research article

Quality assurance procedures based on dosimetric, gamma analysis as a fast reliable tool for commissioning brachytherapy treatment planning systems

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Background. Fast and easily repeatable methods for commissioning procedures for brachytherapy (BT) treatment planning systems (TPS) are needed. Radiochromic film dosimetry with gamma analysis is widely used in external beam quality assurance (QA) procedures and planar film dosimetry is also increasingly used for verification of the dose distribution in BT applications. Using the gamma analysis method for comparing calculated and measured dose data could be used for commissioning procedures of the newly developed TG-186 and MBDCA calculation algorithms. The aim of this study was dosimetric verification of the calculation algorithm used in TPS when the CT/MRI ring applicator is used.

Materials and methods. Ring applicators with 26 and 30 mm diameters and a 60 mm intra-uterine tube with 60° angle were used for verification. Gafchromic® EBT films were used as dosimetric media. Dose grids, corresponding to each plane (dosimetric film location), were exported from the TPS as a raw data. Gafchromic® films were digitized after irradiation. gamma analysis of the data were performed using the OMNI Pro I'mRT® system, as recommended by the AAPM TG-119 rapport criterion for gamma analysis of 3%, 3 mm and a level of 95%.

Results. For the 26 mm and 30 mm rings, the average gamma ranged, respectively, from 0.1 to 0.44 and from 0.1 to 0.27. In both cases, 99% of the measured points corresponded with the calculated data.

Conclusions. This analysis showed excellent agreement between the dose distribution calculated with the TPS and the doses measured by Gafchromic films. This finding confirms the viability of using film dosimetry in BT.

Key words: brachytherapy; quality assurance; film dosimetry; ring applicator

Introduction

Radiochromic film dosimetry with gamma analysis is widely used in quality assurance procedures for external beam radiotherapy (EBRT). The main advantage of this method is the ability to collect dosimetric data with very high planar resolution in contrast to other methods that are based on point dose measurements.

Introducing fast and easily repeatable methods for commissioning procedures for brachytherapy

(BT) treatment planning systems (TPS) is a complex undertaking in most cases.[1,2] The relatively low energy range of BT sources induce very high spatial dose gradients in irradiated volumes; as a result, it is difficult to use point dose measurement in high dose volumes because small errors in detector positioning can induce large uncertainties in the measured values.

Planar film dosimetry is increasingly used to verify dose distributions in BT applications. When the stepping source is used, the overall dose distri-

bution in the medium is a product of the contribution from each source position and the modulated step time, which are governed by optimization routines.[3,4] An advantage of film dosimetry is that it offers the possibility of collecting the dose data in the planar area and using techniques of additive measurements.[5,6]

Self-developing dosimetry films have long been used to successfully verify dose distributions.[7,8] Although this approach still needs to be customized—in terms of its technical possibilities and BT TPS realization regime in particular facilities.

Most TPS used for treatment plan preparation are still based on the TG-43 recommendations. These algorithms and optimization routines have been verified by many authors in homogenous conditions.[9,10] The Sivert integral and modular dose calculation models allow calculations of dose rates under the assumption that the elemental source position is surrounded by a homogenous water environment.[11,12]

The TG-186 recommendations use the MBDCA (Model Based Dose Calculation Algorithm). Because these recommendations deliver accurate tissue segmentation and take into account the elemental composition of the structure, their use continues to make inroads because they provide better accuracy in BT dosimetry.[13,14,15]

Ring applicators are widely used in high dose rate (HDR) BT applications for patients with cervix cancer. This model is convenient to use due to its fixed geometry and availability in versions compatible with computed tomography (CT)/magnetic resonance imaging (MRI) and many variations including additional interstitial needles. The most common observed problems with setup are associated with source positioning uncertainties during treatment compared to the dwell position placements used to calculate the dose distribution. This problem occurs when source path models from libraries are used and can also occur when the path is modeled manually.[16]

To our knowledge, no previous studies have attempted to perform dosimetric verification of the calculation algorithm used in TPS when the CT/MRI ring applicator is used. For this reason, we conducted the present study, in which we also sought to develop treatment planning commissioning procedures for current and further use based on the planar film dosimetry.

Materials and methods

For the preparation of the treatment plans Oncentra Brachy® 4.3 were used as this is the main treatment planning software used in authors department. This version of the system was equipped with TG43 based calculation algorithms only.

Two treatment plans were prepared for evaluation purposes. Standard CT/MRI ring applicator sets were used. The setup was based on 26 and 30 mm diameter rings and a 60 mm intra-uterine tube with 60º bent angle. Reconstruction of the application geometry was based on the applicator library module in Oncentra Brachy® 4.3. The reference dose of 3 Gy was prescribed to the standard Manchester A points using a HDR iridium source.

Gafchromic® EBT films were used as the dosimetric media. Irradiation setup was based on a PMMA phantom.

The phantom was build using large PMMA blocks with prepared cavity for intrautherine probe. Blocks of PMMA with different thickness were used to prepare repeatable setup and for assuring dosimetric media flatness and proper (parallel and perpendicular) positioning relative to the applicator. The dose to water in PMMA (calibration) and dose to water in water (measurements and TG43-based dose calculations) are not equivalent. However, $D_{w,w}$ and $D_{w,PMMA}$ differ only by 0.8% for distances of 25 mm from an 192Ir source. For this reason, relative character of the performed measurements and that PMMA is commonly available in radiotherapy facilities this material was chosen and used.
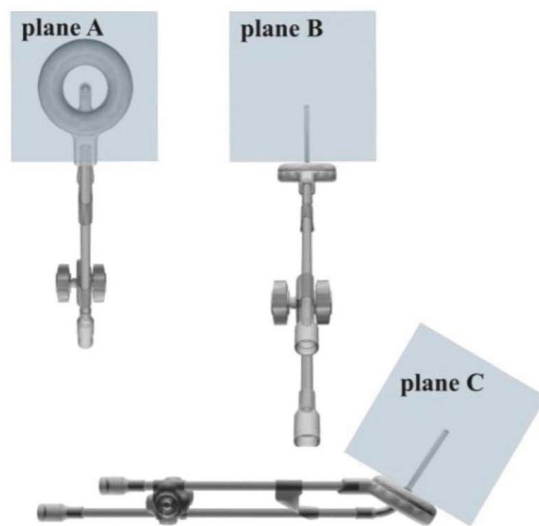

FIGURE 1. Geometry of the measurements, tandem ring applicator and Gafchromic® film located in planes **(A)**, **(B)** and **(C)**, respectively.

Dosimetric films (Gafchromic® EBT) were then placed in three planes. The first plane (plane A) was located at the surface of the ring part of the applicator with a round hole for the intra-uterine probe. Plane B was located on the surface of the probe in parallel orientation to the plane where Manchester A points were located. The third film (plane C) was placed on the surface of the probe perpendicular to the previous (plane B) localization. Geometry of the measurements is presented on the Figure 1.

After preparation of the treatment plan dose grids corresponding to each plane (dosimetric film localization), these were exported from the TPS as a raw data. The smallest available dose grid resolution was 1 mm x 1 mm, although under this condition only a small part of the data collected from film analysis could be used for comparisons. In the plane A area that included the hole data were removed from the analysis to avoid obvious differences in the no-film area. Additionally, the dose limit in the export module of the TPS was set to 400% of the reference dose and any dose values exceeding this limit were exported as 400% value in the dose grid.

After 72 hours, the irradiated Gafchromic® films were digitized with a flat table scanner (Epson® Perfection V750 Pro), all with the same orientation. Bitmap representation of the digitized films was then converted to the dose data and then local gamma analysis of the data were performed using the OMNI Pro I'mRT ® package with 3% and 3 mm criteria.

Calibration data for the films were collected by separately irradiating 14 sheets (20 mm x 30 mm) of Gafchromic® EBT (Lot #: 47207-031, ISP) films with doses ranging from 0.25 Gy to 8.0 Gy using an HDR Ir-192 (192-Ir-mHDR-v2) source. To assure homogenous dose distribution, the films were placed between two blocks of 25 mm thick PMMA and two catheters were placed above and below the films at a distance of 25 mm. The doses were prescribed to the dose points in the centre of the film. After 72 hours, the films were digitized with a flat table scanner (Epson® Perfection V750 Pro) 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 x 5 mm) were calculated using the VeriSoft® package. In region of interest of 10 mm x 5 mm the dose variation was estimated below 5%. Then the calibration curve was prepared and used recalculate the optical density (analog to digital conversion value; ADC) to the doses.[17]
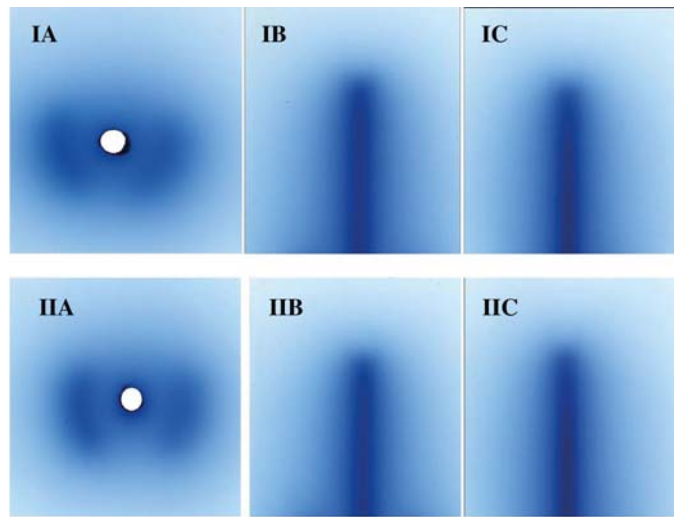

FIGURE 2. Digitized dosimetric films as a visual input data for two applicators setup and for all three analyzed dose planes. **(I)** Applicator ring diameter 26 mm, Gafchromic® film located in planes **(A)**, **(B)** and **(C)**, respectively. **(II)** Applicator ring diameter 30 mm: Gafchromic® film located in planes **(A)**, **(B)** and **(C)**, respectively.

Results

Co-registration of data imported from TPS and dose distribution from scanned film were guided by centre of the intrauterine probe. Dose was normalized to 400% as maximum measured dose by OmniPro® software for each analyzed film. The films were scanned at 250 DPI (Dots Per Inch) resolution, always with the same orientation. Treatment planning system export files contains dose data with 1 mm resolution therefore the data from film have to be downsampled by analyzing software. The dose inside the hole in the films - prepared for insertion intrauterine probe was manually changed to 0 Gy, in both - film data and TPS exported ones.

We assumed that dose distributions (planned and measured) were consistent if the count of pixel values from 0.00 to 1.00 (blue and green representation) in the gamma analysis was over 95% and the average pixel value was lower than 1.00. Pixel values higher than 1.00 (yellow and red representation) show the regions of inconsistencies (Figures 3–8).

The gamma analysis showed that all measured dose distributions were consistent with the planned distributions. Table 1 presents average and maximum gammas and percentage of the analyzed dose points that met the 3% and 3 mm criteria.

It's difficult to clearly state the uncertainties during realizing this study (based on gamma analysis), the main source of possible error is the mechani-
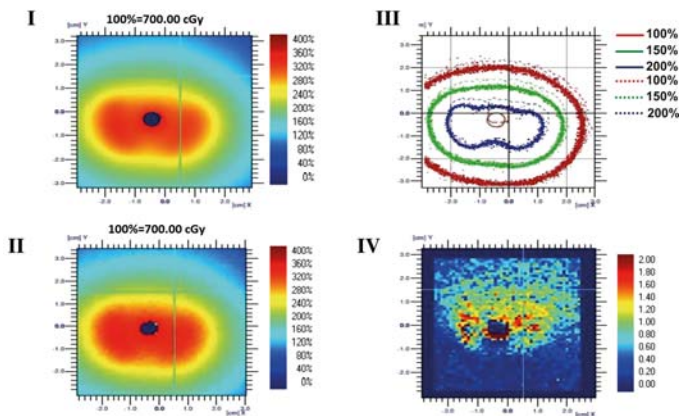
FIGURE 3. Data analysis for the 26 mm ring in plane A. **(I)**- dose distribution obtained from film, **(II)** - dose distribution obtained from TPS, **(III)** - isodoses obtained from film (dots) and TPS (lines), **(IV)** - gamma factor map.
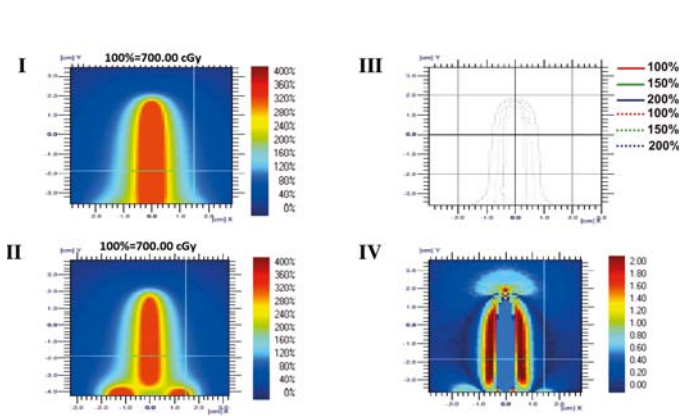

FIGURE 4. Data analysis for the 26 mm ring in plane B. **(I)** - dose distribution obtained from film, **(II)** - dose distribution obtained from TPS, **(III)** - isodoses obtained from film (dots) and TPS (lines), **(IV)** - gamma factor map.

FIGURE 5. Data analysis for the 26 mm ring in plane C. **(I)** - dose distribution obtained from film, **(II)** - dose distribution obtained from TPS, **(III)** - isodoses obtained from film (dots) and TPS (lines), **(IV)** - gamma factor map.
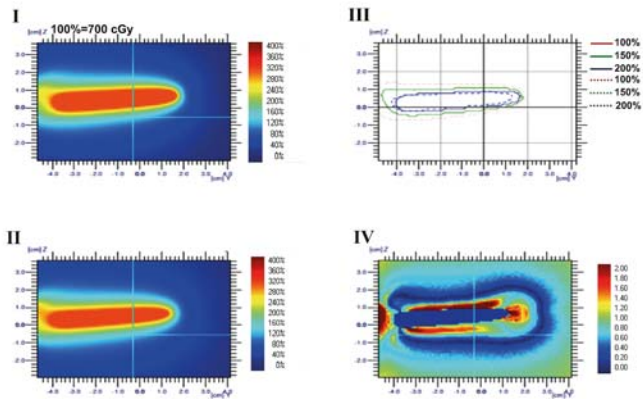

FIGURE 6. Data analysis for the 30 mm ring in plane A. **(I)** - dose distribution obtained from film, **(II)** - dose distribution obtained from TPS, **(III)** - isodoses obtained from film (dots) and TPS (lines), **(IV)** - gamma factor map.
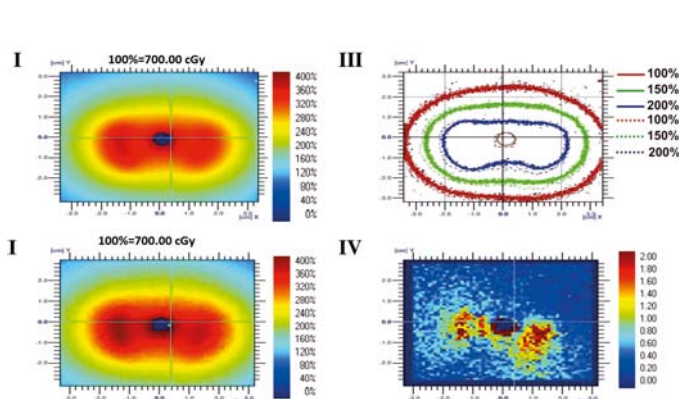

FIGURE 7. Data analysis for the 30 mm ring in plane B. **(I)** - dose distribution obtained from film, **(II)** - dose distribution obtained from TPS, **(III)** - isodoses obtained from film (dots) and TPS (lines), **(IV)** - gamma factor map.
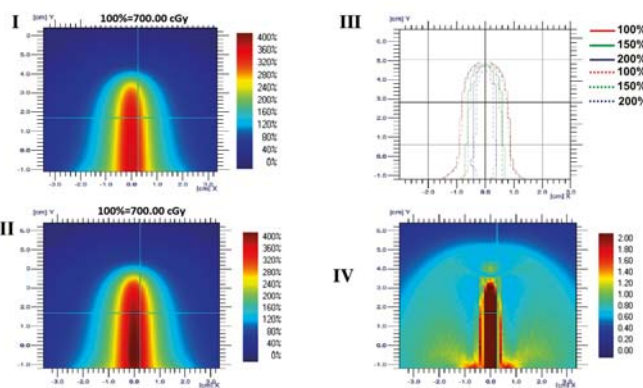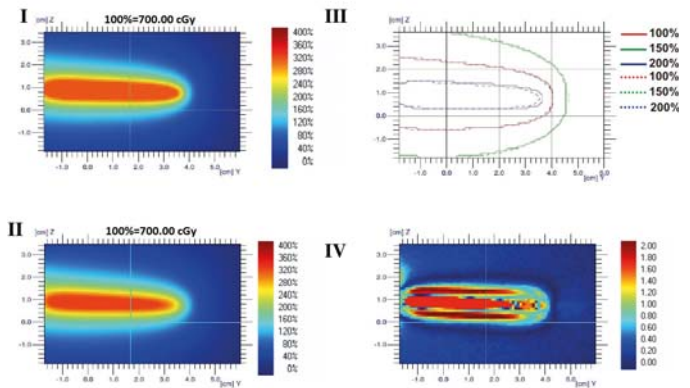

FIGURE 8. Data analysis for the 30 mm ring in plane C. **(I)** - dose distribution obtained from film, **(II)** - dose distribution obtained from TPS, **(III)** - isodoses obtained from film (dots) and TPS (lines), **(IV)** - gamma factor map.

cal positioning of the films in phantom. Another problem could be find in the spatial aligning of the two types of analyzed data. Authors decided to manually register two data series using intrauterine probe position assuming that the film was flat and properly placed. Authors estimated possible positioning errors at less than 1 mm level.

During the calibration - homogenous irradiation of film detector with a point source in one position isn't achievable, therefore a special arrangement

of irradiation based on Khushdeep Singh's[18] work with two catheters was used, which allowed to deposit not less than 95% with standard deviation of 0,82% of reference dose on a defined film area.

Discussion

In the study, we have attempted to use the typical BT setup with tandem ring applicator as a test platform to develop a commissioning procedure to verify the MBDCA algorithm recommended in TG-186. The main finding was that self-developing flat film dosimetry is a fast and reliable commissioning method in TG-43 conditions that could easily be adopted to almost any clinical setup in which point dose dosimetry is difficult to use and cannot provide valuable information.

The data packages obtained from digitizing the Gafchromic® films were prepared for comparison with the planar dose distribution data exported from the TPS. The OMNI Pro I'mRT® software typically used for IMRT was used to perform gamma analysis of the data. In this approach, a commercially available method, typically used for external beam radiotherapy (EBRT), was used to compare the calculated and measured dose distribution. Overall dose distributions from EBDRT and BT is significantly different in terms of the dose gradients.[19] For brachytherapy dose distributions we observe much larger dose ranges in small volumes. As a result, the use of point dose detectors to make measurements is highly difficult due to positioning errors. In contrast, film dosimetry seems to be offer a fast and reliable method for commissioning calculation algorithms, and planning and treatment delivery procedure.[2,20,21]

The common rule for the gamma criterion when BT verification using gafrchromic films is performed has not been established. For purposes of this study, we adopted the AAPM TG-119 rapport criterion for gamma analysis: 3%, 3 mm and a level of 95%.

The results of the analysis were acceptable for two applicator size on all three planes at the 95% level and above. This results confirms the correctness of this measuring method and is a positive reference for further analysis in more complex cases with more complicated density and geometry setup.

Another important issue is the use of shields and commissioning of the calculation result for shielded applicators, where high density material is placed in the close proximity of the source.[22]

TABLE 1. Results of Gamma analysis for the 26 mm ring and 30 mm ring applicator

Ring, 26 mm	Gamma average	Gamma max	Gamma (0.00 – 1.00)
plane A	0.22	1.42	99.04%
plane B	0.10	1.29	99.31%
plane C	0.44	1.75	98.88%

Ring, 30 mm	Gamma average	Gamma max	Gamma (0.00 – 1.00)
plane A	0.25	1.96	98.11%
plane B	0.27	2.00	97.94%
plane C	0.10	1.22	99.54%

In most TPS in current use, the elemental composition of the structures is not taken into account during the calculation (atomic number - Z) and dose distribution is based on geometric models of the shields. The TG-186 recommendations with MBDCA introduce the need to develop reliable verification methods that are more convenient and accurate, which can be performed in a more repeatable manner than point dose methods.[23,24]

Better accuracy in BT dosimetry appears to be a common need when the benefits from accurate tissue segmentation and the structure's elemental composition are considered as an important step up.[13,14,25]

It bears mentioning that for the analysis performed in the present study, we only used a small amount of the data from the digitized dosimetric films. The planar resolution of the films is very high and limited only by the chemical structure of the dosimetric media itself and physical resolution of the scanner. On the other hand, the maximum resolution of the exported dose grid was only 1 mm. But the most important factor for QA in BT is the possibility to export data exactly from the plane where the film was located during the measurements. This allows for the design of very effective phantoms with convenient and repeatable geometry.[2,26]

The film dosimetry used to verify the dose distribution and also for the direct reconstruction of the source path should be considered the method of choice for commissioning these newly-designed applicators. Precise reconstruction of the real source positions allows the dose distributions calculated by the planning system to be checked and leads to more conformal treatment planning.[27] It should be noted that introducing effective, repeatable and easy-to-use QA procedures for BT is es-

sential. Numerous factors, including relatively high doses, dose gradients, limited number of fractions, and advanced optimization algorithms with extensive dwell time modulation, make it nearly impossible to apply *in-vivo* dosimetry, thus leaving virtually no room to implement plan corrections during treatment. In these conditions, developing convenient "offline" methods for commissioning calculation routines, applicators and also for more frequently used QA procedures is very important and merits more study.

Conclusions

The analysis performed in this study showed excellent agreement between the dose distributions calculated using TPS and the doses measured by Gafchromic films. This confirms the viability of using film dosimetry in brachytherapy. The proposed commissioning procedure for further use with the MBDCA algorithm was established for use at the authors' facility, and it seems likely that the same procedure could be replicated at other centers.

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