

ABSTRACT

Purpose: Lung stereotactic body radiotherapy (SBRT) is now standard of care for oligometastatic disease and small pulmonary lesions, where very small radiation fields are often required. Although inhomogeneity correction algorithms have been well validated for larger fields, limited data exist for small fields in low-density media. This study evaluates the performance of modern treatment planning system (TPS) inhomogeneity corrections for small fields in lung-equivalent material, supported by measurements using detectors appropriate for small-field dosimetry.

Methods: A lung phantom constructed from cork slabs (density: 0.25 g/cm³) was designed to approximate patient anatomy and scanned for treatment planning. Three contemporary TPS platforms (Eclipse, RayStation, Monaco) were investigated using all available dose-calculation algorithms, alongside EGSnrc-based Monte Carlo simulations, for a 6 MV beam. Measurements were performed in the phantom using small-field-appropriate detectors: microSilicon, microDiamond, SunSilicon and a plastic scintillation detector (PSD). Field sizes ranged from 0.5 × 0.5 cm² to 10 × 10 cm², with all data normalized to a 10 × 10 cm² reference field.

Results: When compared with EGSnrc Monte Carlo calculations, algorithm performance varied substantially. For field sizes <1 cm², discrepancies ranged from -22% to +16%. For fields >1 cm², differences were within ±4% for all algorithms except AAA, which showed larger deviations. When inhomogeneity correction was disabled (water-equivalent assumption), notable differences were observed only for fields <1 cm², as expected. The observed inaccuracies likely arise from limited or inaccurate TPS beam data for fields <2 cm². Monte Carlo-based algorithms demonstrated better agreement than convolution-based methods.

Conclusions: None of the evaluated modern TPS algorithms provided consistently accurate small-field dosimetry in low-density lung media, with discrepancies up to -22% to +16% for the smallest fields. Measurements in heterogeneous media also exhibit challenges related to detector positioning, orientation, and material composition. Extreme caution is warranted when using fields <1 cm² in lung SBRT, given the potential for clinically significant dose deviations.

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INTRODUCTION

Small field dosimetry is mainly discussed in the context of homogeneous water phantom where extensive data do exist such as TRS-483¹ and TG-155² and references within these reports. However, the field output factor (FOF) has been significantly different from one publication to the other. Additionally, the data in the lungs do not exist for small fields. Inhomogeneity correction and impact of TPS or type of algorithms have been investigated. It has been shown that most treatment planning systems (TPS) do not provide accurate dosimetry.^{3,4} Van Esch et al⁵ tested Eclipse algorithm for fields >3x3 cm² and measured with ion chamber in lung phantom which has been shown in error by Ding et al⁶. Fogliata et al⁷ discussed the issue of small fields in lung SBRT comparing A, B, and C types of algorithms from various (TPS) but again limited to fields up to 2 × 2 cm² to 5 × 5 cm² that showed significant differences between various algorithms.⁷ Ojala et al³ also provided comparison of various lung algorithms with variable results. Recently, Das et al⁸ provided data in lung SBRT from Eclipse AAA. This project is taken to provide dosimetric variability in various advance (TPS) such as Ray station, Monaco, Eclipse (AAA & Acuros) as well as EGSnrc Monte Carlo along with measurement in small fields suitable dosimeters.

METHODS AND MATERIALS

PTW microdiamond (PTW 60019), microSilicon (PTW 60023), Standard Imaging microchamber, sunSilicon model-4018 (Sun Nuclear, Melbourne, FL) which has been designed for small field and characterized by Anders et al³⁵ were used. Additionally, EBT4 Gafchromic film was also used. Two sets of film from same batch were used; one for calibration in a water tank and other for use in cork phantom at identical position where TPS data were sought. Field size was varied and a new cut film was used for exposure. Films were scanned using Epson XL12000 scanner as recommended in various published references. Analysis were performed using Image J software. Measurements were performed in cork phantom (Fig 1) and in water phantom to compare IC with each detectors in identical set up condition as that of the planning with various TPS.

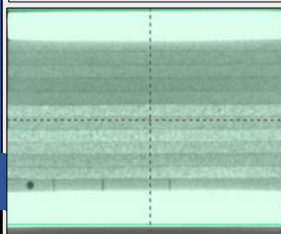


Figure 1. Cork phantom for treatment planning and measurements was created that was sandwiched between 2 slabs of solid water. The cork density was measured to be 0.25 g/cm³.

RESULTS

TPS planning and measurements were made in cork phantom (as shown in Fig 1) at a depth of 10 cm at 100 cm SAD. Figure 2 shows photon and electron tracks in large and small fields. Figure 3 shows dosimetric differences of various algorithms compared to EGSnrc Monte Carlo simulation without inhomogeneity. Figure 3 shows calculated dose with inhomogeneity correction. Two vertical lines at 1 and 2 cm² fields are shown to reflect the magnitude of differences which is significant for fields < 1 cm². It is not surprising as most TPS are commissioned only for fields >2 cm² but treatment is performed with fields smaller than 2 cm². Among all the algorithms, AAA seems like an outlier. Figure 4 is shown when inhomogeneity correction is turned off e.g. water medium. The results are as expected where differences are only seen for fields <1 cm². Figure 5 shows the differences between MC and measured data indicating very large differences that requires additional study. The differences could be due to centering of the detector in the phantom, detector orientation and density of detector causing perturbation.

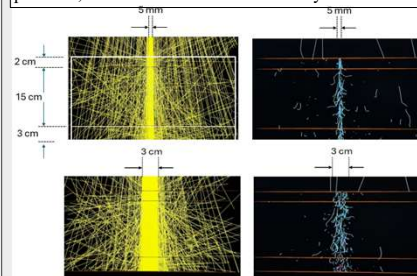


Figure 2. The left figure shows the geometry of phantom in while line box (2 cm solid water, 15 cm cork and 3 cm solid water) and the tracks of photons (yellow), electrons (blue) and positron (red). The right figure shows only electrons and positrons only,

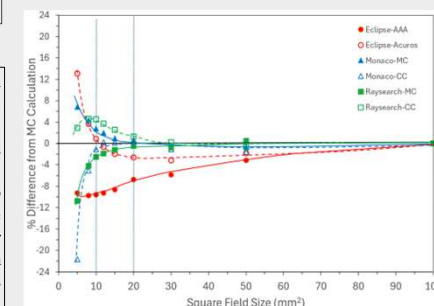


Figure 4. Calculated dose in cork phantom with inhomogeneity as shown in Figure 1 for various TPS.

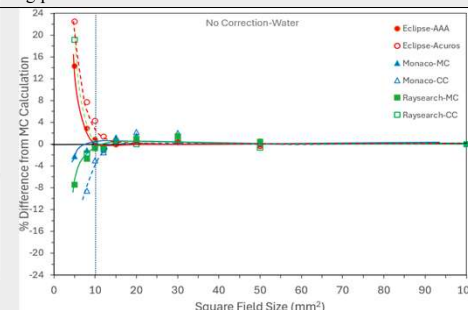


Figure 3. Calculated dose without inhomogeneity correction assuming entire phantom in homogeneous water.

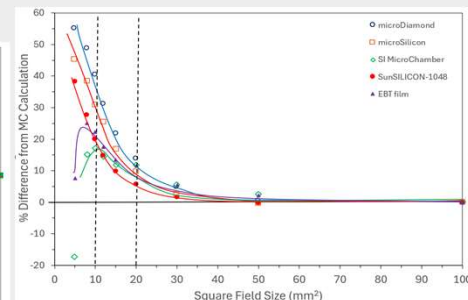


Figure 5. Measured dose in cork phantom with inhomogeneity as shown in Figure 1 used for TPS and measurements.

CONCLUSIONS

- It is found that none of the TPS calculated accurate dose compared to Monte Carlo dose in small fields with inhomogeneity.
- Validation of inhomogeneity correction may require different detectors other than that are traditionally used in the context of TRS-483 and TG-155 e.g. microSilicon, microdiamond, plastic scintillator (PSD) as differences are significant and mainly over-estimated small field outputs.

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