Computer simulations concerning influence of target motion on dose distribution delivered by the GSI raster scanner

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Target motion is a very big problem in conformal radiotherapy (CRT), especiallly for a charged particle beam because of its less lateral scattering and sharp Bragg peak. In the pilot project of the heavy-ion cancer therapy at GSI, patients with head and neck tumors are treated with a magnetic raster scanner[1]. However, if the raster scanner is used to treat patients with body tumors, motion of tumors is present in the lung, breast, liver, kidney and other disease sites, e.g. due to respiration. Therefore, applying the static dose optimization schemes[2] to the moving target by the advanced beam scanning technique could lead to a inhomogeneous dose distribution. So computer simulations about target motion were performed and Gaussian beam profile and sinusoidal movement are assumed as follows,

$$I(x,y) \sim e^{-\frac{x^2+y^2}{2\sigma^2}}, FWHM = \sqrt{8\ln 2}\sigma \tag{1}$$

$$\vec{r}(t) = A_r \sin(2\pi \frac{t}{T_r} + \Phi_0) \cdot \vec{r}_0 \tag{2}$$

here A_r, T_r and Φ_0 are the amplitude, period and initial phase of the movement, respectively. In clinical situation, the average amplitudes of respiration in cranio-caudal and lateral directions are 15mm and 5mm, respectively[3][4]. So maximum displacements of 15mm and 5mm of target volume with 40x40cm^2 in area under beam's eye view along the two different sides were assumed. Realistic raster scanning parameters for the irradiation of the rectangle were supposed, that is, scan stepsizes in x and y directions are 2mm, respectively, and the raster scanner keeps waiting till the prescribed particles have been deposited at a raster point, and then moves to next one with a maximum speed of 10m/s.

The computer simulations were carried out with an experimentally measured beam-spill profile. Fig.1(a) and (b) show the dose distributions for static and moving targets delivered by the raster scanner. It is obvious that the dose homogeneity in the target volume decreases considerably in the case of target motion. In order to assess the inherent variability of dose homogeneity resulting from randomly initial phases, all the calculations repeated 10 times with randomly initial phases and the average values were regarded as the results.

Fig.2(a) shows the relationship between dose homogeneity and rescan at different prescribed particles per raster position. The dose fall-off width through the center of the target volume from the edge to 10% average dose level were also caculated. The dose homogeneity would be improved as the rescan time increases at the expense of the dose fall-off width. Moreover, the increment of dose homogeneity is small and the average dose fall-off widths increase by factors of 2.9 and 1.4 in x and y directions respectively when the rescan exceeds 5 times. In fact, the dose homogeneity will not be better than 82% only by means of rescan for a moving target.

The influence of moving period from 2s to 8s on the dose homogeneity was investigated. The results shows the medial respiratory cycle, for example 4s to 6s, would increase the dose homogeneity when the particle number per raster point is less than 4×10^5. Usually the displacements of target volume due to respiration in different directions are not the same, and the raster scanner has different scanning speeds in horizontal and vertical directions. So the influence of scanning direction along different movement amplitude on dose homogeneity was also evaluated. The result shows if the fast scanning direction (x axis in the simulations) of the raster scanner coincides with that of target movement with large amplitude, for instance the cranio-caudal direction, the dose homogeneity would be improved for prescribed particles per raster point less than 8×10^5 in comparison with the contrary case. When the particle number exceeds this limit, the situation is just contrarious. Different ratios of raster spacing(δ) to FWHM would result in variable dose homogeneity in the static target volume with the raster scanner[1] as shown in the upper part of Fig.2(b). The computer simulations of moving target were made for raster scanning parameter with different δ/FWHM ratios from 0.25 to 0.5. As shown in the lower part of Fig.2(b), it is apparent that the dose homogeneity for raster scanning parameter with large δ/FWHM ratio would be better than that with small one for same specified particles at each raster position

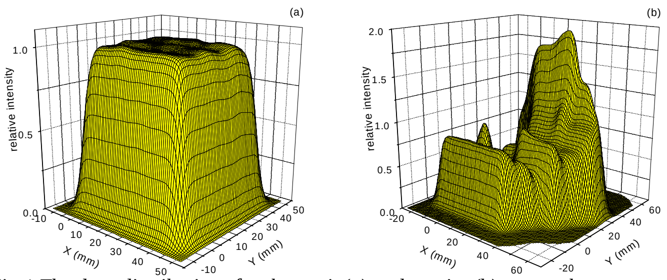

Fig.1 The dose distributions for the static(a) and moving(b) rectangle targets at the particle number per raster position of 5×10^5.

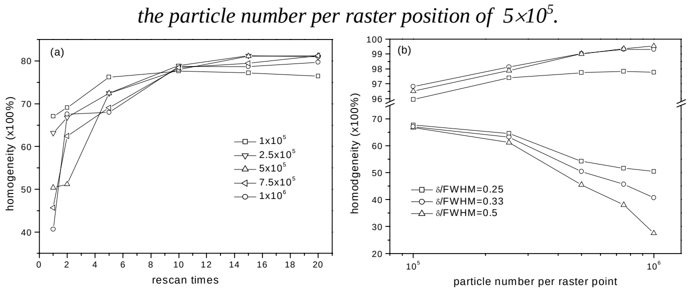

Fig.2 The relationships between dose homogeneity and rescan(a)and ratio of FWHM to raster spacing(b) at differing prescribed particles each raster point.

The simulations here provide a means for evaluating the dose distribution, and the results and implications of this work are being incorporated into the design of a method to compensate for the target motion with the raster scanner at GSI.

References

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