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A Review of the Effectiveness of Shielding Curtains for Improving Radiation Safety Management of Electromagnetic Radiation in Diagnostic X-ray Rooms

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During diagnostic radiography examinations, due to problems such as patient falls, the door between the examination room and the control room is often opened for quick action. Therefore, the purpose of this study is to evaluate the effectiveness of curtain-type shielding for worker radiation protection. Shielding efficiency, weight, cost, and user opinions were analyzed for leaded, leaded rubber, lead-free shielding sheet, and chainmail. The results showed that the shielding efficiency was 97.7 % for the steel door, 97.5 % for the lead sheet, 97.0 % for the lead rubber, 96.0 % for the lead-free sheet, and 91.3 % for the chain mail, and the weight was 7,399 g for the lead sheet, 8,482 g for the lead rubber, 1,148 g for the lead-free sheet, and 8,127 g for the chain mail. The cost was $46.9 for the lead sheet, $126 for the lead rubber, $270.5 for the lead-free sheet, and $147.8 for the chain mail. Based on this, it is believed that shielding curtains can be used to provide both worker and patient safety by considering the conditions of diagnostic radiography rooms in each medical institution.

Keywords : electro-magnetic radiation shielding, electro-magnetic radiation, curtain, lead

1. Introduction

Electromagnetic wave radiation is a type of ionizing radiation and is used in various fields such as chemistry, food, engineering, and medicine [1-5]. In particular, electromagnetic wave radiation has a longer wavelength than particle radiation, which allows it to pass through objects, and this characteristic is used in medical imaging [6-9]. In general, the energy of electromagnetic radiation used in medical imaging is in the range of tens of kV to hundreds of kV, which is hundreds to thousands of times higher than the voltage of electrical appliances used in daily life [10, 11]. The penetrating power of electromagnetic radiation used in medical imaging depends on the energy and the atomic number of the interacting material [12-14]. This is known as the reaction cross section, which is proportional to the fourth power of the energy and inversely proportional to the third power of the atomic number [15]. For dose assessment in terms of radiation safety management through accurate interaction probabilities, the energy of electromagnetic radiation used in the field of medical imaging is calculated through the atomic number of the interacting substance, but the energy of electromagnetic radiation used for medical imaging examination is not fixed, and the energy distribution is a continuous spectrum [16-18]. In addition, the atomic number composition of the material varies depending on the patient's body type and the examination area in the examination room, making accurate calculation difficult [19, 20]. Therefore, radiation shielding is performed from a conservative perspective to minimize the occupational exposure of radiologists performing medical imaging examinations [21-23]. For the wall structure that separates the inside and outside of the examination room, concrete and lead plates are used to construct a complete shielding according to the first-order linear velocity using the highest energy electromagnetic wave radiation [24-27]. In addition, the door between the examination room and the patient waiting room is shielded by applying a door made of lead or iron [28, 29]. Similarly, the door between the examination room and the adjustment room is also shielded by applying lead or iron

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doors, and radiologists can be said to receive very little occupational exposure because they perform radiological investigations with all the doors of the examination room closed [30-32]. However, when a radiologist performs a medical imaging examination in a clinical setting, there are various factors that change [33, 34]. In general, in the case of medical imaging examinations performed in a simple imaging room, the time required per examination is within 4 minutes to 7 minutes [35], and the optimal number of examinations per radiologist is 75 per day, and a study of the number of examinations in some university hospitals showed an increase of about 17.4 % in the number of optimal examinations [36]. This indicates an increase in the number of examinations per radiologist, and this increase occurs in all examination rooms in the hospital. Therefore, measures to prevent the decline in the quality of medical imaging examinations due to excessive workload must be sought [37, 38]. Therefore, it is not uncommon for radiologists to perform medical imaging examinations without closing the door between the examination room and the control room. In addition, if the patient's condition is unstable during the medical imaging examination, there may be a problem of falling or collapsing accidents [40, 41]. In order to take immediate action in the event of such problems, it is more necessary to keep the door between the examination room and the control room open than to keep the door closed [42, 43]. Therefore, if the patient's condition is unstable, the door may be opened and the examination performed [44, 45]. In these various situations, the door between the examination room and the control room should be closed to reduce occupational exposure, but it is often opened to perform examinations, which increases occupational exposure. Therefore, we aim to evaluate the change in occupational exposure by using a curtain-type shield that does not open or close the door when moving between the control room and the examination room. Through this, we aim to accommodate radiation safety management as well as patient safety during medical imaging examinations by radiologists.

2. Material and Method

To evaluate the radiation shielding efficiency, DK2325R (DK Medical Solution, Korea), a general imaging device used in medical institutions, was used as the irradiation device, and INSPECTOR (S.E. International, USA), a measurement device, as shown in Fig. 1. The structure of the general imaging room is shown in Fig. 2, and the entrance door is a 45 mm thick steel door. There are four types of shielding curtains that replace the door. The first

Fig. 1. (Color online) (Left) Image of DK2325R, a diagnostic electromagnetic radiation generator, and (Right) image of INSPECTOR, an electromagnetic radiation measurement device.

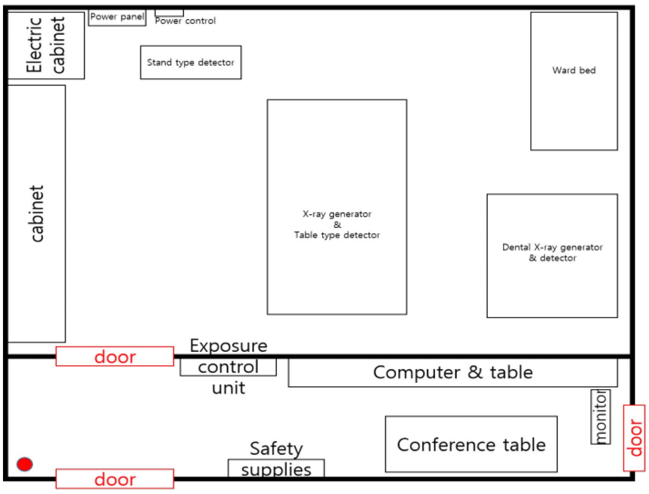

Fig. 2. (Color online) Schematic representation of an imaging room with a diagnostic electromagnetic radiation generator.

is 0.5 mm soft lead, the second is a 0.5 mm leaded rubber sheet. The third is a combination of two 0.25 mm lead-free shielding sheets, and the fourth is a chainmail type with hexagonal 0.5 mm lead sheets mounted on a plastic base frame, as shown in Fig. 3. Lead doors are generally used, but lead rubber plates, which are used for industrial purposes at airport checkpoints, lead-free shielding sheets, which are increasingly used due to the development of new materials, and finally the chainmail type, which takes geometric factors into account, were considered. The size of the shielding curtain is shown in Fig. 4, which consists of two overlapping sheets, 45 cm wide and 145 cm long, covered with fibers. For the evaluation of the radiation shielding, the measuring device was placed at a height of 1 meter above the adjustment device. Radiation shielding was evaluated by making measurements in six cases: with the door open and closed, and with each of the four shielding curtains in place. The weight and cost of the four curtains were also compared. User evaluation was

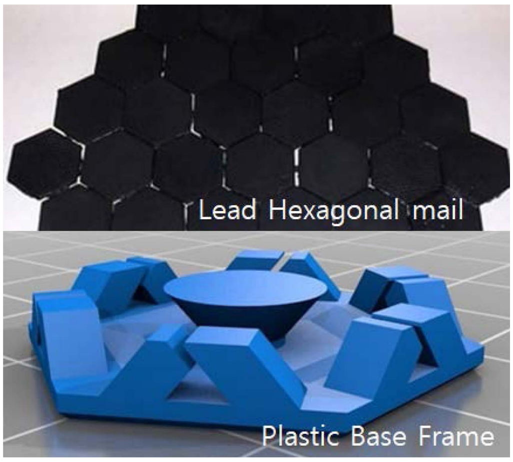

Fig. 3. (Color online) (Top) Image of a lead hexagonal mail structural shield and (bottom) image of a plastic-based attachment frame to connect the lead hexagonal mail.

Fig. 4. (Color online) Image of a lead curtain hanging over the door of a diagnostic electromagnetic radiation generator.

qualitatively assessed by questionnaires for 12 users who entered the general shooting room from March 1, 2023 to June 30, 2023.

2.1. Radiation Shielding Efficiency

During the validation of the shielding curtain, the efficiency of radiation shielding was evaluated. The evaluation method was to evaluate the efficiency of shielding by inversely calculating the ratio of the measured value of each type of shielding to the measured value without shielding by setting the irradiation condition to 100 kVp 200 mAs in a diagnostic radiation generator.

2.2. Weight after shielding

When using each type of shielding, the weight of the shielding tool is also a consideration. Therefore, the weight of each type after manufacturing was measured and compared. The size of the shielding tool was the same.

2.3. Production Cost

The manufacturing cost of each type of shielding was considered and compared. To account for the difference in cost of each material, the lowest price that can be purchased on the Internet was used for comparison, and if the material is sold with a larger area than the material required for production, the price was divided by the area of the material for the minimum size. Comparison prices were converted to US dollars, an international currency.

2.4. User evaluation

Finally, the opinions of the radiologists who are the users of each type of shielding were obtained and compared. This is a qualitative field, but it is the most important one.

3. Result

3.1. Radiation Shielding Evaluation

The results of the radiation shielding evaluation are shown in Table 1. The shielding effect of the iron door was 97.7 %. The shielding effect was 97.5 % for leaded sheet, 97.0 % for leaded rubber plate, 96.0 % for lead-free shielding sheet, and 91.3 % for chain mail. The graph of the shielding efficiency relationship according to conditions for each type of shielding is shown in Fig. 5.

3.2. Weight Evaluation

The weight evaluation results are as shown in Table 2: 7,399 g for soft lead, 8,482 g for lead rubber sheet, 1,148 g for lead-free shielding sheet, and 8,127 g for chainmail.

3.3. Cost Evaluation

As shown in Table 3, the cost evaluation results were:

Table 1. Results of radiation shielding evaluation.

Type	Iron Door	Soft Solder	Lead Rubber	Lead-free Sheet	Chain Mail
Result	97.7%	97.5%	97.0%	96.0%	91.3%

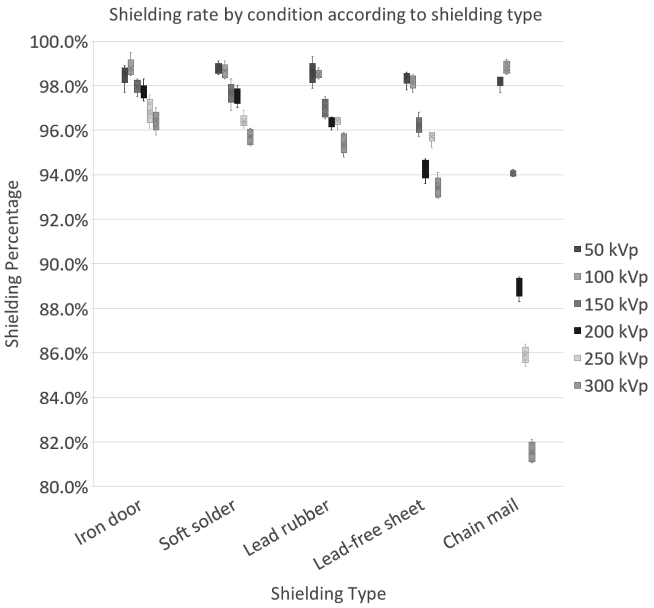

Fig. 5. Shielding efficiency relationship graph according to conditions for each type of shielding.

Table 2. Results of weight evaluation.

Type	Soft Solder	Lead Rubber	Lead-free Sheet	Chain Mail
Result	7,399 g	8,482 g	1,148 g	8,127 g

Table 3. Results of cost evaluation.

Type	Soft Solder	Lead Rubber	Lead-free Sheet	Chain Mail
Result	$ 46.9	$ 126.0	$ 270.5	$ 147.8

46.9 dollars for the soft lead, 126 dollars for the lead rubber plate, 270.5 dollars for the lead-free shielding sheet, and 147.8 dollars for the chainmail.

3.4. User Evaluation

The user evaluation results are shown in Table 4. The disadvantage of the soft lead was the lack of flexibility, the disadvantage of the lead rubber plate was the secondary risk of fire, the lead-free shielding sheet was a problem of worker exposure due to bending in the wind due to its light weight, and the chainmail was a problem of sound generation.

4. Discussion

As the use of diagnostic X-ray equipment increases, so does the workload of users and the burden on institutions that manage and monitor radiation-producing equipment. And in order to provide safe diagnostic services to patients, it is paramount that minimum safety measures are in place. However, there are currently no regulations governing patient safety when radiologists use diagnostic X-ray equipment in medical facilities. Therefore, the opening of the door between the examination room and the control unit is bound to be one of the causes of increased occupational exposure for radiologists. In the case of diagnostic CT and MRI, the patient lies on a table, while in the case of diagnostic X-rays, the patient is in an elevated position, which requires changes in radiation work instructions and regulations. However, this will take time to be fully discussed, so the implications of this study are important for short-term action. Shielding in the form of curtains made of shielding material, rather than steel doors that take time to open and close, can reduce radiologists' occupational exposure and ensure patient safety. However, since the types of shielding materials used in this study are very limited, it is necessary to implement more efficient shielding curtains by using more diverse types of shielding materials. In particular, in the case of fabric-type shielding curtains, materials such as nanoceramic microparticles and polymer resins are coated on the fabric, and more diverse fabric-type shielding curtains, such as carbon-based nanopowder-type fabric-type shielding curtains, are not applicable. In addition, there are limitations in the application depending on the diagnostic X-ray equipment conditions and

Table 4. Results of flexibility evaluation.

Type	Result
Soft Solder	Leaded curtains are not as flexible as regular curtains, causing inconvenience in movement and risk of injury to workers due to bumping.
Lead Rubber	In the case of lead rubber, it has a certain weight and is easy to fix, but there is a risk of soot in case of fire due to the rubber material.
Lead-free Sheet	In the case of lead-free shielding sheets, there is no need to distinguish between the inner and outer fiber sides compared to other types, but the weight is relatively low, so it can be opened by wind from air conditioners, etc.
Chain Mail	Chainmail has good flexibility but generates sound when the curtain is opened and closed, and has the advantage of partial removal or repair.

examination room structure, so separate evaluations should be made in each medical institution.

5. Conclusion

Based on the results of this study, it is judged that a shielding type with moderate efficiency is relatively better than a shielding type that has extreme disadvantages in the results of each item such as cost, weight, and shielding efficiency. Therefore, the shielding type using lead rubber plate is judged to be the best in terms of weight, cost, and shielding efficiency, and can be recommended because it does not have serious disadvantages that are perceived as major problems in use by users. However, these conclusions are based on the replacement of shielding doors in a typical diagnostic radiation generator, so the most efficient shielding type may vary depending on the purpose of each institution or facility. Finally, since 0.5 mmPb was used to equalize shielding performance, there is a limitation that the results cannot be extrapolated to shielding performance. In the future, it is hoped that safer and more effective shielding curtains can be obtained under different conditions. In addition, the use of shielding curtains for electromagnetic radiation with energies in the MeV range, such as nuclear medical examinations, should also be investigated.

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