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Dosimetry evaluation of ^{192}Ir Flexisource using gafchromic EBT3 film

Aziz Oustous[1,2], Zouhair Airouss[3,†], Yacine EL Attaoui[3,†], Yassine Oustous[4,†], Mohammed Khalis[1,†] and Rajaa Sebihi[5,†]

[1]Physical Sciences and Engineering, ENPT, Moulay Ismail University, Faculty of Sciences, Zitoune, Meknès, Morocco; [2]Regional Oncology Center, Beni Mellal, Morocco; [3]Laboratory of Engineering in Chemistry and Physics of Matter (LICPM), Sultan Moulay Slimane University, Faculty of Sciences and Techniques, Beni Mellal, Morocco; [4]Doctoral Study Center for Life and Health Sciences, Faculty of Medicine and Pharmacy of Rabat, Impasse Souissi, Rabat, Morocco and [5]Department of Physics, Mohamed V University, Faculty of Sciences, Rabat, Morocco

Original Article

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Corresponding author:
Aziz Oustous; Email: aziz.oustous@gmail.com

†These authors contributed equally to this work.

Abstract

Introduction: Brachytherapy is a widely used cancer treatment technique requiring precise dose delivery for optimal outcomes. This study evaluates the dosimetric properties of the ^{192}Ir Flexisource using Gafchromic EBT3 film, adhering to American Association of Physicists in Medicine guidelines.
Methods: The EBT3 film was calibrated with a linear accelerator to establish the relationship between optical density and absorbed dose. Measurements were conducted in a water-equivalent solid phantom to simulate human tissue. The dosimetric properties measured included the dose rate constant, radial dose function and anisotropy function.
Results: The results showed a close alignment with reference data: a maximum deviation of 3·1% for the dose rate constant, 2·3% for the radial dose function and 5·67% for the anisotropy function. These deviations are within acceptable limits, indicating high accuracy.
Conclusions: Gafchromic EBT3 film demonstrates reliable dosimetric measurement in high-dose rate brachytherapy. The film's accuracy in evaluating the ^{192}Ir Flexisource ensures precise treatment delivery and enhances patient safety, supporting its continued use in clinical practice.

Introduction

Brachytherapy utilizing high dose rate (HDR) is extensively employed and recognized as a treatment modality for various cancer types. In clinical application, the dose distribution is computed by the planning system software, relying on the guidelines provided by the American Association of Medical Physicists' Task Group No. 43. The precise delivery of radiation doses to malignant tissues, while sparing the adjacent healthy structures, is essential in optimizing therapeutic outcomes and reducing side effects. The inherent steep dose gradients associated with ^{192}Ir sources underscore the necessity for meticulous dosimetry to ensure the accurate deposition of the prescribed radiation dose.

In brachytherapy, radiochromic films (RCF), notably Gafchromic EBT films, have emerged as indispensable tools for dosimetric evaluation.[1,2] These films have a high spatial resolution, which is paramount in accurately delineating the dose gradients characteristic of ^{192}Ir brachytherapy. Moreover, their near tissue equivalence facilitates a more accurate simulation of the dose absorption in the human body, thus providing a more reliable representation of the therapeutic dose distribution.[3] Gafchromic EBT films are suitable for brachytherapy applications due to several properties. The low sensitivity to visible light reduces the risk of exposure-related errors, enhancing the reliability of the dosimetric data.[4] The energy independence of their response is especially critical in HDR brachytherapy, where the energy spectrum of the radiation source can significantly influence the dose distribution.

Efforts have been made to employ Gafchromic films for the dosimetric assessment of ^{192}Ir HDR sources, which has provided essential data like dose rate constants and radial dose functions. Studies have demonstrated the effectiveness of Gafchromic EBT film in measuring brachytherapy dosimetric functions with high resolution, adhering to the standards described by the American Association of Physicists in Medicine (AAPM) TG-43.[5] This approach is part of broader efforts to ensure precise dose delivery in HDR brachytherapy, which is pivotal for maximizing the treatment's efficacy while minimizing the exposure to surrounding healthy tissues.

This study aims to verify the dosimetric characteristics of the Flexisource 192Ir using the EBT3 Gafchromic film, following the guidelines established by the AAPM.[6]

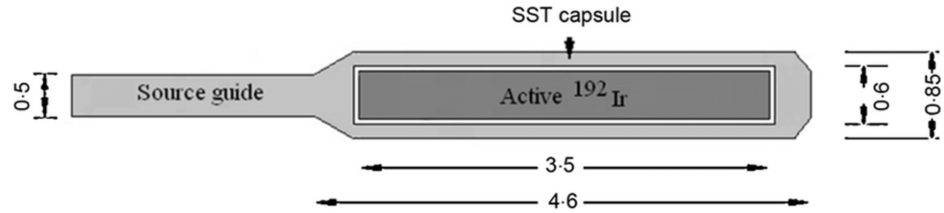

Figure 1. Geometry of the Ir-192 Flexisource used in this study.

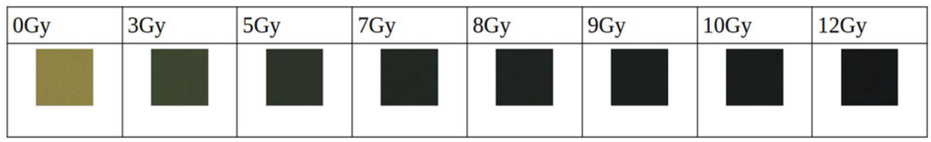

Figure 2. Scanned images of calibration and background films.

Materials and Methods

Flexisource HDR 192-Ir source

The brachytherapy source used in this study is a Flexisource (Veenendaal, The Netherlands), made of a 3·50 mm long, 0·60 mm diameter ^{192}Ir radioactive core enclosed in a 0·85 mm diameter AISI-304 stainless steel capsule (density 7 8 g/cm^3). The end of the encapsulation has a conical section of 0·108 mm thickness with a half angle of 23.6° and a radius of 0·17 mm. The full geometry of the source is presented in Figure 1.

Dosimetric tools and equipment

The materials employed in this study include Gafchromic films (EBT3), a solid water phantom for positioning and an Epson scanner for film digitization.

The EBT3 film consists of five layers: two active layers (17 μm) surrounding a surface layer of approximately 6 μm thickness and two outer layers made of clear polyester (97 μm). In the conducted research, EBT3 RCF sheet was sectioned into squares with respective sizes of 3 × 3 cm ^{2}.

For consistency in the experimental conditions, all the film samples utilized originated from an identical batch.

Dosimetric calibration of Gafchromic films

The first step was to calibrate EBT3 films. The films were cut into 3 × 3 cm^2 sections and irradiated using a linear accelerator VERSA HD with a 6 MV photon beam at 200 monitor units and a field size of 10 × 10 cm^2 at a depth of 1.5 cm in solid water. These sections have been irradiated with increasing doses of 1Gy to 10Gy, and one piece of EBT3 was kept in brachytherapy room environment to measure the background dose (Figure 2). The films were analysed after irradiation using ImageJ software, with the red channel specifically selected for dosimetry. The calibration curve resulting from the irradiation displays the optical density (OD) as a function of the absorbed dose (Figure 3). This curve enables the correlation of the dose received by the film to the intensity of each pixel in the film.

Optical density (OD):

$$OD = \log_{10}\left(\frac{I_0}{I}\right)$$

This equation represents the logarithm of the ratio of incident light intensity to transmitted light intensity through a material. In

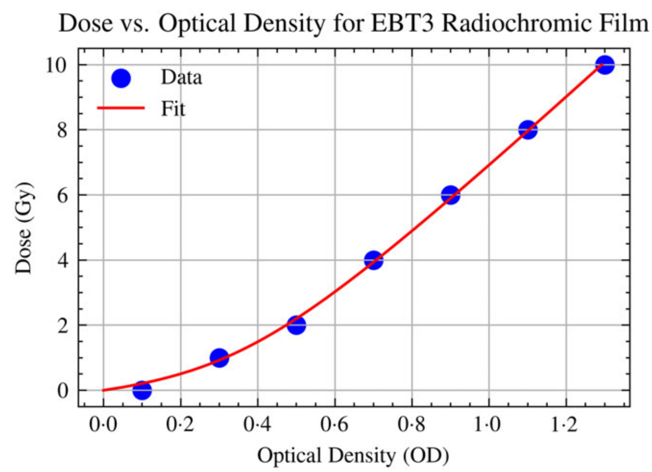

Figure 3. The dose-response curve of EBT3.

the context of EBT3 film dosimetry, OD represents the response of the film to absorbed dose.

$$\Delta OD = OD - OD_0$$

This equation calculates the change in OD relative to a reference point (OD_0). It is commonly used to analyse the response of the film to dose changes, where OD_0 represents the initial OD before exposure to radiation.

Second-order Rational Function[6]:

$$OD = \frac{a_2 \cdot D^2 + a_1 \cdot D}{D^2 + b_1 \cdot D + b_0}$$

This equation relates OD to dose (D) using a second-order rational function. It is commonly used for fitting dose-response calibration curves in RCF dosimetry, including EBT3 film calibration. The parameters a_1, a_2, b_0, and b_1 are determined through curve fitting to experimental data, representing the film's response characteristics.

Film scanning process

To digitize films, a waiting period of over 24 h post-measurement is required to ensure accurate results. When preparing the EPSON scanner, the reflective white plate must be removed. A cardboard

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Figure 4. Setup for exposing EBT3 radiochromic films (RCFs) using PMMA plates.

template must then be carefully positioned so that it does not obstruct the calibration window and is aligned with the upper edge of the scanning surface.

Regarding the scanner's settings, it should be configured to 'Professional Mode'. For transmission scanning, the document type should be set to 'Film', with 'Positive Film' as the selected film type. Colour scanning should be performed in RGB mode with a 48-bit colour image type. The resolution should be adjusted to either 72 dpi or 142 dpi. It is essential to avoid any colour correction or manipulation within the configuration settings.

PMMA phantom

The phantom used in the experiment is a water-equivalent polymethyl methacrylate (PMMA) with a density of 1·18 g/cm^3. It had cubic dimensions of $30 \times 30 \times 30$ cm^3 and was composed of PMMA slabs, including one plate of 1 mm thickness, two plates of 2 mm, one plate of 5 mm and 29 plates of 10 mm. Figure 2 shows the arrangements of the source and Gafchromic films. The 16th slab featured a horizontal groove measuring $0.1 \times 0.1 \times 2$ cm^3, into which the Flexisource HDR ^{192}Ir was inserted. The EBT films were positioned horizontally above the HDR source between the

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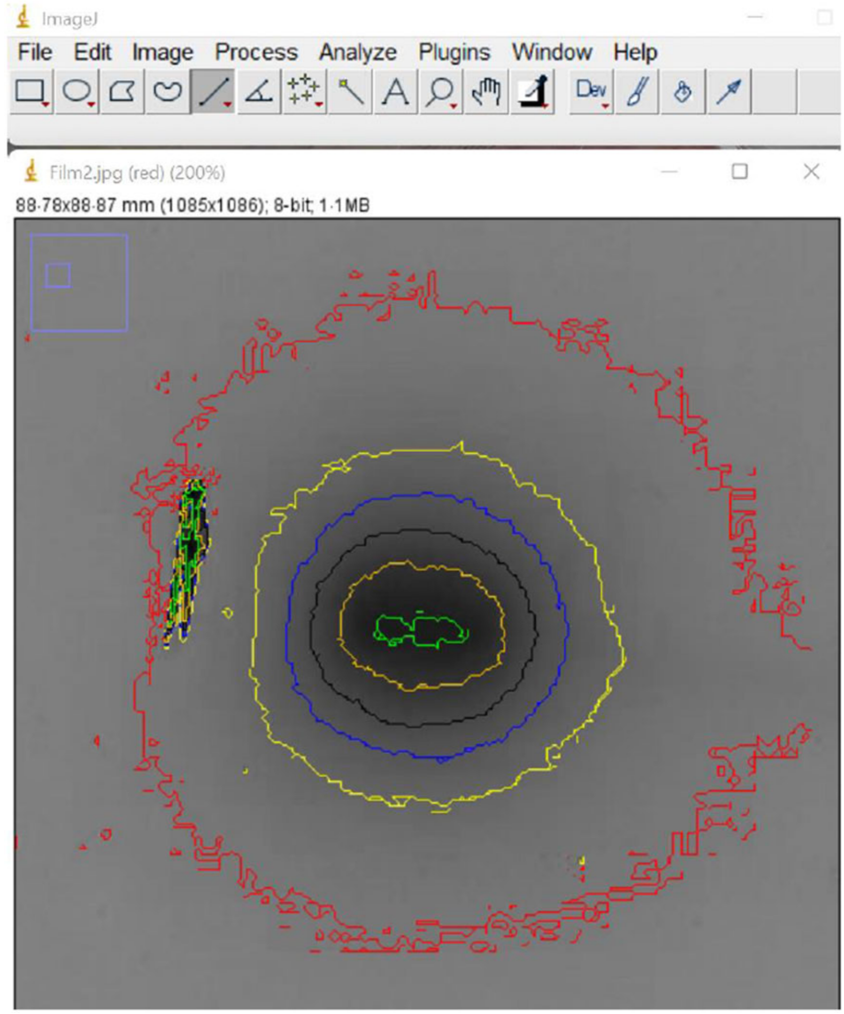

Figure 5. Dose distribution around the 192Ir Flexisource.

14th and 15th slabs (Figure 4). The other slabs above and below ensured full backscatter conditions.[7,8]

TG-43 dosimetry formalism for brachytherapy

The aim of the TG-43 dosimetry Protocol is to define a formalism expressed as a mathematical equation, allowing the calculation of dose distributions and dose rates around radioactive sources used in clinical routine.[5] The calculation of the dose around an encapsulated brachytherapy source adopted by the AAPM is as follows[5]:

$$D(r,\theta) = S_k \Lambda \frac{G_L(r,\theta)}{G_L(r,\theta_0)} g_L F(r,\theta) \tag{1}$$

- r: the radial distance from the centre of the source
- θ: the polar angle
- S_k: the air Kerma strength in a unit of U, 1 U = 1 cGy/h cm^2
- Λ: the dose rate constant in water, expressed in cGy.h^{-1}.U $^{-1}$
- $G_L(r,\theta)$: is the Geometry function

Results

The calibration curve for the EBT3 RCF

Figure 3 shows the calibration curve for the EBT3 RCF that was used to define the relationship between OD and absorbed dose. This correlation was established by irradiating the RCF using the VERSA HD linear accelerator.

Data fitting (absorbed dose versus OD) was performed by using the Rodbard equation, available in the ImageJ software. This calibration function allows for the interpolation of the dose for OD values that lie between established calibration points. The resulting calibration curve demonstrates a coefficient of determination (R^2) of 0·998, indicating very high accuracy and reliability in the dose range of 0 to 10 Gy. The manufacturer of the EBT3 film also notes that the measurable dose range can extend up to 10 Gy.

TG-43 dosimetric parameters for Flexisource 192 Ir

The results of the EBT3 film exposed with the Flexisource 192Ir are shown in Figure 5, illustrating the dose distribution around the source,

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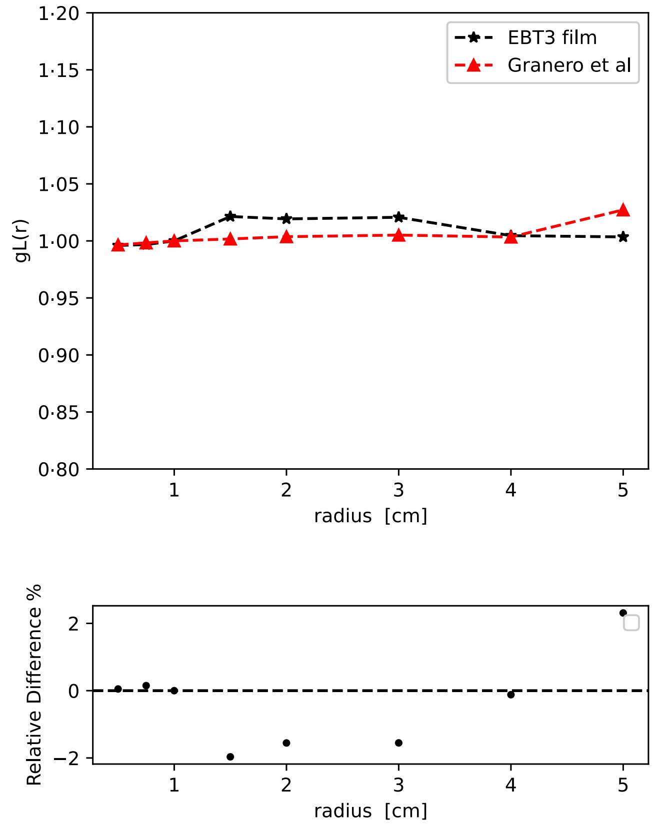

Figure 6. Differences between radial dose functions calculated with EBT3 film and Granero et al.[9]

and indicate the symmetry of this distribution. The effect of the cable used during film exposure can also be observed in the results.

The dose rate constant, Λ, for the Flexisource HDR ^{192}Ir was found to be 1.078 $cGyU^{-1}h^{-1}$ using EBT3 film, which shows a 3 .1% deviation from the reference value provided by Granero et al.[9] The radial dose function $g(r)$ shows also a maximum deviation of 2.3% (Figure 6).

The anisotropy function in two dimensions, denoted as $F(r, \theta)$, was determined for radial distances ranging from 0.5 to 5 cm, using EBT3 within a PMMA phantom. Figure 7 illustrates a comparison between the measured 2D anisotropy function and the reference data, indicating a difference of 2.9% for $\theta > 15°$, 5.67% for $\theta < 15°$ and 3.6% for the $165° < \theta < 180°$.

Discussion

The high coefficient of determination ($R^2 = 0{\cdot}998$) for the calibration curve indicates the reliability and accuracy of the EBT3 film in the dose range of 0 to 10 Gy. This is critical for ensuring that the dosimetric measurements are precise and can be confidently used in clinical settings.

Dose rate constant (Λ) for the Flexisource HDR ^{192}Ir showed a minimal deviation of 3·1% from the reference value provided by Granero et al.[9] suggesting that the EBT3 film provides an accurate representation of the dose rate constant.

Radial dose function's maximum deviation of 2·3% further supports the film's reliability. These findings are consistent with existing literature and reinforce the EBT3 film's utility in brachytherapy dosimetry. Anisotropy function results also align closely with reference data, with differences attributed to exposure inconsistencies, film handling, and potential discrepancies in source modelling. Despite these minor deviations, the overall agreement supports the EBT3 film's effectiveness in characterizing the anisotropy function of brachytherapy sources. The symmetry of the dose distribution is an important measure of the accuracy of the brachytherapy source, while the effect of the cable can provide an understanding of distortions in the expected dose distribution in this region.

Results have significant implications for clinical practice. The high accuracy and reliability of the EBT3 film ensure precise dose delivery, which is crucial for optimizing therapeutic outcomes and patient safety in brachytherapy. This study confirms the film's role in HDR brachytherapy dosimetry, offering a reliable method for dose measurement and quality assurance.

There are limitations to this method. Factors such as film handling, exposure inconsistencies and potential discrepancies in source modelling can introduce deviations. While these factors were minimized in this study, they highlight the need for careful procedural adherence and potential further refinement of the calibration process.

EBT3 film demonstrates high reliability and accuracy in HDR brachytherapy dosimetry, supporting its use in clinical practice for precise dose measurements. The minor deviations observed are within acceptable limits, reinforcing the film's role in ensuring accurate treatment delivery and enhancing patient safety. Future studies should focus on further minimizing potential sources of error and exploring the film's applicability across different brachytherapy sources and treatment conditions.

Conclusion

The study demonstrates that GAFCHROMIC EBT3 film is highly sensitive and reliable for calculating brachytherapy dosimetric parameters described in AAPM TG-43 with high resolution. The EBT3 film showed minimal deviations in dose rate constant (3·1%) and radial dose function (2·3%) compared to Granero et al., confirming its accuracy. The anisotropy function results also closely matched reference data, despite minor deviations due to handling and exposure inconsistencies. These findings highlight the film's precision in HDR brachytherapy dosimetry, ensuring accurate dose delivery and enhancing patient safety. It is recommended that measurements be repeated and averaged to further enhance accuracy, emphasizing the film's critical role in clinical practice.

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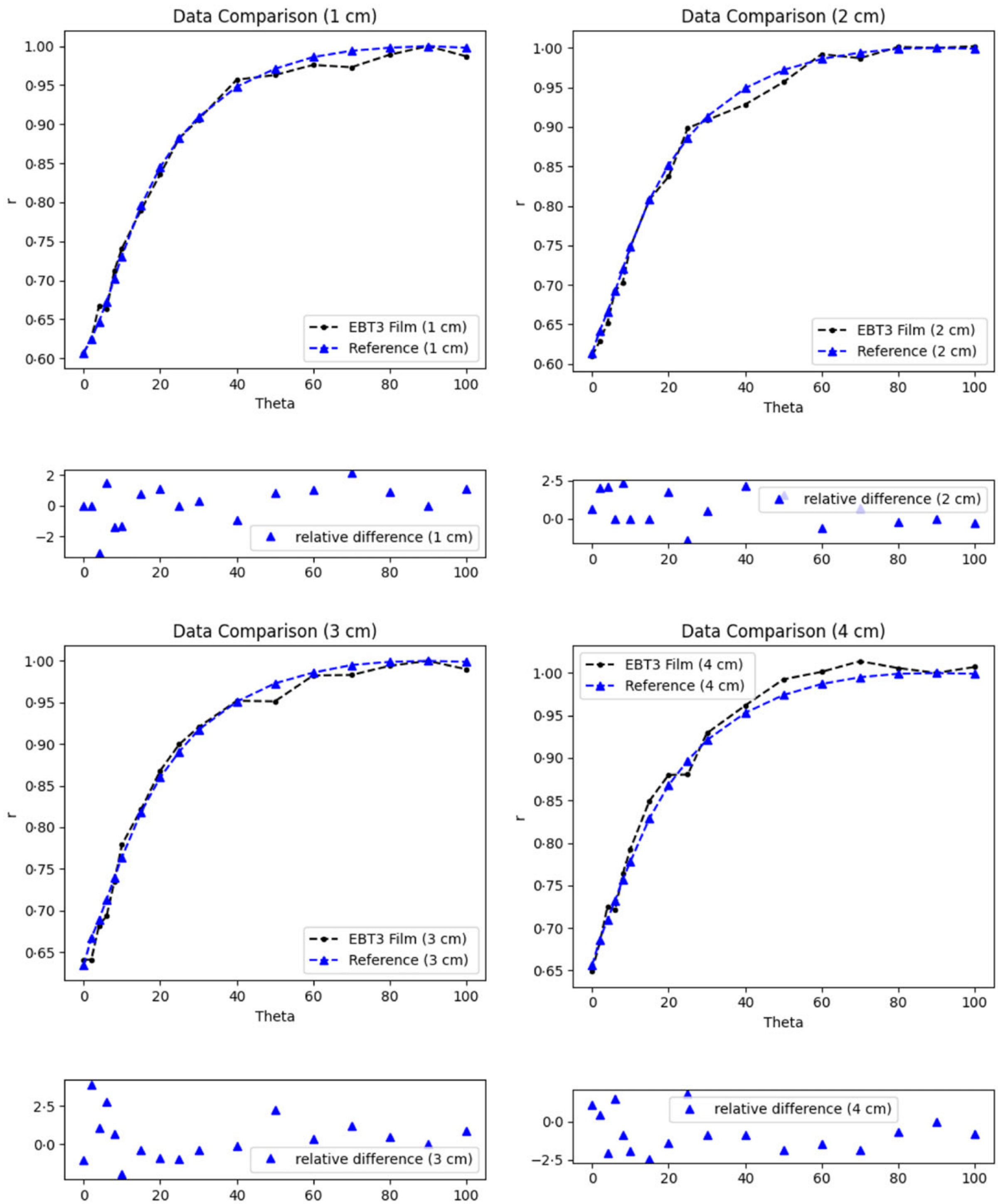

Figure 7. Anisotropy function at distances from 1 to 4 cm and angles from 0° to 180°: EBT3 film versus Granero et al.[9]

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