Producing a Manual for the Multidetector-Row Computerized Tomography (MDCT) Imaging Method for Lung Cancer Screening

(Technical Committee Report 2005)

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1. Introduction

Thanks to joint research with the Japanese Society of Radiological Technology (JSRT), the Technical Committee of the Japanese Society of Computerized Tomography Screening (JSCTS) has been producing a manual for single-detector CT (SDCT) and MDCT imaging methods and has published the results in the *Journal of the Japanese Society of CT Screening*, *Japanese Journal of Radiological Technology*, and both the JSCTS and JSRT websites.[1)-5)] The present report is a revision of the *Manual of MDCT Imaging Method 2004*. The table of contents of the manual and the authors for each chapter are as follows:

1. Introduction (Toru Matsumoto)
2. Multidetector-Row CT imaging conditions for lung cancer screening: Issues to be discussed to determine optimal imaging conditions (Ito)
3. Radiation dosimetry for MDCT screening (Nishizawa, Okamoto)
4. Control of image quality and radiation exposure (Muramatsu, Gomi, Takayama)
5. Equipment configuration of MDCT system (Masao Matsumoto, Okamoto)
6. Imaging method (Tsuda, Nakamura)
7. Quality control of X-ray CT system (Hanai)
8. MDCT Risk-Benefit analysis for lung cancer screening (Murano)
9. Terminology (Tsuda)

This manual is targeted for 4-row and 16-row MDCT scanners for screening among the ever-evolving variations of multi-functional MDCT scanners and is organized with the basic concept of “providing conditions of exposing examinees to less radiation than SDCT imaging from the previous manual.” This report is the abridged version of the manual. We have paid attention to providing the latest technology. Practical knowledge of the CT imaging method discussed in Chapter 6 will be very useful for people and institutions currently performing CT screening, as well as those who plan to use it in the future. MDCT screening safety standards have been added to Chapter 8. In addition to enhancing the content of Chapters 2, 4, and 5, we will review the issues that are not currently standardized and will produce a detailed version, including experimental data to support the manual guidelines and publish the full text of these results on the JSCTS website.

This report is the culmination of a joint project with the JSRT Scientific Committee (Chairman: Tsukasa Yoshitomi) Research and Survey Group (Leader: Toru Matsumoto). We would like to thank all of the people who have provided support to this project.

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2. Multidetector-Row CT imaging conditions for lung cancer screening: Issues to be discussed to determine optimal imaging conditions

2-1 Basic policy to determine MDCT imaging conditions for lung cancer screening

As is the case with single-detector row CT (SDCT), the fundamental principle is "acquiring images that allow you to reliably identify solid pulmonary nodules with a diameter of not less than 5 mm and ground-glass pulmonary nodules with a diameter of not less than 10 mm, with the minimum radiation dose within one breath-holding period." In addition, it is necessary to acquire images with at least the same radiation dose as that of the standard imaging conditions of the present SDCT.

The issues discussed in the SDCT for lung cancer screening are as follows. (1) About 5-10% of nodules with a diameter of 5-10 mm can be overlooked. (2) The percentage of examinees who require reexamination due to inaccurate evaluation of nodule size and characteristics is comparatively high. It is desirable that these points be addressed in MDCT screening, with precise measurement of the size of uncalcified nodules with a diameter of 5-10 mm to replace the first thin-slice CT screening criterion at follow-up.

2-2 Setting the MDCT imaging conditions for lung cancer screening

In this report, when a value of *table feed (mm/rotation) / whole detector thickness* is around 1.5, the setting is referred to as "high pitch." Settings with a value of around 1 and 0.7 are referred to as "median pitch" and "low pitch," respectively. Tables 1 and 2 show the imaging conditions to acquire images of whole lung field (30 cm) within 15 s by 4-row and 16-row MDCTs with a speed of 0.5 s/rotation and the measured results of radiation dose and noise by utilizing Aquilion (Toshiba) under these conditions. When the 30 cm field in the cranio-caudal direction is acquired under the imaging conditions, the detector thickness is 5 mm, pitch 2 (table feed 10 mm/rotation), and tube current 50 mA (25 mAs) in the same type of SDCT. The manufacturer's nominal value of weighted CT dose index (CTDIw) is 1.1 mGy. Consequently, it would appear the reference values are 50 mA (25 mAs) for high pitch, and 25-35 mA and 12.5-17.5 mAs for median pitch and low pitch, respectively. Moreover, to acquire images with constant image quality over the whole lung field, application of the technology to control the tube current in the X-Y and Z axes is more important for MDCT with thin detector thicknesses.

Even if thinner slices can be acquired, imaging conditions causing significant dose increases are undesirable for screening. According to our measurements, a detector thickness of 0.5 mm should not be adopted because it enhances over-beaming and deteriorates dose efficiency and results in a higher noise level.

Setting the detector thickness should be considered as follows. When the role of screening CT is confined to no oversight of nodules not less than 5 mm and determination of whether the nodule size is larger than 5 mm with prominent calcification, and the images are acquired with a comparable dose of radiation, smaller detector thicknesses increase noise levels and acquisition times with the same image reconstruction thickness. For this reason, detector thicknesses of 2-2.5 mm may be appropriate. Additionally, detector thicknesses of 4-5 mm are considered to be appropriate for 4-row CT.

In contrast, if the purpose of CT screening is to eliminate the first thin slice CT by evaluating the size and characteristics of the nodule precisely, it is desirable to use detector thicknesses of 2-2.5 mm for 4-row CT and 1-1.25 mm for 16-row CT. Although this method has the advantage of lessening examinee burden due to reexamination, there are some issues needing to be solved. It is necessary to determine if the images with high noise level that are acquired with low radiation dose can provide the same information as that of regular thin-slice CT. In addition, software that can measure the size of 5-10 mm diameter nodules precisely and repeatedly is required. It is also necessary that this software works precisely with low-dose images for screening and to acknowledge the effects that differences between detector thickness and image reconstruction thickness can have on measurement accuracy.

According to our basic evaluation of the pitch setting, when radiation dose and detector thickness are constant, high pitch causes (1) high noise level, (2) larger measurement error of dummy tumor diameter, and (3) deteriorated visual evaluation of dummy tumor. For this reason, it may be advisable to set the pitch lower when the detector thickness is 4-5 mm for 4-row CT and 1-1.25 mm for 16-row CT.

Regarding the image reconstruction setting, image reconstruction with a 5 mm thickness and 5 mm interval is realistic for film reading. In contrast, although image reconstruction with a 3 mm thickness and 3 mm interval seems realistic for monitor reading, further evaluation is required, considering the loads of image reading and storage. Moreover, if replacing the first thin slice CT with the screening CT is intended (as described earlier), some measures need to be implemented because reconstruction of thin slice images over the whole lung field causes too large of a load.

Because of the difficulty in deciding MDCT imaging condition standards for lung cancer screening, evaluating the optimal imaging conditions for each medical institution is necessary, considering the issues described above and the characteristics of the screening.

Table 1 Measurement results of radiation dose and noise level for 4-row MDCT (reference value of Aquilion; Toshiba)

Detector thickness (mm)	4	4	2
Pitch factor *1	1.375	0.75	1.375
Tube current (mAs)	25	12.5	20
CTDIw (mGy)	1.30	1.30	1.24
Noise ratio *2	1.0	1.15	1.23
Acquisition time (s)*3	6.8	12.5	13.6

*1: table feed (mm/rotation) / whole detector thickness

*2: Ratio to the conditions with minimum noise level

*3: Assume scan length of 300 mm

Table 2 Measurement results of radiation dose and noise level for 16-row MDCT (reference value of Aquilion; Toshiba)

Detector thickness (mm)	2	2	1	1	1	0.5
Pitch factor *1	0.9375	0.6875	1.4375	0.9375	0.6875	1.4375
Tube current (mAs)	17.5	12.5	25	17.5	12.5	22.5
CTDIw (mGy)	1.36	*4	1.30	*4	*4	1.31
Noise ratio *2	1.0	1.06	1.27	1.11	1.2	1.49
Acquisition time (sec)*3	5	6.5	6.5	10	13.6	13

*4: To get the same radiation dose, the conditions for dose measurement were set to approximate the value of *tube current* × *acquisition time*, but the dose is slightly lower for low pitch due to the restriction of the tube current selection.

3. Radiation dosimetry for MDCT screening

3-1 Introduction

Developments in, and improvements to, the CT imaging system have been remarkable. In 1999, the MDCT was introduced and is equipped with 4-row detectors in opposite axis directions. Increasing the number of detector rows is still progressing. The number of institutions utilizing the MDCT is increasing, and currently there are about 2,000 CT imaging systems installed in Japan. However, diagnostic CT examination draws some concern because examinee radiation exposure is generally high. In screenings that may include healthy examinees, measures to reduce radiation dose are implemented and low-dose screening is realized. MDCT with improved operability and functionality enables wide-range imaging, but radiation dose tends to increase. Therefore, when screening conditions are determined, it is very important to take radiation dose into consideration, as well as quality assurance (QA) and quality control (QC).

3-2 Radiation dosimetry for quality assurance and quality control

When an X-ray CT system is installed, medical institutions should make note of the following issues in radiation dosimetry:

(1) Dose output is sufficient for screening.

(2) Dose output is not excessive.

As with SDCT, it is very important to abide by these two points. Whether or not the dose is sufficient to meet analytical needs is verified as part of the inspection process during system installation. After installation, whether the system can maintain the adequate dose also is checked.

<u>Conditions to be met by dose index</u>

(1) To be explicitly defined and easy to measure for wide use.

(2) To be consistent with other notations of dose when used normally.

(3) To be meaningful indices for examinees' radiation exposure, considering the specifics of scan technology used in each scanner.

<u>Radiation dose of CT</u>

There are many methods to evaluate CT radiation dose, and each method has its advantages and disadvantages. The CT Dose Index (CTDI) is commonly used both within Japan and abroad and is recommended to assure reproducibility and accuracy. However, the CTDI requires rather expensive dedicated measuring instruments and phantoms, which makes it a challenge for all facilities to be equipped with such tools. It is acknowledged that conventional CTDI measurements use a pencil ionization chamber of 100 ± 5 mm in length, not more than 10 mm diameter, and PMMA phantoms of 140 mm in length (160 mm diameter for head, 320 mm diameter for body) and might not support the broad penumbra and increased radiation scattering when the beam width per rotation increases concomitant with increases in the number of detector rows. However, this measured value is used to elucidate temporal dose changes.

Before the measurement, MDCT manuals and technical data used in the facility should be consulted, and the measured $CTDI_{100}$ value, slice thickness, and number of detector rows at the time of measurement should be checked (please refer to SDCT manuals for details of $CTDI_{FDA}$, $CTDI_{100}$, $CTDI_w$, MSAD, and DLP, etc.). Please note that the slice thickness setting and the number of detector rows at the time of measurement for $CTDI_{100}$ differ depending on the manufacturer and the type of CT system. $CTDI_w$, or $CTDI_{vol}$ (*Volume CTDI = 1/pitch factor* × $CTDI_w$), and DLP displayed in the scan parameters at the actual scanning are calculated from adjustment factors such as the $CTDI_{100}$ measured above and the normalized scan mode value. Dose efficiency also is displayed as an index of the degree to which the X-ray beam contributes to the image reconstruction.

In the actual measurement for $CTDI_{100}$, perform the measurement under the scanning conditions described in the manual, and confirm whether there is a difference between the referenced and measured values. It may be that not all doses, including scattered radiation, are measured when the X-ray beam width is large; therefore, it is necessary to perform the measurements of all slice thickness settings and number of detector rows for routine use and compare them to the reference values. In this case, dose efficiency is important, and it becomes necessary to evaluate the X-ray beam spread by using films or other methods.

When the actual measurement cannot be performed because dosimeters or PMMA phantoms are not available, confirm that inspections, beam collimator adjustments, and voltage adjustments are properly performed, and assume that the data described in the manuals are standard. It is necessary to confirm the degree to which $CTDI_w$, or $CTDI_{vol}$, and DLP displayed in the scan parameters during routine chest screening differ from those during MDCT imaging described in Chapter 2.

It is not necessary to perform dosimetry after CT system installation as frequently as other checks, and it is sufficient to perform it at the time of X-ray tube replacement and system change. Not all facilities need to have dedicated measuring instruments, and shared use of instruments on a regional basis may be appropriate. For CT systems to be installed in the future, an effective option is to include radiation dosimetry in the CT system maintenance contract for QA/QC purposes. It is desirable to select the method which fits best for each medical facility, because measuring and recording the result should be considered from a long-term perspective. Therefore, it is recommended that each facility select the best option from the available methods and instruments, including film, TLD glass dosimeter, and commonly used ionization chambers, as long as it can ensure effective monitoring of dose variations and data storage for long periods of time.

3-3 Example of Radiation dosimetry for MDCT screening

Examinee dose during screening must be reduced as much as possible, as long as image quality does not deteriorate. Recommended conditions to maintain image quality are described in Chapter 2. Table 3 shows an example of dose measurements within major 4-row and 16-row MDCTs that are commonly used in Japan. MDCT has various settings options, and radiation dose varies depending on the settings. Values shown in Table 3 were measured using a body-shape tissue equivalent phantom (164 cm tall, manufactured by Kyoto Kagaku) under constant tube voltage, tube current, irradiation time per tube rotation, pitch, and scan range. For organ tissues such as lung and breast exposed to direct X-ray, radiation dose was about 1-4 mGy, and the effective dose was about 0.8-1.7 mSv under these conditions. This means that an examinee's dose varies more than two-times depending on the model when tube voltage, mAs, pitch, and others factors are held constant. Even in the same model, dose sometimes varies by about 30% depending on each system. Table 4 shows air doses at the center of gantry for three models of 4-row MDCTs. One of the causes of these differences may be that hardware systems such as the X-ray tube and the shape of the filter may be changed depending on when the system was manufactured. Depending on the maintenance contract, this situation might not be resolved. Considering that these situations may arise, it is necessary to monitor year-to-year changes within a certain hospital and perform measurements in a manner to enable comparisons between facilities or systems. In addition, information sharing between facilities may be warranted.

Table 3 Example of organ/tissue dose evaluation

Tube voltage	120 kV		Organ/tissue (mGy)	Average	Range
Tube current × time /rotation	22.5 mAs		Red marrow	0.7	0.5-1.0
Beam width	20 mm		Lung	2.1	1.5-3.0
Pitch	1.375		Breast	1.7	1.5-2.3
Scan range (whole lung field)	30 cm		Thyroid	2.6	1.5-3.7
Effective dose (mSv)	Average	Range	Thymus gland	2.4	1.3-3.8
Male	1.1	0.8-1.7	Surface (skin) Mean value of 4 points (front, back, left, and right)	2.2	1.5-3.3
Female	1.2	0.8-1.7			

Table 4 Example of doses measured at the center of gantry for the same models under the same conditions

Air dose (mGy・cm)	120 kV, 75 mAs/r			
	Model	2mx4	4mx4	8mx4
	A	33.8	59.0	104.
FOV:L	B	30.4	53.4	95.2
	C	24.8	44.9	86.7
	A	33.7	58.9	104.
FOV:M	B	31.2	54.0	95.9
	C	24.6	44.9	86.6

Ideally, medical exposure is to have no dose limitations because of the following reasons:

① Examinees exposed to radiation will be benefited directly.
② Examinee dose is considered to be low enough for the purpose of medical diagnosis/treatment when the radiation is justified and protection is optimized.
③ Dose limitation may restrict the necessary medical intervention and may not be beneficial to examinees.

However, it is recognized that even medical exposure should require a certain upper limit (dose constraint, guidance level, or reference level) for the typical diagnostic practice, and there is a movement to establish such limitations. Especially for mass screening, the procedure cannot be directly justified similarly to other medical exposures, and careful attention to radiation dose is required.

The number of factors affecting MDCT radiation dose is much greater than that of SDCT. Factors that users can select are tube voltage (kV), tube current (mA), scan time (s), beam thickness, beam number, and pitch, etc. Factors relating to the system are beam geometry, dose quality, and X-ray detector characteristics, etc. These factors should be carefully set according to the clinical requirements (refer to Chapter 2, MDCT imaging conditions).

3-4 Conclusion

In screening CT, radiation dose is greatly reduced compared with CT imaging conditions applied in common medical facilities. Precision control of the system directly affects the protection of examinees. It is expected that dose reduction efforts, which retain diagnostic quality, will continue through improved hardware (e.g., peripheral equipment including computer parts) and software. Radiation dose, which is a trade-off with image quality, needs to be measured regularly and be precisely controlled. In addition, examinee dose ranges corresponding to individual conditions need to be considered.

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4. Control of image quality and radiation exposure

4-1 Significance of this chapter

Exposure dose of chest CT screening will be more strictly controlled than that for routine clinical examination because this screening is targeted for a group of examinees who have no subjective symptoms. For this reason, it is necessary to understand appropriate image quality and dose level and to perform continuous quality control. Moreover, when the chest CT screening is performed with multi-detector row CT (MDCT), the scanning condition settings will be more complicated. In this chapter, a control method for MDCT image quality and radiation dose using a dedicated phantom for chest CT screening will be discussed, and details concerning image quality and radiation dose in the example MDCT imaging conditions for chest screening will be outlined.

4-2 Components, structure, and usage of the phantom for chest CT screening

In our recent report, *Manual of CT Imaging for Thoracic Screening – Targeted for Single-Slice CT* (in Japanese; referred to as the SDCT manual), we proposed an evaluation system using a dedicated phantom (LSCT-001, manufactured by Kyoto Kagaku) as a “foot rule” to consolidate radiation dose and image quality. The greatest advantage of this phantom is that image quality and radiation dose can be evaluated in a single phantom system. The phantom consists of four parts: appearance, dummy tumor, radiation dosimetry, and image display scale.

The LSCT-001 consists of a standard chest equivalent phantom and linearity phantom. The chest wall and mediastinal part of the phantom are made of a muscle-equivalent substance, and the thoracic cage is made of a bone-equivalent substance. The phantom is equipped with dummy lungs and dummy tumors (ball-shaped) enclosed at the apex of the lung, bifurcation of the trachea, and base of the lung in both lung fields. The CT value of the dummy lung is designed to be –900 HU. The contrast (ΔCT) of dummy tumor is designed to be 100 HU and 270 HU against the background dummy lung. There are five sizes of tumors for each contrast, ranging from 4-12 mm diameter in 2 mm steps for ΔCT = 100 HU, and 2-10 mm diameter in 2 mm steps for ΔCT = 270 HU. Radiation dose is measured by a pencil chamber that is inserted into the radiation dosimetry holes drilled along the central axis of the phantom.

The linearity phantom has eight varieties of rods 30 mm in diameter enclosed in a concentric circle 160 mm in diameter. CT values of the enclosed rods are designed to be within the range of –1000 to 400 HU (150-200 HU steps).

4-3 Measuring method

(1) Setting the rotational center of the phantom

With the phantom at the center of the gantry, acquire one scan image at the apex and one at the base of the lung, respectively. It is very important to position the phantom properly so that the dosimetry holes along the center of the phantom overlap with the center of the scale.

(2) Measurement of the ability to depict dummy tumors in the phantom, image noise, and contrast noise ratio (CNR)

Acquire the data change in each scan parameter. Reconstruct the images in 1 mm steps from the center of the dummy tumor, and process the images under standard display conditions. Perform visual estimation of images and obtain the minimum detectable diameter under each condition.

Measure the standard deviation (SD) in the Z-axis direction of dose of soft tissue-equivalent substance inserted into the dosimetry hole, and evaluate the image quality. Measure the CNR of the dummy tumor (10 mm diameter, ΔCT = 270 HU) in the left lung.

(3) Radiation dosimetry

Insert pencil chambers into the radiation dosimetry holes, and perform the measurement while changing scan parameters.

(4) Measurement of image display scale

Scan the linearity phantom under standard scan conditions. Set the ROI (20 × 20 pixel) on each material part in the acquired images, and measure the CT value. Perform image processing with the display conditions of WW2000 and WL-600, and measure the base density, density of each material part, and background density (maximum density).

4-4 Image quality and dose characteristics under the imaging conditions example of each facility

When the chest CT screening is performed with MDCT, the setting of scanning conditions will be more complicated. Several scan conditions can be selected with 4-row MDCT, and increasing the number of rows increases the user's options. Using the LSCT-001 phantom developed for SDCT, compare the image quality and radiation dose under the scan conditions for 4-row MDCT (Anti-Lung Cancer Association, ALCA) and 16-row MDCT (National Cancer Center, NCC). In the comparison of 10 mm slice images acquired under these two scan conditions, visual evaluation makes no difference in minimum detectable diameter. But, in the case of 2 mm slice images, 16-row MDCT can recognize the shape of dummy tumors. This results from the low pitch factor of 16-row MDCT, and accordingly the dose is almost doubled compared to that of 4-row MDCT. Further evaluation is required for the optimum dose and image quality for 16-row MDCT. In the screening conditions where a low X-ray dose is set, overlap reconstruction methods sometimes achieve good results compared to thin slice thickness.

4-5 Image quality and dose characteristics in chest CT screening images

Image and dose characteristics of helical scan, tube current/mAs characteristics, and hardcopy display conditions are described in Chapter 5 (Image quality and dose characteristics of CT images) of the *SDCT Manual* published previously. In this report, image quality and dose are described in the subject size.

(1) Subject

The relation between subject size and SD is expressed with an exponential equation, and increased size causes rapid image quality deterioration. The rate of X-ray absorption of the chest also varies widely at each slice position. X-ray output required at the apex of the lung is about three-times that required at the tracheal bifurcation, and about twice that required at the base of the lung to obtain almost the same SD.

(2) Imaging method using CT automatic exposure control (CT-AEC)

Scan conditions recommended for chest CT screening use constant low tube current and cause overdose or shortage of dose due to the differences in subject thickness, which leads to differences in image quality depending on the subject and the slice position. CT-AEC imaging conditions improve CNR and image noise (SD) at each slice position, and enables optimization of radiation exposure and image quality because flat images can be obtained independent of subject thickness.

4-6 Rental system of LSCT phantom (foot rule for image quality and dose)

Performance evaluation phantom, such as the LSCT phantom, is not in widespread use, and it is difficult for every facility to own such a phantom due to high cost. For this reason, a “Rental System” for base facilities to rent such phantoms to other facilities is expected to be introduced. If the data obtained by each facility is consolidated into a dedicated file format, we believe that management with a higher degree of precision can be realized by sharing data between all facilities. However, this requires managing facilities and staff to create such a system.

4-7 Conclusion

There is a trade-off between CT image quality and radiation dose. Especially in chest CT screening, more appropriate and careful scan condition settings are required. Moreover, MDCT widens (and subsequently complicates) scanning condition options. Increases in the number of detector rows have enabled breath-holding imaging with lower pitch, but it is necessary to evaluate the optimal pitch considering radiation exposure. Image quality and radiation exposure standardization among facilities using a phantom is urgently needed. For this purpose, phantoms that are easy to handle and are suitable for accuracy control are required. Although the LSCT phantom introduced here was developed for the purpose of quality control in chest CT screening images with SDCT, it enables sufficient quality control of MDCT screening images.

To reduce conventional differences of noise level due to slice thickness, and to acquire constant image quality, it is necessary to apply imaging conditions using CT-AEC even at low dose levels.

In this chapter, new evaluation methods with a physical (analog) phantom were proposed and added to the SDCT manual as an evaluation method to integrate radiation dose and image quality of chest CT screening images. Evaluation methods with digital phantoms also are necessary and should be reviewed in the future.

5. Equipment configuration of MDCT system

5-1 Introduction

In chest CT screening, imaging equipment with performance standards (referred to as "equipment") shall be used to obtain high quality images with high spatial resolution and high contrast at low dose levels (the absorption dose of the lung is not more than 3 mGy). Imaging conditions (scan time ≤ 0.8 s/rotation; tube voltage = 120 kV; tube current ≤ 50 mAs; detector thickness ≤ 5 mm, not less than 2 rows; pitch factor ≤ 1.5; acquisition time ≤ 15 s), detectors, data collection systems, data processing systems (reconstruction interpolation: 180-degree interpolation method, multi-point interpolation method, Feldkamp method, etc.; reconstruction thickness/interval ≤ 5 mm/5 mm), technical factors (e.g., scattered X-ray elimination), and positioning shall be optimized. It is necessary to develop an integrated quality assurance program for these factors and to proceed according to the proposed plan.

5-2 Equipment configuration and performance

(1) X-ray CT system for chest screening

a) Power supply equipment

It is necessary to prepare the power supply equipment (voltage, capacity, apparent resistance of power supply, etc.) to meet system requirements to obtain stable X-ray output.

b) X-ray generator

An X-ray generator consists of a high voltage system for the X-ray, X-ray tube, and collimator. High voltage X-ray systems are controlled by high-frequency inverters and are installed in a gantry. Such systems shall have the following functions: tube voltage generation (standard: 120 kV), tube current control by filament heating (not more than 50 mAs, standard: 25-35 mAs; automatic controlling mechanism is desired), and rotation drive control. The X-ray tube shall have ≥ 2 MHU heat capacity, computerized target temperature and case temperature, and be controlled not to exceed the limit. The collimator shall be able to cut soft X-ray and adjust the intensity distribution of the X-ray. The collimator shall be able to be adjusted so that the user controls the width of the X-ray slit as appropriate for the detector thickness of not more than 5 mm × 2 rows or more at the time of scanning to form an X-ray fan-beam which is radiated to the subject.

c) Detector and data collection unit (Scan system)

The detector is a device that can convert the X-ray intensity transmitted through the subject into an electric signal. Semiconductor detectors, semiconductor photo-detectors with scintillators, Xenon ionization chamber detectors, etc., are used. As the number of channels increases and the pitch factor (standard ≤ 1.5) decreases, the spatial resolution of the detector generally increases. As the number of detector rows increases, the resolution in the direction of table movement increases. However, as the matrix size of the detector decreases, the ratio of the detector partition wall thickness increases, and consequently, X-ray capture efficiency drops. Data collection units shall be able to perform analog/digital (A/D) conversions of the faint electric signals from numerous detector channels, scan data collection, and data transmission to the image reconstruction system (dedicated processor).

d) Scan gantry

The rotational part of the scan gantry is equipped with an X-ray tube and detector that are placed facing each other symmetrically to the center of the aperture, as well as a high voltage system for the X-ray and data collection units. The fixed part consists of a rotation mechanism, a slip-ring mechanism, a gantry tilt mechanism, and a scan gantry controller, etc. The X-ray tube and detector with not less than two rows shall rotate around the subject in a single body and collect projection data at constant intervals. Sliced images with thicknesses of not more than 0.5 mm are available. It is desirable that the gantry tilt angle can be changed by operation of a switch placed on the gantry or the table, or by remote control from the operation console, to obtain oblique slice images without producing examinee discomfort.

e) Scanning table

The scanning table shall have vertical and horizontal driving mechanisms that enable the positioning of the table with an examinee within the gantry aperture by switch operation. Up-and-down motions of the table shall be designed to be sufficiently large so that examinees can safely get on and off the table. When the scan position changes or when scanning/helical scanning for positioning is performed, the horizontal driving mechanism shall be remote controlled by the operation console. When the table is moving horizontally with scanning, it shall be able to be controlled in synchronization with X-ray generation and the data sampling of the data collection unit.

f) Operation console

The operation console shall consist of a switch panel, keyboard, CRT (or LCD) monitor, touch panel and display, optical disk drive, and intercom to the CT examination room, etc. These input/output devices shall be organically connected, and form a man-machine interface to perform basic operations such as input of examinee information, change of scan parameters, scanning, diagnosis, image processing, and file management.

g) Data processing system

The data processing system should perform the following: operation and control of the scan, scan data reception, image reconstruction (180-degree interpolation method, multi-point interpolation method, Feldkamp method, etc.; reconstruction thickness/interval ≤ 5 mm/5 mm), image display (window width = 1200 to 2000, window level = -500 to -800), image processing, data storage, file management, transmission to networks, etc.

(2) Image recorder (Laser Imager)

Laser Imager is a passive device to process the image signals from the X-ray CT system and record them onto film.

(3) Image viewer

a) Display case

The display case is lighting equipment to help read information generated by light passing through the film. The brightness of the display screen shall be not less than 3000 cd/m^3 according to JIS standards.

b) CRT

The diagnostic capability of CRT is not equal to, but very close to, that of film. The CRT is operated in non-interlaced scan mode. There are two scanning systems for the same screen size: 2000-line (CRT-2K) and 4000-line (CRT-4K). High brightness is obtained, and a dynamic range of density and resolution are fairly improved. In addition, maximum brightness and service life are improving, and a calibration function has been installed.

c) LCD

LCD is a display device that consists of a liquid crystal layer between two orthogonal polarization plates and glass basal plates. The transmission factor is controlled by the impression of an electric field. There are two types of display methods: TN (Twisted Nematic) and IPS (In Plane Switching). Optical characteristics of the TN method vary depending on the viewing direction and cause narrow viewing angles. On the other hand, the IPS method has a wide viewing angle because optical characteristics do not change in any viewing direction. LCD resolution has steadily improved to be comparable to, or better than, CRT for both methods.

(4) CT examination car

At present (as of the end of January, 2005), there are 28 in-vehicle CT systems in operation (11 manufactured by Hitachi Medico, 13 manufactured by Toshiba Medical, 3 manufactured by GE, and 1 manufactured by Siemens). Seven are following the MDCT method: Asterion (Toshiba Medical, 4-row detector, scan time = 0.75 s), ROBUSTO (Hitachi Medico, 4-row detector, scan time = 0.8 s), and Emotion Duo (Siemens, 2-row detector, scan time = 0.8 s).

6. Imaging method

6-1 Display of imaging information, preparation for imaging

(1) Display of imaging information

In the case of MDCT imaging, the first thing to be considered is the final method of displaying the acquired images. Two types of methods are available: film recording and screen device (CRT and LCD monitor). Although film recording dominates presently, considering the characteristics of MDCT, screen device displays may be more popular in the future.

However, a subject recorded on film is usually a frame of images displayed on a screen, and there is no informational difference between these two images. Information displayed on a screen is the basis of MDCT, and information recorded on film is only a copy of it. In other words, film recordings of information become wasteful in some cases. For example, there is no need to print an examinee’s name on each frame of the film. It is enough to print the name in one location and eliminate unnecessary printing. Some film recorders already have this function, which can be used if necessary.

Of course, screen display also has a disadvantage, in that commonly used screens are too small to display all information. Large screens or multiple screens can resolve this issue but can also generate new issues such as cost increases and adequate space for installation. Taking these issues into consideration, this chapter discusses the minimum information required for screening.

a) Name of facility

Record the name of the facility to avoid possible confusion with other facilities that have similar names. Japanese is recommended, if possible. Alphabets are acceptable, but do not use abbreviations or acronyms.

b) Name of examinee

Record the full name of the examinee. Katakana or Hiragana is recommended to make it easy to read. Chinese characters or alphabets are acceptable, but they require careful attention to detail to avoid misreading.

c) Sex and age

Both Japanese and alphabet are acceptable.

d) Data and start time of imaging

Both Japanese and alphabet are acceptable. Both Christian year and Japanese year are acceptable to record the date.

e) Imaging conditions, reconstruction conditions

Imaging conditions vary depending on the system used. Following are parameters of typical conditions: tube voltage, tube current, table feed, pitch, number of detectors, image slice thickness, reconstruction slice thickness, interpolation method, imaging function, etc. Each parameter shall be described in its relative unit.

f) Imaging position

Set the apex of the lung as a reference position. It is desirable to describe the imaging position as a distance from the reference position in mm units. When other reference positions are used, define them.

j) Additional number

It is desirable to assign unique identification numbers to individuals. Additional numbers shall be created based on personal IDs, order numbers for imaging, or other numbers in each facility.

k) Window Width/Window Level

l) Imaging direction and body position (R/L, P/A, Feet First/Head First, Supine/Prone)

m) Viewing direction (View from Feet/View from Head)

n) Field of View (FOV)

Display in the size of FOV (mm, cm) or in magnifying power

o) Scale (cm)

If there is space on the film or screen to record the information described above, it is recommended to put the information together and record only the imaging position (and other conditions such as tube current) when they are variable in each frame.

When the information described above is shown, the minimum of information is maintained.

(2) Preparation before imaging

It is very important to perform MDCT system, peripheral startup, and operation checks to allow for smooth screenings.

a) Startup check

Check items after system startup.

[1] Safety mechanism of table/bed (operation of mat switch in front/rear side and tape switch)

[2] Oblique motion of table/bed

[3] System operation

[4] Free space of built-in hard drive for storing image data and raw data

[5] Frequency and voltage of electric generator (in the case of MDCT examination car)

b) Execution of operation

[1] Execution of warm-up

[2] Air calibration

[3] Image check using phantom

Image display, adjustment of window width/window level, absence of artifacts, CT value (mean, SD).

c) Other checks

Microphone test, auto voice test, confirmation of surveillance camera operation, and adjustment of air conditioner.

Preparation of disks to store images (initialization, preparation of backup disk)

In the case of an MDCT examination car: grounding wire, car jack, handrail setting, and safety check.

d) Cleaning

Keep the places that come into the examinee's view clean and neat, as well as the waiting room, dressing room, CT examination room, and bed. It is good to check everything from an examinee's perspective along the examinee's path from entering the room to exiting the room prior to daily imaging.

Surprisingly, adequate attention is not paid to "odor." Some examinees detect musty odors emanating from the towel used while cleaning, body odor, cologne, and hair dressing of previous examinees. Keep in mind that odor can cause unpleasantness in some examinees. It is necessary to provide a good environment for imaging in a broad sense by using deodorant available on the market and by ventilating the air well.

6-2 Consideration for examinee

(1) Note

Screening is different from examination in hospitals or clinics, because most examinees screened are healthy people or people who have no awareness of illness even if they feel some disorder. For this reason, the examination quality often is judged by the "appearance" (i.e., impression or atmosphere of examination facilities rather than the accuracy of examination). One of the factors affecting the overall impression of a facility is the service provided by the technician, who has one-on-one contact with an examinee directly in a closed room. Their role is significant.

Considering that examinees feel heightened anxiety before the examination, give them enough explanation about the examination. It is recommended to assign a staff member to explain the examination and to prompt gowning, if possible.

Because examinees tend to be injured most when they lay themselves on the bed and rise from the bed, examinee positioning requires some attention. During the examination, because there is danger that examinees may be caught in the machine, miss his/her step, or fall down due to dizziness, it is very important to monitor blind corners with cameras and pay attention to the examinee.

Especially while the bed is moving at the time of imaging, you have to keep watching the examinee and respond quickly to any accidents.

When the imaging is over, tell the examinee that the examination is over, then quietly return the bed to its original position, and make sure that the bed has completely stopped. When getting off the bed, help the examinee in a casual manner and make the change of examinees smooth.

Keeping an examinee in the supine position for a long time may cause a change in the posterior lung field. When an examinee has to wait for a long time due to machine failure, etc., it is necessary to make him/her wait in a sitting position rather than lying down on the bed.

You also should pay attention to "sound." Music can be used depending on the facility's circumstance. When only the sound of the machine operation is heard in a silent room, this may cause oppressive feelings in the examinee. In addition, chatter between staff members often may make examinees feel uncomfortable.

(2) Appearance and delivery

Clean white coats and neat hairstyles are essential. Polite and clear delivery, without hesitation, is a basic element to giving the examinee a favorable impression. Technicians should check their deliveries with each other on a regular basis. Refrain from wearing sandals, which never give a good impression to examinees.

Smiling is the best service. When you make eye contact, do not forget to smile.

(3) Expertise

In most screening sites, "faster" and "more" image acquisitions are required. For this reason, when you are under time pressures, you may often answer abruptly and rapidly to examinees' questions.

However, you should understand that screening is a rare opportunity for examinees to ask questions that they usually cannot ask doctors directly, and attempts to answer precisely and concisely with good faith should be made. To this end, it is important not only to have expertise but also to absorb state-of-the-art knowledge and be cognizant of topical information broadcast in the mass media.

Moreover, it is necessary that you are ready to explain the importance and safety of the examinations performed at your site, in your own words, that is easy for examinees to understand.

6-3 Efficient screening method

(1) Gowning

Because imaging is basically performed with clothes on, it is important to understand the cause of obstacle shadows fully. Usually, most plastic buttons in shirts or blouses are not obstacles for imaging, but necklaces or inner clothing with metal parts can be a source of artifacts. Ask the examinee to take them off, explaining the reason. If there is no clothing worn in this case, ask the examinee to wear an examination gown. Additionally, it is good to provide written guidance of screening in advance to ask the examinees to arrive at the facility wearing plain T-shirts and the like to avoid the necessity of gowning.

It is desirable to have several places for gowning adjacent to the CT imaging room to enhance throughput. Instead of merely explaining the examination in advance, it is very user-friendly to post notices with illustrations of gowning rooms for examinees to avoid confusion. However, in the case of on-site screening, sometimes gowning rooms are not available, and examinees have to do gowning in a waiting room or a scanner room of an MDCT examination car. For this reason, to perform the screening smoothly, it is necessary to take some measures such as adding the item about clothes in written notices for screening so that examinees take examinations without gowning.

(2) Entering room and exchange of examinees

There are two methods for positioning an examinee. One is the method of elevating the bed to the imaging position first with an examinee just lying on the bed. The other method is to adjust the examinee’s position to some extent when the bed is in a lowered position, where right and left adjustments can be performed precisely. The most important thing at the time of positioning is to ensure an examinee's safety. Especially when many examinees are to be examined, it is necessary to pay attention to ensuring safety.

Exchange of examinees is the most time-consuming part of the entire examination process, and this greatly affects throughput when not performed smoothly. One measure that can be taken is to place stairs or a foot stool at the base of the examination table (Fig. 1).

Using this, the bed position can be adjusted by vertical movement within several centimeters, which leads to improved throughput. However, because the bed is very high from the floor, you have to pay enough attention to safety and be ready to respond quickly to accidents. It is desirable to place a handrail or a safety fence to prevent falling (Fig. 2).

(3) Pre-registration

If examinee names and dates of birth are available by the day before screening, register them in advance, and pick up the name of the examinee from the pre-registered list to proceed with imaging registration on the screening day. Using pre-registration enables a reduction in typographical errors and registration time at the screening and leads to improved throughput.

(4) Imaging method

a) Positioning

Because positioning is usually performed in the supine position with arms up, ask the examinee to keep his/her elbows close to the head. To make the posture stable, cross the arms around the wrist or hold one arm with the other arm (Fig. 3). It is desirable to adjust the height of the wrist a bit higher than horizontal level, which is parallel to the bed, by using some tools to reduce the burden on both shoulders (Fig. 4).

There are many elderly examinees in a screening site. In the case of examinees whose arms cannot be raised, perform the image acquisition with the one arm down (or both arms) that cannot be raised. In this situation, it is necessary to pay enough attention at the time of moving to the bed to keep the arm away from the body or put the arm on the stomach. When the arm is on the stomach, the entire arm can be placed on the body appropriately by letting the fingertips of the arm touch the iliac crest at the opposite side of the lowered arm. When the arm is put near the bellybutton, the upper arm and elbow are placed on the side of the body, and noise and artifacts increase because of the increased absorption dose in the direction of the side of the body. Therefore, when the arm position is different from the ordinary position, it is very important to write down this fact in some field as a comment for the radiologists to understand the cause of the noise and/or artifacts.

It is recommended to use a thin pillow, because the images of the lung apex are affected when the level of the head is not flat. For example, one measure is to use a regularly sized towel folded several times with a soft sheet on top. This is excellent from a hygiene point-of-view because it can be changed frequently (Fig. 3). For examinees whose legs cannot be stretched due to lower back pain, a triangle of sponge is useful to support the legs when the knees are bent slightly. For examinees whose lordosis is very severe, body posture can be corrected by inserting a pillow or a towel under the back parts to acquire cross-sectional images of the lung apex.

Then adjust the body position in the right and left direction so that the body is placed in the center of the bed, and adjust the body height so that the body part with maximum body thickness (the base of the lung) is placed in the center of the FOV. In addition, it is desirable that apexes of both lungs are parallel to the imaging plane, and that the apex to the base of the lung is imaged symmetrically to the center of the mediastinum. It is very effective to explain notices and examination methods again at the time of positioning. It is a good idea to prepare standard expressions in advance: "Breath-holding lasts about 10 seconds." "Please take a deep breath and hold it." "Please follow woman's instructions." However, some examinees are extremely nervous, and it is important to take time to talk at the pace of an examinee's understanding and looking at individual responses.

It is necessary to pay attention to the positioning because comparative image reading becomes difficult when positioning is not constant. Especially in the case of a small examinee, positioning in the right and left direction tends to be less careful compared to a large examinee. Remember that positioning is an indispensable technique among a lot of MDCT imaging techniques to provide easy-to-read images.

b) Scanning method

In principle, positioning images (scanogram, scout view, etc.) are not taken to reduce radiation dose and time. But, in the case of some types of CT with no real-time function, or in the case that the imaging range needs to be determined by body shape, or in the case that an automatic tube current controller is used, the scanogram shall be taken at a minimum dose.

The starting point of imaging is normally 1.5 finger-breadths above the upper edge of the manubrium of sternum, but fine adjustment of the position based on body shape shall be determined by the technicians. It is considered that about 2 finger-breadths above the upper edge of the manubrium of the sternum for extremely thin bodies, and not more than 1 finger-breadth above for fat bodies, are standard.

As for scan direction[1], the cranio-caudal direction seems to be standard considering convenience, but when breath-holding is difficult for the examinee, the caudal-cranio direction will be effective. For examinees who cannot perform long breath-holding, including elderly people and people who are losing lung function, perform the scanning in the caudal-cranio direction from the base to the apex of the lung, and provide them guidance to hold inspiration first and to exhale slowly when they feel choky. For examinees who cannot perform breath-holding at all, perform the scanning in the cranio-caudal direction with normal breathing.

Imaging range[1] [2] shall be set at 300 mm for males and 280 mm for females as a standard. Of course, regardless of this standard, the value to fit the length of an examinee's lung should be set, but it is necessary to compromise to some extent for the primary screening. And in the case of the MDCT system where scan images can be monitored in real time, set the scan range a little bit longer, and interrupt X-ray radiation as soon as the base of the lung is scanned.

It is desirable in principle to acquire the images with maximum inspiration (deep inspiration). This is because it is easily inferred that contrast discrimination of CT images will significantly drop on the normal tissue of the lung when the inspiration is not sufficient. Among the well-differentiated adenocarcinomas, low contrast shade such as BAC (bronchiolo-alveolar carcinoma) is a typical example. Moreover, because tremendous value is placed on comparative image reading, reproducibility of images is strongly recommended. Maximum inspiration seems to be the best method to suppress the fluctuation at a minimum level when images are taken so as to be the same. However, when the maximum inspiration affects stability, perform the imaging with normal inspiration.

(5) Image reading environment

It would not be an exaggeration to say that technicians operating CT systems are the primary image readers, because MDCT systems that can provide almost real-time monitoring at the time of imaging are dominant. Therefore, eye-friendly monitors are one important consideration for the imaging environment. Because the system is used for screening, it is necessary to take examinees' impressions of the system into account, rather than that of the hospital. Also, stable imaging requires sufficient equipment and maintenance.

The following are required for an image reading environment: brightness of the MDCT system monitor, brightness of computer monitor for the automatic diagnosis and comparative image reading, brightness of the display case, and luminance of the room.

MDCT system monitor brightness shall be adjusted by using a luminance meter with an SMPTE pattern[*1] at the time of installation. Record the adjusted value and readjust the brightness of the monitor periodically at the time of maintenance or monitor replacement. Also, PC monitors shall be used after the brightness adjustment using a luminance meter.

Although display cases do not require brightness as high as that used for reading mammography images, proper attention shall be paid to deterioration of brightness, and fluorescent lamps shall be replaced properly.

It is desirable that image-reading rooms are equipped with brightness-controllable light fixtures. When real-time images are displayed on the monitor screen, they are difficult to see in a room that is too bright, and reflection of light on the screen also makes them difficult to see. However, a room that is too dark is not safe because certain things cannot be seen, and it is well known that a room that is too dark is bad for the eyes. The CT examination room also requires a brightness-controllable light fixture. A room that is too bright makes the examinee feel restless. On the other hand, a room that is too dark is dangerous. It is necessary to adjust the brightness, taking the weather into account. If the light fixture is not controllable, it is necessary to keep the brightness of the room constant by using a lightproof curtain or window shade. To realize this environment, it is necessary to take it into account at the design stage.

Moreover, in the case of an MDCT examination car, brightness of the room varies depending on the weather or the place in which the vehicle is parked. To keep the brightness of the room constant, it is necessary to place light-shielding films on the windows or install lightproof curtains.

Room temperature controls also tend to be overlooked. When temperature is controlled based on the sensible temperature of examination staff, sometimes examinees feel uncomfortable. It is necessary to pay attention to the adjustment based on ambient conditions.

6-4 Contraindication

There are some reports that malfunction of implantable cardiac pacemakers or defibrillators is caused by CT imaging. Keep track of information such as name of manufacturer and model number, and post written notices so examinees are aware of this hazard. It is necessary to take into consideration that imaging shall be canceled in some cases, even if the model used is other than reported models.

([*1]SMPTE pattern: Society of Motion Picture and Television Engineers pattern. Used to adjust distortion, density difference, and resolution by displaying it on the monitor.)

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2) Health and Welfare Statistics Association: Annual Statistical Report of National Health Conditions 2004, 51(9): 434, 2004 (in Japanese)

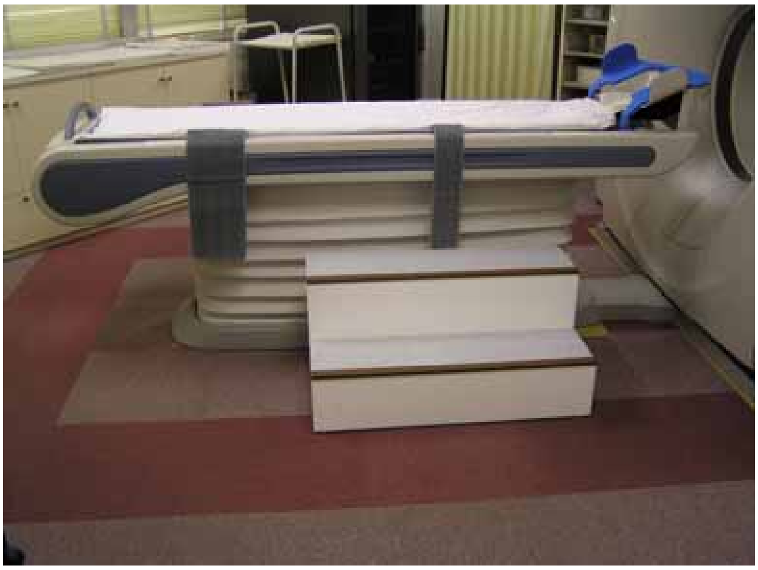


Fig.1

Fig.2

Fig.3

Fig.4

Fig.5

Fig.6

7. Quality control of X-ray CT system

7-1 Failure and maintenance of the system

What is required in the process of using MDCT as well as SDCT is first to stably maintain the specified performance of the system. To ensure this, it is necessary to prevent system failures from occurring, and second, to fix failed equipment quickly should they occur. For this purpose, it is essential to perform a daily routine check and periodic maintenance specific to the system.

7-2 Daily routine preventive maintenance (Table 5, Fig. 7)

(1) Maintenance of the environment specified by the system

Increases in stressors, such as temperature, dust, vibration, and corrosive environment, can be triggers of system failure. Especially in the case of electronic parts, it is said that as temperatures increase by 10ºC, the life of the system will be halved and the failure rate will be doubled (10 degree rule). For this reason, failure of an air conditioner may cause an unstable condition of the entire system.

(2) Warming-up the X-ray tube

Serial load of high voltage not less than 120 kV is given to an X-ray CT system. Therefore, the system requires warming-up from low voltage before clinical operation. Especially when the system has not been used for a long time, the electric strength characteristics of the X-ray tube will decrease. In this situation, if high voltage is given to the X-ray tube, in-tube discharge occurs easily and sometimes may cause explosion of an X-ray tube. After long holidays, it is necessary to perform the warming-up procedure sufficiently by the method designated by the manufacturer. Warming-up of the X-ray tube is an important maintenance step that leads to stability of the X-ray tube and enhanced service life.

(3) Operational check for gantry and bed

Accretion of contrast medium and neglected needles may cause abnormal behavior and abnormal images, etc. Therefore, before an operational checkup of the mechanical drive, cleaning of covers and elimination of foreign objects shall be performed first. In the region where manual operation is possible, check the following items with a distinct understanding of the operating instructions for each region.

① Whether there is an abnormal sound or vibration in the mount rotation drive. In the case of a system with a tilt mechanism, check for abnormal sound or vibration during tilt operation.

② Whether operation of the wedge, slit, etc. is normal.

③ Check bed movement in vertical and horizontal directions and whether switches turn on properly and readings on instruments are correct. When abnormal sounds or vibrations are detected, open the scanner cover and check the mount rotation or mechanical drive manually.

(4) Water (standard) phantom scan

After warming-up and gantry system checkup, perform test scanning for a specific size phantom or water (standard) phantom equipped with the system. Perform test scanning under constant conditions, then measure and record the CT value and image SD (noise) value within the specified ROI for scanned images. When abnormal images are presented on the scanned images, contact a service agency to resolve the situation.

Table 5 Routine checkup items required for CT systems

	Item	Objective	Example of failures	Example of measures
1	Warming-up of X-ray tube	Extension of life-time and stabilization of X-ray tube	Emergence of abnormal images, repetition of over current due to pressure resistance failure	Repeatability is low.
2	Water phantom test scan	1. Record of CT value and SD 2. Functional evaluation of whole system	1. Emergence of abnormal images etc. If the phenomenon lasts, contact service agency	1. Check up repeatability 2. Reapplication of power 3. Change scan conditions and check for emergence of abnormal images 4. Re-collect complementary water data
3	Cleaning of gantry and bed. Operational checkup	1. Elimination of foreign objects in mechanical drive 2. Check whether there are abnormal sounds and motions	Emergence of abnormal images due to contrast medium and needles, etc. in the mechanical drive	Elimination of foreign objects and material, cleaning, etc.
4	Check humidity, temperature, and dust	Maintenance of environment	Malfunction of electric parts	Cleaning of air filter, operational check of air conditioner

(5) Recording system such as CRT monitor, film (Fig. 8)

According to an aging (deteriorating) CRT monitor, brightness decreases, and contrast varies. These are greatly affected by the brightness of ambient lighting. A CRT monitor and laser printer are adjusted properly with each test pattern by manufacturers at the time of installation. However, considering deterioration with age, users should manage and control max/min density of the CRT monitor for image observation and film images as final output, specified differences of density, contrast, vertical and horizontal display resolution, etc. by storing test patterns (SMPTE pattern[*1], refer to Section 6-3 (5) in Chapter 6 Imaging method above) and gray scale patterns in the CT system. In the images under a lung field condition, the ability to depict intra-lung blood vessels or mediastinal parts is determined by a Look Up Table (LUT)[*2] attached to a CRT system. In addition to a method of adjusting images by changing window width, there is a method of controlling LUT by Laser Imager or CT system software.

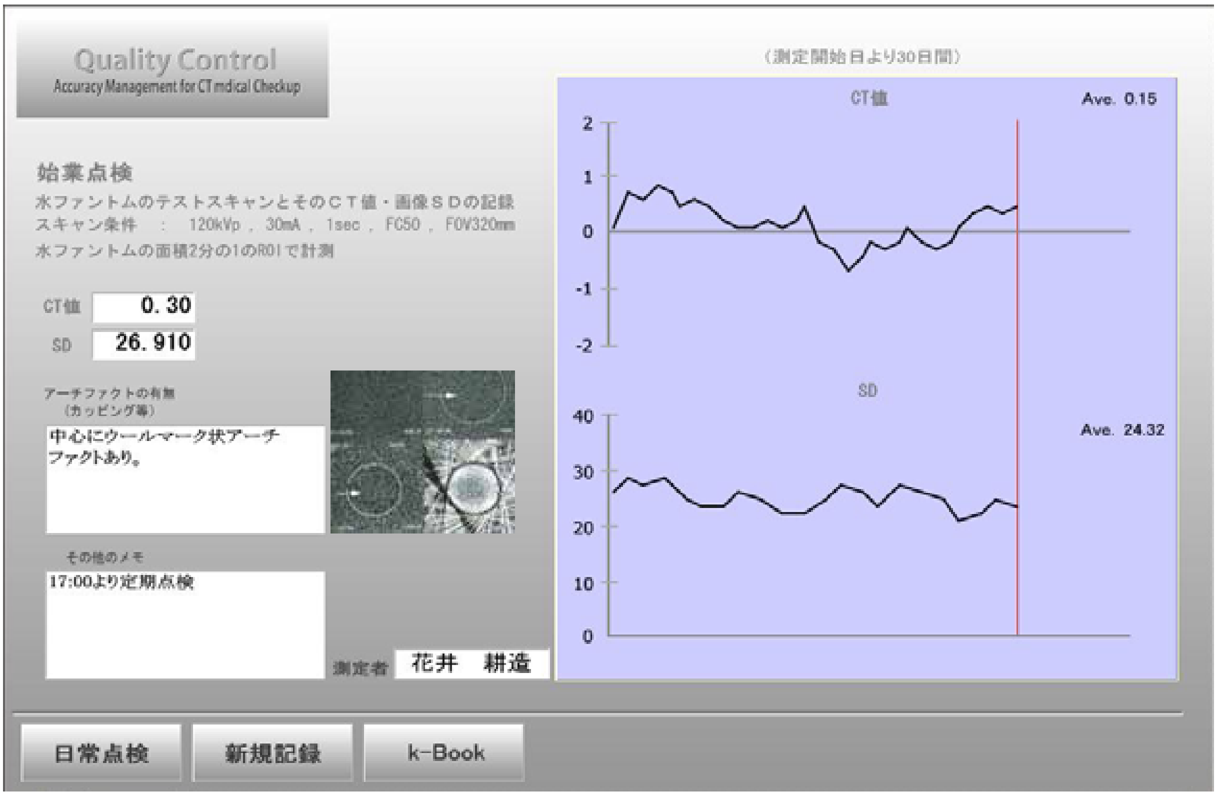
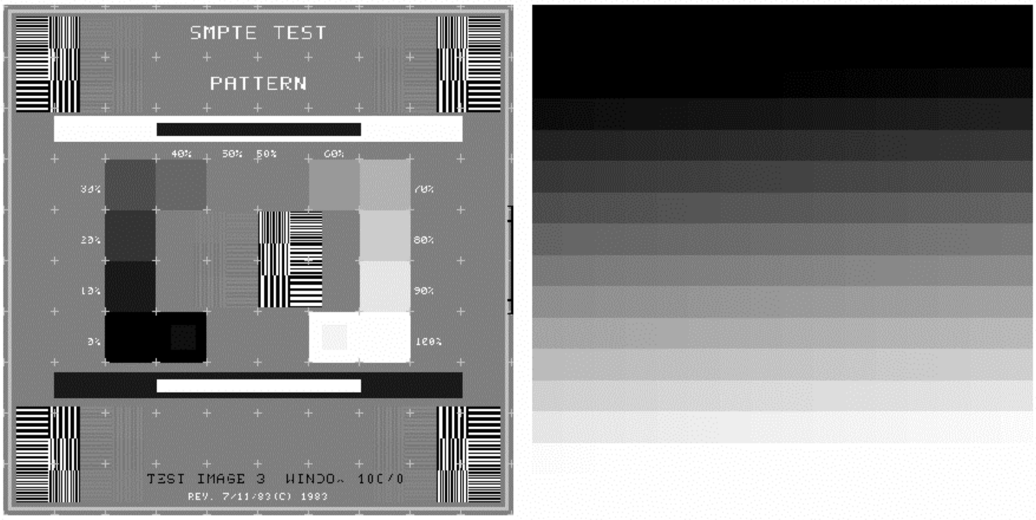


Fig. 7 Example of daily checkup record manual



SMPTE pattern

12 bit gray scale pattern

Fig. 8 Checkup of CRT monitor, film, etc.

([*2] Creating the table to convert pixel to pixel value, density of each pixel can be converted by this table. This conversion table is called LUT, or Look Up Table. Image enhancement or contrast adjustment can be performed by the change of LUT.)

7-3 Breakdown maintenance

When a system failure occurs, the most important thing is how fast we can finish repairing the system and how short we can make the down-time (inoperable time). If you can diagnose the characteristics of the failure, you can decide the necessary steps to take during breakdown maintenance.

When you focus attention on breakdown maintenance, its time-series processes are as follows: ①detection of failure, ②confirmation of abnormality, ③determination of failure point, ④diagnosis, ⑤acquisition of parts, ⑥fix and replace, ⑦final check. The first step is diagnosing the failure. Following are measures to take to diagnosis reasons for failure of an X-ray CT system.

(1) Determination of failure points from user's side

The CT system is a group of precise measurement equipment. When certain equipment is down due to failure, the failure point can be determined by using other units operating properly.

a) Method using scan data stored in disk

In this method, procedures start with reconstruction of projection data (raw data) stored on a magnetic disk. As shown in Fig. 7, re-reconstruction of projection data (raw data) acquired properly before failure enables the following:

① If the result of reconstruction is “NG,” the failure is identified as a reconstruction system failure.

② If the result of reconstruction is normal, the failure is identified as the one that occurred before the data acquisition system (DAS).

③ Error pixels can be found by the subtraction of abnormal images from re-reconstructed images.

In this way, failure points can be divided simply into two parts (①and②) by using the function of the system.

b) Method using scanogram

Using the scanogram, failure points can be roughly identified as the one in the CH system or in the projection angle.

The Scanogram used for positioning the CT scanner has a structure where the CH position is defined as the X-axis, and projection angle is defined as the Y-axis. Therefore, abnormal data appear in the X-axis direction when an abnormality occurred in the X-ray tube output, and similarly they appear in the Y-axis direction when an abnormality occurred in data collection of each projection angle. Abnormal data can be easily identified because count values are different from those of surrounding CHs.

c) Estimation of failure points based on artifacts (abnormal images)

During the process of scanning to image reconstruction, various forms of artifacts (abnormal images) emerge depending on various failure factors. The most important thing to understand is to use the emergence mechanism (failure factors) of these artifacts as clues to identifying failure points.

Artifacts of CT images routinely seen are as follows:

① Artifacts caused by examinee’s motion (motion artifacts)

② Artifacts caused by a high absorption substance such as contrast medium (residual barium), metal body (clip, button, hook, denture)

Other important artifacts include:

① Artifacts caused by the shape of the subject (change of radiation quality, partial volume effect, etc.)

② Artifacts caused by system failures

7-4 Conclusion — Aiming for a zero failure rate of the CT system

The important thing for maintaining a system is to define the scope of work and to decide how much to cover. Practically, some maintenance or repair requires measurement equipment, special tools, and test programs. It is debatable that the unseen parts protected by covers or chassis are included in the scope of user maintenance. The level of maintenance should be increased by performing collaborative work with manufacturers at the time of periodical maintenance, and to decide which maintenance level is appropriate for each facility.

References

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8. Risk-benefit analysis of MDCT for lung cancer screening

Cancer screening would not be beneficial for most people from the point of view of life expectancy, because it is usually targeted at healthy groups. For this reason, it is necessary to evaluate the benefit of life-saving for examinee groups and the risk of shortening life expectancy (hereinafter referred to as "life shortening") due to radiation exposure, and compare the effects quantitatively. Following are the results of evaluating the risks and benefits of MDCT for lung cancer screening.

For calculating life shortening, software that incorporated the ICRP method was used [1]. When a person is exposed with equivalent doses of D_H at the age of u_0, life shortening value $Si(u_0)$ was obtained, and the life shortening value $S(u_0)$ was calculated by summing all organs and tissues. Exposure dose varies widely depending on the imaging conditions. In this research, exposure dose under the imaging conditions shown by Nishizawa et al. was used. $S(u_0)$ is given by the following equation, where dp/du is the probability of cancer deaths per year, r_{mi} is the risk factor, $Bi(u)$ is the background rate of cancer death, d is the dose effectiveness factor, and T is life expectancy.

$$\left(\frac{dp}{du}\right)_{rad,i} = P(u) \cdot Bi(u) \cdot r_{mi}(u) \cdot D_H / d \qquad Si(u_0) = \int_{u_0+10}^{\infty} \left(\frac{dp}{du}\right)_{rad,i} \cdot T(u)\,du \qquad \mathrm{S}(\mathrm{u}_0) = \sum_i Si$$

To evaluate life extension as a benefit, Iinuma's equation to calculate saved person-year was used.

Number of saved persons (N) = Population (P)×Disease rate (D)×Sensitivity of screening (Fs)×Participation rate of close examination (S)×Sensitivity of close examination (Fd)×[Five year survival rate of examined group(Ws) - Five year survival rate of outpatient group(Wo)]

Saved person-year (NT) =Number of saved persons (N)×Life expectancy(T)

Our research used the following conditions: *Fs*=90%, *S*=85%, *Fd*=95%, *Ws*=71%[3].

The MDCT risk-benefit ratio for lung cancer screening was calculated from the risks and benefits obtained from these equations. Table 6 shows these results.

In MDCT lung cancer screening, the risk-benefit ratio surpassed 1.0 at the age of 35-39 years for men and 45-49 for women. Consequently, screening seems to be beneficial for people older than this. The reason why the age of men whose risk-benefit ratio surpasses 1.0 is lower than that of women is that the lung cancer rate for men is higher than that for women.

The exposure dose of MDCT evaluated presently was about 1.0 mSv in effective dose.

Because exposure dose and sensitivity are related to each other, we believe that it is necessary to discuss appropriate imaging conditions by considering this relationship.

Table 6 MDCT Risk-Benefit ratio for lung cancer screening

Age	Male	Female
20～24	0.04	0.01
25～29	0.08	0.05
30～34	0.38	0.12
35～39	1.54	0.24
40～44	1.35	0.54
45～49	2.44	1.07
50～54	4.01	1.82
55～59	6.53	2.80
60～64	13.67	3.95
65～69	22.37	5.15
70～74	64.86	10.81
75～79	59.64	11.28
80～84	277.55	42.70
85～89	192.66	33.94

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9. Terminology

1) **AEC: see *CT-AEC* below** (see Chapter 4, “Control of image quality and radiation exposure”)
2) **CRT: cathode ray tube, or Braun tube**. In this manual, CRT is synonymous with *monitor* (see Chapter 5, “Equipment configuration”).
3) **CT-AEC: computerized tomography-automatic exposure control**. In this manual, CT-AEC is synonymous with *automatic tube current controller* (see Chapter 4, “Control of image quality and radiation exposure”).
4) **CTDI: CT Dose Index**. CTDI refers to radiation dose at the center slice acquired with MDCT. In this manual, CTDIw, which is a weighted average of center and peripheral, is used in accordance with the actual examination (see Chapter 2, “Imaging conditions,” Chapter 3, “Radiation dosimetry”).
5) **DAS: Data Acquisition System**. DAS is a system for converting detector output from analog to digital. In this manual, DAS may be used synonymously with the number of MDCT detector rows.
6) **LCD: liquid crystal display**. In this manual, LCD is synonymous with *monitor* (see Chapter 5, “Equipment configuration”).
7) **MDCT: multi detector row CT**. MDCT is a helical CT that has multi-detector rows. In this manual, a CT that has not less than two detector rows is called MDCT. Notation which includes the number of rows, such as *4DAS*, sometimes is used (see all chapters).
8) **SDCT: single detector row CT**. SDCT is a helical CT that has a single detector row. Such a helical CT was only referred to later as SDCT, in contrast to MDCT. In this manual, conventional CT before helical CT is not included in SDCT (see all chapters).
9) **Automatic Tube Current Controller**. This system acquires optimal image quality by changing tube current according to the subject, thereby avoiding unnecessary excessive doses of radiation. Several systems, including Real EC and Auto-mAs, are available. Automatic tube current controller is synonymous with *CT-AEC* (see Chapter 4, “Control of image quality and radiation exposure”).
10) **Single slice**. This refers to SDCT or images acquired with this system. In this manual, when *single slice* refers to the system rather than images, SDCT is used as a uniform notation. It is often used in colloquial language.
11) **Whole detector thickness**. This refers to the width of the detectors that are used. In the case of MDCT, it is the index showing the effective width of detectors that varies depending on the imaging conditions. Under 4 rows × 2 mm imaging conditions, the whole detector thickness is 8 mm (see Chapter 2, “Imaging conditions”).
12) **Monitor**. This refers to the display device, such as CRT or LCD (see Chapter 6, “Imaging method”).
13) **Pitch: see *Pitch factor* below** (see Chapter 2, “Imaging conditions”)

14) **Pitch factor**. This is a unit of an imaging condition in the form *table feed (mm/rotation)/whole detector thickness*. When the bed moves ahead in concert with the whole detector width and the gantry rotates once, pitch factor = 1.0 (see Chapter 2, “Imaging conditions”).
15) **Helical pitch: see *Pitch factor* above** (see Chapter 2, “Imaging conditions”).
16) **Multislice**. This refers to MDCT or images acquired with MDCT. In this manual, when this term refers to the system rather than the images, MDCT is used as a uniform notation. It is often used in colloquial language.