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Analysis of Use Factors in CT (Computed Tomgraphy) Safety Management of High-Energy Electromagnetic Radiation

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The use of CT scans, which possess optimal advantages for diagnosing diseases in the human body, has been increasing annually, serving as a source of increasing patient radiation doses. This study sought to provide foundational data useful for designing radiation shielding walls in CT examination rooms by measuring and analyzing radiation doses for the derivation of use factors in MDCT and Mobile CT examination rooms. The average cumulative radiation dose measured over three months using a glass dosimeter immediately before penetrating the patient viewing window in the MDCT examination room was 100.9 ± 2.93 mSv; with 107.7 ± 5.03 mSv in the ceiling direction, 105.6 ± 4.13 mSv in the wall direction, and 114.2 ± 3.78 mSv in the floor direction. In the Mobile CT examination room, the values were 0.35 ± 0.03 mSv; with 0.51 ± 0.02 mSv in the ceiling direction, 0.52 ± 0.02 mSv in the wall direction, and 0.55 ± 0.03 in the floor direction. Evaluations of image quality from different CT devices showed very satisfactory results in contrast, clarity of boundaries, and lesion detection rates. In terms of image satisfaction against exposure dose, Mobile CT showed more satisfactory results than MDCT. The results of this study are expected to provide information for a more secure and efficient system in medical radiation safety management.

Keywords : high-energy electromagnetic devices, Computed Tomography (CT), leakage dose, image quality evaluation, shielding, magnetic sensor dosimeter

1. Introduction

Computed Tomography (CT) devices, which use high-energy electromagnetic radiation, are technologies that reconstruct projection data of the human body using a computer to produce cross-sectional images. The examination using a CT device involves probing the targeted area of the human body from various angles, collecting the penetrated X-rays using a detector, and then employing a computer to reconstruct the differences in X-ray absorption for that area using mathematical techniques [1-3].

Compared to X-ray imaging techniques that do not use cross-sectional imaging, it has superior resolution and contrast for distinguishing blood, cerebrospinal fluid, white matter, gray matter, tumors, etc. It is capable of representing subtle differences in absorption, making it a very crucial domain in the field of radiological diagnosis. The fundamental principle of a CT device entails the X-ray tube circulating around a section of the human body, probing with an X-ray beam. Detectors collect the intensity of each beam, and the computer calculates the absorption intensity for each section, reconstructing and displaying the image on a monitor based on the calculated data [4-7].

CT devices penetrate X-rays into the human body and reconstruct the absorption differences using a computer to produce cross-sectional images or three-dimensional images of the human body. For this reason, it can distinguish even very slight density differences in human tissues, making the diagnosis of small lesions about 5mm in size possible, and the examination can be applied to any part of the body [8, 9].

The initial CTs took several minutes just to capture the projection data needed to reconstruct a single sectional image. Additionally, it took dozens of minutes to reconstruct a three-dimensional image from the projection data. Over the past 40 years, the history of CT development has largely been about reducing imaging time. Today's 128-channel MDCT can capture the entire chest in a matter of seconds, and the time needed to reconstruct

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a three-dimensional image of the entire chest is within a few minutes. With its dramatic advancement, CT has broadened its clinical application range. For instance, even tiny structures inside the body, like a 2 mm diameter lung tumor, can now be imaged without the wobble caused by breathing [10, 11].

Due to the optimal advantages CT offers in diagnosing human diseases, the number of CT scans is increasing annually. This increase in scans not only raises the radiation dose from the device but also increases the overall radiation dose for patients. In medical radiation safety management, testing facilities using radiation must install protective shielding. When installing a radiation protective facility for a radiation examination room, the type of device, weekly operating volume of the device, energy usage, and direction of energy use should be considered. When calculating the thickness of the shielding, the usage factor (Useful factor) that indicates the direction of radiation use becomes an important factor [8-10, 12].

Glass dosimeters have excellent repeatability and reproducibility, can be reused after heat treatment, have a wide range of dose measurements, and can measure accumulated radiation doses over a certain period. In examination rooms using medical radiation, in order to adequately compute the protective shield, instead of using the traditionally fixed uniform usage factors, it would be rational to analyze the proportion of radiation heading to the point of concern according to the device's characteristics and derive the thickness of the shield accordingly [13-16].

In this study, we aim to measure and analyze the dose for determining the usage factor of the recently widely-used MDCT device and Mobile CT examination rooms using a glass dosimeter. The results of the dose measurement analysis will be presented as useful foundational data when designing protective facilities by calculating the shielding wall thickness of the CT examination room. Furthermore, this study aims to present foundational data that can contribute to reducing exposure doses, seeking standards and methods for medical radiation safety management.

2. Subjects and Methods

2.1. Devices for acquiring 2D and 3D CT images for user factor analysis

For appropriate radiation safety management, it is necessary to calculate the thickness depending on the material of the radiation barrier. In this experiment, the SOMATOM Definition AS? (Siemens, Germany) CT scanner, which can acquire 128-slice images with a single rotation, and the mobile CT imaging device Phion CT (NFR system, Korea) were used to analyze the user factor for appropriate shielding design (Fig. 1, 2).

Fig. 1. (Color online) MDCT device and examination room for acquiring 2D, 3D medical images and measuring radiation doses.

Fig. 2. (Color online) Mobile CT device and examination room for acquiring 2D, 3D medical images and measuring radiation doses.

General CT devices were selected from hospitals that

Table 1. Additional factors for the CT device settings for acquiring 2D, 3D medical images for user factor analysis.

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

perform over 350 examinations monthly, and the cumulative radiation dose was measured over one month. The scan conditions used a tube voltage of 80-140 kVp, the tube current was set automatically, and the exposure time ranged from 10-30 sec (Table 1).

The mobile CT device used the narrow beam to acquire images with the Phion CT (NFR system, Korea) in hospitals that perform over 150 examinations monthly, and measured the cumulative radiation dose over a month. Specific scan conditions were similar to (Table 1), using a tube voltage of 105-195 kVp, the tube current was set automatically, and the exposure time was 7.81 sec.

2.2. Cumulative radiation dose measurement and evaluation analysis for user factor analysis

In medical examination rooms using medical radiography, radiation shielding facilities must be installed to prevent radiation exposure to radiation workers, patients, and patient guardians. The term "radiation protection facility" refers to radiation shielding facilities and protective equipment for the location where diagnostic radiation generators are installed.

In Korea, when determining the thickness of the shielding material for the protective wall of a facility using a diagnostic radiation generator, various factors such as radiation energy, weekly operating amount, user factor, and occupancy factor are considered.

The thickness of the protective wall should ensure that the sum of radiation leakage and scatter measured outside the protective wall does not exceed 2.58×10^{-5} C/kg (100mR per week). This method involves measuring the instantaneous exposure dose and converting it to a weekly exposure dose. Due to these reasons, there is a difference between the actual measured cumulative leakage dose and the calculated dose in hospital examination rooms using diagnostic radiation generators. To measure the actual accumulated radiation dose, a dosimeter that can measure the absorbed dose over a long period, such as a glass dosimeter, must be used.

In this study, the globally recognized environmental glass dosimeter (Glassbadge:GB) RS type from Chiyoda Technol Corporation of Japan was used to measure the cumulative radiation dose (Fig. 3). Chiyoda Technol's environmental radiation measuring glass dosimeter is suitable for measuring the cumulative leakage dose of environmental radiation X-rays and γ-rays depending on the type of CT device.

For this study, the environmental glass dosimeter was directly imported from Japan and after measuring the cumulative dose in the medical institution's examination room for one month, it was sent by air to Chiyoda Technol's radiation measurement center in Japan for dosimeter reading.

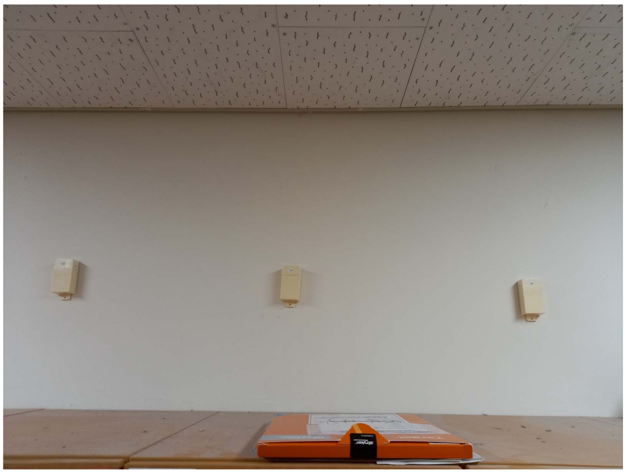


Fig. 3. (Color online) Environmental glass dosimeter for measuring cumulative radiation dose in diagnostic radiation generator examination room.

Fig. 4. (Color online) Installation location of the glass dosimeter for user factor analysis for calculating the radiation shielding facility protective wall.

The positions for monitoring the cumulative dose of radiation in facilities using diagnostic radiation generators were installed on the floor, walls, and ceiling according to international standards. The glass dosimeter was directly attached to the ceiling, walls, and floor directions of the CT device to measure the cumulative dose for one month and analyze the user factor. For diagnostic radiation environment monitoring, considering the position of the radiation generator, the dosimeter was installed at a height of 150-170 cm from the floor at the entrance barrier wall, door, CT device control room door, barrier wall, and patient viewing window to measure and analyze the cumulative dose (Fig. 3, 4).

After completing the cumulative dose measurement, the dosimeter was collected, sent by air to Chiyoda Technol in Japan, and the measurement results were analyzed. The results of the environmental cumulative dose measurement were compared with the existing user factor's international recommended standard, which is 1/16 for the ceiling, 1/4 for the wall, and 1 for the floor, and analyzed with the new international recommendation.

2.3. Image evaluation

Acquired images were analyzed qualitatively to identify usefulness in medical treatment. Qualitative analysis of images was done about image contrast, clarity of boundaries, lesion detection rate and regarding satisfaction with the image in relation to the exposure dose. Five specialists (2 medical doctors specializing radiology and 3 radiologists with working experiences over 10 years) were asked to classify the results on the 5-point scale (1 - very poor; 2 - poor; 3- average; 4 - good; 5 - very good).

2.4. Statistical Analysis

The data analysis was performed using the SPSSWIN (Ver 22.0) statistical program, and the t-test was performed to verify the significance of the average value of the exposure dose measurements of the control group and the experimental group. The significance level of all statistics was set to $p < 0.05$.

3. Research Results and Discussion

3.1. Evaluation of Radiation Dose Measurements for Analysis of Usage Factors in Examination Rooms by Type of CT Device

In South Korea, safety management of medical radiation protection facilities requires a single inspection when a diagnostic radiation generating device is first installed and when the equipment or facility is changed. This safety management system has its drawbacks.

The first issue is that the shielding standards for diagnostic radiation generating facilities are set based on the maximum weekly usage. However, in actual medical institutions, there is a significant deviation in the maximum weekly usage depending on the season. The second issue is that even if there is a change in the maximum weekly usage, the radiation protection facility cannot be reinforced periodically.

Given these reasons, it's crucial to predict and reflect accurate figures for weekly device operation, usage factors analyzing the direction of radiation use, and the occupancy factors indicating accessibility to radiation-generating spaces when setting the shielding wall thickness of diagnostic radiation generating facilities. In this study, we used an environmental glass dosimeter to measure the radiation dose based on the direction of radiation use to provide basic data for systematic safety management of the examination room's protective facilities for diagnostic radiation generating devices.

Results of radiation dose measurements for analysis of usage factors in examination rooms by type of CT device are shown in (Table 2). We selected three general hospitals using the same MDCT and measured the radiation dose in the examination room. The monthly average usage for hospitals A and C was around 500, while for hospital B it was around 350. Radiation dose measurements were made in examination rooms of hospitals D, E, and F, which use the same model of Mobile CT, and they conducted an average of 150 tests per month.

In the MDCT examination room, the average accumulated radiation dose over three months measured by the glass dosimeter just before passing through the patient observation window was 100.9 ± 2.93 mSv. Measurements in the direction of the ceiling were 107.7 ± 5.03 mSv, wall direction was 105.6 ± 4.13 mSv, and floor direction was 114.2 ± 3.78 mSv.

These results provide important information for determining the user factors dependent on the direction of

Table 2. Results of radiation dose measurements for analysis of usage factors in examination rooms by type of CT device.

Device Type		Ceiling (mSv)	Wall (mSv)	Floor (mSv)	Patient Observation Window (mSv)
MDCT	A	116.5±5.82	114.3±4.89	123.7±3.63	110.2±3.05
	B	89.5±2.54	91.3±3.68	96.4±4.01	84.60±1.53
	C	117.0±5.03	111.3±4.13	118.4±3.78	108.00±2.93
	Mean	107.7±5.03	105.6±4.13	114.2±3.78	100.9±2.93
Mobile CT	D	0.50±0.03	0.54±0.03	0.55±0.03	0.36±0.03
	E	0.51±0.02	0.52±0.02	0.54±0.03	0.34±0.03
	F	0.53±0.02	0.51±0.03	0.55±0.04	0.35±0.03
	Mean	0.51±0.02	0.52±0.02	0.55±0.03	0.35±0.03

radiation use in the MDCT examination room.

In examination rooms where simple X-ray examinations are conducted, there are many instances of examining towards the floor, thus the floor is the most frequently used, followed by walls, then ceilings in the frequency of radiation examination.

In the case of the MDCT examination room, unlike simple X-ray examinations, due to the structural characteristics of the CT device, which rotates 360 degrees and scans with X-rays, it is understood that a similar radiation dose is detected in all directions such as floor, ceiling, and walls, regardless of the direction of use. Therefore, when designing the protective wall of the MDCT examination room, it is necessary to refer to these results, set the weekly operation amount to the maximum detected amount regardless of the direction of radiation use, and calculate and construct the thickness of the shielding wall.

In the radiation area where the radiographer works in the Mobile CT examination room, the average accumulated radiation dose measured over three months by the glass dosimeter just before penetrating the patient viewing window was 0.35 ± 0.03 mSv, in the ceiling direction 0.51 ± 0.02 mSv, wall direction 0.52 ± 0.02 mSv, and floor direction 0.55 ± 0.03 mSv. The Mobile CT device was measured with a smaller radiation dose than the Mobile CT due to the use of a narrower range of X-ray beams and relatively low tube voltage and tube current.

This is a result that shows that the radiation dose varies depending on the exposure conditions such as the tube voltage, tube current, and exposure time of the diagnostic radiation-generating device, and it is a result that shows that the radiation dose varies depending on the X-ray energy characteristics and the use range of the X-ray beam. From the above results, depending on the type and characteristics of the CT device, it is necessary to predict the radiation dose generated and design and construct the protective wall of the examination room using the diagnostic radiation-generating device so that safer radiation area safety management can be achieved.

3.2. Comparative analysis of dose measurement results for user factor analysis by type of CT device and image acquisition evaluation

Recently, computer tomography devices (MDCT, Multi Detector Computed Tomography) and mobile computer tomography devices (MCT, Mobile Computed Tomography) have been used as essential examinations to diagnose and treat diseases early using X-rays.

MDCT devices have the advantage of being able to acquire reconstructed images using thin sections with high resolution in a shortened examination time and are becoming a factor that increases the patient dose as they commonly use 3D reconstruction functions. Additionally, recently there has been an increase in the use of Mobile CT, which has advantages over X-ray images taken with simple X-ray imaging devices in terms of image resolution and contrast. This is due to the non-invasive imaging capability to obtain images for suspected simple fractures or soft tissue injuries and surgical plans. There is a concern that the increase in Mobile CT use will increase the patient's exposure dose.

Table 3. Comparison of usage factors for radiation shielding wall design in examination rooms based on CT device type.

Device Type		Ceiling	Wall	Floor
Existing Recommendations		1/16	1/4	1
Modified Recommendations	MDCT	1(0.94)	1(0.93)	1
	Mobile CT	1(0.93)	1(0.95)	1

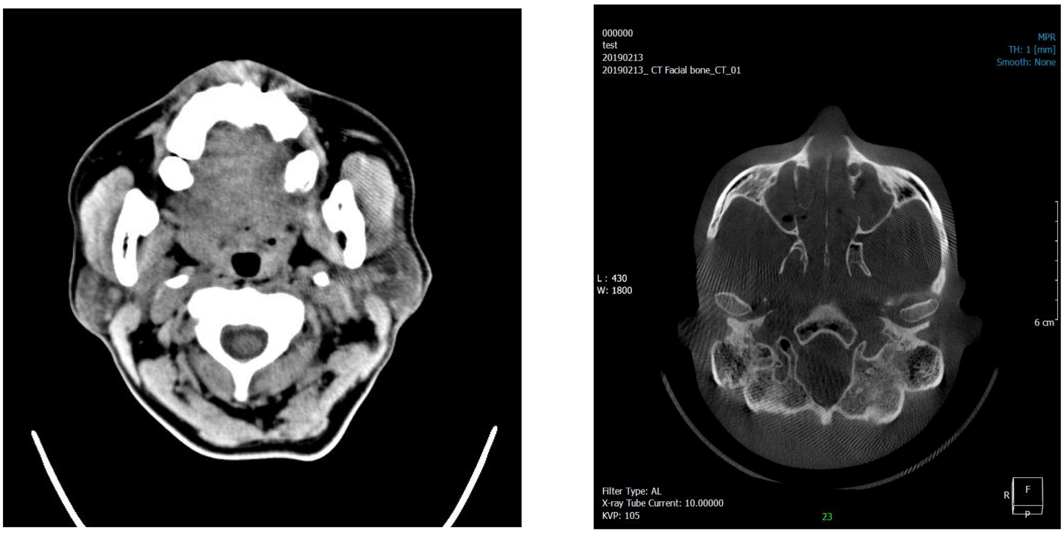
In this study, based on the recommended usage factors derived from the radiation usage on the floor in traditional X-ray examinations, radiation dosage measurements were conducted and analyzed for the direction of radiation use in MDCT and Mobile CT examination rooms (Table 3).

In the examination room using the MDCT device, based on the measured dosage on the floor, the radiation dose in the ceiling direction was 0.94, and the radiation dose in the wall direction was 0.93. In the examination room using the Mobile CT device, the radiation dose in the ceiling direction was 0.93, and the radiation dose in the wall direction was 0.95.

These results are believed to be due to the characteristics of the CT device, which revolves and emits X-rays to retrieve information from the human body. Based on this study, unlike examination rooms where regular simple X-ray examinations are conducted, it is necessary to design and construct shielding walls for CT examination rooms with a usage factor of 1.

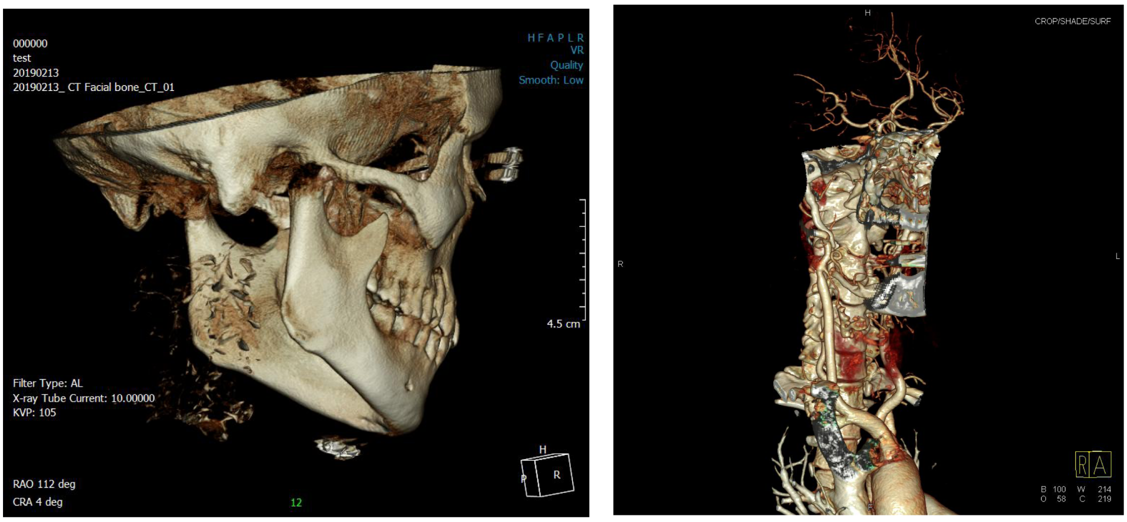
Qualitative evaluations were conducted on the acquired images based on the CT device type. The qualitative analysis was divided into five groups (1: Very Unsatisfactory, 2: Unsatisfactory, 3: Average, 4: Good, 5: Excellent) to evaluate the image contrast, clarity of the boundary, lesion detection rate, and satisfaction level of the image compared to the exposure dose. The evaluations were analyzed by one radiology specialist and five radiographers with over 10 years of experience. The results for contrast, clarity of boundaries, and lesion detection rate showed very satisfactory outcomes for all acquired images (Fig. 4, 5).

Mobile CT showed very satisfactory results, while MDCT showed somewhat satisfactory results (Table 4).



(a) (b)

Fig. 5. MDCT and Mobile CT 2D image acquisition for image quality evaluation based on exposure dose by CT device type. (a) MDCT image (b) Mobile CT image.



(a) (b)

Fig. 6. (Color online) MDCT and Mobile CT 3D image acquisition for image quality evaluation based on exposure dose by CT device type. (a) MDCT image (b) Mobile CT image.

These study results are expected to serve as a fundamental resource in selecting CT devices considering the exposure dose for specific examination sites in the future. Determining the thickness of the shielding wall when designing protective facilities in diagnostic radiation safety management is of utmost importance. In Korea, since the initial installation is examined, one should approach the shielding wall design conservatively and

Table 4. Image satisfaction and quality evaluation based on exposure dose by CT device type.

Device Type	Contrast	Boundary Clarity	Lesion Detection Rate	Image Satisfaction vs Exposure Dose
MDCT	5±0.5	5±0.5	5±0.5	5±0.5
Mobile CT	5±0.5	5±0.5	5±0.5	4.0±0.5

future-oriented by considering the maximum weekly operation amount, usage factor, and occupancy factor.

Such practices should become a basic safety consideration in diagnostic radiation safety management, promoting the advancement of safer diagnostic examinations using radiation. It is believed that long-term and continuous research on environmental dose measurements and analyses for examination rooms using diagnostic radiation-emitting devices will be needed in the future.

4. Conclusions

In order to establish a systematic and stable human medical radiation safety management system, we conducted dose measurement analysis to suggest improvements based on the measurement of usage factors that depend on the direction of radiation use in the CT examination room by type of CT device. Additionally, we analyzed the image quality and satisfaction level in relation to the exposure dose.

In the MDCT examination room, the average cumulative radiation dose measured by the dosimeters on the window just before penetrating the patient's viewing window over three months was 100.9 ± 2.93 mSv, with the ceiling direction showing 107.7 ± 5.03 mSv, the wall direction 105.6 ± 4.13 mSv, and the floor direction 114.2 ± 3.78 mSv. In the Mobile CT examination room, the average cumulative radiation dose measured by the dosimeters on the window just before penetrating the patient's viewing window over three months was 0.35 ± 0.03 mSv, with the ceiling direction showing 0.51 ± 0.02 mSv, the wall direction 0.52 ± 0.02 mSv, and the floor direction 0.55 ± 0.03 mSv.

The results of the image quality assessment by CT device showed very satisfactory results in all the acquired images in terms of contrast, clarity of boundaries, and lesion detection rate. Regarding satisfaction with the image in relation to the exposure dose, Mobile CT showed better results than MDCT. These research findings are expected to be very useful for medical institution diagnostic radiation safety management personnel in planning and practicing medical radiation safety management. We propose ongoing research in related fields.

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