Initial Clinical Application of Cone-beam CT Scan in Pulmonary Imaging

Ji-Chen Wang[1)] Shusuke Sone[1)] Feng Li[1)] Osamu Karakida[1)]
Kazuhiro Oguchi[1)] Hiroshi Hirano[1)] Hiroshi Takagi[2)]

1) Department of Radiology, Shinshu University School of Medicine 2) Research & Development Center, Hitachi Medical Corp.

コーンビームCTの胸部疾患への応用
－初期経験－

王　継琛[1)]，曽根　脩輔[1)]，李　峰[1)]，
唐木田　修[1)]，小口　和浩[1)]，平野　浩志[1)]，
高木　博[2)]

II-CCDカメラを受像系に用いたコーンビームCT装置を試用した．胸部疾患を有する13例に応用し，同時期に行った高分解能CT像と比較した．対象は12名(15病巣)であり，おもに淡い肺野の腫瘤影(大きさ2cm以下)を対象にした．試験期間中に偶然遭遇した主気管支の膜様狭窄症1名にも応用した．肺野の結節影について，その内部構造あるいは関連する細い気管支の見え方をみると，高分解能CT像よりやや劣っていた．濃度分解能不足によるとみられた．左主気管支の膜様狭窄症については，これを広い視野の冠状断像で観察でき，全体像が明瞭に把握できた．高分解能CT像のデータを用いた3-D再構成縦断像よりすぐれていた．上下方向に走る肺血管や縦隔大血管が存在する胸部領域の画像診断において，特に造影診断やIVRにおいて，本法は有用になると思われた．画質のさらなる改良が望まれる．

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1) 信州大学医学部放射線医学教室
2) 株式会社日立メディコ

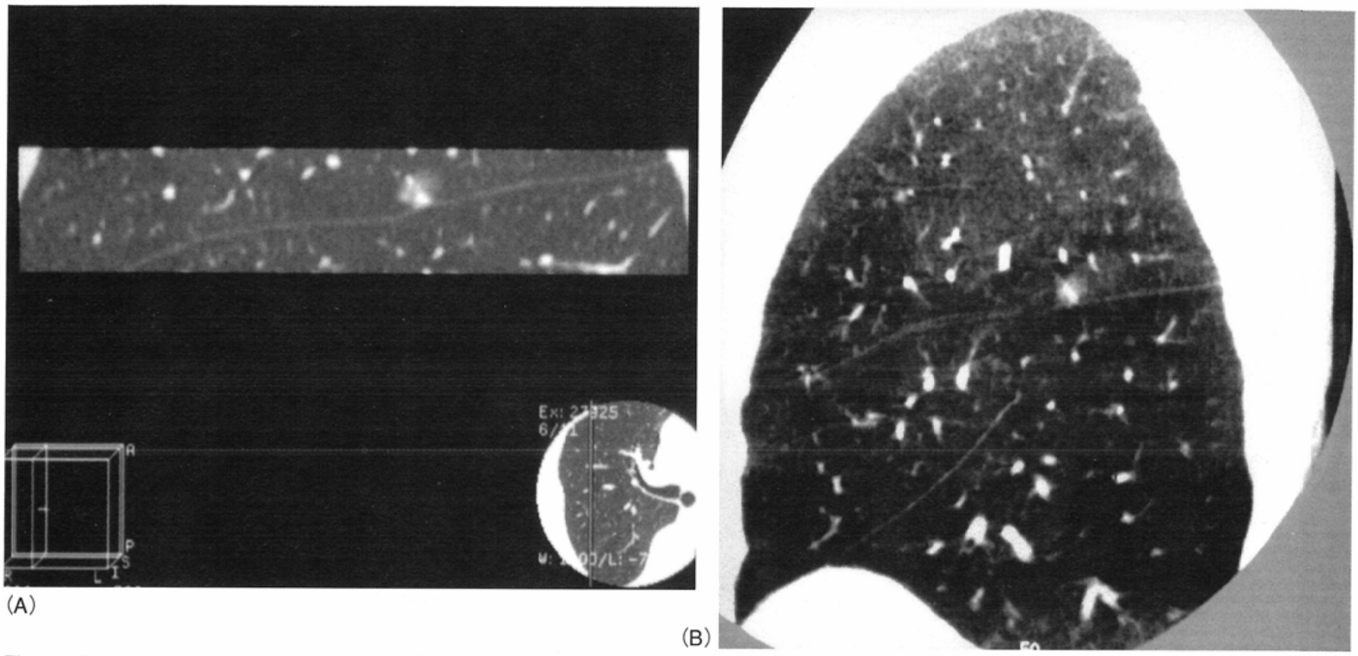
Introduction

High-resolution (thin-section) computed tomography (HRCT) has been the most effective imaging modality for the roentgenologic diagnosis of focal and/or diffuse lung diseases.[1)] However, HRCT is limited in directly obtaining high-resolution coronal or sagittal images that would provide a three-dimensional understanding of lung lesions and the surrounding anatomical structures. Cone-beam CT, in which volume data are acquired from the patient's body during a single breath hold and a single rotation of the scanner's imaging unit, solves this problem.[2),3)] We describe the initial clinical application to lung lesions of a cone-beam CT scan system.

Materials and Methods

We used a recently developed cone-beam CT scan system (CB/CT, Hitachi Medical Co., Tokyo, Japan) that consisted of an X-ray tube, which could continuously irradiate cone-beam X-rays during scanning, and an image intensifier as a detector, which was mounted on a single frame together with the X-ray tube. The rotation time of the scanner was 5 or 10 seconds, during which 288 or 576 projection images of the object were obtained from different angles to calculate X-ray attenuation for the 512 voxels and reconstruct axial, sagittal, coronal, or oblique images of the object. The display mode of the image intensifier was 9 or 16 inches, effective FOV 25 cm, and matrix size 512×512 (pixel size 0.4 mm). The estimated contrast resolution (ΔCT) was 40 HU. The reconstructed images could be postprocessed to display varying thicknesses, ranging from a thickness of 1 pixel (0.4 mm) to several centimeters (slab). We used images of one pixel in thickness to reconstruct three-dimensional images and display maximum-intensity-projection (MIP) images.

We performed scans on 13 patients with this system and also conducted HRCT examinations of the patients. Twelve of the patients had a total of 15 lung nodules smaller than 2 cm. The size of the lesions ranged from 5 mm to 20 mm (mean size 10.6 mm); six lesions were round or irregular in shape, well-demarcated, and showed soft-tissue density; three were irregular in shape, ill-defined, and heterogeneous in density; and six were irregu-



(A) (B)

Fig. 1 An 85-year-old woman with right S3 nodule.
A: Sagittal reconstruction HRCT image of 1 mm in thickness shows an ill-defined nodule of heterogeneous density.
B: A directly obtained large-scale sagittal image of cone-beam CT displays the lesion with almost the same clarity as HRCT. The lesion's relationship with the pleura is as clearly displayed as in the HRCT image. The double lines of the pleura are a motion artifact. The image is heterogeneous due to veiling glare.

lar or round and showed low, but heterogeneous density (CT numbers ranged between -200 HU and -850 HU). The remaining patient had bronchostenosis. Comparison HRCT images were obtained with a state-of-the-art CT scanner (Hi-Speed Advantage, GE Medical System, Milwaukee, WI). The scan factors were 120 kV and 200 mA. Scans targeted to cover the entire lesion were done with an X-ray collimation of 1 mm, and the images were reconstructed with an interval of 0.5 mm and FOV of 20 cm, using a bone algorithm.

We compared the cone-beam CT images with those of HRCT, with respect to demonstration of the lesion margin, shape, density, and relationship of the lesion with the pleura, bronchi, or pulmonary vessels.

Results

All lung nodules visible on the HRCT images were also demonstrated on the cone-beam CT images. Well-defined margins of the nodules were equally well visualized by cone-beam CT and HRCT. The shape and margin of nodules, together with the surrounding broncho-vascular structures, were well demonstrated. Ill-defined margins of nodules were also fairly well demonstrated (Fig. 1). Cone-beam CT was inferior in demonstrating heterogeneity of the internal structures, although a small translucent area was recognized (Fig. 2). The CT values measured with the current unit differed from those obtained with the standard CT scanner when the measurement was done for an area of interest in which veiling glare artifacts were present.

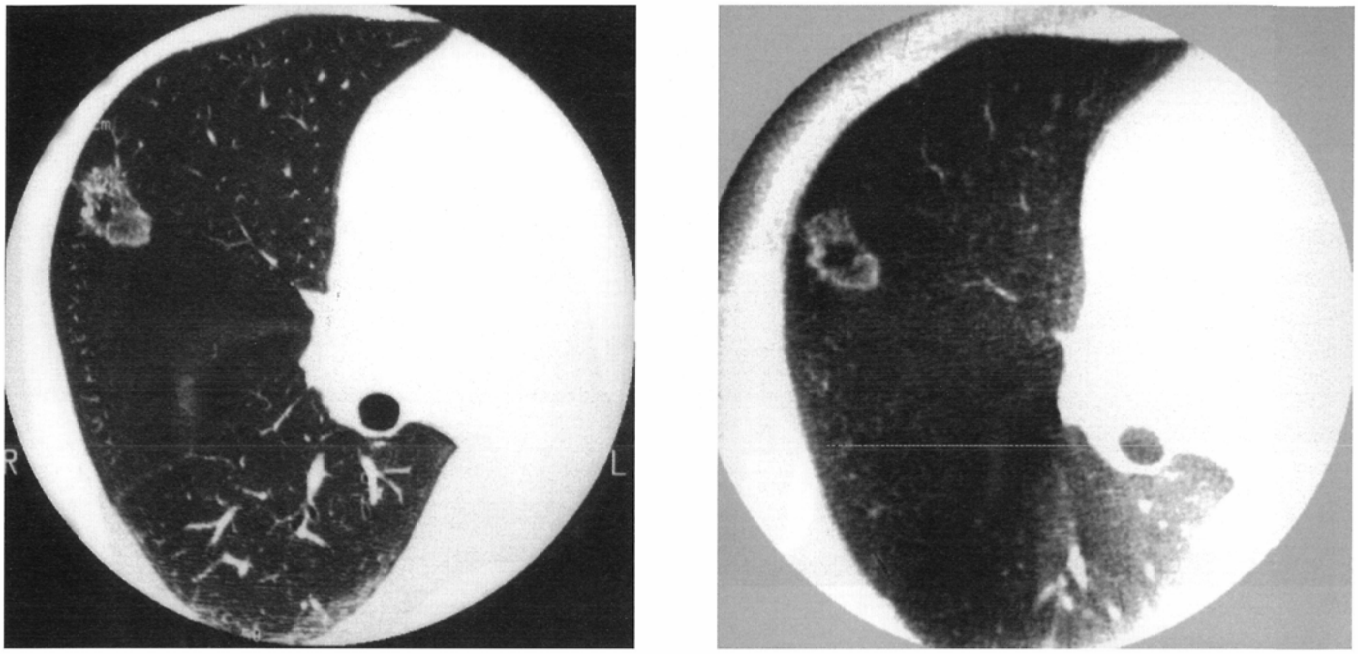
A remarkable advantage of the cone-beam system was seen in a patient with congenital bronchial stenosis. This 57-year-old woman 57-year-old presented with cough, and an abnormal sound like "piu, piu" could be heard in front of her chest when she took a deep breath or slept on her side. The chest X-ray film showed stenosis in the left main bronchus. The expiratory chest X-ray film showed air trapped in the left lung. Conventional CT showed stenosis in the left main bronchus. Cone-beam CT afforded a better perspective on the disease and displayed not only the full extent of the bronchial lumen but also the membranous septum in the left main bronchus (Fig. 3). Bronchial endoscopy demonstrated stenosis of the left main bronchus and the membranous septum.

Cone-beam CT images provided an easier three-dimensional understanding of all lesions in spatial relationship with the pulmonary vessels. Pleural tag or thickening could be well demonstrated (Fig. 4A). The low contrast resolution of cone-beam CT limited demonstration of small bronchioles, although the availability of longitudinal images meant that bronchioles could occasionally be better delineated (Fig. 4B).

Cone-beam CT revealed two types of artifacts in the prototypes of images: one was image heterogeneity due to veiling glare (Fig. 1B), and the other was ring artifact (Fig. 2B). Post-processing to correct these artifacts is under investigation. Because the patient needs to hold his or her breath for 5 or 10 seconds during cone-beam CT examinations, any slight movement will induce motion artifacts (Fig. 1B).

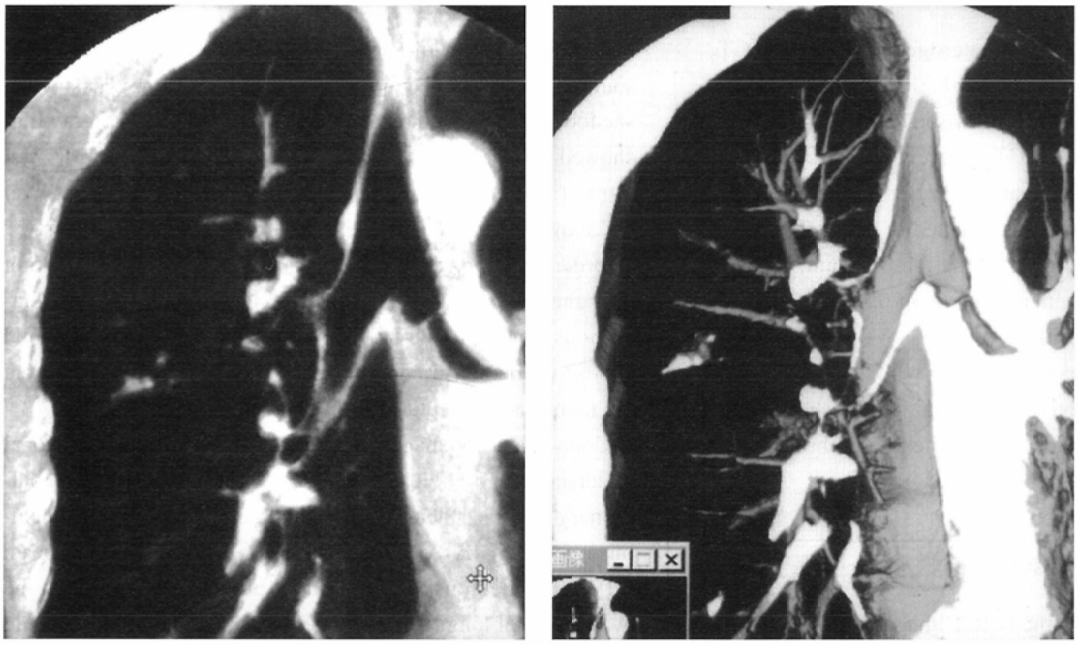
Discussion

Conventional CT is limited in terms of multi-planar display of the body's structures and of lesions. Even though spiral CT



(A) (B)

Fig. 2 A 69-year-old man with right S2 lesion.
A: Axial HRCT shows an irregularly shaped nodule with a central translucency.
B: Axial cone-beam CT shows a similar appearance of the lesion. Ring artifacts are present in the central region of the image.



A | B

Fig. 3 A 57-year-old woman with bronchostenosis.
A: Direct coronal image of cone-beam CT shows stenosis of the left main bronchus and a membranous septum.
B: Three-dimensional MIP image provides a similar appearance of the lesion.

is used for volume data acquisition, it is still unable to acquire large-scale, high-resolution, longitudinal images. This is because the longitudinal resolution of spiral CT is not as good as its transverse resolution. Further, the volume data of spiral CT are acquired progressively, and it is difficult to synchronize all the data in the same phase of organic movement to obtain large-scale image data.

Cone-beam CT makes it possible to acquire volume data of the object in a short, synchronous time, which aids in the reconstruction of multi-planar images and the diagnosis of lesions from a suitable planar image. High-resolution thin-section images in planes other than the axial plane, yet all taken at the same depth of breath holding, are available through this technique. Thus, cone-beam CT benefits the three-dimensional demonstration of morphologic features and offers dynamic contrast examination of a relatively large body volume, advantages that are not available with current, conventional CT. Longitudinal images are frequently effective in demonstrating lesions together with the related broncho-vascular structures.[4]

These immediate longitudinal images reduced the effect of partial volume averaging and did not show shifting of the slice level in thin-section images acquired during different breaths.

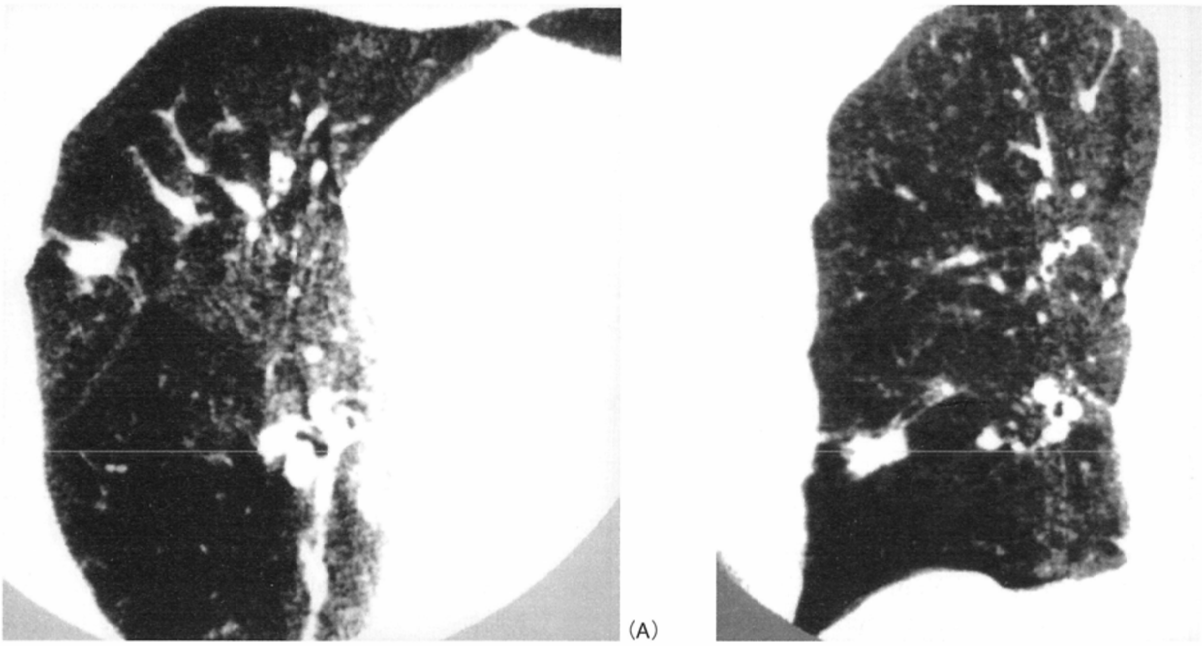


Fig. 4 A 75-year-old woman with right middle lobe nodule.
A: Cone-beam CT axial image displays the soft-tissue density nodule and has a pleural tag.
B: Cone-beam CT coronal image shows the nodule's shape together with the surrounding bronchial structures.

Thus, they helped to clarify the characteristics and distribution of calcifications relative to soft components of the lesion and discriminated calcifications from dense fibrous tissue.

It has already been demonstrated that cone-beam CT is useful in high-contrast parts of the body, for example, three-dimensional display of large thoracic vessels and bone structures.[3),5),6)] In this study, we demonstrated that cone-beam CT holds promise for the imaging of pulmonary parenchymal diseases.

The disadvantage of the current cone-beam CT system is its contrast resolution; the detector system, which is composed of the image intensifier and CCD camera, has low quantum efficiency and a narrow dynamic range[5)] and causes heterogeneity in the lung lesions. In this system, the optical iris is equipped and controlled in real time during scanning, to enlarge the dynamic range, and the contrast resolution is estimated to be $\Delta CT = 40$ HU. Another disadvantage is X-ray scatter, which may be inevitable with non-collimated X-ray irradiation such as that in cone-beam X-rays. However, a highly promising advantage of this system was revealed in a patient with membranous septum in the major bronchus, which was clearly recognized in the coronal plane images of cone-beam CT to an extent that was not available with conventional CT.

In conclusion, our current cone-beam CT system was adequate for demonstrating clinically significant small lung nodules, however, it did not permit excellent demonstration of ground-glass opacity or inhomogeneity in the lung nodules. It has the advantage of easy reconstruction of thin-section longitudinal computed tomography images, and is not subject to the problems of the partial volume effect. Three-dimensional volume data are beneficial in postprocessing, including the construction of MIP images, which assist in the three-dimensional understanding of lung lesions in relation to the surrounding anatomical structures.[6)] These features may be widely used in the future clinical practice of radiology, particularly in the fields of interventional radiology and radiation therapy. It is hoped that in the near future an innovative solid-state X-ray detector may be used instead of the image intensifier, to improve the quality of cone-beam CT images and reduce artifacts.

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