The Performance of Heavy Ion CT System with Fluorescent Screen and CCD Camera

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ABSTRACT

We have developed and proposed the heavy ion CT system which consists of fluorescent screen and CCD camera equipped with image intensifier. In our system, we have measured the residual range of particles that passed a phantom and reconstructed the CT image for the distribution of relative stopping power by filtered back projection method with Shepp & Logan filter.

The heavy ion ^{12}C accelerated up to 400 MeV/u by HIMAC (Heavy Ion Medical Accelerator in Chiba) was used. Intensity of the beam output changes like macro pulse, the period being 3.3 sec and the width being 2 sec. The series of data was acquired in synchronizing with the pulse, leading to the improvement of S/N in the CT image.

The fundamental performance was experimentally evaluated in the proposed system. The spatial resolution was estimated to be about 1 mm and the density resolution (electron density referred to water) to be about 0.01.

Keywords: Heavy ion, ^{12}C, stopping power, spatial resolution, density resolution.

1. INTRODUCTION

The heavy ion is effective with respect to the dose distribution and relative biological effectiveness (RBE) compared with X-ray in radiotherapy. However, since the heavy ion has Bragg-Peak, the treatment planning is required more precision than a radiotherapy using X-ray. The treatment planning is usually based on X-ray CT image data[1]. X-ray CT data sometimes gives a different water equivalent thickness from what is taken by range measurement for He and Ne[2]. The heavy ion CT theoretically allows the distribution of stopping power to be obtained directly according to the Bethe-Bloch equation[3]. The equation is also able to apply to ^{12}C ion CT. An axial image was reconstructed from projection data that are integral of stopping power on a track of the particle[4, 5].

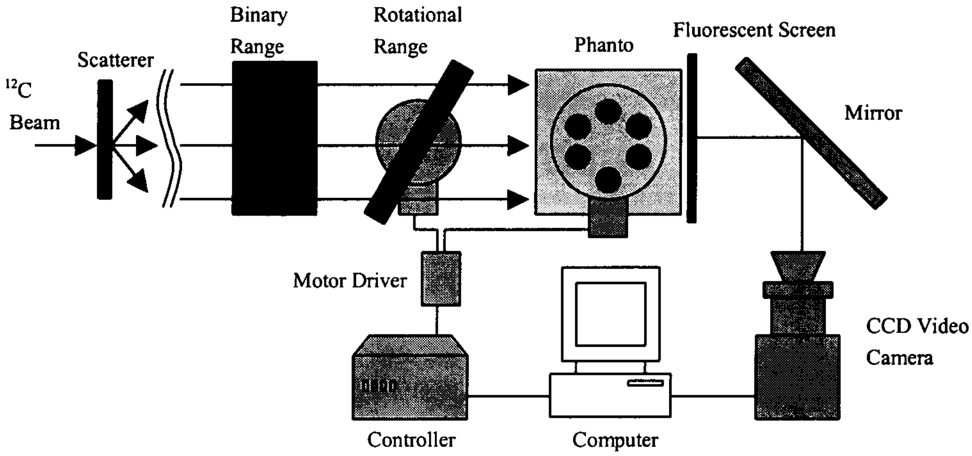


Fig.1 Schematic diagram of the devises used in our experiment. The system consisted of a fluorescent screen, CCD video camera with intensifying screen and two types of range shifters. The distance between a scatterer and a phantom was 9 m. As the residual range of the heavy ion varied by changing the thickness of the rotational range shifter, an intensity of a light from fluorescent screen also varied.

We have studied and developed the heavy ion CT system which measures 2D residual range data with a fluorescent screen and CCD camera. In this study, we investigate fundamental performance of the system to evaluate spatial and density (electron density referred to water) resolutions.

2. MATERIALS AND METHODS

Heavy ion ^{12}C beam accelerated up to 400MeV/u by HIMAC was used. The beam intensity was 3.6 x 10^8 pps, the beam-spill time width was about 2 sec and the period was 3.3 sec. The system consisted of a X-ray intensifying screen (Fuji, HR-4) viewed by a CCD video camera (Andor, DH5H7-18F-13), and two types of range shifters (binary and rotation) as shown in Fig.1.

Figure 2 shows the spatial and density resolution phantoms used in this study. In the spatial resolution phantom, there are an amount of 24 rods which were symmetrically arranged. The diameters of the rods were 3, 2 and 1mm. The rods were made of 4 kinds of materials (PMMA, Nylon, Polyethylene and Polycarbonate). They were immersed in water. The 6 rods in the density resolution phantom were made of 6 kinds of materials (POM, ABS, Polypropylene, Nylon, PMMA, Polyethylene), and they were also immersed in water. The maximum and minimum difference of relative electron density was about 0.454 and 0.004 as shown in Table 1[5].

Both of phantoms were rotated with the 128 steps and each projection images with 512 x 128 matrix size and 16 bit gray scale level were taken for 13 different thickness of rotational range shifter to obtain the residual range. The rotations of the phantom and range shifter, and CCD video camera were controlled with a single personal computer (Windows 98). The residual range of the particles passed through a phantom was determined by the thickness corresponding to the mean value of maximum and minimum pixel value in the curve of the thickness of range shifter vs. pixel value[5]. To acquire a series of projection data acquisition was synchronized with the beam-spill[6].

After a sinogram was made from a series of residual range distributions, the tomography of the phantom was reconstructed by filtered back projection method with Shepp & Logan filter. A series of projection data was corrected for reducing a noise which led to artifacts in a reconstructed image. First, projection data were corrected by median filter to reduce spike noises. Next, variation flux in beam-spills was corrected by multiplying factors so as to make the average pixel value in the ROI placed outside of phantom region constant. At last, uniformity in FOV (field of view) was corrected.

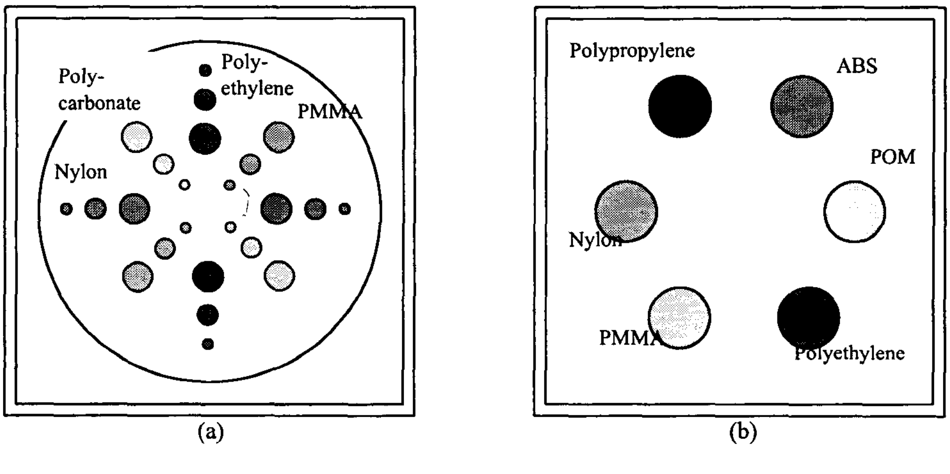
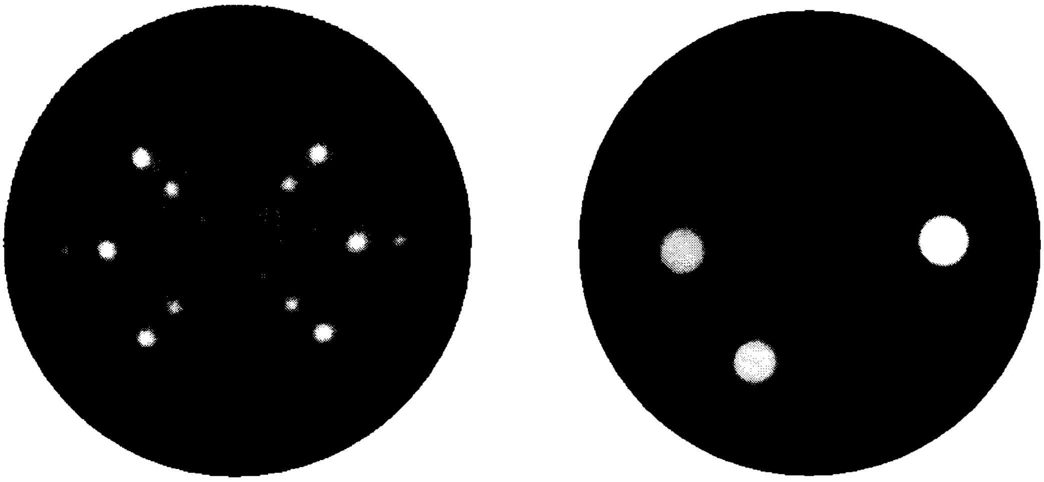


Fig.2 Horizontal cross-sectional views of spatial resolution and electron density resolution phantom. Each element was immersed in water-filled container made of PMMA. The size of the container was 100 mm x 100 mm. The spatial resolution phantom (a) consists of 4 kinds of rods made of PMMA, Polyethylene, Polycarbonate and Nylon. The rods were in a column that was the 95 mm in the diameter and made of PMMA. The diameters of the rods were 1, 2 and 3 mm. The electron density resolution phantom (b) consists of 6 kinds of rods made of POM, PMMA, Nylon, ABS, Polyethylene and Polypropylene, each with



(a) (b)

Fig.3 CT images of the spatial (a) and density (b) resolution phantoms. The images were reconstructed by the filtered bac projection method with Shepp & Logan filter after processing of median filter to reduce noise and with correction o beam intensity and uniformity.

3. RESULTS AND DISSCUSION

The axial images of the two kinds of phantoms shown in Fig.2 were reconstructed by each sinogram based on a series of projection data and both images are shown in Fig.3. The median filter was applied only once and the spike noises were almost removed. The correction of beam intensity was effective in the sinogram. The correction of uniformity in sinogram affected that part of background in the reconstructed image.

All of the rods with 3, 2 and 1 mm diameter were observed except polyethylene rods as shown in Fig.3(a). So the spatial resolution of our heavy ion CT system was estimated about 1 mm experimentally. The spatial resolution was improved in this study compared with that reported previously[5]. All six kinds of rods can be observed clearly in Fig.3(b) Table 1 shows the relative electron density of each rod, mean pixel value (M.P.V) and standard deviation (S.D.) of pixel value in the ROI on each rod, the size of which was 1025 pixels. The relative electron densities are calculated values reported in the past[5]. The relation between relative electron density and M.P.V. is linear as shown in Fig.4. Using the S.D. and the slope of fitting line in Fig.4, we experimentally evaluated the relative electron density resolution in our heavy ion CT system. The resolution at the physical density of 1.0 g/cm^3 was about 0.01, which is less than previously reported[5] one of 0.07. The two kinds of correction for beam intensity and uniformity as well as fine step of range shifter may contribute this result.

Table 1 Relative electron density, mean pixel value (M.P.V) and standard deviation (S.D.) of pixel value in the ROI of each rod.

Material	Relative Electron Density	M.P.V	S.D.
Polypropylene	0.913	141	0.65
Polyethylene	0.969	151	0.68
Water	1.000	147	0.92
ABS	1.004	153	0.65
Nylon	1.135	175	1.32
PMMA	1.178	179	1.22
POM	1.367	216	1.05

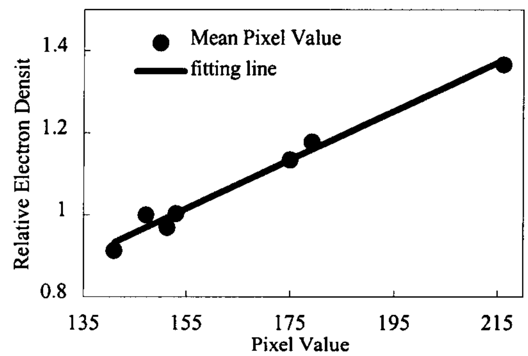


Fig.4 Relation between relative electron density and pixel value. The electron density was linear to the pixel

4. CONCLUSION

We have developed and improved heavy ion CT system and evaluated the spatial and electron density resolution. Three corrections were applied on the projection images and sinogram. The spatial resolution was estimated about 1 mm and the relative electron density resolution to be about 0.01.

5. REFFERENCES

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