginal cylinders of three diameters were used in the water phantom. Measurements were performed without any shields and with three shields combination. Gamma analyses were performed using the VeriSoft® package.

Results: Calibration curve was determined as third-degree polynomial type. For all used diameters of unshielded cylinder and for all shields combinations, Gamma analysis were performed and showed that over 90% of analyzed points meets Gamma criteria (3%, 3 mm).

Conclusions: Gamma analysis showed good agreement between dose distributions calculated using TPS and measured by Gafchromic films, thus showing the viability of using film dosimetry in brachytherapy.

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Key words: brachytherapy, film dosimetry, QA, Gamma analysis, shields.

Purpose

Designing and introducing reliable methods of verification treatment planning systems (TPS) used in brachytherapy is a complex project in most cases [1,2,3]. The TPS used in most of the cases are still based on the TG-43 recommendations, which have been verified in homogenous conditions [4]. However, one of the well-known defects of the calculation algorithms based on the Sivert integral and modular dose calculation models is that such dose rate calculations are based on a single source position in a homogenous water environment [5,6,7], whereas the overall dose distribution in the medium is a product of the contribution from each source position and the modulated step time, which are governed by optimization routines [8,9].

Three-dimensional (3D) reconstruction of the geometry is a common technique [10,11,12] but the benefits from using these imaging methods are not fully realized because of the lack of usable information about the cross-sections interaction, which are determined not only by electron density but also by the atomic number (Z) of the applicator itself and surrounding tissues [13]. As a result, for the relatively low energy range commonly used in brachytherapy, it is impossible to determine the influence of heterogeneities on dose calculations. TG-186 recommendations provide greater accuracy in brachytherapy dosimetry. The TG-186 recommends the use of the MBDCA (model-based dose calculation algorithm), and emphasizes the need for accurate tissue segmentation by identifying the tissue type in terms of density and elemental composition [14,15,16]. However, for the clinical use of these new calculation methods, reliable and repeatable methods of TPS verification are needed.

Large share of recent studies is focused on Monte Carlo (MC) simulations, which are independent of accuracy of manual setup of experiment [17,18,19]. Many facilities

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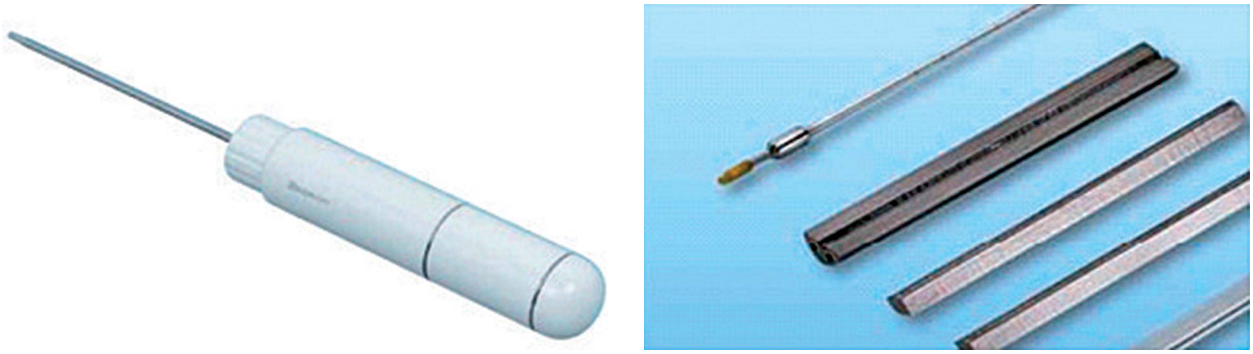

Fig. 1. Standard vaginal cylinder with a set of interchangeable shields (Elekta Brachy®)

do not perform MC simulations and are dependent on different verification methods. Self-developing dosimetry films have been used to verify dose distributions, and their use has been well documented [20,21,22,23]. However, they need to be adapted to the technical capacities of the particular facility [24]. Our department is preparing to introduce MBDCA soon. For this reason, a setup was prepared, which was verified using algorithms based still on TG-43 recommendations. For this reason, a common brachytherapy setup was used, involving vaginal cylinders and internal shields as a test platform to develop a verification procedure for reaffirmation of the MBDCA based algorithms recommended in TG-186, which will be used after implementation of MBDCA.

The aim of this study is to develop dose distribution verification procedure based on film dosimetry, which may be easily introduced in brachytherapy department.

Material and methods

Film calibration

Calibration data were collected by separately irradiating 14 sheets (20 mm × 30 mm) of Gafchromic® EBT (Lot #: 47207-031, ISP, Ashland, Covington, USA) films with doses ranging from 0.25 Gy to 8.0 Gy, using HDR ^{192}Ir (^{192}Ir-mHDR-v2, Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden) source. To assure homogenous dose distribution, films were placed between two blocks of 25 mm thick PMMA, and two catheters were located above and below that films at a distance of 25 mm. Doses were prescribed to the dose points in the center of a film. After 72 hours, the films were digitized with a flat table scanner (Epson® Perfection V750 Pro, Seiko Epson Corporation, Suwa, Japan) with light source on the one side and the detector on the other side of the film, all with the same orientation. Mean values from the most homogenous central part of the film (10 mm × 5 mm) were calculated using the VeriSoft® (PTW, Freiburg GMBH, Freiburg, Germany) package. In region of interest of 10 mm × 5 mm, the dose variation was estimated below 5%. The calibration curve and calculation of the optical density to the doses was prepared (analog to digital conversion value; ADC).

Verification of the dose distribution

Standard vaginal cylinders (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden) with three different diameters (25, 35, and 40 mm) were used as applicators (Figure 1). Oncentra Brachy 4.3.1 with implemented applicator modelling, including shielding for gynecological applicators was applied.

Dosimetric media (Gafchromic® EBT dosimetric films) were prepared by cutting a round hole in the center of the sheets to fit precisely to the diameter of the cylinders. The OLFA® Circle Cutter (Olfa Corporation, Osaka, Japan) was used to assure sharp, clean edges of the cut, in order to minimize water penetration into the layered structure of the film. Film sheets were placed perpendicular to the axis of the applicator, in the position corresponding to the center of the planned active length of 25 mm (6 active positions of the source) (Figure 2). The computed tomography (CT) of the cylinder was performed with markers on surface of the cylinder to ensure the plane in which the film was to be placed. OncentraBrachy® 4.3.1 (TG-43) (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden) was used to calculate the dose distribution.

The applicator was then submersed in the water phantom (50 × 50 × 50 cm). Measurements were performed for all three cylinder diameters without using any shields, and separately, with a combination of three shields. Three shielding angles (90°, 180°, and 270°) were used (Figure 3). After 72 hours, the films were digitized. Scanning was performed on Epson Perfection V750 Pro scanner (Seiko Epson Corporation, Suwa, Japan) with 96 dpi resolution and 48 bit colour depth in red light colour spectrum.

Gamma analysis of the data was performed using the VeriSoft® (PTW, Freiburg GMBH, Freiburg, Germany) package. The dose distributions calculated by the TPS were

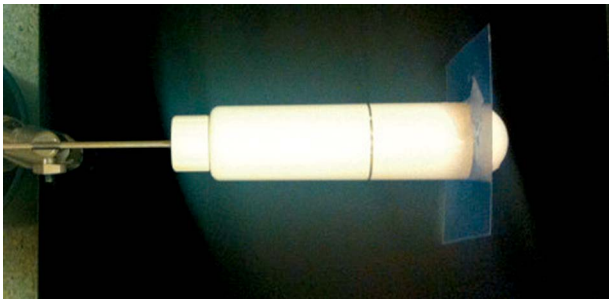

Fig. 2. Measurement setup with dosimetric film fixed perpendicular to the applicator, ready for submersion in the water phantom

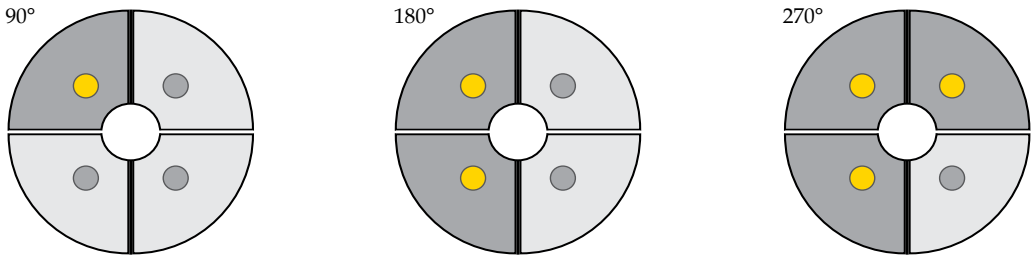

Fig. 3. Cross-section of three different shields combinations for 90°, 180°, and 270° shielding angle (yellow dot presents the shielding)

Fig. 4. Digitized sheets of the films used to obtain calibration data. Deposited doses from left to right are: 0.0 Gy, 0.25 Gy, and 0.5-5.0 Gy with 0.5 Gy intervals, and 5-8 Gy with 1.0 Gy intervals

prepared as dose grids with a planar resolution of 1.0 mm. Data packages obtained in this process were imported into the VeriSoft® software and compared to the data obtained from Gafchromic EBT films. As there are no general rules for Gamma analysis in brachytherapy dosimetry, we used the AAPM (The American Association of Physicists in Medicine) TG-119 recommendations for Gamma analysis in IMRT (3% and 3 mm, with a level of 90% for acceptance). Analyses were performed for the treatment plans with and without shields, and for the various cylinder diameters 25 mm, 35 mm, and 40 mm. Three shields combinations were used: 90°, 180°, and 270°, respectively.

Results

Calibration data

To determine the calibration data, 14 sheets of films were irradiated separately using the PMMA phantom, as described previously. Figure 4 shows the darkening

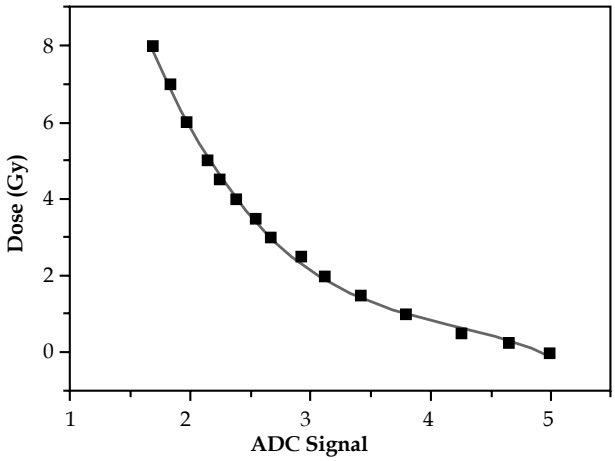

Fig. 5. Calibration curve for the Gafchromic EBT films and ^{192}Ir source

(bluing) of the film for doses used during the calibration process. Standard deviation of the measured ADC values was 0.82%.

The calibration curve (Figure 5) was determined as the third degree polynomial type:

$$y = A_0 + A_1x^1 + A_2x^2 + A_3x^3,$$

where: $A_0 = 29.02$, $A_1 = -18.89$, $A_2 = 4.35$, $A_3 = -0.35$.

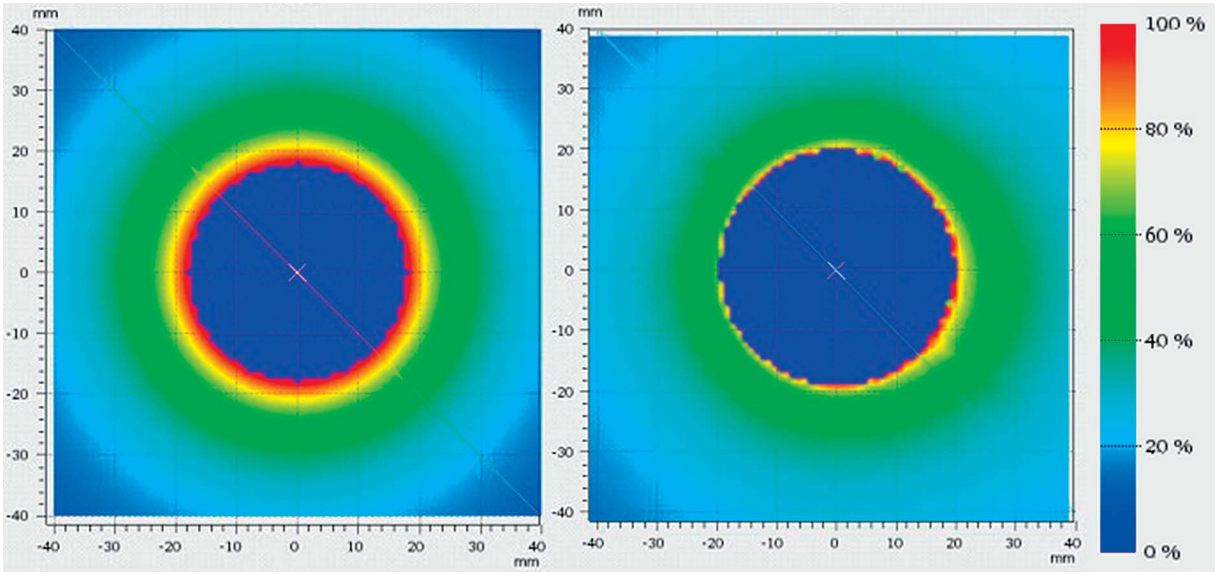

Fig. 6. Dose distribution for the 35 mm unshielded cylinder (100% = 6.024 Gy). On the left side is the calculated dose (TPS), and on the right side, the film-measured data

The goodness of fit of calculated polynomial: r_a^2 = 0.99725.

Dosimetric verification of the dose distribution using Gamma method

Co-registration of data imported from TPS and dose distribution from scanned film were guided by the center of cylinder. Rotation of the film was corrected in shielded applicator by seeking the steepest dose gradient in the shielded/unshielded area, and was performed manually. Dose was normalized to 100% as maximum measured dose by VeriSoft® software for each analyzed film. Graphical representation of the Gamma values obtained for 35 mm cylinders is presented as an example in Figure 6 to Figure 13. Dose distribution was not normalized. The Figures are presentation of calculated dose distribution in TPS and ADC obtained from scanned Gafchromic films. For the graphical representation of the Gamma values, green and blue shades represent agreement at 100-95% level, yellow at 95-90%, and red below 90%.

Tables 1, 2, and 3 provide summarized data of the Gamma analysis for the three different cylinder diameters, both unshielded, and with the three shield combinations. Number of analyzed points varied due to film rotation in software (the rotation closer to 45°, additional data was lost).

In all the cases, Gamma analysis showed good agreement between the dose distribution calculated with TG-43

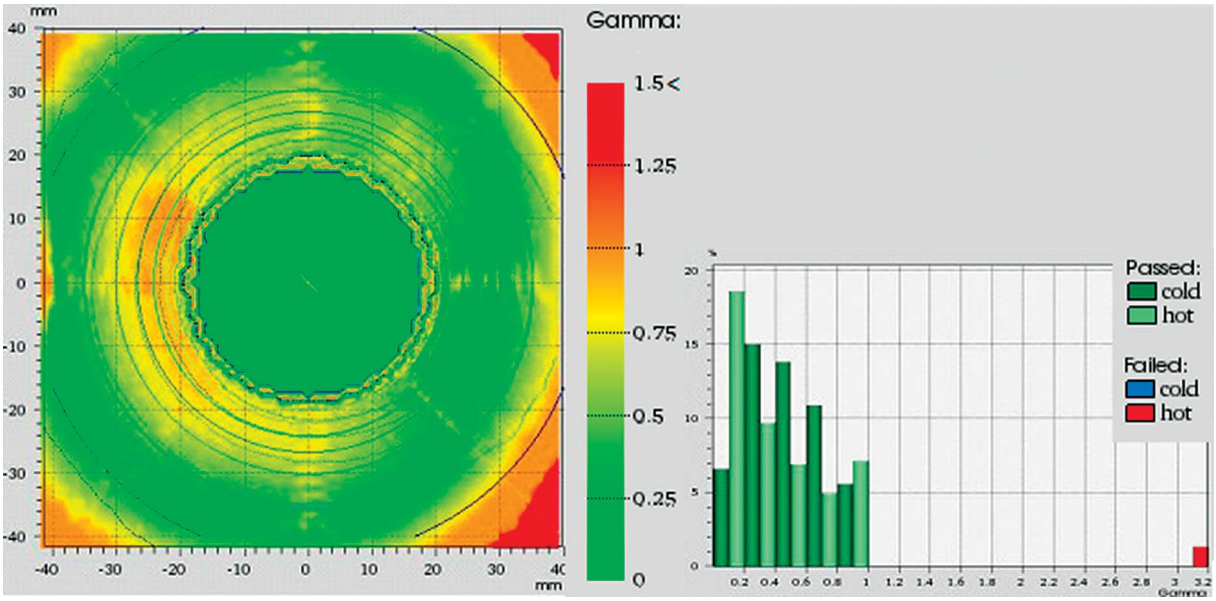

Fig. 7. Gamma values for the 35 mm unshielded cylinder. The left side shows the graphical representation (see text), and the right side shows the Gamma values histogram

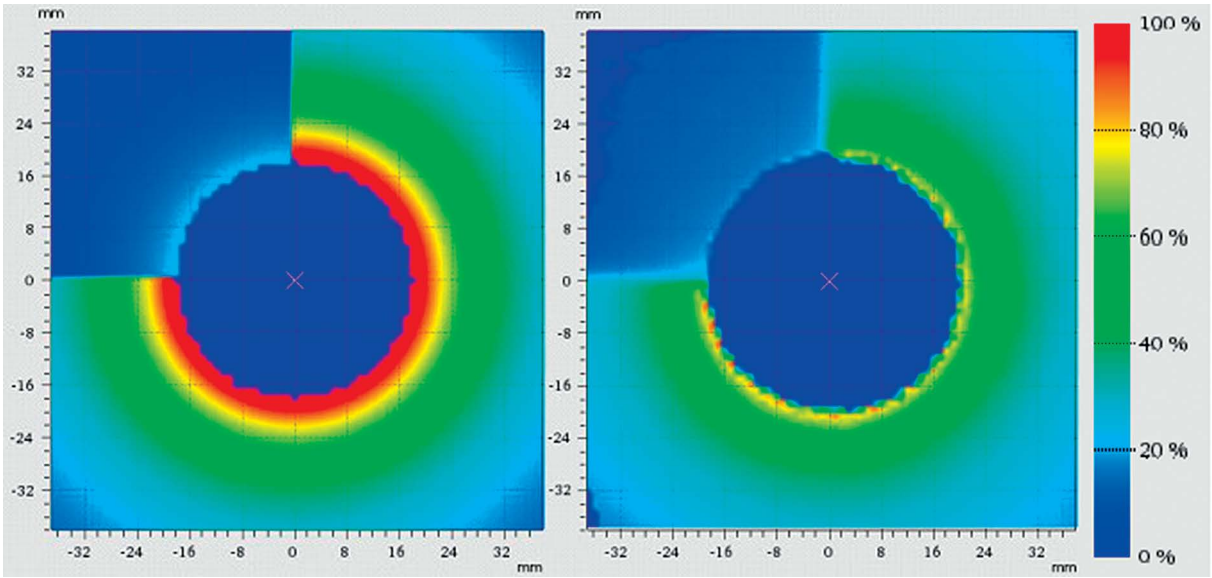

Fig. 8. Dose distribution for the 35 mm cylinder with 90° shielding (100% = 6.155 Gy). On the left side is the calculated dose (TPS), and on the right side, the film-measured data

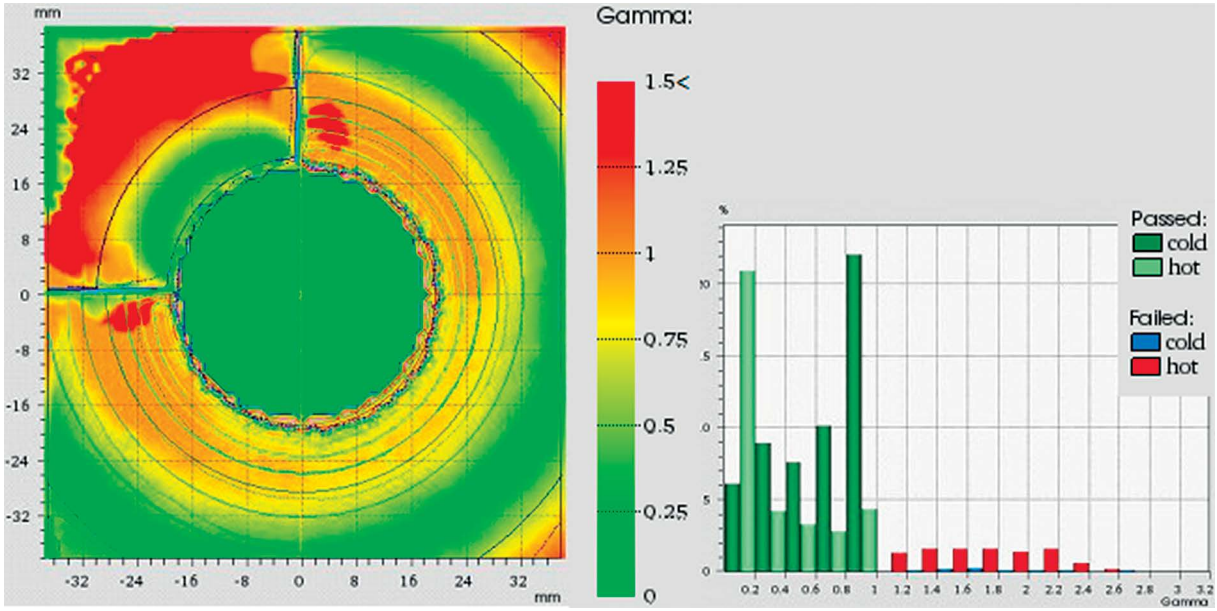

Fig. 9. Gamma values for the 35 mm cylinder with 90° shielding. On the left side is the graphical representation (see text), and on the right side, the Gamma values histogram

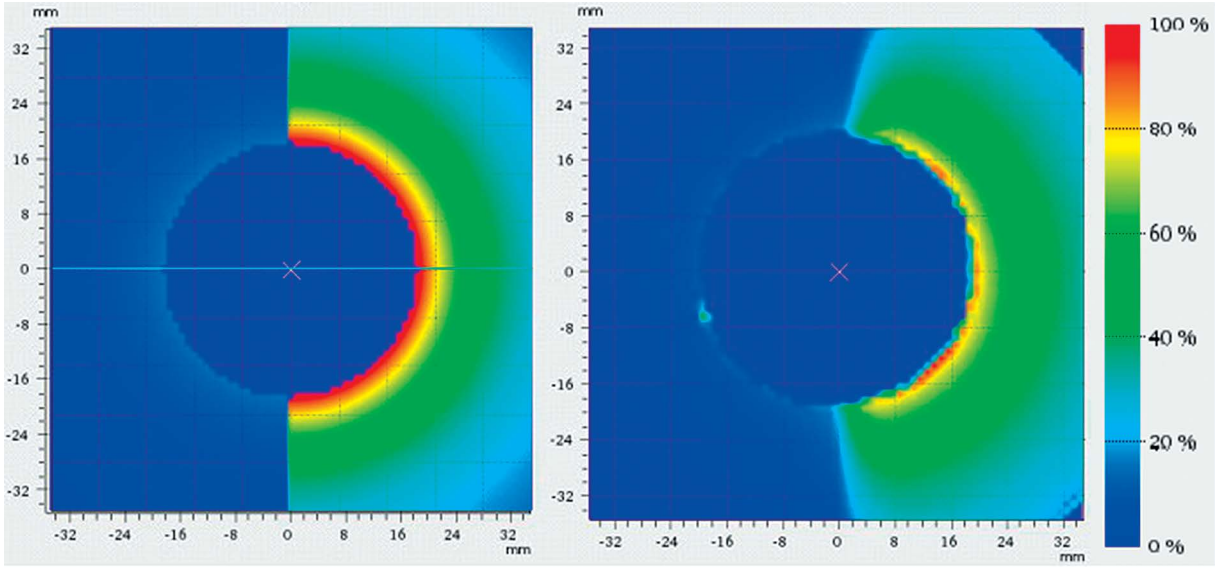

Fig. 10. Dose distribution for the 35 mm cylinder with 180° shield (100% = 6.029 Gy). On the left side is the calculated dose (TPS), and on the right side, the film-measured data

based TPS and measured with Gafchromic® films. For all diameters of unshielded cylinder and for all shield combinations, Gamma analyses showed that over 90% of the analyzed points met Gamma criteria (3%, 3 mm).

Discussion

In this study, we have attempted to use the typical brachytherapy setup with vaginal cylinders and internal shields as a test platform to develop a quality assurance procedure, verifying the calculation algorithm implemented to TPS. The main finding of our study was that self-developing flat film dosimetry is a reliable verification method that could be easily adapted to almost any clinical setup where point dose dosimetry is difficult to use, and cannot provide valuable information.

Calibration

Many Gafchromic EBT film detector calibration methods are available. One such method involves the use of externally generated photon beams, which was the easiest calibration method to implement. However, even though this calibration method was common [25,26,27], its use has been abandoned. Chiu-Tsao *et al*. [28] demonstrated that the films response to irradiation with 21 keV and 6 MV photon beams is practically independent of the energy, but is notably worse at low energies. Similar

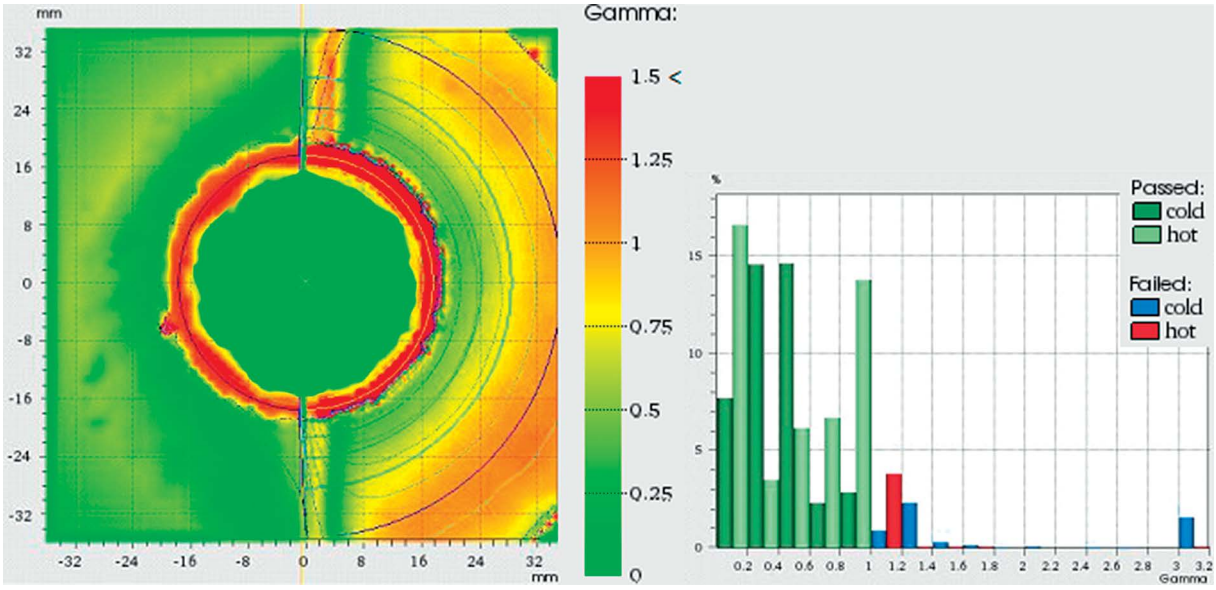

Fig. 11. G Gamma values for the 35 mm cylinder with 180° shielding. On the left side is the graphical representation (see text), and on the right side, the Gamma values histogram

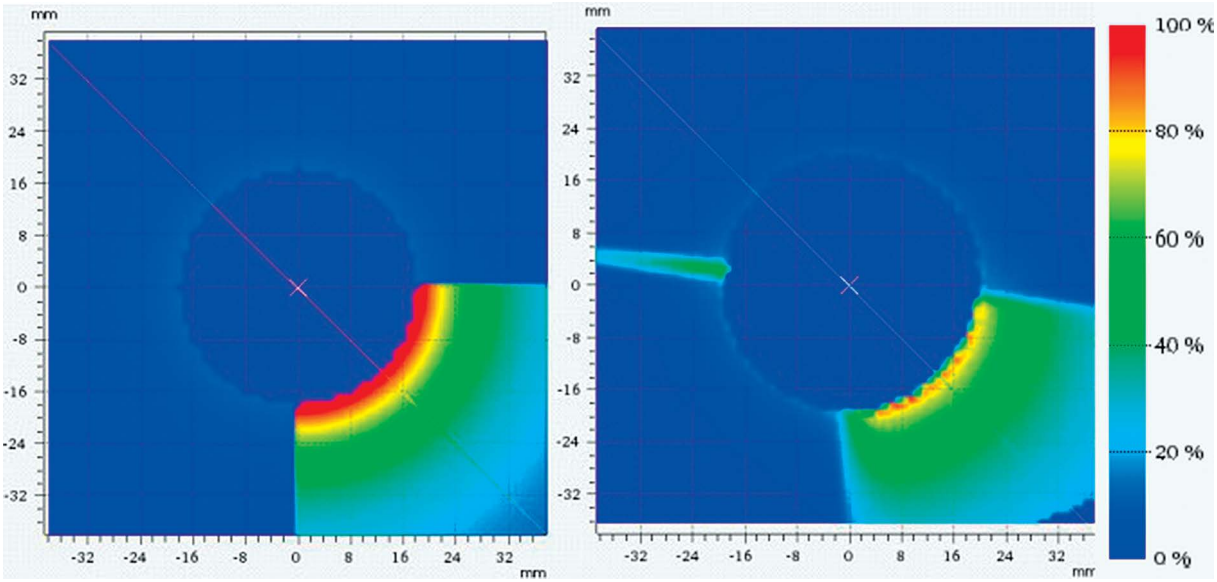

Fig. 12. Dose distribution for the 35 mm cylinder with 270° shield (100% = 5.804 Gy). On the left side is the calculated dose (TPS), and on the right side, the film-measured data, with leakage clearly visible

results for EBT films were demonstrated by Butson *et al.* [29] for the 50 keV – 6 MV energy range. However, Brown and Hongstrom [27], irradiated EBT films up to 3 Gy with beams of energies varying between 25 keV and 4 MV, and proved that films were sensitive to the beam energy. Richter reached a similar conclusion [30]. These contradictory results may be due to varying reasons. Lack of unanimous results, which would support definitely the statistical insignificance of the dependence of radiochromic film's reaction to radiation energy (especially lower than 500 kV), convinced us to use iridium source for film calibration. Homogenous irradiation of a piece of film detector with a point source in one position [31] is not achievable, therefore, a special arrangement of irradiation based on Khushdeep Singh's [21] work with two catheters was used. That allowed to deposit not less than 95% with standard deviation of 0.82% of reference dose on a defined film area.

Dose distribution analysis

After calibration of the Gafchromic films using a phantom, and digitization of irradiated films, the data for analysis was obtained. The software-converted data sets were compared to digital data imported from the TPS using a 2D gamma comparison in Verisoft®, a software package, which is usually used for dosimetric analysis

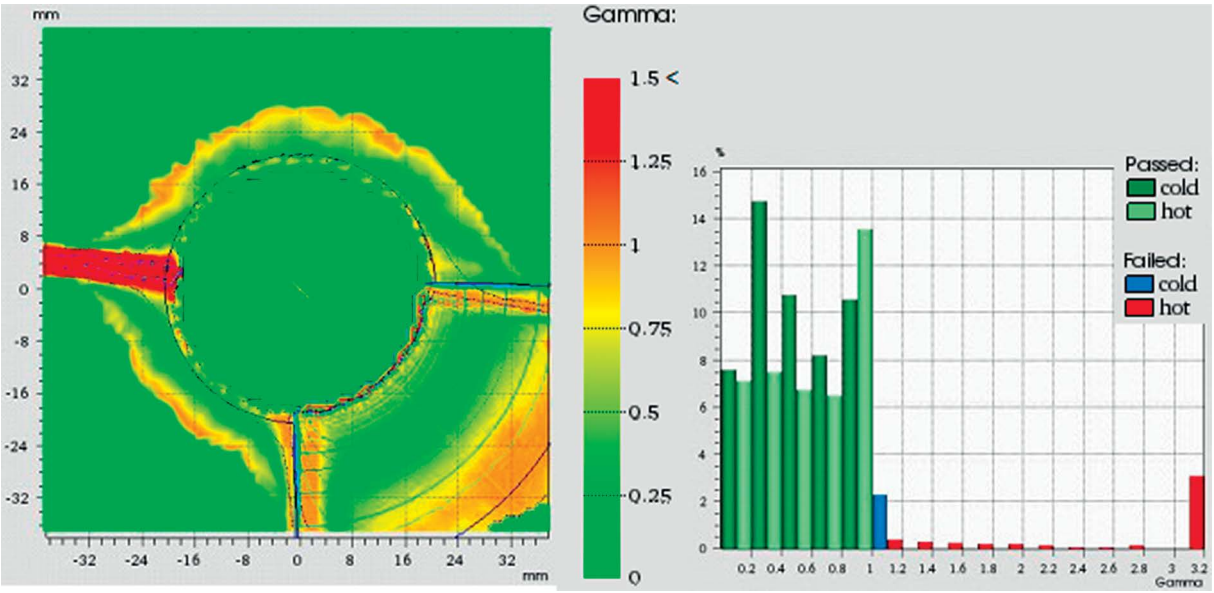

Fig. 13. Gamma values for the 35 mm cylinder with 270° shield. On the left is the graphical representation (see text). The image on the right shows the Gamma value histogram with leakage clearly visible

Table 1. Summarized Gamma parameters for 25 mm diameter cylinder

2D Gamma parameters (25 mm)	Shield 0° (none)	Shield 90°	Shield 180°	Shield 270°
No. of analyzed points	6562	6561	5041	6561
Points meeting Gamma criteria [%]	**95.2**	**91.0**	**89.1**	**92.2**
2D Gamma values				
Mean	0.735	0.841	5.216	0.706
Minimum	0.000	0.000	0.000	0.001
Maximum	16.126	16.625	18.665	1.803
Median	0.363	0.521	0.711	0.726

Table 2. Summarized Gamma parameters for 35 mm diameter cylinder

2D Gamma parameters (35 mm)	Shield 0° (none)	Shield 90°	Shield 180°	Shield 270°
No. of analyzed points	6561	5852	5041	5929
Points meeting Gamma criteria [%]	**98.7**	**90.0**	**92.6**	**93.1**
2D Gamma values				
Mean	0.521	0.610	0.650	0.790
Minimum	0.000	0.000	0.000	0.000
Maximum	12.323	2.740	7.026	15.728
Median	0.400	0.577	0.466	0.548

in IMRT. As there is no general rule for Gamma analysis in brachytherapy dosimetry, we used the AAPM TG-119 recommendations for Gamma analysis in IMRT (3% and 3 mm, with a level of 90% for acceptance). Although this range is the most popular, it is not the only one used in common practice. The criterion value depends on the type of analysis and required acceptance level in the established area. The gamma comparison of 12 films was acceptable in 11 cases at the 90% acceptance level. The highest level of acceptance was achieved for all the applicator diameters not filled with tungsten shields. This confirms the accuracy of the measurements and encourages for further analysis when shields are included. These findings also acknowledge that the TG-43

Table 3. Summarized Gamma parameters for 40 mm diameter cylinder

2D Gamma parameters (40 mm)	Shield 0° (none)	Shield 90°	Shield 180°	Shield 270°
No. of analyzed points	6561	6561	5041	5504
Points meeting Gamma criteria [%]	**95.1**	**90.3**	**91.4**	**90.7**
2D Gamma values				
Mean	0.507	0.841	0.821	0.902
Minimum	0.000	0.000	0.000	0.000
Maximum	2.500	16.625	7.147	14.430
Median	0.445	0.421	0.602	0.602

based calculation algorithm is correct, and the stainless steel elements nor plastic shielding of the applicator have a significant effect on the dose, which has also been reported by Lymperopoulou [32] who used Monte Carlo calculations for the same applicator but with a different TPS (based on TG-43) Plato v.14.2.7 (Nucletron, an Elekta company, Elekta AB, Stockholm, Sweden).

Our analysis of the dose distributions for applicators with tungsten shields did not provide equally good results in terms of similarities between the calculated and measured doses. The strongest disagreement of dose distribution was measured in the area closest to the applicator. This occurs because the TPS does not take into account the loss of scattered radiation due to the tungsten shielding. Therefore, since the TPS calculates the dose differently only in the shielded quarters, the dose values where the shields do not directly shield the field are counted as if there was no shield at all. Chen showed the same thing with Monte Carlo simulations [33], as did the first published survey with a thimble ionization chamber performed by Waterman and Holcomb [34]. Another factor that influenced differences in dose distributions was the shifting of the shields inside of the applicator, which was an unexpected finding when 270° shielding was used. The shifting was noticed as radiation leakage between shields that left a mark on the films. As a result of this shifting, an extra dose was delivered to the area that was theoretically blocked, but also this shield movement reduced the dose in the treatment area, an area that was supposed to be unshielded according to the TPS plan. The leakage itself may be not clinically significant; the chance of occurring again in the exact same spot during subsequent radiation fractions is quite low. However, shielding of a region that is supposed to be irradiated is clearly undesirable. We were unable to measure the extent of these shifts because this was not feasible with the measuring methods used in the study.

Other reasons for the observed difference between the calculated and measured doses are related to the measurement methods. Although much research has been carried out in various aspects of dosimetry, few studies of brachytherapy dosimetry used films. The reason for this is that films are time-consuming, whereas ionizing chambers and Monte Carlo simulations are considered as faster and better tools. As a result, the lack of published data on film dosimetry in brachytherapy provided a limited foundation to prepare our study, and we only discovered areas that needed improvement after the dose comparisons. For example, we cut films with two different tools and placed the films in water; this procedure affected the final results. The quality of the edge of a film is important due to water penetration inside the film structure, and any imperfections were magnified during the digitizing procedure. In addition, small mismatches in the sizes of the holes cut to fit applicators also influenced the final result (Figure 14).

In our study, we did not used all the potential capabilities of radiochromic films. Although these films have a very high spatial resolution, the TPS permits exporting plans only in 1 mm resolution of the dose grids. Nevertheless, radiochromic films can be successfully used in dosimetric verifications in brachytherapy, as it is shown above. In addition, our method of placing

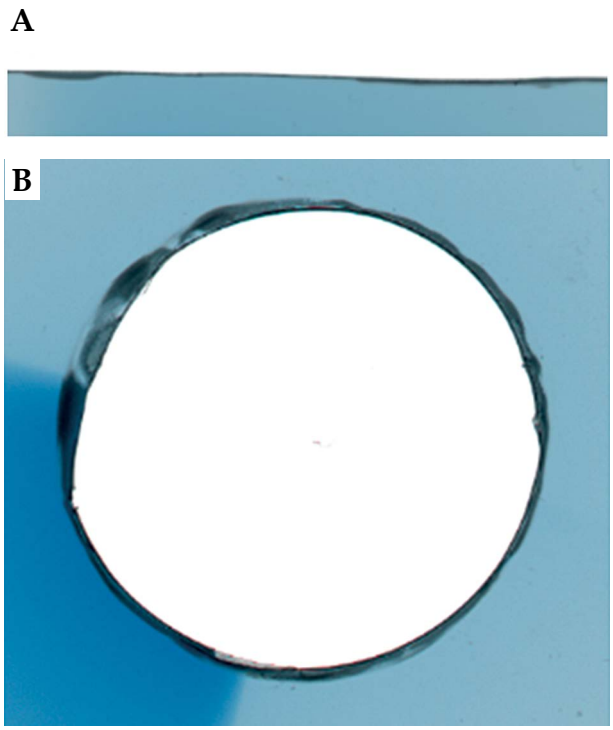

Fig. 14. Influence of cutting technique (**A**) lancet and (**B**) circle cutter on the edge of film

the radiochromic films can be used to check the spatial arrangement of shields inside the applicator before irradiation.

Planning of the dose distribution for the cylindrical applicators used in the study, which have only one channel positioned centrally within the applicator, did not allow using sophisticated optimization algorithms. Nevertheless, for areas that do not require advanced "dose painting", this simple applicator is sufficient. In addition, for the relevant clinical cases with localized target area requiring irradiation with an intracavitary applicator, the use of shielded cylindrical applicator permits for the protection of healthy tissues.

Conclusions

Gamma analysis showed good agreement between the dose distributions calculated using TPS and the doses measured by Gafchromic films, thus showing the viability of using film dosimetry in brachytherapy.

Disclosure

Authors report no conflict of interest.

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