Basic Performance Evaluation of the First Model of 4-Dimensional CT-Scanner

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ABSTRACT

This work was carried out to evaluate the basic performances for 4D CT, which employed continuously rotating cone-beam. The performances were evaluated with the same method as the conventional CT, because the standard method of evaluating 4D CT has not yet been established, and we think this result was helpful to establish it. 4D CT can give dynamic volume imaging data continuously and with high-speed. The results were isotropic except for the evaluation of distortion in which small distortions gradually appeared as coming off the center of phantom in longitudinal direction.

Keywords: Cone-beam, 4-dimensional CT, performance evaluation, dynamic volume

1. INTRODUCTION

The present CT system is possible to take a few slices of transverse image in less than 1 sec. The technique for multi-slice CT-scanner enables us to use 3D images more easily. In recent years, concern has been raised concerning diagnosis and radiotherapy planning using 3D images. It takes a long time to acquire 3D images using the multi-slice technique, and their images are low continuity between each slice. It is also difficult to scan the moving object such as heart or lung with the multi-slice CT. In order to solve these difficulties we have developed and researched 4D CT-scanner, which takes dynamic 3D image. 4D CT will enable us to apply to not only new diagnoses but also examinations and treatments, which need real-time observation. In this study we evaluated basic performances of 4D CT-scanner and compared them with those of a state-of-the-art CT-scanner.

2. MATERIALS AND METHODS

2.1 4D CT

4D CT-scanner can give dynamic volume imaging data continuously and with high-speed [1]. It uses a wide-area 2D detector designed on the basis of the present CT technology. The number of elements are 912(channels) x 256(segments), element size is approximately 1mm x 1mm, scanning time is 1sec, and data sampling rate is 900 views (frames)/sec. Feldkamp algorithm [2] is used for reconstruction.

2.2 Phantom

We used cylinder phantoms with the standard diameter of 200mm, which could be also used to evaluate the longitudinal images. We carried out the evaluation of the image noise by using a water-filled acrylic cylinder phantom. A phantom for high contrast detectability had some spheres and cylinders with a diameter of 2, 3, 5, 7 and 10mm. A phantom for low contrast detectability had some spheres and cylinders with a diameter of 3, 5, 7 and 10mm, whose CT-number differed from background at 0.5, 1.0 and 1.5%, respectively. A spatial resolution phantom was specially designed small cylinder containing five sets of high contrast wires. Each set consisted of three wires with the same diameter and material. The diameters were 0.5(stainless steel), 1.0, 1.6, 2.0 and 3.0mm(aluminum), respectively. Distortion phantoms were lucite slabs on which straight grooves of 1.0mm width, 15mm depth and 15mm spacing were machined to form a grid.

2.3 Evaluation Methods

We measured six items as follows with stationary phantoms for 4D CT by the same method as that of the conventional CT, and compared them with the results of a state-of-the-art multi-detector CT (MDCT) in transverse and longitudinal sections. 1. Noise, 2. distortion, 3. low contrast and high contrast detectability, 4. spatial resolution, 5. artifact, 6. exposure dose measurement. An X-ray tube voltage of 120kVp and X-ray tube currents of 200-250mA were used as the scan conditions. Transverse and longitudinal images were reconstructed with a 0.5mm slice interval.

3. RESULTS AND DISCCUSION

Fig.1 shows the image of the noise phantom. A variation of CT-number in ROIs was about 3.7. But in the center of the longitudinal direction, there was an artifact which CT-number became a little high. A variation of CT-number on the profile line along the longitudinal direction was within 1. This was namely almost uniform. Fig.2 shows the image of the resolution phantoms. In longitudinal section, wires of 0.5mm were separable and also in transverse section, so wires of 0.5mm were separable by changing window levels and widths, because the difference of CT-number between the wires and spacing was more than 1000. Fig.3 shows the image of the distortion phantom. Fig.4 shows a profile through the image of the distortion phantoms along the longitudinal direction. The difference between grid widths in transaxial direction was within 0.5%, standard deviation was 0.25 pixel, while the difference in longitudinal direction was within 11.4%, and the standard deviation was 0.53 pixel. The results were isotropic except for the evaluation of distortion in which small distortions gradually appeared and increased CT-number of grid grooves as coming off the center of phantom in longitudinal direction. This may be caused by the incompleteness of cone-beam as data acquisition geometry. The image of the phantom for high contrast detectability (Fig.5) was as same quality as that of MDCT (Fig.6). Fig.7 shows that the relationships between the normalized CT-number of cylinder and the reciprocals of cylinder diameter. The normalized CT-number was obtained by subtracting the CT-number of background from that of objects and normalizing it to unity at 0.1 mm^{-1}. The slopes of the 4D CT and MDCT curve decreased at a same rate, but the CT-number in the center of the cylinder with a diameter 7, 10 mm in MDCT was low. At the images of the phantom for low contrast detectability in Fig.8, 9, objects of all sizes were separable in difference of 1.5% CT-number from background, spheres or cylinders of 3 mm diameter could not be separated in the differences of 1.0% CT-number in 4D CT and MDCT, but those of 2,3 mm diameter could not be separated in the difference of 0.5% CT-number in 4D CT. This result of 4D CT was attributed to the artifact, because present condition, 4D CT has not yet equipped with the application removing a ring artifact. With the assumption that this artifact is disappeared, 4D CT may demonstrate the low contrast detectability equal to MDCT.

4. CONCLUSION

The results were isotropic except for the evaluation of distortion in which small distortions gradually appeared as coming off the center of phantom in longitudinal direction. With regard to other items 4D CT shows same performance as conventional MDCT. Expecting there to be room for improvement of the artifact and reconstruction algorithm etc., we develop and research 4D CT to improve performance.

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REFERENCES

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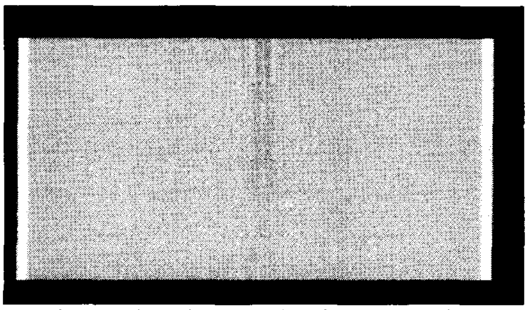

Fig.1 Noise phantom (longitudinal section)

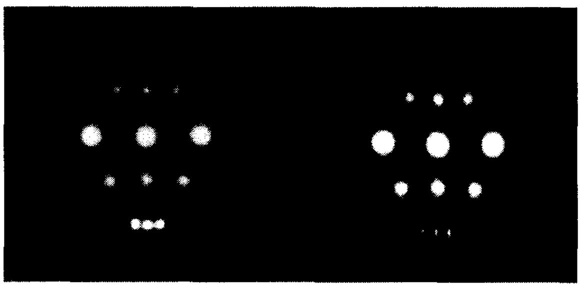

Fig.2 Resolution phantom
(left: transverse section, right: longitudinal section)

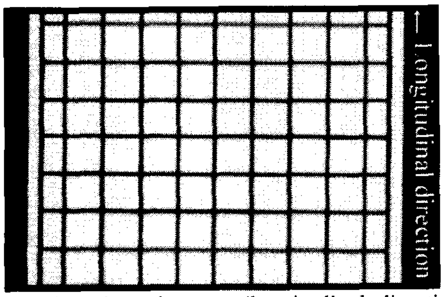

Fig.3 Distortion phantom (longitudinal direction)

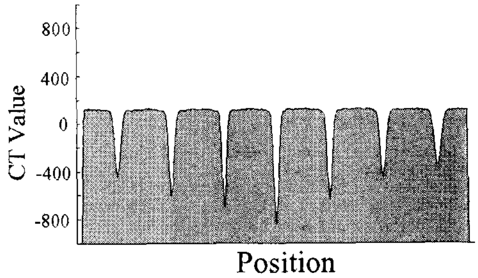

Fig.4 Profile through the image of the distortion phantoms along the longitudinal direction

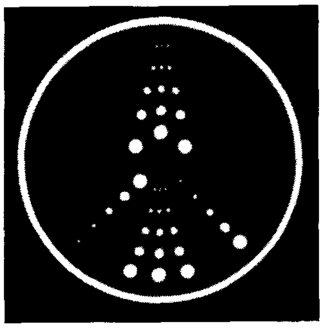

Fig.5 High contrast phantom
(4D-CT, transverse section)

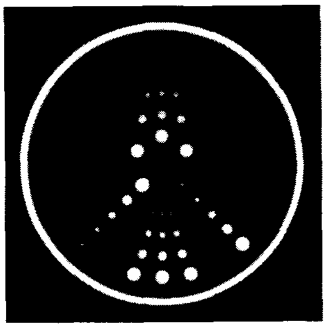

Fig.6 High contrast phantom
(Conventional MDCT, transverse section)

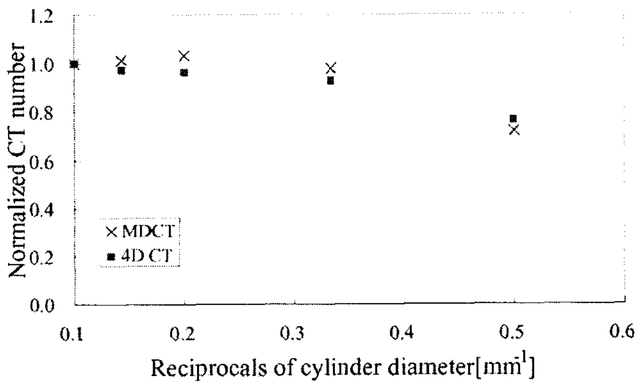

Fig.7 Relationship between the normalized CT-numbers of cylinders and the reciprocals of cylinder diameter

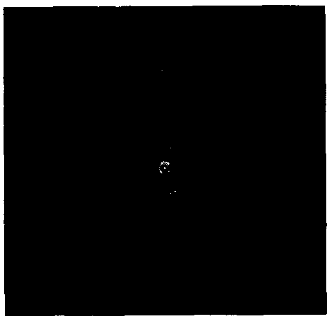

Fig.8 Low contrast phantom
(4D-CT, transverse section)

Fig.9 Low contrast phantom
(MDCT, transverse section)