COMPARISON OF SELECTED MATERIALS EFFICIENCY FOR SFRT GRID COLLIMATOR USING TOPAS MONTE CARLO MODELING METHOD

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Abstract— **This study evaluated block materials for delivery of spatially fractionated radiation therapy (SFRT). SFRT is a technique for delivering radiotherapy within spaced, grid-like patterns to treat bulky tumors in a single fraction. Particularly relevant to low-and-middle-income countries, where late-stage disease presentation is common. The geometry and design of the grid block as well as the radiation transport and dose scoring were carried out using Monte Carlo Toolkit for Particle Simulation (TOPAS). Phase space files capturing particle attributes such as position, direction, and energy were obtained from the manufacturer for a 6 MV medical linear accelerator (TrueBeam, Varian Medical Systems). A grid collimator was modeled as a solid rectangular structure with dimensions of 22 cm x 22 cm x 7.5 cm, divergent circular holes were arranged in a hexagonal pattern. The dose distribution in a water phantom was evaluated for multiple materials; steel, brass, and Cerrobend (alloy of barium, lead, tin, and cadmium). Peak-to valley dose ratio (PVDR) of stainless-steel, brass, and Cerrobend grid blocks at a depth of 10 cm in water were determined (4.01, 4.13 and 4.78 respectively). PVDR of stainless steel was observed to be near brass, a commonly used material. This study provides support for potential use of steel as an alternate material in grid therapy.**

Keywords— **TOPAS, grid-block, Monte Carlo code.**

I. INTRODUCTION

SFRT (Spatially Fractionated Radiation Therapy) is a radiation treatment approach that delivers a non-uniform dose of radiation to the tumor site, alternating between high and low doses. Research by Mohiuddin et al. (1990) showed surprisingly positive outcomes for patients treated with SFRT compared to traditional radiation therapy. SFRT has advantages when treating large tumors, offering a combination of high-dose "hot spots" and low-dose "cold spots" throughout the tumor. This approach is also known as grid or Lattice SFRT [1,2]

The grid SFRT technique was pioneered by Alban Köhler in 1909 [3]. At the time, orthovoltage beams delivered the highest dose to the skin's surface, limiting the dose that could be given to deeper tumors. SFRT was created to allow for higher doses to be delivered to hard-to-reach tumors while keeping skin dose at a safe level. The grid collimator or block helped reduce skin damage by creating areas of protected skin and tissue that could regenerate. However, with the introduction of medical linear accelerators that produce megavoltage photon beams and modern skin-sparing techniques, the original motivation for SFRT with grid was no longer a concern.

Although grid radiotherapy has shown promise, its use in clinical settings is hindered by a lack of understanding of the underlying radiobiological processes. Historically, these blocks were made of materials like Cerrobend or brass alloys with perforations that created the grid pattern, yet access to these blocks is limited, especially in low-and-middle-income countries. Several studies have explored fabrication techniques. For instance, Zhu et al. examined the possibility of producing Cerrobend grid blocks through 3D printing [4]. Almendral et al. proposed a straightforward method for creating a hybrid grid pattern combining both block and multi-leaf collimator (MLC) technologies [5].

Previous studies have employed grid blocks manufactured from dense materials that can radiation, including: Cerrobend, brass, lead and tungsten. In the current study we investigate and unexplored material, stainless steel, which has promising characteristics including readily availability in limited resource settings. Dosimetric characteristics of brass, Cerrobend, and stainless steel have been compared using computational methods.

II. METHODOLOGY

Geometry of simulation

The grid block is a solid rectangular structure with dimensions of 22 cm × 22 cm × 7.5 cm, made from different materials for its radiation attenuation properties. The upper stream of the block features a hexagonal pattern of holes and arranged in a closely packed lattice which are diverging in size as they progress from the upper stream to the downstream portion of the grid. Each hole is circular and characterized by its diameter. Starting from the upper stream portion, the holes have a diameter of 0.6 cm. These holes are spaced apart with a center-to-center distance of 1.14 cm. As we move downstream, the holes size gradually increase to 0.85 cm while maintaining the same center-to-center distance of 1.14 cm.

The divergent holes size help in achieving the desired spatial distribution of the radiation beam. The smaller holes at the upper stream region focus the radiation, while the larger holes at the downstream region permit the passage of the divergent of the radiation beam. Properties of materials used in this study are shown in Table 1.

Table 1: Physical properties of different materials suitable for fabrication of grid block

Material	**Density (g/cm)**	**Advantages**	**Disadvantages**	**References**
Cerrobend	9.30	High density, effective radiation attenuation	Expensive, toxic	Zhu et al. [4]
Lead	11.34	High density, effective radiation attenuation	Toxic, requires special handling	Trapp et al. [6]
Tungsten	19.30	High density, effective radiation attenuation	Expensive, difficult to machine	Kijima et al. [7]
Brass	8.50	Good radiation attenuation, cost effective, easy to machine	Lower density	Karimi et al. [8]

Model Validation

Percentage depth dose curves were calculated for depths from 0 cm to 40 cm for field size 10 cm × 10 cm in water phantom. To validate the TOPAS model, twenty phase space files were used to calculate the percentage depth dose for the open beam. The commissioning data obtained with 3D scanning tank; golden beam was used as reference data were used for comparison with the TOPAS simulation. The commissioning data, golden beam and the Monte Carlo simulated results of the percentage depth dose are shown in Figure 2. Both the reference and evaluated data were normalized to the value of maximum dose along the central axis of the beam. The depth at maximum dose for commissioning data, golden beam and the Monte Carlo simulated results are 1.59 cm, 1.5 cm and 1.5 cm. The Monte Carlo simulation results were bench marked against golden beam and commissioning data in term of absolute dose difference.

The geometry and design of the grid as well as the radiation transport and dose scoring in the water phantom was performed with the Monte Carlo based Tools for Particle Simulation (TOPAS). TOPAS is an easy-to-use extended Monte Carlo based GEANT4 simulation Toolkit for Medical Physicists. The description of TOPAS platform for research and applications are detailed in the publication [9].

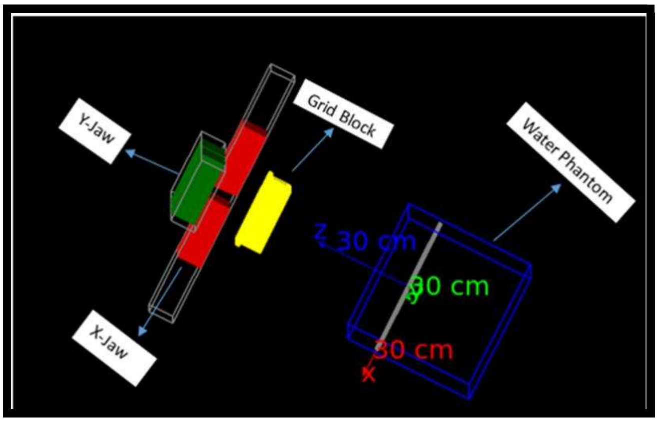

Figure 1: Schematic diagram of the Varian TrueBeam Linac

Monte Carlo Simulations

Using a 6 MV phase space file, the Varian TrueBeam Monte Carlo was modeled in TOPAS (Version 3.8) [10,11]. The Phase space file was placed 26.7 cm downstream from the target position, as described by Varian [11]. For both upper and lower Jaws, TOPAS TsJaws was used in order to simulate the collimators, although not a precise model of the TrueBeam's collimators, the diverging angles provide a close approximation. The upper and lower jaws were placed below the phase space plane, collimated to a 10 cm × 10 cm field at 100 cm source to surface distance (SSD) with the grid block at the distance of 56 cm which is the distance to the block tray. Five billion histories were simulated with an open field using common calibration parameters to validate the TOPAS model [12].

III. RESULTS

Model validation

The validation results from our Monte Carlo model indicate a high level of accuracy when compared to the actual data from commissioning scan and golden beam data. This is evident in the alignment of the model output with the data of the depth dose for 10 cm × 10 cm field size. This suggest that our model is a reliable representation the TrueBeam machine.

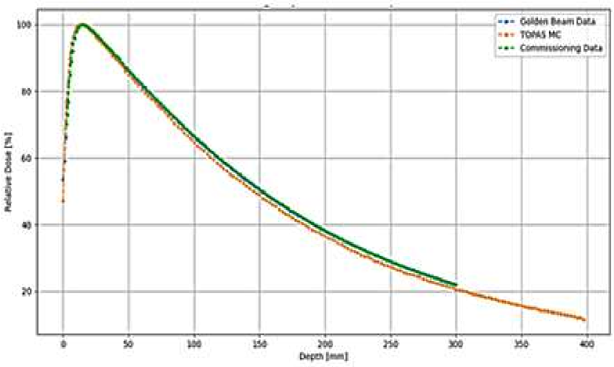

Figure 2: The 6 MV depth dose curve for golden beam, simulation and commissioning data for open field 10 cm × 10 cm

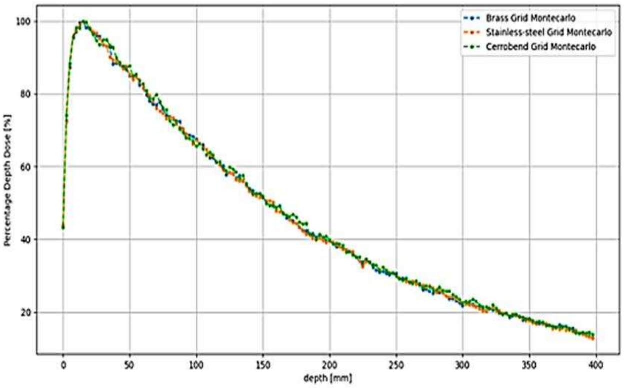

Figure 3: The 6-MV depth dose curves for materials with Brass, Stainless steel and Cerrobend for grid field 10 cm × 10 cm

The three materials exhibit similar depth dose curves, with a rapid increase in dose up to 13 mm depth, follow by a gradual decrease in the tail region. The dose distribution is relatively homogeneous at a shallow depth, with variations of less than 5% among the materials.

Peak to Valley Dose Ratio

The peak to valley dose ratio (PVDR) is defined as the ratio between the high-and low dose points in the cross-plane profile created by grid block. A peak to valley dose ratio of one indicates a perfectly uniform dose distribution, while higher PVDR values indicate a less uniform distribution. In this study, we utilized a Python script to analyze the data collected.

PVDR values of 4.04, 4.13, and 4.78 for stainless steel, brass, and Cerrobend at 10 cm depth for 6-MV and 10 cm × 10 cm calculated along the cross-plane profile. The PVDR of Cerrobend is the highest, demonstrating greatest difference between min and max dose of the three materials. The graphical representation is shown in Figures 4, 5 and 6.

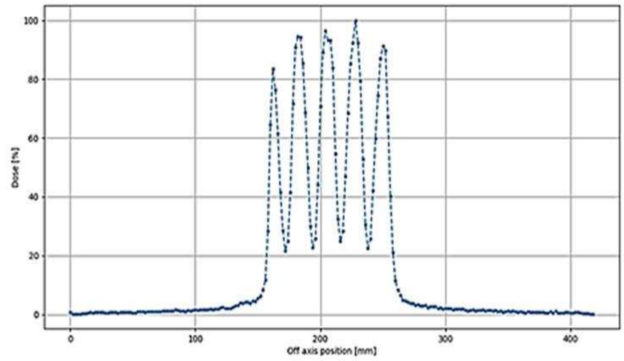

Figure 4: The Monte Carlo simulated beam profile of a 6-MV spatially fractionated photon beam at 10 cm depth in a water phantom for brass

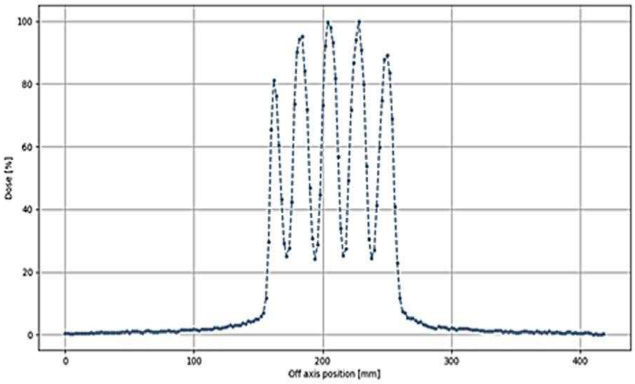

Figure 5: The Monte Carlo simulated beam profile of a 6-MV spatially fractionated photon beam at 10 cm depth in a water phantom for Cerrobend

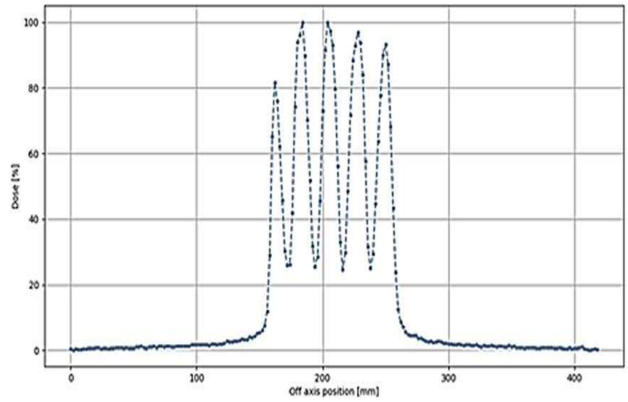

Figure 6: The Monte Carlo simulated beam profile of a 6-MV spatially fractionated photon beam at 10 cm depth in a water phantom for stainless steel

Table 2: Peak to valley dose ratio of 6 MV for different grid blocks

Grid material	**Peak Dose**	**Valley Dose**	**Peak to Valley Dose ratio**
Stainless steel	100	24.75	4.04
Brass	100	24.21	4.13
Cerrobend	100	20.92	4.78

IV. CONCLUSION

This study reveals that stainless steel offers a PVDR similar to brass, often used in the fabrication of grid block collimators for clinical applications. This thus translates that the stainless-steel has a potential use as an alternative material for grid collimators in radiotherapy, most especially to extend access to radiation treatment, improve efficiency, optimize treatment outcomes for bulky tumours, and reduce financial expenses in low-resource settings.

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