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A Study on Dose Evaluation in DR System depending on Grid Use

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Abstract - The purpose of this study was to suggest strategies for the appropriateness of grid use and reduction of exposure dose by conducting a survey on the use of a digital radiography (DR) system in 30 general hospitals located in the capital area. With the goal of using its results as basic data in the future, this study measured the change in dose depending on use or no use of a grid. The study method was to conduct a survey on the possession of DR equipment and grid use for examination of the extremities among 30 general hospitals in the capital area. In regard to exposure dose, acryl phantom was used to measure the change in dose depending on use or no use of a grid. The results of the survey questionnaire showed that a grid was used for examination in 97 out of 135 total pieces of equipment, while a grid was not used in the remaining 38 pieces of equipment. With respect to dose evaluation, the dose for each body part depending on use or no use of a grid was measured at 81.50±9.01 μGy and 129.80±0.26 μGy in the acryl phantom thickness of 2.54 cm+1.0 mmAl, 67.08±0.22 μGy and 110.94±34.66 μGy in the thickness of 5.08 cm+1.0 mmAl, and 297.99±0.63 μGy and 567.39±1.58 μGy in the thickness of 7.62 cm+2.0 mmAl. In conclusion, there was a difference of about two-fold or more in the dose depending on use or no use of a grid.

Key words : DR system, Grid, Exposure dose

INTRODUCTION

With use of film or a detector, the X-ray has been available to image the human body and diagnose disease; this technique has contributed greatly to the medical industry and development of modern medicine. The picture achieving and communication system (PACS) was introduced in the 2000s and quickly replaced the X-ray as a film/screen method. The PACS system has also paved the way for digital radiation equipment such as computed radiography (CR) and digital radiography (DR), which have been widely used (Körner *et al*. 2007). Digital radiation equipment has many benefits, such as convenient medical image acquisition, a wide dynamic range, and ability to reuse the image storage medium, so that the equipment increases work efficiency in terms of patient and business management (Strotzer *et al*. 1998).

Remarkable development has been made in patient dose and image quality management in radiation scan technology (Rapp-Bernhardt *et al*. 2003). And, dose reduction at a certain level does not influence image quality, so that it is possible to reduce the dose without degradation of image quality (Pascoal *et al*. 2005). It is also possible to reduce the dose in scanning the skeletal system without degradation of image quality (Lee *et al*. 2011). A study that used a hand phantom showed a better diagnostic performance than the film/screen method under the same dose conditions and enabled reduction of dose without any difference in diagnostic accuracy (Strotzer *et al*. 2000). The factors that determine

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image quality in the DR have to do with dose, and a dose increase in the dose range improves the signal to noise ratio (SNR) (Samei *et al*. 2005). However, it has been reported that the scattered ray that is generated after the ray passes through a patient leads to degradation of image quality in terms of contrast or sharpness of image (Axelsson *et al*. 2000).

A collimator, filter, air gap, and grid have been used to remove the scattered ray. The grid has been widely used since 1913, when Gustave Buckey developed the grid to minimize the adverse effect that the scattered ray had on image quality by removing the scattered ray that was generated from the human body (Hong *et al*. 2009). The scattered ray is removed in the same manner in the digital system, which was developed based on the film/screen method.

In scanning various body parts, the extremities show the lowest patient entrance dose. The patient entrance dose of the wrist, elbow, and knee anterior posterior (AP), which are shallow body parts for scanning, is recommended to be around 0.12~0.51 mGy. It has been reported that the patient entrance dose of pelvis AP is 0.59~12.69 mGy and that of spine AP is 0.64~23.84 mGy (Lee *et al*. 2010). However, a grid is used for shallow body parts, such as the extremities, which increases patient exposure dose. Therefore, it is believed that the role that radiologists should play for patients is to reduce the exposure dose for infants and children, even though the dose is considered to be low. In particular, use of DR equipment has recently become a factor in increasing the exposure dose due to strengthened scan conditions for the detector. In examination of the extremities, which does not require grid use, the grid tends to be used for scanning because of the convenience of scan and characteristics of the DR equipment, which increases unnecessary exposure to patients. Recently, hand PA scanning in photographing the musculoskeletal system has been an increasing trend in determining infant bone age. In theory, education is provided to ensure that the grid should not be used for photographing shallow body parts of the extremities. However, the reality is that the grid is used for examination of the extremities in clinical institutions where the DR system is utilized. Against this backdrop, this study targeted 30 general hospitals in the capital area to conduct a survey on the possession of DR equipment and the use or no use of a grid in examination of the extremities based on the examination conditions. In regard to the exposure dose, the acryl phantom was used to compare and evaluate the change in dose depending on use or no use of a grid, and this study's aims were to suggest strategies for the appropriateness of grid use, reduce the exposure dose, and ensure that the study results are used as basic data in the future.

STUDY METHOD AND EQUIPMENT

1. Study Method

1.1 Survey

This study conducted a survey with a questionnaire in 30 general hospitals in the capital area for one month in October 2019. The survey items included the amount of DR equipment in possession; manufacturer of such equipment; photographing room; function of grid attachment, detachment to and from equipment, and if such function was available; and use or no use of a grid in examination of the extremities.

1.2 Dose Measurement

In the DR system, selection was made for the body parts that did not require use of a grid in examination of the extremities before such parts were divided into three groups. The thickness of acryl phantom for the hand, wrist, forearm, and foot was 2.54 cm + 1.0 mmAl for infants and children and 5.08 cm + 1.0 mmAl for adults. In addition, the thickness of acryl phantom for the knee and shoulder was 7.62 cm + 2.0 mmAl.

For dose measurement depending on use or no use of a grid, the FFD was set at 110 cm, which was the distance for examination of the extremities, as shown in Fig. 1, while the dosimeter of Unfors Mult-O-Meter was placed under the Fluke Biomedical RMS (25 × 25 × 2.54 cm, 1.0 mmAl) acryl phantom (Fig. 2 and Fig. 3).

Then, Piview (Version 5.0.9.52) was used to calculate the dose area product (DAP) value that was the effective area dose (Fig. 4).

In regard to beam quality used in the examination, the beam quality of RQA3, among the four kinds of beam quality regulated in the IEC 61267, was used when the thickness of acryl phantom for the hand, wrist, forearm, and foot was 5.08 cm + 1.0 mmAl at 50 kVp and 5 mAs. In addition, the beam quality of RQA5 was used when the thickness of acryl phantom for the knee and shoulder was 7.62 cm + 2.0 mmAl at 70 kVp and 10 mAs (Table 1).

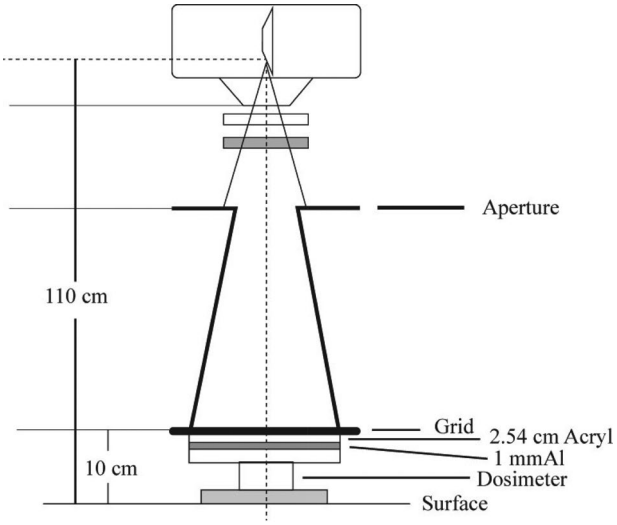

Fig. 1. Extremity phantom placed on the detector surface.

Fig. 2. Unfors Mult-O-Meter.

When the thickness of acryl phantom for the hand, wrist, forearm, and foot was 2.54 cm + 1.0 mmAl for infants and children, the clinical conditions of 48 kVp and 4 mAs were applied to the examination. The measurement was repeated 10 times in total when the grid was used and not used. Since the aforementioned conditions were used as basic conditions, the value of mAs was reduced by 0.5~2 times without use of grid to analyze the change in image quality according to the exposure dose. SPSS 12.0 statistics program was used to calculate descriptive statistic values [Mean ± Standard deviation (SD)] based on the data obtained from the study results. In order to verify the difference in dose depending on use or no use of a grid and on thickness of each acryl phantom at equal doses, the paired t-test was conducted in repeated measurements. One-way analysis of variance (ANOVA) was conducted for comparison and analysis of the difference in dose depending on the value of

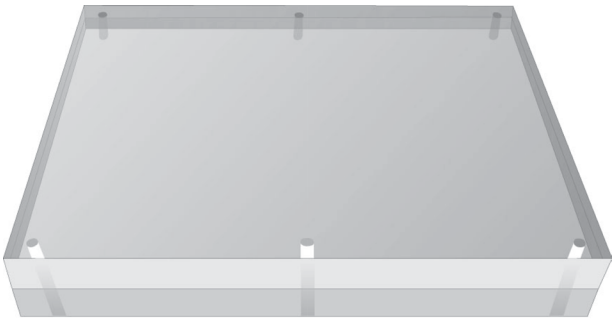

Fig. 3. Fluke Biomedical, RMS (25×25×2.54 cm, 1 mmAl).

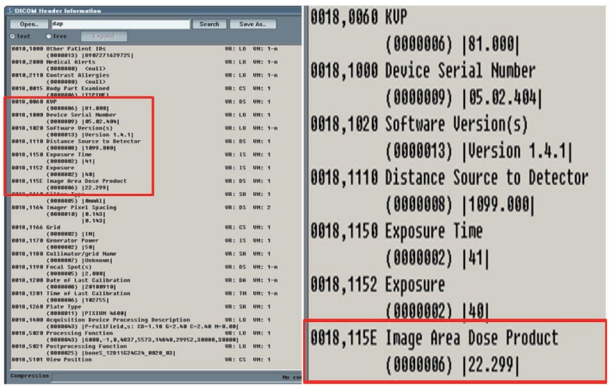

Fig. 4. DAP (Dose Area Product) in DICOM Header Information.

Table 1. Medical diagnostic X-ray equipment-Radiation condition for use in the determination of characteristics (IEC 61267)

Radiation quality No.	Approximate X-ray tube voltage	HVL[a] mmAl	Additional filtration mmAl
RQA3	50	4.0	10.0
RQA5	70	7.1	21.0
RQA7	90	9.1	30.0
RQA9	120	11.5	40.0

[a]Half-value Layer

mAs for each thickness of acryl phantom without use of a grid. In addition, Dunnett was used for post-hoc analysis in order to elucidate the difference more accurately. A p value of 0.05 or less was considered to be statistically significant.

RESULTS

1. Survey

This study conducted a survey with a questionnaire in

30 general hospitals in the capital area. According to the survey results, the number of pieces of DR system equipment was 135, including 94 pieces where a grid could be attached or detached and 41 pieces where a grid could not be attached or detached. This means that it is impossible to conduct an examination with the grid removed when scanning is performed for shallow parts or the extremities of infants and children. In addition, there were 50 pieces of equipment where a grid was not removed for scans due to the difficulty in attaching or detaching the grid, even though the grid could be attached or detached. There were 6 pieces of equipment where the grid was not removed in the examination due to image quality reasons. There were also 38 pieces of equipment where the grid was removed during the examination. In other words, a grid is not used in 38 pieces of equipment, while the grid is used in the remaining 97 pieces of equipment for examination of the extremities (Table 2).

Table 2. The result of research on 30 general hospitals in the capital area

No. of pieces of equipment		135 (%)
Attachment or detachment of grid	Yes	94 (69.6)
	No	41 (30.4)
Use or no use of grid	Used	56 (59.5)
	Not used	38 (40.5)
Total	Grid	97 (71.8)
	No grid	38 (28.2)

2. Dose Measurement

Dose was measured depending on use or no use of a grid for each body part. In the phantom thickness of 2.54 cm + 1.0 mmAl and depending on use or no use of a grid, the DAP value (effective area dose) was 1.1474 μGy·cm^2 and 0.7160 μGy·cm^2, which showed about a two-fold difference when comparison was made with the exposure index (EI) value of 200. In the phantom thickness of 5.08 cm + 1.0 mmAl and 7.62 cm + 2.0 mmAl, the DAP value showed a 1.5-fold to 3-fold difference when a similar EI value was found and compared with the DAP value (Table 3).

The difference in dose was analyzed depending on use or no use of a grid at the equal dose and according to thickness of each acryl phantom. As shown in Table 4, the analysis

Table 3. The measured dose value of using or not using grid for each part of body

Thickness of phantom	Use or No use of grid		Photographing conditions		DAP (μGy·cm^2)	Exposure index	Average value of dose measurement (μGy)
			kVp	mAs			
2.54 cm + 1.0 mmAl	Grid		48	4	1.1474	200	81.5
	No grid	1	48	4	1.1445	125	129.8
		2	48	3.2	0.9116	160	103.1
		3	48	2.5	0.7160	200	79.83
		4	48	2	0.5694	320	62.64
		5	48	1.6	0.4543	400	48.49
5.08 cm + 1.0 mmAl	Grid		50	5	1.5921	320	67.08
	No grid	1	50	5	1.5914	160	110.94
		2	50	4	1.2692	200	99.04
		3	50	3.2	1.0198	250	78.67
		4	50	2.5	0.7928	400	58.62
		5	50	2	0.6362	500	47.98
7.62 cm + 2.0 mmAl	Grid		70	10	7.1107	65	297.99
	No grid	1	70	10	7.1179	40	567.39
		2	70	8	5.6986	50	457.28
		3	70	5	3.5518	80	278.25
		4	70	2.5	1.7687	200	138.98
		5	70	2	1.4121	250	112.39

Table 4. The dose difference according to acryl phantom thickness of use or no use of grid at the same dose

Thickness of acryl phantom	Photographing conditions	Grid Mean ± SD		t	p
		Use	No Use		
2.54 cm + 1.0 mmAl	48 kVp, 4 mAs	81.50 ± 9.01	129.80 ± 0.26	−17.06	0.001**
5.08 cm + 1.0 mmAl	50 kVp, 5 mAs	67.08 ± 0.22	110.94 ± 34.66	−4.01	0.003**
7.62 cm + 2.0 mmAl	70 kVp, 10 mAs	297.99 ± 0.63	567.39 ± 1.58	−459.62	0.001**

Note: Interaction effect using paired t-test. **p < 0.01

Table 5. The dose difference according to the acryl phantom thickness mAs in a non-grid

Thickness of acryl phantom	Photographing conditions (kVp, mAs)	No grid Mean ± SD	F	p
2.54 cm + 1.0 mmAl	48 kVp, 4 mAs*	129.82 ± 0.26	105130.38	0.001**
	48 kVp, 3.2 mAs†	103.1 ± 0.54		
	48 kVp, 2.5 mAs‡	79.83 ± 0.31		
	48 kVp, 2 mAs§	62.64 ± 0.16		
	48 kVp, 1.6 mAs‖	48.49 ± 0.13		
5.08 cm + 1.0 mmAl	50 kVp, 5 mAs*	110.94 ± 34.66	26.41	0.001**
	50 kVp, 4 mAs*†	99.04 ± 6.18		
	50 kVp, 3.2 mAs†‡	78.67 ± 6.48		
	50 kVp, 2.5 mAs‡§	58.62 ± 0.18		
	50 kVp, 2 mAs§	47.98 ± 6.61		
7.62 cm + 2.0 mmAl	70 kVp, 10 mAs*	567.39 ± 1.58	37755.62	0.001**
	70 kVp, 8 mAs†	457.28 ± 5.91		
	70 kVp, 5 mAs‡	278.25 ± 0.46		
	70 kVp, 2.5 mAs§	138.98 ± 3.67		
	70 kVp, 2 mAs‖	112.39 ± 0.99		

*Group 1, †Group 2, ‡Group 3, §Group 4, and ‖Group 5, Interaction effect using ANOVA test and Dunnett test. **p < 0.01

results demonstrated that all three parts showed difference with statistical significance depending on use or no use of a grid (p < 0.05).

When the thickness of acryl phantom was 2.54 cm + 1.0 mmAl, the average and standard deviation was found to be 81.50 ± 9.01 μGy and 129.80 ± 0.26 μGy, respectively, depending on use or no use of a grid. When the thickness was 5.08 cm + 1.0 mmAl, the value was found to be 67.08 ± 0.22 μGy and 110.94 ± 34.66 μGy. When the thickness was 7.62 cm + 2.0 mmAl, the value was found to be 297.99 ± 0.63 μGy and 567.39 ± 1.58 μGy. In summary, there was about two-fold difference in the dose, depending on use or no use of a grid.

When the grid was not used, the dose difference depending on the value of mAs was analyzed with the fixed value of kVp for each thickness of acryl phantom. As shown in Table 5, there was statistically significant difference (p < 0.05). First of all, when the thickness of acryl phantom was 2.54 cm + 1.0 mmAl, the value was changed from 4 mAs to 3.2 mAs, 2.5 mAs, 2 mAs, and 1.6 mAs with the kVp value fixed at 48. In this case, the dose was 129.82 ± 0.26 μGy, 103.10 ± 0.54 μGy, 79.83 ± 0.31 μGy, 62.64 ± 0.16 μGy, and 48.49 ± 0.13 μGy, showing significant difference for each group (p < 0.05).

When the thickness of acryl phantom was 5.08 cm + 1.0 mmAl, the value was changed from 5 mAs to 4 mAs, 3.2 mAs, 2.5 mAs, and 2 mAs with the kVp value fixed at 50. In this case, the dose was 110.94 ± 34.66 μGy, 99.04 ± 6.18 μGy, 78.67 ± 6.48 μGy, 58.62 ± 0.18 μGy, and 47.98 ± 6.61 μGy, showing significant difference. The results of post-hoc analysis in Tucky HSD demonstrated that there was no significant difference under the photographing conditions

of 4 mAs and 3.2 mAs, 3.2 mAs and 2.5 mAs, and 2.5 mAs and 2 mAs. Therefore, when such photographing conditions were applied, it was possible to conduct examination under the low-dose photographing condition in compliance with the as low as reasonably achievable (ALARA) principle that was recommended by the International Commission on Radiological Protection (ICRP).

When the thickness of acryl phantom was 7.62 cm + 2.0 mmAl, the value was changed from 10 mAs to 8 mAs, 5 mAs, 2.5 mAs, and 2 mAs with the kVp value fixed at 70. In this case, the dose was 567.39 ± 1.58 μGy, 457.28 ± 5.91 μGy, 278.25 ± 0.46 μGy, 138.98 ± 3.67 μGy, and 112.39 ± 0.99 μGy, showing significant difference for each group ($p < 0.05$).

DISCUSSION

In modern medicine, medical radiation plays a significant role in the diagnosis and treatment of disease, but at the same time, it can be a health hazard due to radiation exposure. However, the reality is that there are insufficient data on the necessary patient exposure dose when using diagnostic equipment. There are also insufficient studies on strategies for reducing the patient exposure dose.

In clinical institutions that currently use a DR system, a grid is frequently used for photographing the extremities. As shown in the results of this study that conducted a survey with a questionnaire on grid use in 30 general hospitals in the capital area, a great number of pieces of DR system equipment used in clinical institutions had no function to attach or detach a grid. In imaging where a grid was not necessary due to difficulty or inconvenience in its attachment or detachment, the grid was used anyway, leading to increase in unnecessary radiation exposure among patients. For reduction of patient exposure dose, it is believed that new equipment should be developed as quickly as possible, so that grid is readily attached or detached, or the existing equipment should be automatically replaced by new equipment that has a low grid ratio in cases of examination of the extremities.

Lee *et al*. conducted a study that reported that the dose was increased from 4.13 times to 4.79 times when measurement was conducted for the entrance dose to a patient, the entrance dose to grid, and the entrance dose to detector depending on use or no use of grid in the acryl phantom thickness of 2 cm and 6 cm.

In this study, dose was measured under the same photographing conditions depending on use or no use of a grid. According to the measurement results, the dose was 81.50 ± 9.01 μGy and 129.80 ± 0.26 μGy when the thickness of acryl phantom was 2.54 cm + 1.0 mmAl. The dose was 67.08 ± 0.22 μGy and 110.94 ± 34.66 μGy when the thickness of acryl phantom was 5.08 cm + 1.0 mmAl. The dose was 297.99 ± 0.63 μGy and 567.39 ± 1.58 μGy when the thickness of acryl phantom was 7.62 cm + 2.0 mmAl, showing about a two-fold difference. Based on the study results, it can be said that no use of a grid in the examination of extremities that are shallow is useful for reducing the patient exposure dose. Consequently, it is recommended that a grid should not be used for examination of shallow parts or infants and children in general.

The recommended radiation dose to which a patient is exposed is specified in the Basic Safety Standards (BSS) No. 115 that was established in 1996 by six international organizations, including the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA). The International Commission on Radiological Protection (ICRP) has asked relevant experts in countries around the world to establish, apply, and utilize international guidelines that reflect the situation of their own countries to reduce medical radiation exposure (IAEA 1996; WHO 2011).

According to the 1990 ICRP recommendations, the main purpose of radiation protection is not to unreasonably restrict useful activities that cause radiation exposure but to determine proper standards for the protection of people. Medical exposure is a permitted and justified activity that is allowed only for medical treatment that brings about direct benefits, rather than damages, to a patient. It is recommended that the radiation dose should be minimized and optimized within an optimal scope such that no problem is caused in clinical practice for diagnostic imaging and that the dose limit should not be fixed for each activity of medical treatment. The ICRP published guidelines on radiation protection and safety in medical treatment to recommend that countries all over the globe apply DRL to reduce medical exposure (ICRP 2003).

A standard dose or radioactivity level for each patient group has been extensively defined for medical procedures such as diagnosis with medical radiation and treatment with radiopharmaceuticals. According to a report, it was expected that application of standard technology to diagnostic and

technological performance would not exceed such levels in standard treatment (IAEA 1996). The DRL is used as supplementary data for professional judgment and evaluated based on the surface entrance exposure dose that is measured by using the thermoluminescent dosimeter (TLD) that is fixed on patient's body or based on the DAP that is measured using an ion chamber-type area dosimeter.

The DAP has been evaluated as a technique that can be managed properly in clinical treatment, because the entire examination is recorded, there are not as many strict rules about the patient's location in the middle of the beam as TLD, measurement does not influence examination of the patient, and the patient does not feel fear or anxiety in scanning.

In this study, the finding that there was about a two-fold or more difference when the dose was measured under the same photographing conditions for each thickness of acryl phantom depending on use or no use of a grid was significant. In addition, the DAP value of effective area dose was measured to increase by two or more times.

An optimal absorption dose provides a high-quality image. However, if the absorption dose is significantly decreased, the pixel noise of an image tends to increase. In other words, significant shortage of the dose that is necessary for image acquisition would lead to degradation of image quality due to noise, which results in the high possibility of recognition. However, an unnecessary and excessive dose does not cause degradation of image quality, and that excessive dose may not be recognized, leading to an increase in the patient dose (FDA 2001).

In conclusion, medical radiation exposure is believed to have no threshold dose for a stochastic effect, so that the degree of harm tends to increase according to an increase in the radiation dose to which ordinary people are exposed. When an image is acquired in the DR system, it is necessary to clearly recognize the factors that increase the patient dose and those that lower image quality before the examination is conducted.

This study found that the patient exposure dose increased by two or more times when a grid was used in examination of the extremities in shallow parts and that there was no significant difference in image quality, even though the grid was removed to lower the dose condition for scanning. Therefore, it is recommended to avoid using a grid to reduce the patient exposure dose when there is no need to use a grid for examination of the extremities.

CONCLUSIONS

A survey with questionnaire was conducted in clinical institutions to investigate if a grid was used for examination of the extremities in the DR system. Acryl phantom was used for dose measurement. According to the results of a survey with questionnaire that targeted 30 general hospitals in the capital area, a grid was used for examination in 97 out of 135 total pieces of equipment, while a grid was not used in the remaining 38 pieces of equipment. Second, the patient dose depending on use or no use of a grid was found to be 81.50 ± 9.01 μGy and 129.80 ± 0.26 μGy under the same photographing conditions when the thickness of acryl phantom was 2.54 cm + 1.0 mmAl. The dose was measured at 67.08 ± 0.22 μGy and 110.94 ± 34.66 μGy when the thickness was 5.08 cm + 1.0 mmAl, and the dose was measured at 297.99 ± 0.63 μGy and 567.39 ± 1.58 μGy when the thickness was 7.62 cm + 2.0 mmAl. As shown in the study results mentioned above, a great number of pieces of equipment were found to have no function to attach or detach a grid. Even when such function was available, it was inconvenient and cumbersome to attach or detach the grid. Therefore, it is necessary to develop equipment to which a grid can be readily attached or detached. In addition, it is believed that the results of this study can be used as basic data to reduce the patient exposure dose in examination of the extremities in the DR system.

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