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# Patient Dose Management: Focus on Practical Actions

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Medical radiation is a very important part of modern medicine, and should be only used when needed and optimized. Justification and optimization of radiation examinations must be performed. The first step of reduction of medical exposure is to know the radiation dose in currently performed examinations. This review covers radiation units, how various imaging modalities report dose, and the current status of radiation dose reports and legislation. Also, practical tips that can be applied to clinical practice are introduced. Afterwards, the importance of radiology exposure related education is emphasized and the current status of education for medical personal and the public is explained, and appropriate education strategies are suggested. Commonly asked radiation dose related example questions and answers are provided in detail to allow medical personnel to answer patients. Lastly, we talk about computerized programs that can be used in medical facilities for managing patient dose. While patient dose monitoring and management should be used to decrease and optimize overall radiation dose, it should not be used to assess individual cancer risk. One must always remember that medically justified examinations should always be performed, and unneeded examinations should be avoided in the first place.

**Keywords:** Radiation, Ionizing; Medical Exposure; Radiation Protection; Optimization; Justification

## INTRODUCTION

After the discovery of X-ray by Roentgen, W. C. in 1895, X-ray based radiology examinations have rapidly evolved to become an essential part of modern medical care. With the additional development and widespread adoption of multidetector computed tomography (MDCT), patient radiation dose exposure has exponentially increased within the last decade. Also, due to the increase in life quality and increase in health and well-being interest, the use of radiation based radiology imaging has skyrocketed. This has resulted in a heightened interest of the public regarding radiation based medical imaging and medical radiation exposure.

After the 2011 Fukushima nuclear disaster, radiation exposure including medical exposure became a common public interest, especially in Korea. After small amounts of radiation material were detected in Korea, widespread fear of radiation exposure appeared in the public mind and media, including a focus on medical radiation exposure. This vague fear of radiation occurred without scientific evidence of harm, which emphasized a need for public education and promotion of proper medical radiation knowledge. The Korean National Evidence based Healthcare Collaborating Agent (NECA) published a research report in July, 2011 titled "Effect of Radiation on the Human Body" (1). This report described that the amount of radiation exposure from the Fukushima disaster in Korea is less than 1 mSv. Therefore this exposure is far less than the minimum 100 mSv threshold that is commonly thought as proven for harmful radiation exposure. The conclusion was that there is no definite evidence of radiation harm by the nuclear disaster. The report also mentioned that even though medical radiation is much larger, the exposure occurs when the diagnostic or treatment gain is thought to be greater than the risk due to radiation. Therefore, it is wrong to compare it with exposure from the nuclear disaster. It is wrong to create a vague fear of medical radiation exposure in the public, especially since the benefits from medical radiation exposure far outweigh the disadvantages.

The International Commission on Radiological Protection (ICRP) declared in the 1991 ICRP publication 60 that radiation exposure must be used to benefit patients and that radiation protection must be optimized (2). Radiation protection consists of "Justification", "Optimization of Protection", and "Application of Dose Limits". There is no defined maximum dose limitation for radiology studies. However, even if there is no maximum dose limitation, all studies must adhere to the "As Low As Reasonably Achievable" (ALARA) principle to optimize radiation dose to the minimum that is clinically necessary for diagnosis and treatment. It is often possible to significantly decrease medical radiation exposure without compromising patient care.

Medical radiation exposure is increasing rapidly, and many



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recent studies suggest that even small amounts of radiation may be detrimental to our health. This has resulted in much effort being made to decrease medical exposure, with about half of the publications published by ICRP in the last 10 years being related topics.

Therefore the importance of efforts to monitor, optimize, and decrease patient medical radiation exposure is continually increasing and becoming hot topics worldwide. There are limits to the efficacy a strategy of simply sharing and promotion of radiation exposure related educational material, with an increasing need for systemic and organized approaches for managing radiation dose. This review discusses the efforts and strategies to decrease medical radiation dose exposure in clinical practice and medical facilities.

## RADIATION DOSE UNITS

The first step of medical radiation management is comprehending the dose exposure of each imaging machine in medical facilities. Facilities often lack proper understanding and frequently do not properly monitor of radiation dose from their medical imaging equipment. Although recent equipments often provide automated easy to view dose reports, older machines frequently lack automated dose reports. In such cases, external computer programs using imaging parameters and look-up tables may be used to estimate radiation dose exposure.

Measuring radiation essentially means measuring the amount of radiation that an object absorbs. This is termed absorbed dose, and the international system of units (SI unit) is Gy (gray). In the past, the rad (radiation absorbed dose) unit has also been used (3).

The SI unit for radioactive material representing radioactivity is Bq (Becquerel). One Bq is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. The Bq unit is equivalent to an inverse second. The becquerel succeeded the curie (Ci), an older, non-SI unit of radioactivity defined as $3.7 \times 10^{10}$ nucleus decay per second. Hence, 1 Ci = $3.7 \times 10^{10}$ Bq (3).

The reason radiation is of interest to us is because of its potential effect on the human body. To represent this biological effect, the Sv (sievert) unit is used. Sv represents the biological effect on the human body regardless of the type of radiation used. Neutron and alpha radiation can cause increased biological harmful effects. These increased effects are reflected in rem units. To represent smaller effects, mSv (millisievert) units representing 1/1,000 of a Sv are used. In the past rem (roentgen equivalent man) was used. For practical purposes, 1 rem can be though of 1 roentgen, and 1 mSv is equal to 100 mrem. A single chest X-ray is equivalent to about 0.1 to 0.3 mSv (3).

It is important to know the concepts of exposure dose, absorbed dose, equivalent dose, and effective dose (2-4).

### Exposure

Exposure describes the strength of gamma and X-rays from a certain location, which determines the amount ionization possible in air. Exposure is only used when gamma or X-rays are used in air, and not when other radiation types or other materials are radiated. The unit used in the past was roentgen (R) and currently coulomb/kilogram (C/kg). One R is the radiation needed to create $2.58 \times 10$ C in 1 kg or air.

### Absorbed dose

Absorbed dose is defined as the energy of ionizing radiation absorbed per unit mass by a body, often measured in Gy (gray). One Gy is defined as absorption of one joule of radiation energy per one kilogram of matter. In the past, rad units were used, with 1 rad equal to 1/100 J/kg, which is equal to 1/100 Gy. Absorbed dose is used regardless of radiation type or radiated material.

### Equivalent dose (uniform dose exposure to single organ or whole body)

Neutrons, alpha particles, and energic ions have different effects of damage when compared with X-ray or gamma particles. Also, the damage varies by area irradiated in the human body. Absorbed dose and equivalent dose have the following relationship; Equivalent dose is equal to absorbed dose multiplied by radiation weighting factor.

The ICRP 103 recommended radiation weighting factors (4). When using Gy units as absorbed dose the resulting equivalent dose unit is Sv. The radiation weighting factor for X-rays and gamma rays is 1.0, and this results in an equivalent dose unit of Sv, but this practice is discouraged as it can lead to confusion with effective dose. In the past rem units were also used with 100 rem equal to 1 Sv.

### Effective dose

Effective dose is defined as the tissue-weighted sum of all equivalent doses in all parts of the body representing stochastic health risk, which is the probability of cancer induction and harmful genetic effects of ionizing radiation. This is because the same radiation can have varying effects according to different parts of the body. The body is divided into different organs. Effective dose is equal to sum of equivalent dose by each organ multiplied by the tissue weighting factor of each organ. The ICRP 103 recommended tissue weighting factors (4) and notice that the sum of tissue weighting factors is 1.000, which represents the weighting factor for whole body exposure. The units used are Sv which are the same as equivalent dose.

Exposure to 1 R of gamma or X-ray leads to 1cGy of absorbed dose, and when the whole body is uniformly exposed, leads to 1 cSv of effective dose. When comparing using layman's terms, exposure can be thought of as "How much is it raining?", absorbed dose as "How much did you get wet?", and estimated dose as

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"What are the chances of getting a cold due to getting wet in the rain?". Table 1 summarizes the relationship between each unit (4).

## DOSE REPORTING BY MODALITY

It is important to know how the radiation dose exposure of medical imaging equipment we use. For this, it is necessary to un-

**Table 1.** Radiation units and conversion

| Classification | | SI unit | Non-SI unit | Conversion |
|---|---|---|---|---|
| Radioactive unit | | Becquerel (Bq) | Curi (Ci) | 1 Ci = 3.7 × $10^{10}$Bq<br>1 Bq = 2.7 × $10^{-11}$Ci |
| Dose Quantity | Exposure | coulomb/kilogram (C/kg) | Roentgen (R) | 1 R = 2.58 × $10^{-4}$C/kg<br>1 C/kg = 3.88 × $10^{3}$R |
| | Absorbed dose | Gray (Gy) | rad | 1 rad = 0.01 Gy = 1 cGy<br>1 Gy = 100 rad |
| | Equivalent dose<br>Effective dose | Sievert (Sv) | rem | 1 rem = 0.01 Sv = 1 cSv<br>1 Sv = 100 rem |


**Fig. 1.** An example of DICOM header of a chest X-ray that includes kVp, mAsm and DAP. The DICOM header shows a kVp value of 117 and DAP of 0.433.

derstand and know the patient dose which varies by each different modality. Plain X-ray radiographs use entrance skin dose (ESD), mammography use average glandular dose (AGD), fluoroscopy and angiography use dose area product (DAP), and CT use CT dose index (CTDI) and dose length product (DLP) for dose reporting (5).

Unfortunately, only recent medical imaging machines display and report patient dose, with older machines often lacking dose report functions. It is also often possible to send dose reports to picture archiving communication system (PACS), but unfortunately it is sometimes omitted simply due to lack of attention. This section will show how each machine shows and report dose. These reports may be used to set diagnostic reference levels (DRL) and optimize patient dose.

### General X-ray radiography

Recent digital radiography equipment display tube potential (kVp), tube current (mAs), ESD, and DAP. However, many equipment only display kVp, mAs, and do not display ESD or DAP. When sending to PACS there are often options to display dose by default in the image. Even if not displayed in the image, they can be checked by looking at the Digital Imaging and Communications in Medicine (DICOM) headers (Fig. 1).

When using radiography films or older machines without ESD and DAP, look-up tables using imaging parameters can be used to estimate dose (6). These look-up tables are created by experimentation and measurement of radiation dose according to various imaging parameters, and can be developed into programs that take input of imaging variables and report estimated dose by internal look-up databases. However, using look-up tables can be somewhat tedious and are not accurate due because they are only calculated estimations.

### Mammography

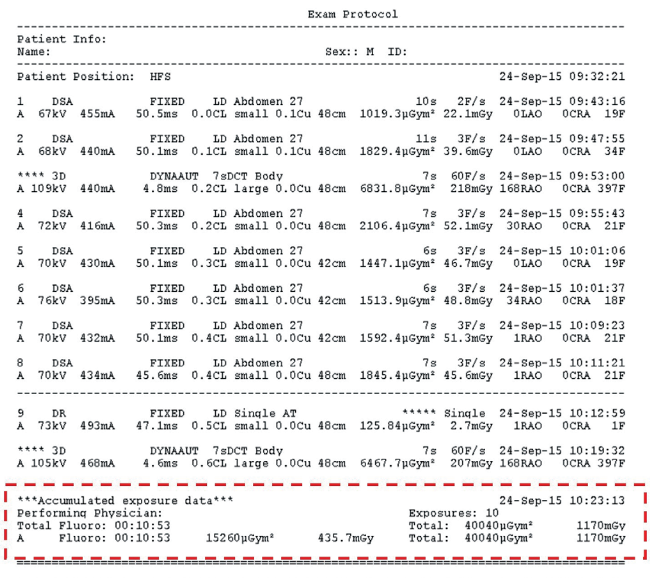
Average glandular dose is reported on recent digital mammography equipment. However, average glandular dose is often missing in film-screen mammography.

### Fluoroscopy and angiography

Both fluoroscopy and angiography similarly use DAP and fluoroscopy time to measure dose exposure. Modern recent machines display kVp, mA, DAP, and calculated ESD (Fig. 2), while older machines require a separate DAP meter to be installed to monitor dose (Fig. 3).

### Computed tomography

CTDI and DLP are important dose values used to monitor dose exposure. However, these values are calculated from a mathematical phantom which does not consider patient height, size, shape, age, and sex. Therefore calculated dose values will differ from the actual patient dose. Most, MDCT machines can create



```
                                  Exam Protocol
--------------------------------------------------------------------------------
Patient Info:
Name:                                       Sex:: M  ID:
--------------------------------------------------------------------------------
Patient Position:  HFS                                        24-Sep-15 09:32:21

1    DSA           FIXED    LD Abdomen 27              10s   2F/s  24-Sep-15 09:43:16
A  67kV  455mA   50.5ms  0.0CL small 0.1Cu 48cm  1019.3µGym² 22.1mGy   0LAO   0CRA  19F

2    DSA           FIXED    LD Abdomen 27              11s   3F/s  24-Sep-15 09:47:55
A  68kV  440mA   50.1ms  0.1CL small 0.1Cu 48cm  1829.4µGym² 39.6mGy   0LAO   0CRA  34F

**** 3D            DYNAAUT  7sDCT Body                  7s  60F/s  24-Sep-15 09:53:00
A 109kV  440mA    4.8ms  0.2CL large 0.0Cu 48cm  6831.8µGym²  218mGy 168RAO   0CRA 397F

4    DSA           FIXED    LD Abdomen 27               7s   3F/s  24-Sep-15 09:55:43
A  72kV  416mA   50.3ms  0.2CL small 0.0Cu 48cm  2106.4µGym² 52.1mGy  30RAO   0CRA  21F

5    DSA           FIXED    LD Abdomen 27               6s   3F/s  24-Sep-15 10:01:06
A  70kV  430mA   50.1ms  0.3CL small 0.0Cu 42cm  1447.1µGym² 46.7mGy   0LAO   0CRA  19F

6    DSA           FIXED    LD Abdomen 27               6s   3F/s  24-Sep-15 10:01:37
A  76kV  395mA   50.3ms  0.3CL small 0.0Cu 42cm  1513.9µGym² 48.8mGy  34RAO   0CRA  18F

7    DSA           FIXED    LD Abdomen 27               7s   3F/s  24-Sep-15 10:09:23
A  70kV  432mA   50.1ms  0.4CL small 0.0Cu 42cm  1592.4µGym² 51.3mGy   1RAO   0CRA  21F

8    DSA           FIXED    LD Abdomen 27               7s   3F/s  24-Sep-15 10:11:21
A  70kV  434mA   45.6ms  0.4CL small 0.0Cu 48cm  1845.4µGym² 45.6mGy   1RAO   0CRA  21F
--------------------------------------------------------------------------------

9    DR            FIXED    LD Single AT            ***** Single  24-Sep-15 10:12:59
A  73kV  493mA   47.1ms  0.5CL small 0.0Cu 48cm  125.84µGym²  2.7mGy   1RAO   0CRA   1F

**** 3D            DYNAAUT  7sDCT Body                  7s  60F/s  24-Sep-15 10:19:32
A 105kV  468mA    4.6ms  0.6CL large 0.0Cu 48cm  6467.7µGym²  207mGy 168RAO   0CRA 397F

***Accumulated exposure data***                               24-Sep-15 10:23:13
Performing Physician:                             Exposures: 10
Total Fluoro: 00:10:53                            Total:  40040µGym²     1170mGy
A     Fluoro: 00:10:53     15260µGym²     435.7mGy  Total:  40040µGym²     1170mGy
================================================================================
--------------------------------------------------------------------------------
```

**Fig. 2.** Dose report for a modern fluoroscopy machine. During transarterial chemoembolization, 9 flurosocopic sessions and one cone beam CT scan were performed. Total fluoroscopic time is reported as 10 minutes 53 seconds with a DAP of 15,260 $\mu$Gycm$^2$, and 10 spot images with a DAP of 40,040 $\mu$Gycm$^2$.

dose reports with volume CTDI (CTDIvol) and DLP. These reports should be sent to the PACS to monitor dose (Fig. 4 and 5). DLP can be multiplied with conversion factors to calculate effective dose, but DLP is the most important value to monitor and optimize dose. Therefore, it is imperative to perform examinations in machines that support dose reports and save dose reports in PACS to frequently monitor these dose reports.

## APPROACHES TO DECREASED PATIENT DOSE IN MEDICAL INSTITUTIONS

### Education of medical teams at medical facilities

Non-radiology physicians often do not probably understand medical radiation exposure, and it is often to grasp proper radiation dose concepts with simple information (7). Most physicians underestimate the radiation hazard from X-ray based studies. A prior study found that 76% of radiologists, 73% of emergency physicians, and 100% of patients underestimated the risk from medical radiation dose exposure (8). Another study found that only few physicians properly understand radiation dose exposure and associated risks (9). It has also been suggested that education regarding the risk of radiation dose exposure is important during medical school training for proper comprehension of the topic (10). Therefore, radiation related education and training is needed for radiologists, non-radiology physicians, and medical students for proper radiation dose knowledge and management. This education and training is currently commonly very insufficient and in much need.

In Texas, USA, all physicians and delegated personnel per-

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**Fig. 3.** Separate installed internal DAP meter (**A**) and display screen (**B**). There are DAP meters that can be installed in the fluoroscopy machine internally to monitor dose.

Accession Number: 2015 Oct 06
Patient ID: Discovery CT750 HD
Exam Description: CT Liver phase 3 dyn

Dose Report

| Series | Type | Scan Range (mm) | CTDIvol (mGy) | DLP (mGy-cm) | Phantom cm |
|---|---|---|---|---|---|
| 1 | Scout | - | - | - | - |
| 2 | Helical | I30.000-I295.000 | 5.77 | 179.56 | Body 32 |
| 200 | Axial | I125.428-I125.428 | 10.24 | 5.12 | Body 32 |
| 3 | Helical | I30.000-I295.000 | 5.11 | 159.02 | Body 32 |
| 3 | Helical | I30.000-I498.750 | 6.09 | 313.71 | Body 32 |
| 3 | Helical | I30.000-I295.000 | 5.30 | 165.05 | Body 32 |
| | | Total Exam DLP: | | 822.46 | |

1/1

**Fig. 4.** An example dose report from a three phase liver CT performed on a GE Discovery CT750HD CT machine. GE machines displace the scan type (helical or axial) and scan length. Series 1 is a scanogram, series 2 is a precontrast examination, series 200 is bolus tracking before initiating contrast scan, and series 3 is the three contrast phase examinations (arterial, portal, delayed). Portal phase scan lower range is the lower pelvic cavity while other phases included only the upper abdomen. Total DLP is 822.46 mGy × cm. When using and multiplying a weighting factor (k factor) of 0.015 to estimate estimated dose, the estimated dose is about 12.3 mSv.

06-Oct-2015 08:07

Ward:
Physician:
Operator:

Total mAs 8585 Total DLP 709 mGycm

| | Scan | kV | mAs / ref. | CTDIvol* mGy | DLP mGycm | TI s | cSL mm |
|---|---|---|---|---|---|---|---|
| Patient Position F-SP | | | | | | | |
| Topogram | 1 | 120 | 35 mA | 0.13 L | 7 | 5.3 | 0.6 |
| Dia~Kid. N | 2 | 80 | 243 / 455 | 4.52 L | 122 | 0.5 | 0.6 |
| PreMonitoring | 3 | 120 | 20 | 1.16 L | 1 | 0.5 | 10.0 |
| Contrast | | | | | | | |
| Monitoring | 4 | 120 | 20 | 4.63 L | 5 | 0.5 | 10.0 |
| Dia~Kid. A | 8 | 80 | 242 / 455 | 4.49 L | 122 | 0.5 | 0.6 |
| Dia~Pel. P | 9 | 100 | 155 / 248 | 6.12 L | 308 | 0.5 | 0.6 |
| Dia~Kid. d | 10 | 80 | 286 / 578 | 5.31 L | 144 | 0.5 | 0.6 |

| Medium | Type | Iodine Conc. mg/ml | Volume ml | Flow ml/s | CM Ratio |
|---|---|---|---|---|---|
| Contrast | None | 0 | 120 | 4.0 | 100% |
| Saline | | | 30 | 4.0 | |

*: L = 32cm, S = 16cm

**Fig. 5.** An example dose report from a three phase liver CT performed on a Siemens SOMATOM Definite AS+ CT machine. CTDIvol and DLP are shown. Siemens machines also report tube potential (kV), tube current (mAs), reference tube current (mAs) when using automated dose modulation, and X-ray time per rotation (TI). The size of phantoms used for calculations are also displayed (L for large 32 cm, and S for small 16 cm). Automated tube current (kVp) modulation was used and precontrast, arterial, and delayed phase images used an 80 kVp, while portal phase uses a 100 kVp. Portal phase scan lower range is the lower pelvic cavity while other phases included only the upper abdomen. Total DLP is 709 mGy × cm. When using and multiplying a weighting factor (k factor) of 0.015 to estimate estimated dose, the estimated dose is about 10.6 mSv.

forming fluoroscopy-guided intervention must undergo radiation related safety education, which is mandated by the 25 Texas Administrative Code §289.227 legislation (11). The education and training contents include basic radiation safety rules, biological effects of X-rays, fluoroscopy fundamentals and operation, air kerma and radiation physics, radiation dose reduction strategies, monitoring radiation dose. This education consists of 8 hours of web-based education and 1 hour of offline education (11).

Most referring physicians underestimate the risk and amount of radiation exposure due to medical imaging, and only 20% of referring physicians refer to clinical imaging guidelines (12). A prior study reported that there was a 44.2% reduction in CT examinations after a 30 minutes length education regarding radiation safety, justification of examinations, CT dose, and alternative evaluation modalities, which targeted referring physicians who mainly ordered CT examinations for hematuria in less than 30-year-old patients (13). This suggests a very high percentage of CT examinations are unnecessary and can be replaced by alternative evaluation methods such as sonography. This suggests that the effectiveness of simply distributing guidelines or educational pamphlets will be limited, and more aggressive radiation dose education strategies are needed.

**Informing patients and informed consent**

Education regarding radiation dose and hazards should not only be targeted at medical personnel, but also the general public. However, incorrect or misunderstood information can easily cause misinformed widespread panic and fear, which can prevent medically necessary and indicated examinations from taking place and cause more harm than the potential radiation exposure. Therefore, there is a need for an easy method and tool for explaining radiation dose and related risks to the public and patients. It is important to develop communication tools that may use comparisons to common ordinary life terms. Once proper understanding by the public and patients occurs, this can be used as a basis for to establish proper policies.

It would be ideal to inform patients of the long term risks related to medical radiation exposure. However, this often impractical, and the ordering physician often does not understand medical radiation exposure properly. It is ethical and ideal for ordering physicians to get prior consent and explain the estimated dose in mSv and realistic risk of cancer to patients (7).

**Examples of common patient questions and appropriate answers**

*Question 1) How much radiation will I receive from the examination?*

Radiation from radiographs will vary according to patient size, examination area, and examination views. Guidelines are available from the Basic Safety Standards (BSS) (14). Although dose will vary between different examinations, common X-ray radiography examinations will often have a total effective dose of about 0.01-1.5 mSv.

For CT, it will vary between 2-20 mSv depending on the examination area and protocol. Upper gastrointestinal fluoroscopy studies for health checkups will be about 5 mSv (15).

*Question 2) Is it okay to get another one even though I already had a recent examination?*

Plain radiographs have very little radiation dose, while CT examinations have a relatively larger radiation dose (16). However, the dose from even CT examinations are classified as low dose radiation. Also, medical examinations should be only performed when considered medically necessary by physicians. Therefore, if the examination is medically necessary, it should not matter whether the patient already had a recent examination.

*Question 3) Will the radiation damage from dose exposure naturally disappear or will it accumulate in my body?*

X-ray passes through objects and will not accumulate in the body. Although small amounts of DNA or cellular damage may occur, these changes are usually repaired by the human body.

*Question 4) Do I have to take a shower or wash after examinations due to radiation?*

X-rays do not accumulate or stick to bodies. So there is no need for washing or taking a shower due to medical imaging radiation exposure.

*Question 5) Is it okay for children to have radiation based imaging?*

Children have a higher rate of cellular division and are more susceptible to radiation exposure and damage compared with adults, and children have a higher risk of cancer due to exposure compared with adults (17). However, even if children are exposed 10 times the yearly radiation limit for radiation related workers, the additional risk of cancer is only 0.05%. Considering the total cancer risk of adults being about 36%, there is little difference between 36% and 36.05%, especially when considering the potential benefits due to imaging examinations. Therefore, if the examination is medically indicated, the examination should be performed.

*Questions 6) Is it okay for the guardian to be next to patient during examinations?*

The guardian would be only exposed to scatter radiation which is very small. Also, the guardian can wear a radiation protection lead apron to further block radiation exposure. There is little radiation related danger and risk for the guardian to be next to the patient during examinations.

*Question 7) How many examinations can I take per year?*

The accumulative dose of examinations is much more important than the number of examinations taken per year. However, there is no threshold for how much is appropriate. This is because if the examination is medically necessary, the examination should be performed regardless of the amount of the previous amount of studies.

*Question 8) Do I have to terminate pregnancy after image related radiation exposure?*

Most imaging related radiation exposure will not expose the fetus to levels likely to cause health effects. When the patient is unaware of pregnancy, the radiation effects usually have an “all or nothing” effect, as the result of dose exposure results mostly

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in normal birth or complete fetal demise and miscarriage. During the first trimester, especially from 2 weeks to 8 weeks, because the rate of fetal growth is very rapid, the fetus is at its most radiation-sensitive stage. So, unless medically urgent, radiation exposure should be delayed or avoided if possible. During the second trimester the overall growth of fetus has slowed down. From the standpoint of future development, this period shows the highest risk for congenital malformations and mental retardation from dose exposure (18).

During the first trimester 50-100 mGy will often result in miscarriage. Afterwards, doses of 100-200 mGy may result in congenital malformations and mental retardation, partially depending on when the fetus is exposed. During the 2-8 weeks of pregnancy, malformations are more common. During the 8-16 weeks of pregnancy, mental retardation is more common. Also, the overall risk of pediatric cancer is increased (19).

The estimated dose to the fetus from a chest X-ray performed on the mother is only about 0.002 mGy. Even pelvic CT examinations will result in only 25 mGy of exposure to the fetus (19). Therefore it is very difficult to go over 100 mGy dose exposure to the fetus from a single examination, and doses of less than 100 mGy do not indicate a need for fetus termination. When deciding on whether to use radiation related imaging to the mother with known pregnancy, it is important to consider the benefits to the mother and potential hazard to the fetus (18).

*Question 9) Is it okay to breast feed after examinations?*

X-ray radiation does not accumulate in the body, therefore it is safe to breast feed after X-ray based imaging studies. Even after contrast CT examinations, normal breast feeding is safe (20). The contrast media used in imaging are actually safe to use in babies. Therefore, stopping breast feeding due to having received imaging examinations is more harmful to the baby, so normal breast feeding should be carried out.

### Educational sites for medical professionals and patients

There are many websites proving information on radiation, radioactivity, and radiation safety. However, many have incorrect or misguided information, with some emphasizing only the dangers of radiation. In the United States of America (USA), the Image Gently (http://www.imagegently.org) and Image Wisely (http://www.imagewisely) campaigns were initiated and efforts were made to decrease pediatric and adult radiation dose while offering extensive radiation dose related information. The Radiologic Society of North America (RSNA) along with the American College of Radiology (ACR) jointly offered radiation examination related patient information including radiation dose related information at Radiologyinfo.org (http://www.radiologyinfo.org).

## PATIENT DOSE MANAGEMENT PROGRAMS

Patient dose management programs can be divided into programs used separately by medical facilities and centrally by the government or central organizations.

### Management by medical facility

The basic way to manage dose is by accurately assessing dose by examination and comparing with national dose reference levels or comparing with the facility averages. This method is easy to implement and cost efficient when using modern digital based equipment. However, older machines may not provide dose reports, and in such cases difficultly may arise. Programs for estimating dose for such older CT machines may be used, such as ImPACT scan (21), CT-expo (22), and ALARA-CT (23). Recently many dose management programs have been developed and systemic management using such programs is increasingly being implemented in various medical facilities throughout the world.

### Management by the government or central organization

Dose tracking and management can be mandated by legislation or voluntarily performed. The data can be also be collected by a central management system. For example, a central dose data collection and management system has been implemented by the ACR Dose Index Registry (DIR) (24). Also, the state of California and Texas, USA have legislation mandating the recording of dose in CT reports.

Texas, USA has mandated installation of radiation protocol committees (11). This is because of several known radiation dose accidents due to technical or operating errors that occurred in the State of California, Florida, and Alabama. The ACR is operating a National Radiology Data Registry (NRDR). The aim of NRDR is to compare radiology examinations by region and national levels. One of the NRDR undertakings is running a DIR. The DIR collects dose data from a regional and national level and evaluates the data. The DIR collects anonymized data into a central database maintained by the ACR. Each participating organization and medical facility receives their dose data averages, statistics, and comparison with other facilities periodically, and can use this data to optimize dose exposure. This information can also be used as a basis for creating appropriate national and State level legislation.

In 2009, incorrect CT settings in California hospitals (Cedar-Sinai Medical Center, Mad River Community Hospital) caused brain perfusion CT examinations to result in greater than 1,000 mSv dose exposures in patients, leading to hair loss and potential increase in cancer risk (25,26). These incidents motivated the ACR and The American Association of Physicists in Medicine (AAPM) to cooperate for measures to decrease CT radiation, and increased the interest of the government in managing radiation exposure. In August, 2010 the USA Food and Drug Administration (FDA) started efforts to decrease radiation exposure (27). Afterwards, in 2010, Arnold Schwarzenegger signed the first USA bill related to radiation dose, the California Senate Bill 1237 (Regulating CT Radiation Dose Practices in California into Law) (28). In 2012, this was modified and passed into law (29). This was related to mandating radiation CT dose monitoring with the California Department of Public Health being the managing organization. The contents include mandating the addition of dose exposure to radiology reports and mandating the transfer of CTDI and DLP values to PACS. In 2013, the States of Texas and Connecticut passed similar legislation mandating medical radiation dose monitoring (30,31).

### Points to consider when monitoring individual radiation dose

There is great interest in legislation regarding individual dose monitoring and tracking. However, the following points much be considered. The dose reports provided by CT examinations are only estimations and not true measurements. These dose values are reported on the basis of calculations using phantoms. Therefore, it is not possible to know the exact dose the patient was exposed. Imaging machines other than CT often do not provide such dose reports, and even when they do, they provide values such as skin dose which are difficult to use to estimate effects on the human body. There can be no limit to individual radiation dose when using for medical imaging purposes. If the examination is medically justified, the imaging should be performed. The question of how many examinations the patient had already taken should not affect the imaging indications. Medically justified examinations should always be performed, and unneeded examinations should be avoided in the first place.

Dose management should be used to decrease overall population based dose, and not applied to individual patients. Dose management and data are useful in population based studies, but not valid in individual based management. ICRP recommends not using dose data for assessing individual dose risk (4).

### Pediatric dose management

Brenner et al. (32) shockingly reported in 2001 that 600,000 CT examinations were performed on pediatric patients annually with about 500 patients estimated to die in the future due to CT radiation exposure related cancer. USA Today reported similar contents in the same year, which caused a heighted interest in pediatric radiation dose exposure (33). To decrease radiation dose exposure, it is utmost important for medical physicians to know about the potential risks related to dose exposure.

Pediatric patients are much more sensitive to radiation than adults, and have a potential long life after imaging for radiation risks to show up. Radiation based examinations are less frequent in pediatric patients compared with adults. Although chest X-rays are cost efficient and clinically helpful, sometimes they are taken multiple times in intensive care unit patients on the same day. However, there is research that suggests hepatoblastoma risk may increase do to such chest X-rays in intensive care unit patients (34). Also, repeated plain radiograph imaging of scoliosis patients can result in increased breast cancer risk (35). So, even though plain radiographs have small amounts of radiation dose exposure, they can still have significant risks to pediatric patients. Therefore, it is important to use the minimum radiation dose necessary for examinations and also avoid unnecessary repeat examinations, and use collimation and radiation protection for sensitive areas not needed in the target imaging field (36).

Although there is still controversy regarding whether diagnostic low levels of radiation can really cause cancer, the prevailing theory is currently the "linear-non-threshold" theory (37). This theory suggests that even small amounts of radiation can cause small increases in cancer risk, suggesting that efforts must always be made to minimize radiation dose. The cells of children are more susceptible to the effects of radiation, which results in a more increased risk for developing cancer from non-deterministic stochastic effects than adults. Also, children's genes from radiation doses may be altered with the possibility of these genetic effects being passed on to their offspring. This is the reason that optimized pediatric specific imaging protocols are needed, which must consider the small size of patients (38). It is often difficult to assess dose exposure from images without looking at dose reports. In the USA, the Society for Pediatric Radiology initiated the "image gently campaign" in 2007 and over 60 related organizations worldwide are now participating. This campaign has expanded to a related "pause and pulse, step lightly" campaign, which is focusing on decreasing dose for pediatric fluoroscopy and intervention (39).

## CONCLUSION

Medical radiation is a very important part of modern medicine, and should be only used when needed and optimized when used. Justification and optimization of radiation examinations must be performed. Reduction of medical exposure starts with education of medical personal including radiologists, technicians, and physicians. It is important to properly prepare for examinations, wear appropriate radiation protective gear, and use optimized examination protocols to decrease radiation. It is relatively easy to educate related physicians on the indications of examination protocols, but it is a somewhat complex problem to justify the need of examinations. This justification will require a social agreement by the government, referring physician, radiologist, hospital management, and patients.

It is important for medical facilities to have a systematic man-


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agement system for patient dose management, and furthermore national level infrastructures for dose management is needed to manage medical facilities. It is also important for professionals to create guidelines for imaging indications, optimized standard protocol, and appropriate educational topics.

There is no radiation dose threshold for diagnostic imaging, and individual dose management and tracking may actually hinder proper dose management and waste the time and money of related organizations. The medical society and government should establish appropriate systems and infrastructure to manage patient radiation dose in a facility, regional, and population model and avoid wasting resources to monitor individual dose. Also, not only medical facilities and physicians, but patients should also try to avoid directly asking and requesting unneeded examinations.

## DISCLOSURE

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## AUTHOR CONTRIBUTION

Conception and design: Jung SE. Drafting of the manuscript: Park MY, Jung SE. Critical revision of the manuscript for important intellectual content: Jung SE.

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