Computer-aided diagnosis workstation and database system based on multihelical CT images

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SUMMARY

Lung cancer is the most common cause, accounting for about 20% of all cancer deaths for males in Japan. Myocardial infarction is also known as a most fearful adult disease. Recently, multi-helical CT scanner advanced remarkably at the speed at which the chest CT images were acquired for screening examination. This screening examination requires a considerable number of images to be read. It is this time-consuming step that makes the use of multi-helical CT for mass screening. To overcome this problem, our group has developed a computer-aided diagnosis algorithm to automatically detect suspicious regions of lung cancer and coronary calcifications in chest CT images, so far. And in this time, our group has developed a newly computer-aided diagnosis workstation and database. These consist in three. First, it is a image processing system to automatically detect suspicious bronchial regions, pulmonary artery regions, pulmonary vein regions and myocardial infarction regions at high speed. Second, they are two 1600×1200 matrix black and white liquid crystal monitor. Third, it is a terminal of image storage. These are connected mutually on the network. This makes it much easier to read images, since the 3D image of suspicious regions and shadow of suspicious regions can be displayed simultaneously on two 1600×1200 matrix liquid crystal monitor. The experimental results indicate that a newly computer-aided diagnosis workstation and database system can be effectively used in clinical practice to increase the speed and accuracy of routine diagnosis.

1. INTRODUCTION

Cancer is responsible for 25% of all deaths in Japan, and this figure is increasing every year. Among deaths from cancer, lung cancer is the most common cause, accounting for about 20% of all cancer deaths for males in Japan. In order to improve the survival rate for lung cancer, early detection and treatment are essential.

The development of single helical CT scanners that can image the lungs in a short time has created interest in the use of these scanners for mass screening. In the mass screening process, single helical CT images are acquired for the entire lung area. Myocardial infarction is also known as the most fearful adult disease.

The same images used in the mass screening process to diagnose lung cancer, can also be used for diagnosis of coronary calcifications.

However, if a single helical CT is used in the mass screening process to diagnose lung cancer and coronary calcifications, the diagnostic efficiency deteriorates because doctors have to read numerous images. Therefore, our group has developed a computer-aided diagnosis (CAD) system to automatically

detect suspicious regions of lung cancer and coronary calcifications in chest CT images of 10 mm intervals for screening examinations.
In addition, we have developed PACS for a computer-aided diagnosis (CAD) system.
We reported the results of these clinical studies in Medical Imaging Proceedings of SPIE. Recently, the multi-helical CT scanner has advanced remarkably to a speed at which the chest CT images were acquired for screening examinations.

As a result, doctors hope to diagnose lung diseases and myocardial infarction by referring from not only the image at 10mm slice intervals but also then to a thinner image at slice intervals at the same time.
A doctor will be able to diagnose lung diseases and cardiac infarction disease accurately by referring to the multi-slice CT images of high spatial resolution so far.
However, mass screening based on multi-helical CT images requires a considerable number of images to be read. It is this time-consuming step that makes the use of multi-helical CT for mass screening impractical at that time.
To overcome this problem, our group has developed a newly computer-aided diagnosis (CAD) workstation and database system for chest diagnosis based on multi-helical CT images.

2. DIAGNOSTIC ALGORITHM

In mass screening for lung cancer, helical CT images are acquired using the scan conditions shown in Table 1. These scan conditions have been determined by taking the scan time, exposure dose, image quality, image reading efficiency, etc. into consideration and have been adopted as the standard scan conditions for lung cancer screening by the Tokyo Health Service Association (Anti-Lung Cancer Association) and many other institutions. This section describes the four main features of our computer-aided chest diagnosis system: an algorithm that detects suspected lung cancers in CT images acquired using the scan conditions shown in Table 1; an algorithm that detects suspected coronary artery calcification; a multiplanar reconstruction technique that displays arbitrary cross sections of CT images; and a method for visualizing the suspected lesions three dimensionally.

Table 1. Scanning Conditions for Screening Examinations

Beam width	2.0 mm
Table speed	22 mm/sec
Tube voltage	120 kV
Tube current	30 mA
Scan Duration	16 sec

2.1 Automated Detection of Lung Cancer Nodules

We have already reported on a prototype CAD system for automatic detection of suspicious regions from chest CT images. The algorithm for the detection of candidate lung cancer regions was applied to the helical CT images of 500 subjects (total: 15750 images). The sensitivity of automatic detection of nodules was about 95%. Figure 1 shows the flowchart of the CAD system with automated detection of lung cancer nodules.

The suspected lung cancer detection algorithm was applied to 15,750 CT images obtained from 500 subjects. Table 2 shows the screening results for these 500 subjects and the results after processing with the suspected lung cancer detection algorithm. As shown in Table 2, 309 shadows in about 15,750 CT images contained suspected lung cancers. When a screening physician who cooperated in the study read about 15,750 CT images without the assistance of a computer-aided diagnosis (CAD) system, 245 of these 309 shadows were true positive (TP) and 64 were false negative (FN). When the same screening physician performed image diagnosis with the assistance of a CAD system in which the suspected lung cancer detection algorithm was installed, 290 of the shadows were TP and 19 were FN. The processing results achieved by the CAD system were 212 TP and 97 FN. In other words, 45 suspected lung cancers that were missed by a physician without the assistance of the CAD system were identified as positive lesions in diagnosis by the same physician with the assistance of the CAD system. This finding suggests that diagnostic accuracy can be increased if physicians perform diagnosis with the assistance of a CAD system.

When reading mass screening CT images, several physicians at the National Cancer Hospital and National Cancer Hospital East sometimes use previously acquired CT images for comparison. Therefore, the CAD system has to be equipped with functions to automatically detect suspicious regions from chest CT images and to assist in the comparative reading of present and past CT images. To meet the needs expressed by the physicians, we developed a new CAD system with a function for assisting comparative reading. The CAD system is equipped with a slice matching algorithm for comparison of slice images of interest in present and past CT scans. It is also equipped with a function for the display of feature measurements of suspicious regions. The slice matching algorithm consists of the extraction of the lungs, heart, and descending aorta and the matching of the slices of the present and past scans using these three extracted regions. After the slice matching algorithm is applied, corresponding slice images of interest in the present and past CT scans are displayed in parallel on the CRT monitor.

We applied this algorithm to 50 subjects(total:150 CT scans). The combination number of the comparison of each slice image in the present and the early CT scans was 100 (total:2,806 slice images). This algorithm could compare correctly the slices in 90 (total:2,734 slice images) of 100 CT scans combination with respect to physician's point of view. Physician's point of views are the region of the blood vessel and the bronchia tube with respect to each slice image. The combination number of false comparison is 10 of 100 CT scan combination. The reason of false comparison is as follows. If the subject does not breath enough in the present CT scan, the size of his lung region may be different from that of earlier CT scan. In this case,we can not compare correctly the slice images of the present and the earlier CT scans by using the information of lung region. If we can not detect correctly the slice image of the aortic arch by the influence of the artifact and the other, we can not copmare correctly the slice images of the present and the earlier CT scan, too. If the result by using information of the lung region and aortic arch is false, the automated comparison of each slice image in the present and the earlier CT scan may be false finally.

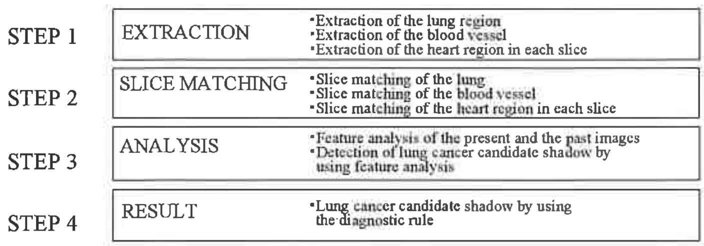

Figure 1. Flowchart of Automated Detection of Lung Cancer Nodules

Table 2. Result of clinical field test program

Judgment	Agreed results	physician		CAD system		physician(with CAD)	
		TP	FN	TP	FN	TP	FN
E	309	245	64	212	24	290	19

Table 3. Criterion of judgment

E-Judgment	Sure Coronary calcifications
D-Judgment	Probably Coronary calcifications

Table 4. Application of our algorithm to 402 patient's data

	Detection ratio
E-Judgment	68/68 (100%)
D-Judgment	102/102 (100%)

2.2 Automated Detection of Coronary Artery Calcification

The CT images acquired in mass screening for lung cancer, which include the entire lung field, were also analyzed using the suspected coronary artery calcification detection algorithm. First, the slice range covering the heart was identified. The uppermost slice position was determined based on the distance between the right and left lobes of the lungs, the positions of the clavicles, and the shape and area of the heart. The lowermost slice position was determined based on the position of the diaphragm. Since the courses of the coronary arteries in each slice were known, the slices were grouped into three zones including the various courses of the coronary arteries based on the shape of the heart, density distribution, position of the trachea, and bony structures.
Table 4 shows the results obtained when the suspected coronary artery calcification detection algorithm was applied to about 13,000 CT images obtained from 402 subjects. An expert physician diagnosed all the data of coronary artery calcification by the criterion shown in Table 3. Shadows classified as category E are strongly suspected to indicate calcification of the coronary artery and therefore require detailed examination. Shadows classified as category D are those for which coronary artery calcification cannot be ruled out. Table 4 shows that 170 shadows in the 13,000 CT images were suspected to indicate coronary artery calcification and that the CAD system with the suspected coronary artery calcification detection algorithm correctly identified all of the 68 shadows in category E (100% detection) as well as all of the 102 shadows in category D (100% detection).

STEP 1	CLASSIFICATION	•Classification the heart slices into three sections which have different coronary geometries
STEP 2	EXTRACTION	•Extraction of the heart region in each slice
STEP 3	DETECTION	•Detection of the candidate regions of the coronary calcifications
STEP 4	RESULT	•Removal of the artifact regions included in the candidate regions by using the diagnostic rules

Figure 2. Flowchart of diagnostic algorithm of coronary calcification

2.3 Multiplanar Reconstruction

Images acquired using a multislice helical CT scanner are cross-sectional (axial) images perpendicular to the body axis. Multiple slices are acquired continuously while the patient couch of the CT scanner is moved at constant speed. From these images, the required data and pixel values are extracted and displayed as images as shown in Figure 3 using the multiplanar reconstruction (MPR) technique. These axial images can be converted into coronal, sagittal, and oblique sections, and the generation and display of such sectional images is referred to as "MPR display". Since the pixel data obtained from a DICOM file does not represent the aspect ratio correctly, three-dimensional voxel data is generated by linear interpolation.

The CT value of each voxel can be obtained by specifying the corresponding address using its three-dimensional coordinates. Sagittal or coronal images can be obtained by converting the coordinate system perpendicular to the body axis to the desired sectional plane. An oblique section can be obtained by slicing the volume data at an arbitrary position and angle. The CT values at the coordinates contained in the section are used to reconstruct the corresponding oblique image. Figure 4 shows an example of image processing and the results of the display by using two black-and-white liquid crystal display monitors with a matrix size of 1600 x 1200. Figure 3 shows the appearance of the operating panel. The operating panel consists of a main window, dialog box I, and dialog box II. The main window displays axial, coronal, oblique, and sagittal images in order from the upper left to the lower right. Dialog box I contains the controls for setting the slice position, threshold, slice thickness, drawing method, and continuous drawing. The settings for the slice position, threshold, and slice thickness can be changed by entering the desired values directly, by clicking the spin control, or by pressing the up/down arrow keys in the edit box. Controls that are not currently available are grayed out. Dialog box II contains the dedicated controls for displaying oblique sections. It includes guide lines for determining the slice position and buttons for selecting the oblique image creation method: linear interpolation or nearest neighbor interpolation. When the values on the display angle control panel are changed, the guide lines move accordingly.

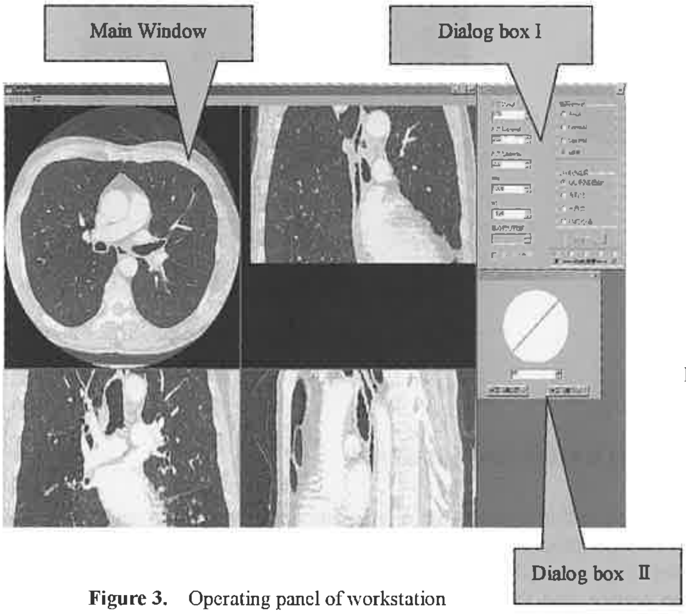

Figure 3. Operating panel of workstation

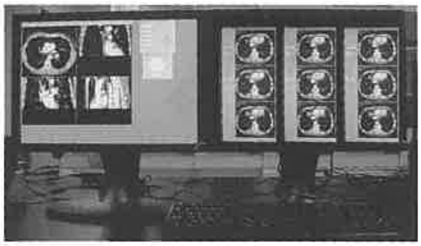

Figure 4. Two black-and-white liquid crystal display monitors with a matrix size of 1600 x 1200

2.4 Virtual Endoscopic Image

In multislice helical CT images of the chest, a continuous tubular structure (pulmonary artery, pulmonary vein, or bronchus) can be extracted automatically by performing comparison repeatedly starting from a predefined point. This automatic extraction technique takes "ambiguity" into account and can extract small tubular structures measuring approximately 1 mm in diameter. A threshold filter is used for extraction. With regard to peripheral blood vessels, however, the differences in CT values between blood vessels and surrounding tissues are very small and filtering with fixed thresholds is therefore difficult. If a threshold suitable for extraction in peripheral regions is specified, unnecessary areas are extracted in the hilum of the lung and good results cannot be obtained even in peripheral regions.

To overcome these problems, the upper and lower limits of the extraction range are set so that the difference between them is large, while the difference between the CT values to be used as criteria for determining whether a voxel is continuous with those of peripheral parts of the target anatomy is set to a small value. Using these settings, the pixels in which the edge value (difference in CT values) reaches or exceeds the specified value are determined not to be continuous with the target anatomy. As a result, good extraction results are obtained both in peripheral regions and in the hilum of the lung. The automatically extracted pulmonary arteries, pulmonary veins, or bronchi can be selectively displayed three dimensionally in color in order to assist in the detection of lesions. Figure 6 shows examples of display of pulmonary blood vessel and bronchial tube.

A three-dimensional display image of the bronchial lumen is referred to as a "virtual endoscopic image". An principle chart of a virtual endoscopic image is shown in Figure 5. In the virtual endoscopy technique, CT images are processed to generate images comparable to actual endoscopic images of the bronchi, thus avoiding the patient discomfort associated with actual endoscopic examinations. This technique is useful as a screening examination for cancers in the hilum of the lung. This computer-aided chest diagnosis system uses high-speed OpenGL 3D graphic display to display the bronchial lumen three dimensionally in real time each time the viewpoint is moved.

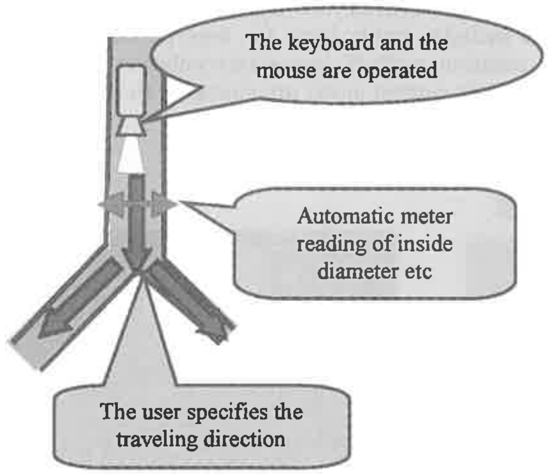

Figure 5. Principle chart of endoscopy

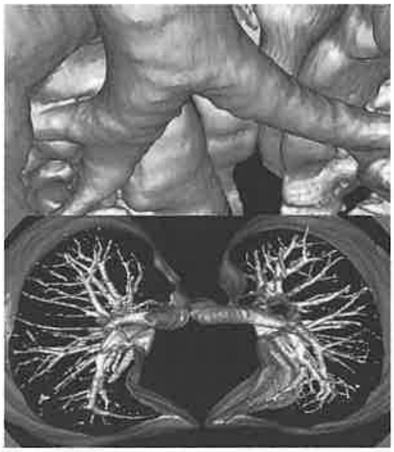

Figure 6. Three-dimensional display image of the bronchial lumen

3. WORKSTATION AND SYSTEM

The computer-aided chest diagnosis system described in this report stores a large amount of multislice helical CT image data for the chest, retrieves images from the database, processes the images, and displays the processed images. This system is also provided with user interfaces that support reading of various types of images and includes three main modules: a data processor, a CAD image filing system, and an image storage and retrieval system. The data processor extracts and displays the bronchi, pulmonary arteries, pulmonary veins, and suspected lesions in a short time. The CAD image filing system retrieves images from the dedicated CT image database and displays them on two black-and-white liquid crystal display monitors with a matrix size of 1600 x 1200 (Figure 8). The data storage and retrieval system (TFS-3000, Toshiba) employs a CD-R autochanger (jukebox). These modules will be all connected via a network shown in Figure 7. The computer-aided chest diagnosis system can display a two-dimensional CT image containing a suspected lesion on one monitor and simultaneously display a 3D image showing the suspected lesion together with the automatically extracted pulmonary arteries, pulmonary veins, and/or bronchi on the other monitor. This helps the physician to clearly visualize the positional relationships between the suspected lesion and surrounding anatomical structures, thus facilitating diagnosis. In addition, the suspected lung cancer detection algorithm discussed in section 2.1 and the suspected coronary artery calcification detection algorithm discussed in section 2.2 will be able to installed in the CAD image filing system shown in Figure 8. Figure 9 shows the two black-and-white high resolution liquid crystal display monitors.

This computer-aided chest diagnosis system is installed in a Dell Precision 340 PC with a 2.6-GHz Pentium 4 processor running Windows 2000. Two black-and-white liquid crystal display monitors (Totoku) with a matrix size of 1600 x 1200 are connected to this system. Clinical trials to evaluate this system are currently underway.

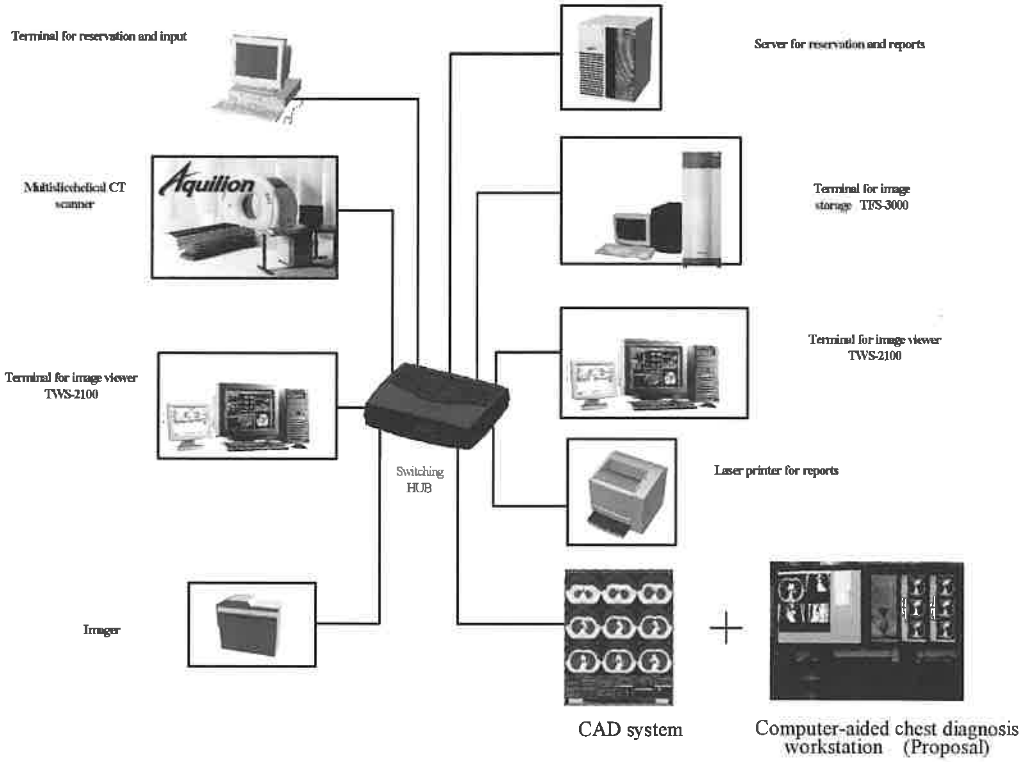

Figure 7. A system chart of facility equipped with CAD system and computer-aided chest diagnosis workstation

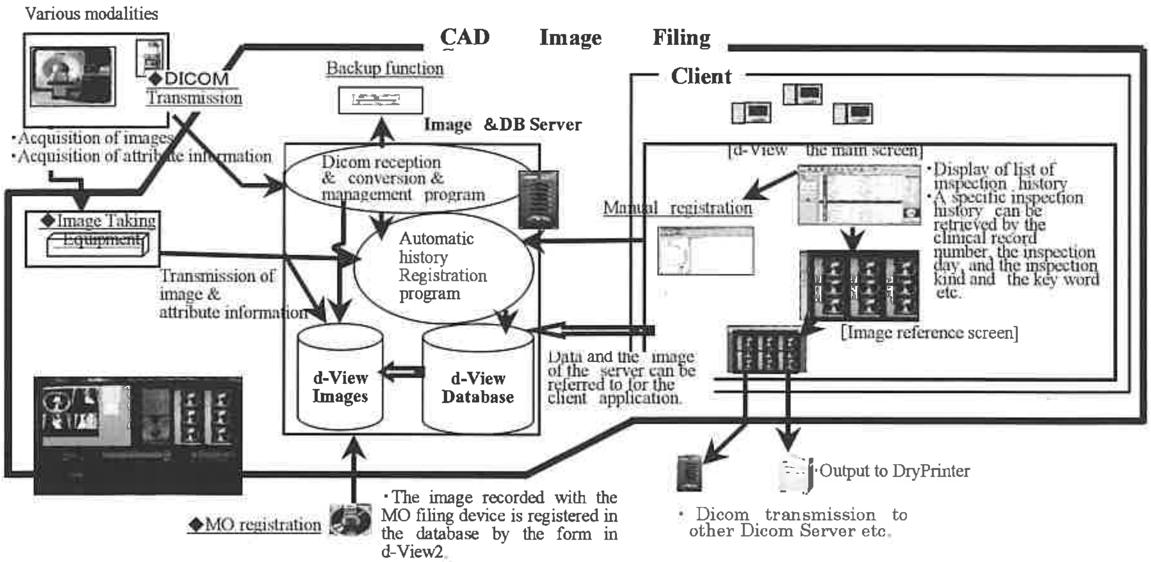

Figure 8. CAD Image Filing System

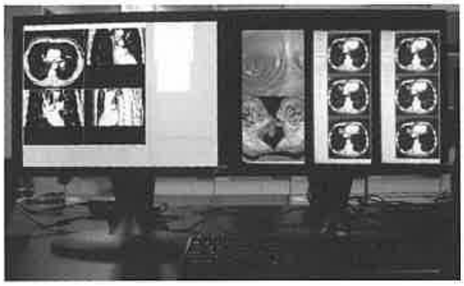

Figure 9. Two black-and-white high resolution liquid crystal display monitors (Computer-aided chest diagnosis workstation)

4. RESULT

Our group has developed a newly computer-aided diagnosis (CAD) workstation and database system for chest diagnosis based on multi-helical CT images. A newly computer-aided diagnosis (CAD) workstation and database system consists of three: First, it is a CAD image filing system. Second, there are two 1600*1200 matrix high resolution liquid crystal monitors. Third, it is a terminal for image storage.

The function of the CAD image filing system and database system consists of

1) display of inspection history list, retrieval of inspection history
2) display of axial, sagittal, coronal and oblique section images in two 1600×1200 matrix high resolution liquid crystal monitors at high speed and in an easy operation based on multi-helical CT images preserved in a terminal for image storage
3) automatic extraction of bronchial regions, pulmonary artery regions and pulmonary vein regions from chest multi-helical CT images of 1.0 mm or 2.0 mm intervals for screening examinations
4) volume rendering 3D displays of internal organs, pulmonary blood vessel and bronchial tube in two 1600×1200 matrix high resolution liquid crystal monitors at high speed and in an easy operation.
5) virtual endoscopic images of bronchial tube based on chest multi-helical CT images of 1.0 mm or 2.0 mm intervals for screening examinations
6) multiplanar reconstruction(MPR) for tubular internal organs at high speed and display in an easy operation

This makes it much easier for the doctor to read images, and be able to diagnose lung diseases and cardiac infarction diseases accurately by referring to the multi-slice CT images of high spatial resolution. The results of our clinical studies have shown that this system improves efficiency in image interpretation and reduces the risk of missing lung cancer shadows and coronary calcification shadows on chest multi-helical CT images. We have conducted studies to assess the usefulness of this system in actual clinical practice. The experimental results indicate that a newly computer-aided diagnosis (CAD) workstation and database system can be effectively used in clinical practice to increase the speed and accuracy of routine diagnosis.

5. CONCLUSION

Due to significant technological advances in multislice helical CT systems, image acquisition has become faster and image quality has been further improved. In addition, the CT images used for lung cancer screening and for screening for coronary artery calcification that may cause a myocardial infarction cover the entire lung field, which is a wide range. Due to these factors, physicians must read a larger number of images and are also required to have higher image-reading skills. The interpretation of CT images for chest screening places a heavy burden on physicians and is extremely time-consuming. To address these problems, we have examined and identified the functions that are required for a computer-aided chest diagnosis system for multislice helical CT images.The results of this study indicate that our computer-aided chest diagnosis system can increase diagnostic speed and accuracy and can be employed effectively at clinical sites.

At present, CT images for chest screening are read twice by different physicians. As CAD systems gain more widespread acceptance in the near future, it is expected that a single physician will be able to read images with the assistance of a computer, thus helping to promote the more efficient use of scarce human resources.

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