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Evaluation of Environmental Radiation and Image Quality by Type of High-Energy Electromagnetic Wave Radiation Computed Tomography

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With the enhancement of national income level, the number of computed tomography (CT) exams to diagnose diseases is increasing more and more. To utilize the data for the safety control of X-ray, the image quality of the environmental radiation at the boundaries in the radiation zone of the exam rooms by type of CT using high-energy electromagnetic wave. The locations of the environmental radiation measurement were shielding wall of the door for patients, door for patients, door to CT control room, shielding wall of the door for CT control room, and window to see the patients, and the glass dosimeters were installed 150 to 170 cm above the floor considering the location of the device to be measured for 3 months and analyzed. The environmental radiations in the MDCT room were measured with 3.09 ± 2.31 mSv, 0.51 ± 0.12 mSv, 0.99 ± 0.43 mSv, 0.27 ± 0.03 mSv, and 0.18 ± 0.03 mSv at the door to the control room, the wall of the control room, door for patients, door wall, and window to see the patients, respectively. In the mobile CT room, the radiation was detected only at the door of the control room with 1.65 ± 0.15 mSv, and no radiation was detected at the other boundaries. In the PET-CT room, the radiations were detected with 0.18 ± 0.03 mSv and 0.27 ± 0.03 mSv at the door and door wall, respectively, without detection at the other boundaries. Upon the results of image quality by CT devices, very satisfactory outcomes were found in terms of contrast, clarity of the boundaries, and detection rate of lesions in all the acquired images, and also very satisfactory in the functional evaluations of the organs in PET-CT only. These results are anticipated to be used as the reference data to establish the systemic and efficient systems and policies in the safety control of X-ray in the future.

Keywords : high-energy electromagnetic wave device, Computed Tomography (CT), leakage, evaluation of image quality, shielding

1. Introduction

Medical images using the general high-energy electromagnetic radiation utilize the principles to transform the X-ray generated from the X-ray tube into the light using scintillator weakened X-ray by penetration of the human body or to make the images at the detector receiving X-ray directly without scintillator.

The general technique to capture the images using the high-energy electromagnetic radiation visualizes three-dimensional structures into two-dimensional images by reflection, so they will be overlapped with anatomical structures. It is difficult to identify the anatomical location or lesion of the structure with minute difference of attenuation. In particular, the identification of the areas where the difference of attenuation is not significant is impossible due to little difference of the contrast.

In case that the structure is composed of the material with uneven X-ray attenuation such as bone, soft tissue, and air, it is hard to differentiate the material with even thickness from that with different thickness and even attenuation in the medical radiation image.

Tomography can separate the overlapped structures in the general X-ray images, however, it cannot eliminate blurring which occurs in the interested image. Also, the scattered ray from open geometry of X-ray causes to lower the contrast.

CT was developed as a tool to overcome the limitations of general X-ray and tomography. The mechanism of CT is to capture the attenuated X ray at the detector after penetration in the cross section of the human body and transform it into the light signal. This is changed into the electric signal to be digitalized, and then sent to the computer to reorganize the image using mathematical

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algorithm.

Also, it is a system to observe the interested structure well by enhancing the contrast highlighting the minute difference of attenuation among tissues or addition of multiple image processing, and to transmit the digital data or save them in the auxiliary storage.

CT is a basic exam tool actively used clinically when the legion in the organ and disease are suspicious or the complete exam is required. The trend of the devices is to be diversified more. Low-dose multi-detector CT (MDCT) lowering the radiation, mobile CT that can assist the exam wherever it can be moved, and positron emission tomography-CT (PET-CT) have been developed and widely utilized in the clinical practices.

According to the report by Korea Disease Control and Prevention Agency, the number of CT exams has been growing, 9.151 million, 9.591 million, 10.897 million, and 11.920 million from 2016 to 2019, respectively. Increase of the exams enhances not only share of radiation but also total patient exposure.

Glass dosimeter has the advantages of excellent recalibration, reproducibility, and reusability after heat processing; and the disadvantages of volatility to contaminants such as dust on the table and weak mechanical features. In addition, the range of radiation measurement is broadly set from 10 μGy to 10 Gy with little dependency on the dose rate and image fading of florescence is very low, hence, it is widely utilized to measure the environmental radiation of X-ray.

According to the Korean guideline of radiation safety control on the CT using X-ray, shielding wall against radiation should be installed in the ceiling, floor, and wall, and the total leakage radiation and scattered doses measured out of the shielding wall should be maintained not more than 100 mR per week.

However, the safety control of X-ray using weekly leakage doses has the limitation because the leakage and scattered doses vary by operational volume per week and used energy continuously. This environment may cause to increase the radiation exposure. Hence, it is necessary to develop new safety control methods of X-ray to lower the exposure doses to the workers as well as the patients.

This study is aimed to offer the basic data to seek the safety control methods upon measuring the environmental radiation in the exam rooms of MDCT, mobile CT, and PET-CT that are used to diagnose diseases in the clinical practices and reviewing the guideline of X-ray safety control.

2. Study Subjects and Methods

2.1. Devices for image capturing and radiation measurement

In this study for MDCT, SOMATOM Definition AS (Siemens, Germany) CT scanner and CT Aquilion-CX (Thoshiba Medical system, Japan) that can capture 128 slide images with one rotation were used to capture the images and measure the environmental radiation around shielding wall in the exam room (Fig. 1).

A hospital that performed over 500 times of MDCT exams per month was selected, and environmental radiation in the exam room was measured from November 19 to December 31. For scanning condition, 80-140 kVp of tube voltage was used with automatic mode of tube current for 10 to 30 seconds (Table 1).

Fig. 1. (Color online) MDCT device and spatial internal structure to evaluate leakage dose per week of environmental radiation.

Table 1. MDCT, Mobile CT and PET CT scan parameter.

Parameter	MOBILE	MDCT	PET CT
kVp	105-195	80-140	120-140
mA	10	AUTO	50
Scan Field of View	300 (large)	300 (large)	300 (large)
exposure time (sec)	7.81	10-30	25-35
Reconstruction	AUTO	AUTO	AUTO
Average number of exams per month	100	500	100

For low dose mobile CT, Phion CT (NFR system, Korea) which uses narrow beam was used with the scanning conditions of head and the limbs in the clinical practices. The conditions were 105-195 kVp of tube voltage with automatic mode of tube current for 7.81 seconds (Table 1). The radiation was measured and analyzed for a month in the hospital where about 100 exams were performed in a month on average.

Biography mCT by Simens was used for PET-CT that diagnoses cancers by accurate identifications of them, its location, shape, metabolic abnormality, and so on combining excellent anatomical image of CT with biochemical information of PET (Figs. 2, 3).

With respect to the scanning condition, 105-195 kVp of tube voltage and 50 mA of tube current were used for 25 to 35 seconds in the hospital where about 100 exams were performed on average for a month.

Fig. 2. (Color online) Mobile CT device and spatial internal structure to evaluate leakage dose per week of environmental radiation.

Fig. 3. (Color online) PET CT device and spatial internal structure to evaluate leakage dose per week of environmental radiation.

2.2. Measurement and analysis of environmental radiation

According to the Korean guideline of radiation leakage, total leakage and scattered radiation doses measured out of the shielding wall should be not more than 2.58 C/kg per week (100 mR per week) in X-ray using facility. The evaluation method is to measure the instant dose using dosimeter and convert it by time. Therefore, the data can be different from the actual ones.

In Japan, they have the regulation to measure and control the accumulated doses. Since no regulation to control long-term accumulated doses is set in Korea, it is hard to compare both data. To secure the data reliability, RS type of Glassbadge (GB) by Chiyoda Technol in Japan which is globally well-known was used (Fig. 4).

The glass dosimeter of Chiyoda Technol to measure the environmental radiation is appropriate to measure the leakage and accumulated doses of environmental X-ray and γ ray.

Hence, after measurement of radiation for a month in the hospital bringing the dosimeter from Japan, the data reading of the glass dosimeter was performed in the radiation measurement center of Chiyoda Technol in Japan.

For the monitoring locations of environmental radiation in the X-ray using facility, the glass dosimeter was installed in the boundary areas of X-ray zones as in the installation guideline in Japan and the measurements were performed.

For the measurement locations of X-ray environmental radiation, the devices were installed 150 to 170 cm above the floor considering the location of the device at the shielding wall of the door for patients, door for patients, door for CT control room, shielding wall, and window to see the patients in the CT exam room (Fig. 5).

The dosimeter that completed the measurements was sent to Chiyoda Technol in Japan by flight to analyze the

Fig. 4. (Color online) Exterior and internal structure of glass dosimeter for measuring leakage dose per week of environmental radiation.

Fig. 5. (Color online) Measurement of leakage dose per week of environmental radiation External structure of laboratory and installation location of glass dosimeter.

results. For the objective comparison with the Japanese regulation on the environmental radiation, the 1month data were multiplied by three to be converted and analyzed as the doses per quarter.

2.3. Evaluation methods of CT images

Qualitative analysis with acquired images was performed to check the utility in the clinical practices. The qualitative analysis was performed by two radiologists and three radiological technologists who had more than 10 years of experiences with the images sorted as five groups (including 1: very poor, 2: poor, 3: normal, 4: good, and 5: very good) on the contrast, detection rate of legion, and clarity of the boundaries.

2.4. Statistical Analysis

The data were analyzed with SPSSWIN (Ver 13.0). T-test and ANOVA were performed for the significance test on the mean values of exposure doses in both control and test groups. All the significance levels were set as $p<0.05$.

3. Results and Discussion

3.1. Evaluation of environmental radiation in the exam room by type of CT

In Korea, the owners or managers of the medical institutions should take the test on the X-ray using devices every three years at the test institution for the safety control. Also, shielding facilities against radiation using X-ray devices should take the test at the test institution according to the test guideline of the radiation shielding facilities.

In case that maximum operation load per week exceeds the value set when the radiation shielding facilities are changed or designed, those shielding facilities should be tested from the test institution, immediately. In this safety control system, X-ray devices are controlled with periodic test every three years, which are managed relatively safely.

However, the safety control on the radiation shielding facilities are set to be tested once at the first installation of X-ray devices and once more when they are changed, which implicates the potential problem for safety control. Hence, boundary radiation doses in the radiation zone by device type were measured and analyzed by environmental glass dosimeter with the subjects of exam rooms using CT to offer the basic data for systemic safety control in the radiation shielding facilities, in this study.

The results of environmental radiation at the boundaries in the radiation zone of the exam rooms by type of CT are shown in Table 2.

Accumulated radiation dose for three months measured by glass dosimeter at the window to see patients in the radiation zone where radiological technologists were working was 0.18 ± 0.03 mSv for MDCT while no radiation was detected for mobile CT and PET-CT. This did not exceed 1.3mSv which was the Japanese standard of accumulated dose by glass dosimeter at the boundary in the radiation zone, reflecting that window to see patients played a role as the shielding wall properly.

Radiation dose was detected at the control room door where radiological technologists stay to control X-ray with 3.09 ± 2.31 mSv and 1.65 ± 0.15 mSv for MDCT and mobile CT, respectively, while no radiation was detected for PET-CT. Radiation dose was detected at the wall of control room with 0.51 ± 0.12 mSv for MDCT and no radiation was detected for mobile CT and PET-CT.

The results can be considered from the number of patients' exams during the measurement period and

Table 2. Measurement results of boundary environmental radiation in the radiation zone of the exam rooms by type of CT.

Device	Control room door	Control room wall	Door	Door wall	Window to see patients
MDCT	3.09 ± 2.31 mSv	0.51 ± 0.12 mSv	0.99 ± 0.43 mSv	0.27 ± 0.03 mSv	0.18 ± 0.03 mSv
Mobile CT	1.65 ± 0.15 mSv	-	-	-	-
PET-CT	-	-	0.18 ± 0.03 mSv	0.27 ± 0.03 mSv	-

differences between the awareness and practice on the radiation shielding by radiological technologists.

In particular, the door which plays a role of shielding wall during the X-ray usage should be closed, however, the found results during the visit may be caused by the work convenience to handle more exams with rapid responses to the first aids for patients.

In the door where patients, caregivers, and non-patients wait, radiation dose was detected with 0.99 ± 0.43 mSv and 0.18 ± 0.03 mSv for MDCT and PET-CT, respectively, and no radiation was detected for mobile CT. In the door wall, radiation dose was detected with 0.27 ± 0.03 mSv and 0.27 ± 0.03 mSv for MDCT and PET-CT, respectively, while no radiation was detected for mobile CT.

These results were related to the number of patients' exams and the energy from the CT device during the measurement period and they did not exceed 1.3 mSv, the Japanese standard of accumulated dose of glass dosimeter at the boundary in the radiation zone, which can be considered to play a role of shielding wall properly. However, caregivers or non-patients are not related to the direct advantage from X-ray, so it is necessary to seek the measures to minimize the exposure of environmental radiation where they can stay.

3.2. Evaluation of acquired image quality by type of CT

In the modern society, CT is used to diagnose and treat diseases earlier as an essential exam item. MDCT has the advantages to shorten the exam time and capture the

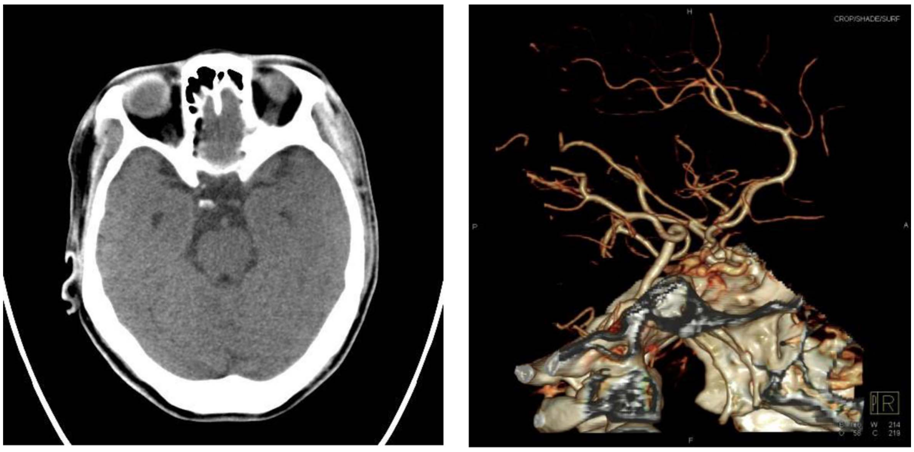

Fig. 6. (Color online) 2D and 3D MDCT acquisition images for evaluation of medical image quality.

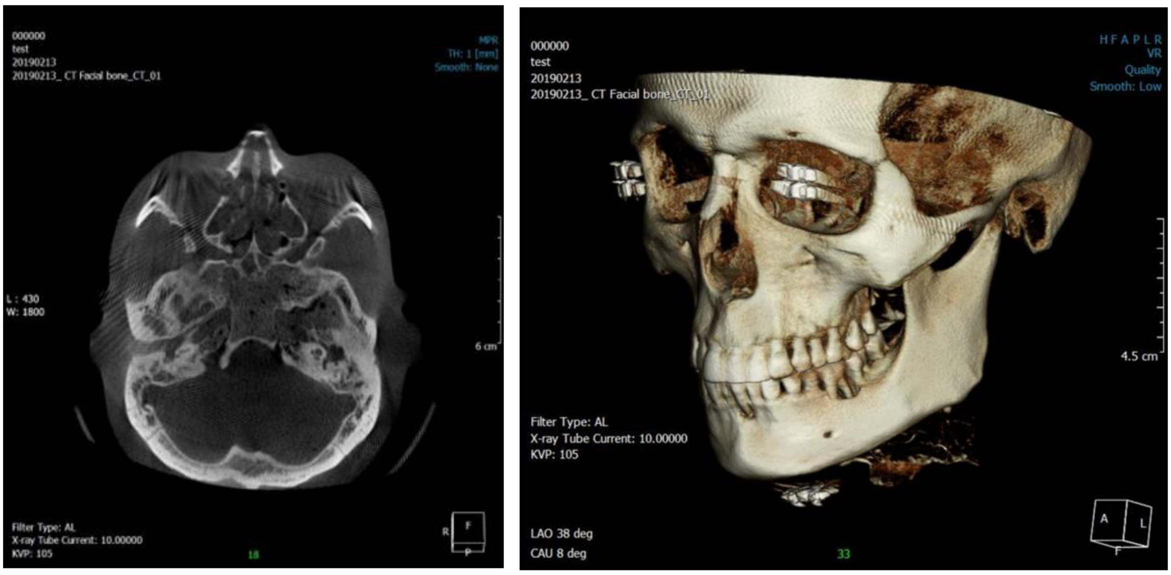

Fig. 7. (Color online) 2D and 3D of Mobile CT 2D and 3D MDCT acquisition images for evaluation of medical image quality.

Table 3. Evaluation of image quality by type of CT.

Device	Contrast	Clarity of the boundaries	Detection rate of legion	Functional evaluation of the organs
MDCT	5 ± 0.5	5 ± 0.5	5 ± 0.5	3.5 ± 0.5
Mobile CT	5 ± 0.5	5 ± 0.5	5 ± 0.5	3.0 ± 0.5
PET-CT	5 ± 0.5	5 ± 0.5	5 ± 0.5	5 ± 0.5

reorganized images using high resolution thin sections, and it causes to increase the radiation dose to patients as 3D reorganization function becomes popular (Fig. 6).

When diagnosing patient, it is important to check the anatomical and functional images of the suspicious human body accurately without physical and mental damages. Because of this, multiple devices using X-ray are used, and simple X-ray device shows poor quality in terms of image resolution, contrast, and so on compared to CT.

Recently, mobile CT is widely used to get the images by the noninvasive way in the case that simple fracture or soft tissue injury is suspicious, or surgical plan is prepared (Fig. 7).

Positron Emission Tomography (PET) is the diagnostic method to check the occurrence of cancer or its recurrence by visualizing the distribution of radiation which is generated inside the body after intravenous injection of radioactive medicine that disseminates positron. Since it finds the metabolic abnormality, prior stage of anatomical change, accurately, early diagnosis of cancer is possible compared to CT. It is a good diagnostic tool to determine the stage of diseases, malignancy of the tumor, efficient treatment methods, and recurrence after treatment.

PET-CT is the tool combining CT which is good to observe the location and shape of the lesion, applying the anatomical changes of the human body accurately.

The qualitative analysis was performed with acquired images by type of CT. The analysis was performed by one radiologist and five radiological technologists who had more than 10 years of experiences with the images acquired from the devices, sorted as five groups (including 1: very poor, 2: poor, 3: normal, 4: good, and 5: very good) on the contrast, clarity of the boundaries, detection rate of legion, and functional evaluation of the organs.

Very satisfactory results were found in contrast, clarity of the boundaries, and detection rate of legion on all the acquired images. However, in terms of functional evaluation of the organs, only images from PET-CT showed very satisfactory results while those from MDCT and mobile CT showed normal level. The results may implicate that PET-CT generates the images combining the advantages of both CT and PET (Table 3).

The above results can be considered to offer the basic data when CT is selected and utilized in the future. Since probabilistic impact can be occurred in X-ray, optimal radiation should be used in CT exam and environmental

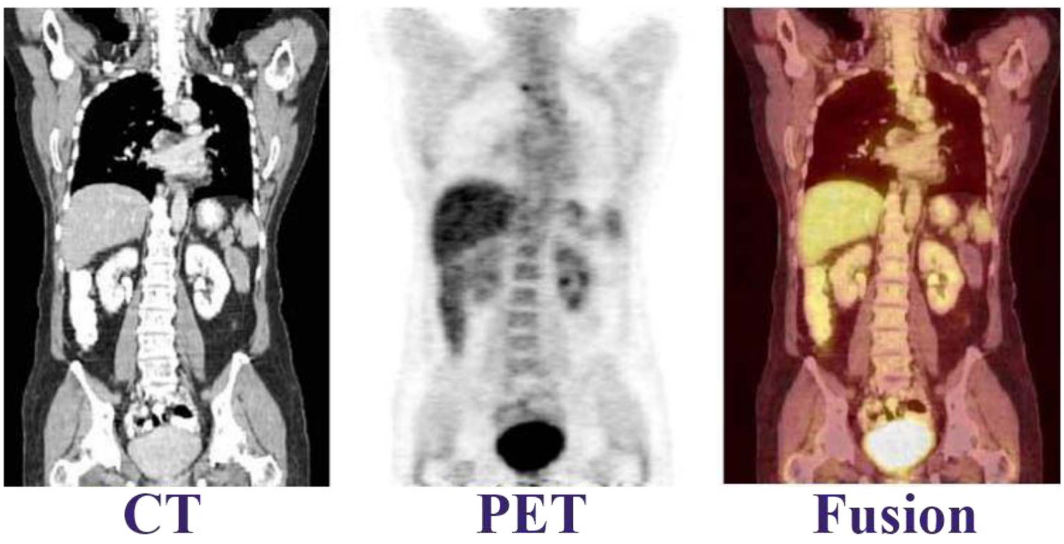

Fig. 8. (Color online) 2D and 3D of PET-CT acquisition images for evaluation of medical image quality. Fusion imaging of PET and CT.

radiation control should be practiced. Further long-term and continuous studies are required on the analysis of environmental radiation at the boundaries of radiation zone.

4. Conclusions

To offer the basic data to perform safety control of X-ray, accumulated leakage radiation for 3 months were measured and analyzed by type of CT at the boundaries in the radiation zone of exam room, and the acquired image quality was also analyzed.

Environmental radiations in MDCT exam room were measured with 3.09 ± 2.31 mSv, 0.51 ± 0.12 mSv, 0.99 ± 0.43 mSv, 0.27 ± 0.03 mSv, and 0.18 ± 0.03 mSv at the door of the control room, the wall of the control room, door for patients, door wall, and window to see the patients, respectively.

In the mobile CT room, the radiation was detected only at the door of the control room with 1.65 ± 0.15 mSv, and no radiation was detected at the other boundaries. In PET-CT room, the radiations were detected with 0.18 ± 0.03 mSv and 0.27 ± 0.03 mSv at the door and door wall, respectively, without detection at the other boundaries.

With respect to the evaluation of image quality by type of CT, very satisfactory results were found in contrast, clarity of the boundaries, and detection rate of legion on all the acquired images. In terms of functional evaluation of the organs, only images from PET-CT showed very satisfactory results.

The study results will be utilized effectively when managers of safety control for X-ray in the medical institutions establish the safety control plan. Further studies are offered anticipating that the results could be useful for the policymakers in the government who establish the safety control policies on X-ray.

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