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MATRIX METAL COLLIMATORS STUDIES FOR THE SPATIALLY FRACTIONATED RADIATION THERAPY

Anokhin I, Ramazanov D. Matrix metal collimators studies for the spatially fractionated radiation therapy. Traditional radiation therapy is hindered by limitations in dose delivery and the risk of over-irradiation, which can harm healthy tissues surrounding tumors. Spatially fractionated and intensity-modulated radiation therapies have emerged as promising techniques to mitigate these issues by reducing damage to healthy tissues. This study explores the potential of enhancing radiation therapy's therapeutic efficacy through spatial fractionation of X-ray beams, a technique that can significantly increase radiation efficiency by reducing the dose load on healthy tissues. This research hypothesizes that microscopic lesions within the paths of micro/mini-beams can be repaired by minimally irradiated cells adjacent to the irradiated tissue slices, based on observations with high-energy (MV) photons. Spatial fractionation is particularly valuable for X-ray and electron radiation therapy, which is more widespread and cost-effective than proton therapy. The study introduces a new type of cost-effective metal matrix collimators designed for beam fractionation. These collimators are constructed using lead plates for thickness variation implementation and employ a 5x5 hole matrix with 1 mm diameter and 3 mm pitch, covering an area of 14x14 mm². To visualize beam distribution, a Timepix detector, capable of providing real-time 2D beam profiles, was employed. Experiments were conducted using a medical LINAC with typical therapeutic energy ranging from 6 to 18 MeV. Results indicate that spatial fractionation can be achieved for X-ray radiation, with a PVDR of approximately 3 for a 3 cm lead collimator. However, issues with hole uniformity and blurring in the peak area prompted a shift to using copper collimators due to their superior manufacturing properties. This study presents a novel matrix collimator design made from various materials for shaping mini beams, aimed at improving the efficiency of spatial dose fractionation for different ionizing radiation types. Geant4 simulations have been instrumental in optimizing collimator features. The findings suggest that high levels of dose fractionization can be achieved for X-rays, electrons, and proton beams. These results warrant further biological studies to evaluate the effects of fractionation on normal and tumoral tissues, supporting the practical implementation of collimation in radiation therapy.
Key words: Radiation therapy, spatially fractionated radiation therapy, metal matrix collimator, PVDR, TimePix detector, Monte Carlo simulations.

Introduction. The efficiency of traditional radiation therapy is decreased by the dose delivery limitations and over irradiation. The spatially fractionated and intensity-modulated radiation therapy can significantly reduce the damage of the healthy tissues around tumors. The present work is dedicated to the researching of the possibility of enhancing the therapeutic effect in radiation therapy by the spatial fractionation of x-ray beams. Fractionation can significantly increase radiation efficiency by reducing the dose load on healthy tissues. The main parameter of fractionization is peak-to-valley-dose-ratio (PVDR). The minimum dose in the central region between two beams is named valley dose and the dose in the center of the beam is the peak dose. The ratio between peak and valley doses is called peak-to-valley dose ratio and plays a pivotal role in biological response. High-quality fractionation is considered with the parameter PVDR 8 and higher. In addition, it is essential that the valley dose is kept to a minimum to ensure the preservation of normal tissue architecture and survival of sufficient cells needed for healthy tissue repair. It was hypothesized that the microscopic lesions in the micro/mini-beams paths are repaired by the minimally irradiated cells contiguous to the irradiated tissue slices [1]. This reparation effect was observed in experiments with high energy (MV) photons. Spatially fractionating is very important techniques for the x-ray or electron radiation therapy that are more spread in most part of countries and cheaper than hardon therapy.

Methods. In the present paper the new type of the cheap metal matrix collimators for the beam fractionization has been presented (see Fig.1). For example, the collimator presented in the upper part of the Fig.1 is made of lead plates for thickness variation implementation. Beam splitting provides by hole matrix 5×5, 1 mm diameter and 3 mm pitch, area covering 14×14mm^2. For the hit distribution imaging a Timepix detector has been used. This is hybrid active pixel detector, which was developed within the Medipix collaboration at CERN. The main part of a Timepix detector is the active sensor layer, which is segmented into a square matrix of 256×256 pixels with a pixel pitch of 55 μm, thus covering an area of 14x14 mm^2. Each pixel is connected to its own readout chain.

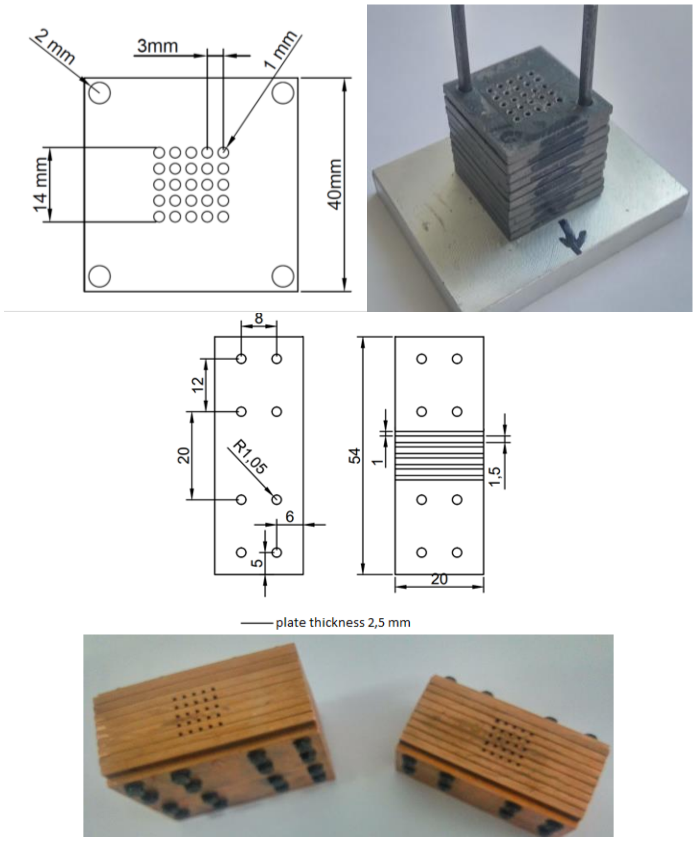
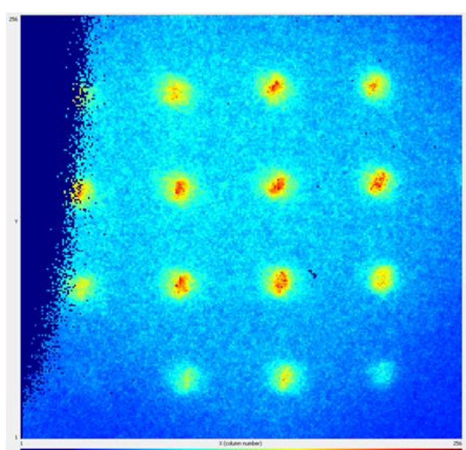


Fig. 1. The prototypes of lead and copper collimators. The drafts and the fabricated prototypes

The detector segmentation allows to get 2-dimension picture of beam profile in real time [2].

Experiment have been conducted on the medical LINAC with typical therapeutic energy 6-18 MeV. Distance from accelerator to collimator was 1 m. Experiment have been implied irradiation Timepix detector by 6 MeV x-ray radiation through metal collimator for studying efficiency of fractionation.



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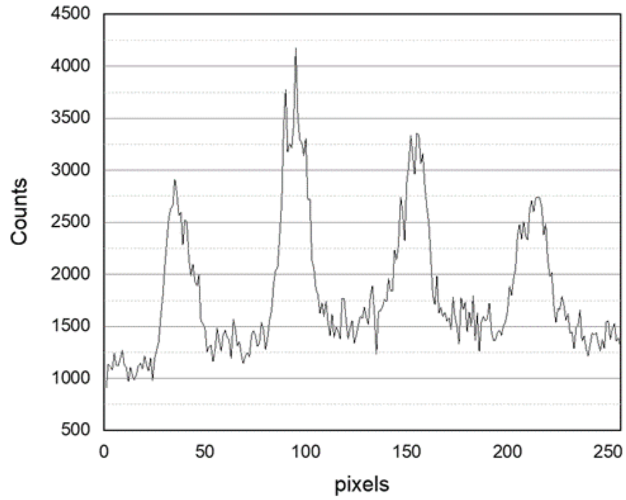

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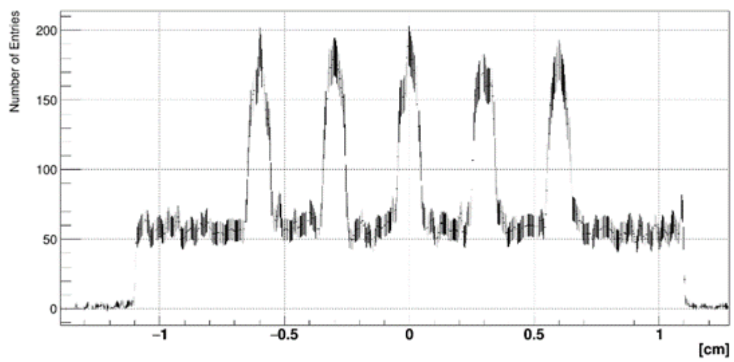
Fig. 2. Fractionation of X-ray radiation with a limiting energy of 6 MeV using a lead matrix collimator 3cm thickness. a) Timepix 2D hit distribution (deep blue area is dead pixels), b) beam profile



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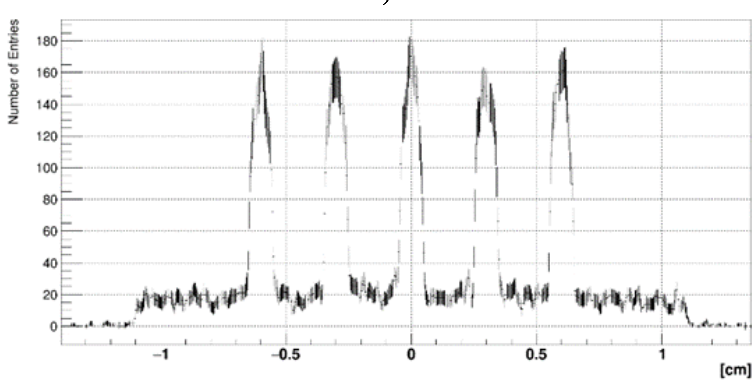

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Fig. 3. Simulated profile of collimated x-ray radiation for a) 3 cm lead collimator and b) 10 cm copper collimator.

Results. Results of experiment report, that spatially fractionation can be achieved for x-ray radiation. PVDR for 3 cm collimator was about 3. It was the maximum thickness available for lead, but even with such a collimator thickness, we can see that the holes are not the same, and the peak area is blurred (Fig.2). This can be explained by the complexity of processing lead and, consequently, the poor quality of the collimator itself, in particular, the holes. That is why it was decided to choose the copper instead the lead for the collimator fabrication. Copper is better in manufacturing and can be used for different types of irradiation. New prototype design was enhanced in favor of collimator scaling and modularity (Fig.1). Detailed results of experiment and simulation for new one will be presented in full paper.

Geant4 toolkit version 10.6 has been used for the simulation of the operation of the presented new type of collimators. For the correct comparison of the simulation and experiment, all experimental conditions (distances, materials, environment) were reproduced. For calculation was used physics list QGSP_BERT_HP with cut 0.1 mm.

Discussions. Results of simulation show possibility for high rate x-ray radiation fractionization. Several types and geometries of collimators were investigated to assess the possible gain in tissue sparing with respect to seamless irradiation. Simulations for the lead collimator show similar to the experiment result (Fig.3a), but graph of simulation is more accurate also, this is a consequence of material disadvantages. Copper collimator with thickness 10 cm (Fig.3b) provides PVDR higher than 8 under 6 MeV X-ray irradiation This is acceptable result for such beam type.

Conclusions. In the present work, a new type of matrix collimator made out of different materials for the shaping mini beams has been developed and tested to improve the efficiency of the spatial dose fractionation for different types of ionizing radiation.

The Geant4 Monte Carlo simulation code has been developed to optimize the features (material, thickness, etc.) of collimating systems (multi slits or matrix) to produce optimal multi-beam structures for maximum efficiency of spatially fractionated radiation therapy It has been shown that the high levels of delivery dose fractionization can be achieved for x-rays, electrons and proton beams.

The general conclusion is that fractionation seems to offer a promising alternative to treat delicate cases. Following this results, biological studies are warranted to assess the effects of fractionation on both normal and tumoral tissues, for which the practical implementation of collimation seems justified.

References

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