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Validation of Ionization Recombination Correction Factor of a Monitor for Carbon Ion Scanning Beam with Ultra-high Dose Rate

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Objectives

FLASH therapy has recently emerged as a novel treatment that uses irradiation at ultra-high dose rates (>40Gy/s, uHDR). FLASH therapy has several merits: it can widen the therapeutic window and shorten the irradiation time. To realize FLASH therapy, precise beam control and accurate beam monitoring are essential. In particular, the measurement of ion recombination is important in dose monitoring under uHDR condition. In clinical settings, the use of air-filled monitors is assumed due to their availability. Osaka Heavy Ion Therapy Center (HIMAK) has developed an air-filled FLASH monitor with a sensitive volume of 12×12 cm^2 and a rated voltage of 1500 V. In this study, we experimentally derived the ion recombination correction factor (k_s^E) using the method currently employed at HIMAK, calculated k_s^T using a theoretical approach based on Boag's theory, and validated its clinical applicability by comparing k_s^E with k_s^T.

Methods

At HIMAK, an experiment was conducted to determine k_s^E of the monitor. The experimental setup consisted of placing the monitor on a treatment couch with Advanced Markus Chamber (AMC) positioned beneath it to serve as a reference monitor. A carbon ion scanning beam with an energy of 208.3 MeV/u and a linear energy transfer (LET) of 15.6 keV/μm was irradiated onto the monitor. The dose rates ranged from conventional level to FLASH level. To obtaine the saturation curve, various bias voltages (V) were applied to the monitor, and its output charge was measured and dividied by the charge collected by the AMC (q). A plot of $1/q$ versus $1/V^2$ was generated and a linear fit was applied. Extrapolation to $1/V^2$ = 0 was performed to obtain the saturation charge (q_0). k_s^E was then calculated as q_0/q. k_s^T was also calculated based on Boag's theory, described by the following formula: $k_s^T = 1 + A/V + BI_{\mathrm{saturation}}/V^2$. To determine $I_{\mathrm{saturation}}$, we measured a beam profile at the monitor surface using EBT3 film and the intensity distribution was fitted with a Gaussian function. Finally, k_s^E was compared with k_s^T.

Results

At FLASH dose rate, k_s^E of the monitor operated at 1500 V was 1.0502, while k_s^T was 1.0702. The largest difference between k_s^E and k_s^T was at most 3.4 % at 800 V.

Conclusions

The experimental results and theoretical predictions showed good agreement in the range up to 5,000 V/cm and at FLASH dose rates. These results demonstrate that ion recombination correction factor of the air-filled FLASH monitor can be accurately obtained using the conventional procedure.

Figure 1 . Experimental setup

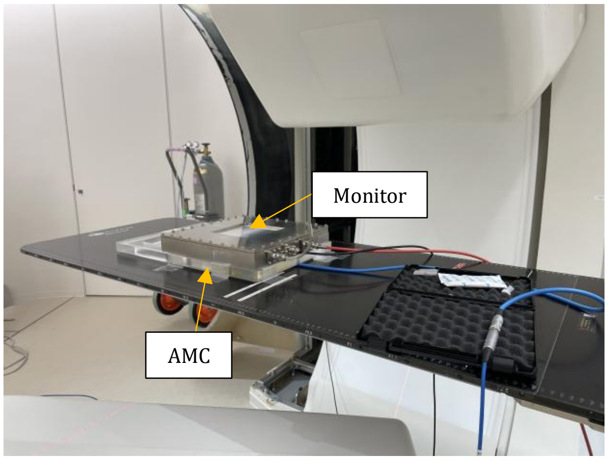

Figure 2 .

- Irradiation conditions

Energy	208.3 MeV/u
LET	15.6 keV/μm
Applied voltage	800, 1000, 1200, 1400, 1500 V
Gain setting	FLASH, 10× conventional, Conventional
Irradiation field	2.1×2.1cm^2, 49 spot

- Scanned field

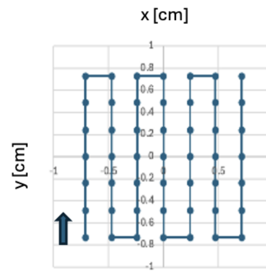

Figure 3 . Comparison of experimental and theoretical k_s