DETERMINATION OF CLINICAL SIZE OF PHOTON FIELDS BY FILM DOSIMETRY USING RADIOCHROMIC FILMS EBT-XD

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This work focuses on the determination of the equivalent square field size (S_{clin}) for small photon fields. We used Gafchromic EBT-XD radiochromic films and a Varian TrueBeam linac. The study aims to provide accurate field size data to calculate field output correction factors according to the IAEA TRS-483 protocol. We measured fields from 5x5 to 100x100 mm. The results show a difference between nominal and actual field sizes as maximum 1.5% difference.

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INTRODUCTION

In modern radiotherapy, such as stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT), the use of small photon fields is essential. However, accurate dosimetry in these fields is complicated by the lack of lateral electronic equilibrium and the physical size of standard detectors. The IAEA TRS-483 protocol was developed to standardize small field dosimetry by introducing the field output correction factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$.

To calculate $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ for new detectors, such as the Razor diode, we must compare their measurements with the measurements made with the water-equivalent detector. Radiochromic films, specifically the Gafchromic EBT-XD series, are excellent for this purpose because they are nearly water-equivalent and offer extremely high spatial resolution. A critical step in this process is determining the clinical field size (S_{clin}), which is based on the actual beam profile rather than the nominal settings of the linear accelerator. This work describes the methodology for determining S_{clin} using film dosimetry.

1. MATERIALS AND METHODS

1.1. RADIOCHROMIC FILM EBT-XD

The choice of Gafchromic EBT-XD as a reference detector is justified by its near-perfect water equivalence and superior spatial resolution. In small-field dosimetry, detectors with high atomic numbers Z or high density (like silicon diodes) can perturb the particle fluence. EBT-XD consists of Hydrogen, Carbon, Nitrogen, and Oxygen, making its effective atomic number (Z_{eff}) very close to water. This ensures that the materials interact with radiation in the same way and there is not need to correct for density differences.

Small fields have extremely steep dose gradients in the penumbra region. Standard ionization chambers suffer from "volume averaging" where the dose is averaged over the chamber's air cavity, leading to underestimated peak doses. EBT-XD is effectively a "pixel-less" 2D detector. When scanned at 1200 DPI, it provides a resolution of approximately 0.02 mm, allowing for perfect capture of the beam's Full Width at Half Maximum (FWHM).

1.2. EXPERIMENTAL SETUP

The experimental part of this study was conducted using Varian TrueBeam linear accelerator. This machine is equipped with a high-resolution Multi-Leaf Collimator (MLC) system, which is essential for shaping small photon fields with high precision. For all measurements, a 6 MV WFF (With Flattening Filter) photon beam was selected. The flattening filter ensures a uniform dose distribution across larger fields, which provides a stable reference for comparing small-field profiles.

The collimation of the beam was performed strictly by the MLC rather than the primary jaws. According to the IAEA TRS-483 protocol, using the MLC is necessary to account for the realistic penumbra and leaf-end transmission. In clinical treatment plans, the beam is almost always shaped by the MLC leaves. Therefore, the TRS-483 protocol requires this effect to be taken into account, as it reflects the actual dose delivered to the patient rather than an idealized geometric shape. The jaws were set to a fixed position (30x30 cm) to minimize the impact of jaw-scatter while the MLC leaves defined the actual field sizes from 100x100 mm down to the smallest 5x5 mm.

To simulate human tissue, we utilized a RW3 slab phantom (also known as Solid Water). This phantom is composed of white polystyrene with the addition of Titanium Dioxide (TiO_2). It is designed to be water-equivalent for both photon and electron beams in the energy range used in radiotherapy. The physical density of the RW3 slabs is approximately 1.045 g/cm^3. The phantom consists of multiple plates with thicknesses of 10 and 5 mm, allowing for precise depth adjustments.

The irradiation geometry was set as follows: source-to-detector distance (SDD) is 100 cm; the radiochromic film was placed at a depth of 9.5 cm of RW3. A total thickness of 5.0 cm of RW3 was placed underneath the film to ensure full backscatter equilibrium. The film was centered at the machine isocenter. All mechanical components, including the gantry and collimator were kept at a 0° position (static geometry) to avoid any angular dependence during the delivery of the 800 Monitor Units. This setup creates a "3D-like" static treatment plan for each field size, ensuring that the primary source of dose uncertainty is limited to the detector response and the beam characteristics themselves, rather than the mechanical setup of the accelerator.

1.3. IRRADIATION AND ANALYSIS

The irradiation procedure was executed by delivering 800 Monitor Units (MU) for each field size to ensure a sufficient signal-to-noise ratio on the radiochromic films. A dedicated film piece was used for each nominal field size. Following the irradiation, a strict 48-hour waiting period was observed before scanning. This interval is critical because the polymerization process in Gafchromic EBT-XD films is time-dependent; the active monomers continue to react and darken slightly after exposure. Scanning too early would lead to an underestimation of the dose, while waiting 48 h ensures that the optical density has stabilized to a near-plateau level.

The conversion of the physical film into digital data was performed using a high-resolution flatbed scanner Epson in 48-bit RGB mode with all image enhancement filters disabled. The resulting images were processed using a custom-developed MATLAB algorithm. Using a pre-established calibration curve (ranging from 1 to 10 Gy), the optical density was converted into absolute dose values. This dependence ensures that every grayscale gradient is accurately mapped to its corresponding radiation dose. To ensure the background extracting, an unirradiated piece of EBT-XD film from the same batch was scanned under identical conditions. This background signal was then subtracted during the dose conversion process in MATLAB to ensure that the final dose profiles represent only the radiation delivered by the Varian TrueBeam. Crossline and inline profiles were extracted by averaging several pixel lines across the central axes of the field to improve statistical stability.

The algorithm automatically identified the maximum dose (D_{max}) and located the coordinates where the dose dropped to exactly 50% of that value. The distance between these two points defines the Full Width at Half Maximum (FWHM), which is the primary parameter for calculating the clinical field size S_{clin} (Equation 1). For the smallest fields, the analysis included a specific offset technique. To reduce the influence of central MLC leakage and inter-leaf transmission, profiles were sampled with an offset of 1.5 to 8 mm from the central axis. This allowed for a more stable determination of the FWHM, as the field remains nominally square.

2. RESULTS

The clinical field size is calculated as

$$S_{clin} = \sqrt{FWHM_{inline} \cdot FWHM_{crossline}}\,. \qquad (1)$$

Nominal vs Actual field sizes (FS)

Nominal FS, mm	$FWHM_{inline}$	$FWHM_{crossline}$	S_{clin}
80.0	82.49	79.98	81.2
60.0	62.10	59.94	61.0
40.0	42.54	39.72	41.1
30.0	32.60	29.71	31.1
20.0	21.87	19.87	20.8
10.0	11.32	10.04	10.7
5.0	6.62	-	-

The experimental data obtained from the EBT-XD films were processed to extract the Full Width at Half Maximum (FWHM) for both crossline and inline profiles provided in Table, ensuring that the actual beam dimensions will be used for further calculations of field output factor corrections.

There is a consistent discrepancy between the nominal field size set on the Varian TrueBeam console and the actual clinical size S_{clin} measured by the films. For the reference 100x100 mm field, the clinical size was found to be 100.7 mm, which is within the expected tolerance for clinical linear accelerators (±1 mm or 1%). For example, the nominal 20 mm field resulted in an S_{clin} of 20.8 mm. This enlargement is primarily attributed to the source size effect.

The most critical observation was made for the 5x5 mm field size. While the $FWHM_{crossline}$ was successfully measured as 6.62 mm, the $FWHM_{inline}$ could not be reliably determined, leading to MLC transmission. In Varian TrueBeam MLC system, even when leaves are positioned to form 0 mm gap, radiation still penetrates through the tungsten material. This includes intra-leaf transmission, where photons pass through the bulk of the tungsten leaves, and inter-leaf leakage, where radiation passes through the microscopic gaps between adjacent leaves. Furthermore, the rounded ends of the MLC leaves create an additional penumbra effect known as leaf-end transmission.

Along the inline axis, this cumulative leakage creates a dose background that does not drop to zero. For the 5 mm field, the dose at the periphery was high enough that the algorithm could not accurately identify the 50% dose level relative to the central peak. This result emphasizes that for fields at or below 5 mm, S_{clin} determinaton might require alternative verification methods.

CONCLUSIONS

The comprehensive analysis conducted in this study demonstrates that radiochromic film dosimetry using Gafchromic EBT-XD is a highly effective and reliable method for the verification of clinical field sizes in photon beams. Due to its near-perfect water equivalence and superior spatial resolution, the EBT-XD film serves as an ideal reference detector that avoids the significant perturbation effects and volume averaging issues commonly associated with standard ionization chambers and high-Z solid-state detectors. The high level of agreement found for the reference 100x100 mm field, which deviated by only 0.7% from the nominal value, confirms that the experimental setup and the Varian TrueBeam delivery system are within the standard clinical tolerance of ±1%.

The experimental results reveal a consistent discrepancy between the nominal field sizes set on the accelerator console and the actual clinical sizes S_{clin}. These differences, ranging from 0.7 to 1.2 mm, highlight the physical reality of the source size effect. The use of MLC-based collimation, as required by the TRS-483 protocol, further confirms that clinical field shaping introduces unique effects, such as leaf-end transmission, which must be accounted for to ensure patient safety in high-precision radiotherapy.

The verified clinical field sizes obtained in this study will serve as the primary input data for determining the field output correction factors.

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ВИЗНАЧЕННЯ КЛІНІЧНОГО РОЗМІРУ ФОТОННИХ ПОЛІВ МЕТОДОМ ПЛІВКОВОЇ ДОЗИМЕТРІЇ З ВИКОРИСТАННЯМ РАДІОХРОМНИХ ПЛІВОК EBT-XD

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Дана робота присвячена визначенню еквівалентного розміру квадратного поля (S_{clin}) для малих фотонних полів. Використано радіохромні плівки Gafchromic EBT-XD та лінійний прискорювач Varian TrueBeam. Метою дослідження є отримання точних даних про розмір поля для розрахунку поправкових коефіцієнтів згідно з протоколом IAEA TRS-483. Проведено вимірювання для полів від 5x5 до 100x100 мм. Результати демонструють розбіжність між номінальним та фактичним розмірами полів у межах 1,5%.