Roundtable D

How are we meeting challenges in patient dose recording, tracking and data management?

RADIATION DOSE TRACKING FROM X-RAY PROCEDURES: WHERE ARE WE AND WHERE SHOULD WE BE?

C. BORRÁS
Medical Health Physics Section of the Health Physics Society
Washington DC, USA
Email: cariborras@starpower.net

F. BECKFIELD, D. ELDER, L. KROGER, B.P. LEMIEUX, M.A. NOSKA, J.A. THOMAS
Medical Health Physics Section of the Health Physics Society
USA

Abstract

Some legislation and accreditation standards in the United States and in Europe require radiation dose tracking, especially for CT scanning and interventional radiology procedures. Doses from radiography, mammography, computed tomography and diagnostic and interventional fluoroscopy, usually estimated from image acquisition parameters and energy absorption distributions within the body, can now be calculated, stored and transferred electronically. The problem is that these software-generated dose metrics are proportional to the radiation emitted by the equipment, but are not patient-specific doses. Their inclusion in patient records without explanations is inappropriate. Even the 'Patient - Radiation Dose Structured Report', being developed by the DICOM Standards Committee, which estimates organ absorbed doses based on individual image acquisition parameters and specific patient characteristics, should be used cautiously, as cumulative organ doses from past imaging should not be used to prevent future clinically justified medical imaging. To alert of potential stochastic effects, dose indices, manually or electronically determined, should be compared with reference dose levels generated for that modality. Only interventional radiology procedures, where tissue effects may occur, should require personalized dosimetry.

1. DOSIMETRIC QUANTITIES IN DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY

The radiation dose received by patients in radiological procedures depends on imaging modality, imaging protocol parameters and patient geometry. The dosimetric quantities defined for projection radiography and fluoroscopy [1] are incident air kerma (K_{ai}), entrance surface air kerma (K_{ae} or ESAK) and air kerma area product (P_{KA}, also called KAP or DAP), and, additionally, for interventional fluoroscopy, reference point air kerma $K_{a,r}$ [2]. P_{KA}, being sensitive to the irradiated volume, is a good dose metric to infer potential radiation stochastic effects, while K_{ae} and $K_{a,r}$ are useful to infer harmful tissue (deterministic) effects. In computed tomography (CT), currently accepted metrics are volumetric computed tomography dose index ($CTDI_{vol}$) dose-length-product (DLP) and size-specific dose estimate (SSDE) [2]. Dosimetric quantities can be determined by placing calibrated ion chambers, diodes, film and/or thermoluminescent or optically stimulated luminescent dosimeters on patients or in phantoms and multiplying the dosimeter response by appropriate dose conversion factors. Alternatively, patient doses can be estimated with Monte Carlo simulations by knowing the radiation beam characteristics and its interaction with a geometric or anthropomorphic phantom or using a voxelized representation of an actual patient obtained from CT images. The best indicator to assess patient risks is the absorbed dose to the irradiated organs ortissues.

2. RADIATION DOSE METRICS INFORMATICS STANDARDS

Manual radiation measurements and dose determinations are tedious and time consuming. CT scanner and fluoroscope manufacturers as well as software developers have programs which can calculate, store and transfer radiation dose indices such as $CTDI_{vol}$ and DLP for CT scans and P_{KA} and $K_{a,r}$ for interventional radiology procedures [2]. Some programs also compute organ doses and effective dose. To handle recording and storage of radiation dose information, the Digital Imaging and Communications in Medicine (DICOM) standard has defined a 'Radiation Dose Structured Report' (RDSR). This report includes the radiation output from imaging devices, which may be used to generate $CTDI_{vol}$ and the DLP dose metrics when needed. It includes information on every irradiation event, patient information and image acquisition protocols. Unfortunately, the generated dose metrics are proportional to the radiation emitted by the equipment but are not patient specific doses. To address patient dose, the DICOM Standards Committee is developing the P-RDSR, where P denotes patient. With information about the x-ray equipment, RDSR data, patient modeling and patient location and orientation, the P-RDSR can compute and display organ absorbed doses in 2 or 3 dimensions, including peak doses and dose distributions [3].

To enable communication between systems which generate RDSR data and systems that receive, store, or process those reports, the Integrating Healthcare Enterprise (IHE) has developed 'Radiation Exposure

Monitoring' (REM) profiles. IHE has REM profiles for CT and interventional radiology procedures and is now generating profiles for radiography, fluoroscopy and nuclear medicine studies. Radiography profiles are complicated. Digital radiography units usually don't display P_{KA} –the preferred dose metric– unless the x-ray unit has a transmission ion chamber attached at the end of the collimator. Displayed Exposure Indices (EI) are calculated values derived from the detector signal and as such do not represent the dose received by the patient. A further complication is that the methodology for calculating EI values has not been standardized among manufacturers [2]. The performance characteristics that radiation dose index monitoring systems must have and how physicists should evaluate them have been published by the American Association of Physicists in Medicine as a medical physics practice guideline [4]. This guideline emphasizes that "all stored radiation dose indices should have associated with them the ability for the user to assign alertvalues".

3. SAFETY STANDARDS ON PATIENT RADIATION DOSIMETRY

3.1. International Basic Safety Standards

Regarding patient dosimetry, the International Basic Safety Standards (IBSS), the set of radiation control requirements adopted/adapted by many countries, states the need to determine "typical doses" received by patients undergoing diagnostic and interventional radiological procedures. It compels the registrant or licensee to perform periodic "local assessments" of those procedures for which diagnostic reference levels (DRLs) have been established – setting DRLs being a requirement for both diagnostic and interventional procedures – and to conduct a review if typical doses exceed or fall substantially below the relevant DRL [5].

3.2. European Basic Safety Standards (EBSS)

The IBSS requirements are designed so that they may be followed by any country in the world. They do not address individualized patient doses, given the calculation complexity of these determinations. The European Commission's Council Directive 2013/59/EURATOM, colloquially known as the European BSS (EBSS), emphasizes the need to "strengthen the requirements concerning information to be provided to patients, the recording and reporting of doses from medical procedures, the use of diagnostic reference levels and the availability of dose-indicating devices". Regarding the latter, it stipulates that "new medical radio-diagnostic equipment producing ionizing radiation – including equipment used for "planning, simulation and verifications" purposes – has a device, or an equivalent means, to inform the practitioner of relevant parameters for assessing the patient dose" and that "where appropriate, the equipment shall have the capacity to transfer this information to the record of the examination." Such transfer is obligatory for interventional radiology and computed tomography systems installed after 6 February 2018, the date the Directive standards have to be incorporated in the radiation control regulations of the European Union [6].

3.3. Regulatory and accreditation requirements in the USA

In the United States (US) there is no federal legislation regarding the use of radiology procedures except for mammography. The US Food and Drug Administration (FDA) regulates manufacturers of medical devices, including radiological equipment. Regarding dose, the only limit imposed by the FDA standards is the fluoroscopy air kerma rate measured under specifically defined conditions [7]. In addition to meeting all relevant federal regulations, all new CT scanners in the US must now comply with the 2010 National Electrical Manufacturers Association XR 25 CT Dose-Check Standard [8]. Due to changes in reimbursement that require compliance with this standard, many CT manufacturers are retrofitting their systems to adhere to it. Compliant CT scanners will notify operators when scan settings would likely yield $CTDI_{vol}$ or DLP values that exceed pre-assigned, user-defined limits.

Radiological procedure regulation is the responsibility of the States. Following media reporting of several CT overexposures in California, in 2010 the State of California passed the first law in the country requiring CT dose and incident reporting. The law was amended in 2011, 2012 and 2013. One of the most controversial features is that the CT dose metrics of each examination, expressed in terms of $CTDI_{vol}$ and DLP have to be included in the patient radiology report and sent electronically – together with the images and the study's technical factors – to the picture archive and communication system (PACS). Another problematic issue are dose limits imposed for repeated exams – unless approved by a physician – one of them in terms of effective dose. The 2013 law amendment requires all the CT facilities in the State to be accredited [9].

Another example of strict radiation control regulations regarding CT dose recording and reporting are those of the State of Texas, enacted in 2013. Texas has extended their regulations to radiography –where entrance air kerma limits for common x-ray projections have been established – and to fluoroscopically-guided interventions, for which it requires the registrant to make and maintain a record of radiation output information,

to include cumulative air kerma or dose area product when that information is available on the fluoroscopic system. If these parameters are not available, "records shall include other information necessary to estimate the radiation dose to the skin in accordance with established protocol". For CT scans, in addition to recording $CTDI_{vol}$ and DLP, there is also a skin dose determination requirement. Texas law also mandates "a recommended reference level for CT procedures performed", and actions to be taken – which may include patient follow-up – if this value is exceeded [10].

Other states are considering similar dose reporting regulations requiring accreditation by organizations such as the American College of Radiology (ACR), The Joint Commission (TJC) and others. While at present it is voluntary, accreditation is beginning to have a financial impact on health insurance. For example, the governmental agency 'Centers for Medicare and Medicaid Services (CMS)', which covers 100 million people in the US, requires accreditation for service reimbursement.

TJC's diagnostic imaging requirements currently encompass magnetic resonance, nuclear medicine and CT. Regarding CT, the requirements specify that the organization must document the values of $CTDI_{vol}$, DLP, or size-specific dose estimate (SSDE) on every study produced during a CT examination and that the radiation dose index should be "exam specific, summarized by series or anatomic area, and documented in a retrievable format". Furthermore, the organization must review and analyze studies where $CTDI_{vol}$, DLP, or SSDE values have exceeded expected dose index ranges for the imaging protocol. Additionally the study dose index is to be compared with external benchmarks [11]. TJC is now in the process of developing fluoroscopy standards. To address the risk of radiation injury during interventional procedures, TJC has defined prolonged fluoroscopy resulting in a cumulative (skin) dose of 15 Gy or more to a single field as a reviewable sentinel event – a sentinel event being defined as "an unexpected occurrence involving death or serious physical or psychological injury, or the risk thereof" [12].

4. TRACKING PATIENT DOSES?

The principles of radiation protection are: justification of the practice, optimization of the protection and dose limitation. To avoid unnecessary patient exposure, it is important to track the radiological imaging exams a patient has received. The question is whether such tracking should contain information on image acquisition protocols – which would allow for retrospective dose reconstruction if needed – or 'radiation dose'. Regarding optimization the IBSS states: "for medical exposures of patients, the optimization of protection and safety is the management of the radiation dose to the patient commensurate with the medical purpose". Furthermore, dose limitation is not applicable to medical exposures [5].

Exposure to radiation can induce lethal (deterministic) and non-lethal (stochastic) transformation of cells. Deterministic effects or tissue injury occur above a dose threshold and their severity is a function of dose. As dose thresholds are known [13], it makes sense to track organ absorbed doses, such as skin in patients undergoing high-dose procedures such as fluoroscopically guided interventions and brain perfusion CT exams. It must be noted, that absorbed dose determinations for these studies are complex and time consuming and that no current software-developed radiation dose indices represent "location-specific absorbed dose in an individual patient" [4]. However, access to some of these indices may facilitate the task; the question is how accurate is skin peak dose estimation from $K_{a,r}$ values. One possibility is to assess the dose distribution with calibrated radiochromic film and compare it with $K_{a,r}$ machine-displayed values for a limited number of patients, to establish a relationship from which peak patient skin doses may be inferred [14]. Radiochromic film may also be used to determine skin doses in CT from $CTDI_{vol}$ measurements/displays [15].

Stochastic effects are assumed to have no dose threshold; their probability of occurrence depends on dose. To account for different tissue sensitivities to radiation, the ICRP introduced the concept of effective dose, which "prorates partial-body radiation exposures to a whole-body exposure with the same risk" [2]. Effective dose is calculated by multiplying organ absorbed doses by tissue-weighting factors which add to unity. It is used to record workers and public dose limits but is not applicable to patient exposures [2] where errors of 500% have been estimated [16]. Most software packages compute effective dose from estimations of organ doses using Monte Carlo-derived data, mathematical phantoms, and a number of simplifying assumptions, without any error indications. When these parameters are documented in a patient record, they can be tracked for the entire patient life. The temptation is to add effective doses from each procedure and assign risks. However, "the concept of effective dose was never devised with the intention of producing risk estimates for an individual patient, but rather for assessing risks to larger populations of individuals (e.g., all patients having a head CT scan, interventional fluoroscopy procedure, or nuclear medicine exam)" [2]. Furthermore, "cumulative or longitudinal dose values obtained from summing radiation dose indices (RDI) or RDI-derived quantities for an individual patient should not be used as a basis for decisions regarding subsequent medical radiological procedures" [4] –practice justification must be a clinical decision.

To optimize patient protection by alerting health practitioners about potential stochastic effects of radio-diagnostic exams, individualized doses are not needed; manually- or electronically-acquired dose indices can be

compared with DRLs generated for that modality. In fact, collective tracked radiation dose indices can be used to derive DRLs, as the ACR does [2]. IBSS and EBSS require establishing and using DRLs [5, 6], yet at the present time, US regulatory requirements – except those of Texas – [7-11] do not. Instead doses are to be compared to 'external benchmarks', even though the US National Council on Radiation Protection and Measurements (NCRP) and the ACR have published DRLs and 'Achievable Dose' values [17, 18].

Clearly, mandatory radiation protection requirements in America and in Europe are to be followed, but given all the caveats involved, medical and health physicists must provide an accurate interpretation of the meaning and significance of 'personalized' tracked 'doses' to radiologists, referring physicians and patients so that risks may be better understood. Unless the documented data are the result of patient-specific measurements – in terms of organ absorbed doses – physicists should insist that their facilities incorporate in each patient radiology record a disclaimer to clarify that the reported radiation dose index is not actual patient dose.

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A WEBSITE TO CALCULATE INCIDENT AIR KERMA IN CT AND CBCT:
A change in practice for quality control and patient dosimetry

H. DE LAS HERAS GALA
Quality Assurance in Radiological Technologies (QUART) GmbH & Helmholtz Zentrum München
Munich, Germany
Email: hugo.heras@daad-alumni.de

F. SCHÖFER, H. SCHÖFER, T. DE LAS HERAS GALA
Quality Assurance in Radiological Technologies (QUART) GmbH
Zorneding, Germany

R.M. SÁNCHEZ-CASANUEVA
Instituto de Investigación Sanitaria del Hospital Clínico San Carlos (IdISSC)
Madrid, Spain

C. ZERVIDES
Zervides Radiation Protection Services & University of Nicosia Medical School
Nicosia, Cyprus

K. MAIR
Strahlentheraptie Süd
Kempten, Germany

Q. AL-ZOUBI
AIKAmed
Amman, Jordan

B. Renger
University Hospital Rechts der Isar
Munich, Germany

H. Schlattl
Institute of Radiation Protection, Helmholtz Zentrum München
Neuherberg, Germany

Abstract

The paper presents an answer to the recommendations expressed at the Technical Meeting for the Optimization of Protection in Medical Imaging, held at IAEA in June 2016. The goal is to use the incident air kerma (Ka,i) for quality control, patient dose information and definition of diagnostic reference levels (DRLs) for every x-ray modality (in addition to modality-specific additional measurements). Indeed IAEA, ICRU and ICRP recommend the Ka,i above all dosimetry quantities due to its simplicity and ease of measurement. However, this requires a standard methodology for tomography applications, including multi-slice computed tomography and cone-beam CT.

Such a methodology has been tested and a simple website has been created to facilitate its use. The website is available free of charge to encourage world-wide use. The user needs to measure radiation output once (without any phantom) and record the following parameters about the x-ray device: beam size, distance source-isocenter and source-detector and rotation time. The website provides the incident air kerma for a reference size as well as estimations for any specific patient size and tube current-time product (mAs). The results enable comparisons of radiation output and patient exposure among any kind of x-ray modalities.

1. INTRODUCTION

Our team has been looking for answers to the recommendations expressed at the technical Meeting on Patient Dose Monitoring and the Use of Diagnostic Reference Levels (DRLs) for the Optimization of Protection in Medical Imaging, held at IAEA in June 2016. In that meeting, it was clear that we need to "improve availability and radiation protection knowledge" of the professionals, "strengthen the motivation and involvement of radiographers in patient dose monitoring", "establish sustainable system to enable frequent updating of DRLs", "establish mechanisms for dose collection and reporting", "improve standardization of classification systems for medical procedures" and "provide dosimetry equipment and improve calibration and quality control" [1].

One practical solution to come closer to the "patient-centric approach" suggested at that meeting would be to use the Ka,i at the skin in all x-ray modalities. Not only for quality control (assuming a standard patient size), but also for radiation dose monitoring (depending on patient size) and for defining DRLs (for a specified series of patients or a specified phantom). This is common for projection (2D) modalities [2,3], but it requires a standard methodology for tomography applications, including multi-slice computed tomography (MSCT) and cone-beam CT (CBCT). Such a methodology to estimate a personalized incident air kerma in tomography (PAKT) has been developed by a team composed of partners in industry, academia, clinical practice, regulatory agents and radiation protection officers (currently submitted for publication).

The purpose of this contribution to the "International Conference on Radiation Protection in Medicine" is to describe a website that helps to apply this methodology in a straightforward manner. The website informs technicians, patients, medical physicists, other scientists, radiologists, regulators, radiation protection officers and consultants about the incident air kerma in any tomography examination..

2. METHODS

The measurement of radiation output is performed with a solid state dosemeter. In the case of CBCT, the detector is attached to the flat panel (Fig. 1.a), as required for quality control measurements [4]. A whole scan with the parameters used for the desired protocol (for example a head protocol) produces a measurement of accumulated air kerma. This measurement is the one required for the calculation. No more measurements are required to obtain estimations for any patient undergoing an examination with the desired protocol.

In the case of multi-slice CT, the dosemeter probe is placed at the isocentre with the help of the alignment lights (Fig. 1.b). A whole scan provides a maximum of the air kerma rate, corresponding to the x-ray tube perpendicularly irradiating the dosemeter. This is the measured value required for the calculation. No more measurements are required, unless the beam is smaller than the probe, in which case the beam size in the axial direction must be measured (an electronic ruler as shown in Fig. 1.b is especially indicated for this purpose, but also radiosensitive film can be used).

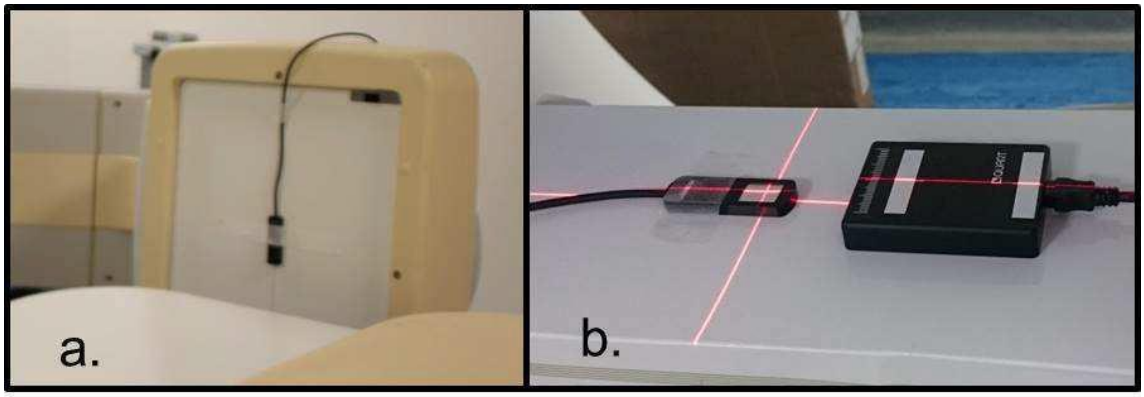

FIG. 1. ***Set-up of the dosemeter*** *in a) the flat panel of a CBCT and b) the isocentre of a multi-slice CT.*

The result can be obtained for a reference size (diameter of 16 cm as usual for standard head sizes of paediatric bodies), or for a specific patient (entering the patient perimeter and the actual mAs used in the examination).

3. RESULTS

The formulas described in the submitted publication have been implemented for ease of use into a Shiny website (prepared with the free software R). The user interface is shown in Fig. 2. The results are visualized in a graph like the one shown for a MSCT examination in Fig. 3.

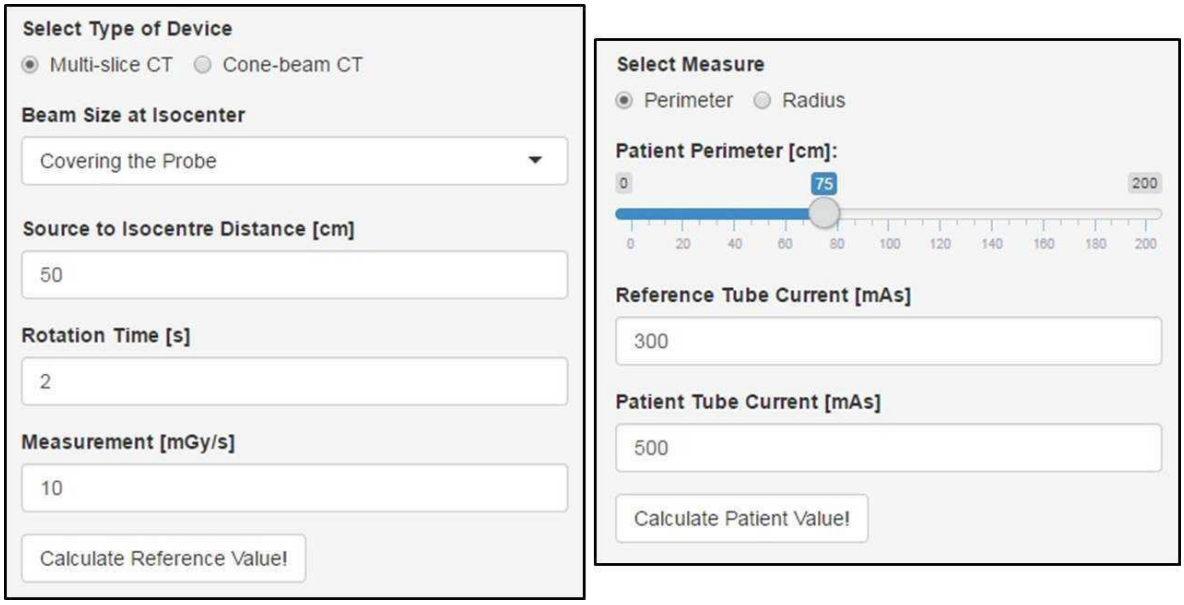

FIG. 2. ***User interface of the PAKT website*** *showing the input parameters required to obtain a reference value (left) and a patient value (right) before or after a specific examination.*

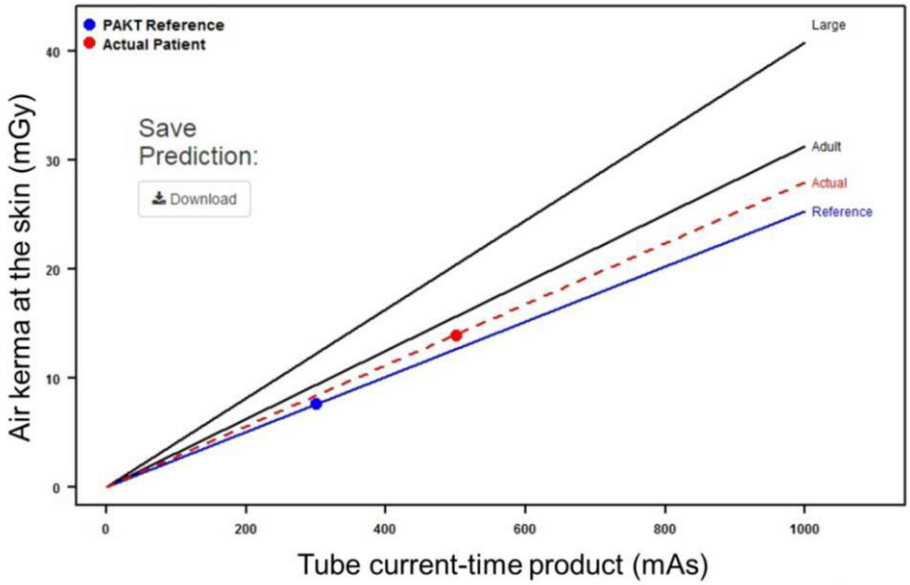

FIG. 3. **Results from the parameters indicated in Fig. 2**. The blue dot indicates a reference value of 7.58 mGy and the red dot indicates a value of 13.94 mGy for the specific patient size. The black lines indicate predictions for an average adult and a large patient. The results can be downloaded as a pdf report clicking the "Download" button.

4. DISCUSSION

The incident air kerma is the simplest dosimetric quantity [5]. It has been used since the beginning of x-ray radiology for quality control and dosimetry of 2D modalities (e.g. radiography, fluoroscopy, mammography). Therefore it seems natural to use this quantity also for 3D modalities. This is achieved with the presented website. This enables a straightforward comparison of the radiation output of any x-ray modality in diagnostic radiology. Since the air kerma is a measure of actual patient exposure, the delivered information can serve both for routine quality control and for patient dosimetryrecords.

The use of the website is simple and requires a few entries to obtain a result. The demonstration of the website to people involved in radiation protection in medicine (in Germany and Spain) has shown great acceptance. As an example of a direct application, the results from these calculations can be introduced into radiation dose monitoring systems. The developers of the system from the University Hospital San Carlos in Madrid (Spain) are already considering its adoption.

The use of incident air kerma for 3D modalities can achieve a change in practice, as suggested in this conference, because it can serve to inform professionals and patients easily and accurately. The website can also be used ahead of the examination to predict the exposure if required.

5. CONCLUSIONS

The presented website is reachable at https://quart.shinyapps.io/PAKT/. It is a practical tool to achieve a patient centric approach to both quality control and dosimetry in diagnostic radiology. It is the fruit of a long collaboration among radiation protection officers, medical physicists, researchers, regulators and industry. Its results have been validated by a recent study (submitted and currently under peer review) and it is available to be used world-wide for free.

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3 YEARS EXPERIENCE OF USING PATIENT DOSE TRACKING SOFTWARE IN TWO BUSY INTERVENTIONAL CARDIOLOGY LABORATORIES

Thomas Heary
Beaumont Hospital
Dublin,
Ireland
Email: thomasheary@beaumont.ie

Ronan Faulkner
Beaumont Hospital
Dublin,
Ireland

Abstract

Using data gathered by commercial dose tracking software, attached to two cardiac interventional laboratories since 2014, the paper presents a breakdown of the dose metrics for over 7000 patient interventions in a single centre, covering 50+ types of diagnostic/interventional cardiac procedures with associated national exam codes. The data covers over 400 Percutaneous Coronary Intervention (PCI) procedures and over 140 complex PCI multi-vessel chronic total occlusion (CTO) studies. In a busy cardiac interventional environment it was found that dose tracking software is an invaluable tool in:

- Quickly providing the range of doses per procedure (i.e. Mean, Median, Max and Min for Dose Area Product (DAP), Reference Point Air KERMA (RPAK) and Fluoroscopy Time (FT) for establishing local reference levels and for comparison with published data.
- Identifying the relative dose distribution of RPAK for high dose procedures
- Identifying the "worst case" RPAK to estimate the peak skin dose.
- Identifying patients who have had single or multiple high dose procedures - for OPD follow-up where appropriate
- Comparing the dose per procedure for different operators – for training /optimisation purposes
- Using all of the above in the process of continuous improvement and optimisation of radiation safety for patients and staff.

1. INTRODUCTION

The radiation dose to the skin of patients undergoing interventional cardiology (IC) procedures, particularly complex procedures, is relatively high compared to that found in other interventional radiological procedures [1], [2]. The requirement to track and manage potentially high radiation doses to the skin of patients in interventional procedures is established [3], but there are technical and practical considerations in estimating and tracking patient skin doses in a busy clinical setting [4],[5],[6]. In 2014 Beaumont Hospital, Dublin, Ireland installed two new GE Innova IGS 520 cardiac interventional systems with patient dose tracking software (DoseWatch®). Around 2500 IC procedures are carried out annually in the in the two IC labs, including low dose cardiac electrophysiology procedures, coronary angiograms and relatively high dose complex IC procedures e.g. Percutaneous Coronary Interventions (PCI) for Chronic Total Occlusion (CTO) of single and/or multiple vessels.

2. METHODS

On completion of each IC study, the DICOM Radiation Dose Structured Report (RDSR) [6] is automatically pushed from the imaging modality to DoseWatch®, which resides on a remote server on the PACS network. The software is set up to automatically interpret the data fields in the RDSR for each completed study and copies it into the appropriate corresponding fields in the database. Each RDSR contains the study details including: the patient demographics, height and weight; the procedure details, including the standard national exam code, the exam accession number and the operator details; the available dose metrics i.e. Dose Area Product (DAP) in $mGycm^2$, Fluoroscopy Time (FT) in seconds, X-ray Field Size (FS) in cm, Reference

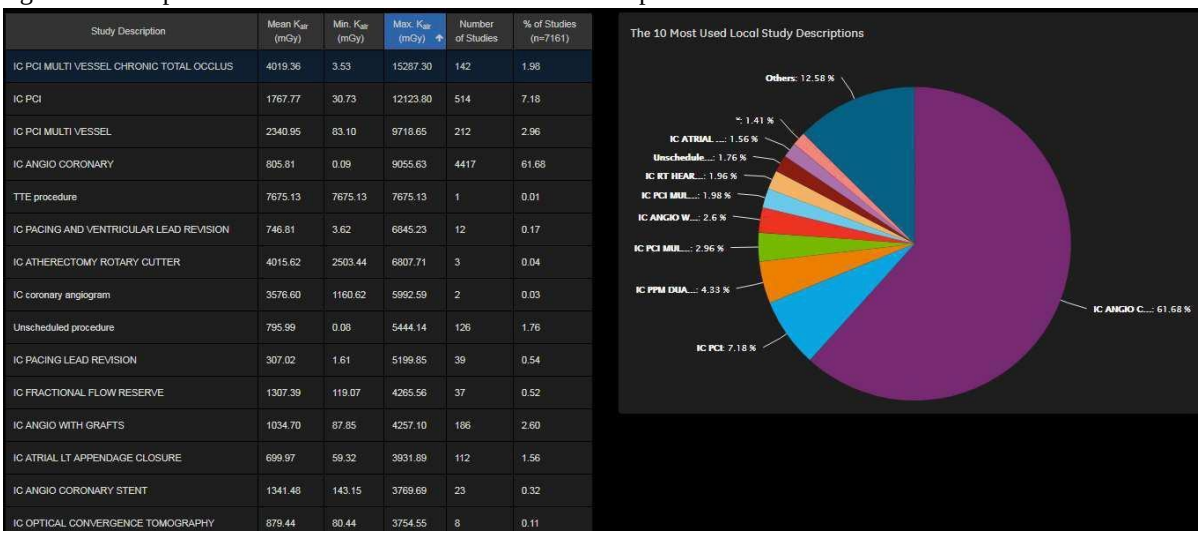
Point Air Kerma (RPAK) in mGy); and positional information about the X-ray beam relative to the patient on the table. The latter is used to produce a distributional map of the RPAK for each beam projection/angle in a single study. The relative distributional map of RPAK is used in reviewing lengthy high dose procedures. Although the software does not calculate skin dose [4], [5], the dose metrics for each patient and/or study can be quickly accessed for analysis by the physicist or clinician. The RPAK distribution map can be used in determining which patients may need post-interventional follow-up. The software can be configured to provide an alert for any high dose procedures e.g. where the DAP has exceeded a threshold of 500Gycm^2 and/or the RPAK has exceeded 5000mGy [3].

3. DOSE TRACKING RESULTS FROM 2014 TO 2017

3.1. Studies with the highest dose indices (RPAK, DAP and FT)

Figure 1 is a screenshot taken from the data analysis in DoseWatch®, showing a table and a pie chart of the global IC dose data. The table lists the top 15 (out of 68) exam codes, in descending maximum RPAK (Max K_{air}). The procedures with the highest RPAK are, as expected, the most complex procedures where multiple coronary vessels are involved i.e. "IC PCI MULTI VESSEL CHRONIC TOTAL OCCLUSION", which represent 1.98% of the total procedures in the lab.
The pie chart on the right of figure 1 shows the relative numbers of different studies from the 7161 IC studies carried out in since 2014. The most common procedure is the "IC ANGIO CORONARY", representing 4417 studies or 61.68% of the total.

Figure 1 Screenshot from DoseWatch® showing a list of the top 15 studies in order of RPAK (K_{air}) together with a pie chart of the relative numbers of different procedures in the two IC labs



Study Description	Mean K_{air} (mGy)	Min. K_{air} (mGy)	Max. K_{air} (mGy)	Number of Studies	% of Studies (n=7161)
IC PCI MULTI VESSEL CHRONIC TOTAL OCCLUS	4019.36	3.53	15287.30	142	1.98
IC PCI	1767.77	30.73	12123.80	514	7.18
IC PCI MULTI VESSEL	2340.95	83.10	9718.65	212	2.96
IC ANGIO CORONARY	805.81	0.09	9055.63	4417	61.68
TTE procedure	7675.13	7675.13	7675.13	1	0.01
IC PACING AND VENTRICULAR LEAD REVISION	746.81	3.62	6845.23	12	0.17
IC ATHERECTOMY ROTARY CUTTER	4015.62	2503.44	6807.71	3	0.04
IC coronary angiogram	3576.60	1160.62	5992.59	2	0.03
Unscheduled procedure	795.99	0.08	5444.14	126	1.76
IC PACING LEAD REVISION	307.02	1.61	5199.85	39	0.54
IC FRACTIONAL FLOW RESERVE	1307.39	119.07	4265.56	37	0.52
IC ANGIO WITH GRAFTS	1034.70	87.85	4257.10	186	2.60
IC ATRIAL LT APPENDAGE CLOSURE	699.97	59.32	3931.89	112	1.56
IC ANGIO CORONARY STENT	1341.48	143.15	3769.69	23	0.32
IC OPTICAL CONVERGENCE TOMOGRAPHY	879.44	80.44	3754.55	8	0.11

Similar global data analysis can be quickly generated in terms of exam protocol name, numbers of procedures and Max, Min or Mean DAP or FT. From the table it is clear that the consistent use of standard local study descriptions is crucial, otherwise the distinction between different study types is lost. For example, in the table in figure 1, there are 125 manually entered exams called "unscheduled procedure". As these exams do not have a standard national exam code it is unclear what type of exam they are and therefore they cannot be analysed without further investigation and/or editing of each exam in the software.

It is possible to look more closely at the dose metrics for similar study descriptions and derive local dose reference values in terms of median and percentile dose metrics. Figure 2 shows a screen shot of such an analysis for all (142) IC PCI MULTI VESSEL CHRONIC TOTAL OCCLUSION procedures. This additionally shows the median, 25th percentile and 75th percentile for RPAK.

Figure 2: Screenshot showing Mean, Max, Min, Median, 25th Percentile and 75th Percentile values of the RPAK (K_{air}) for all 142 PCI Multi-Vessel CTO studies in the database.

From such analyses, it is also possible to quickly compare the local reference values with published data. Table 1 provides a breakdown of the top 4 procedures with the highest local dose indices in terms of mean, median, range and 75th percentile (P75) for RPAK (mGy), DAP ($mGycm^2$) and FT (minutes). The right-hand column of Table 1 also contains published values of RPAK for similar studies for direct comparison [1], [7].

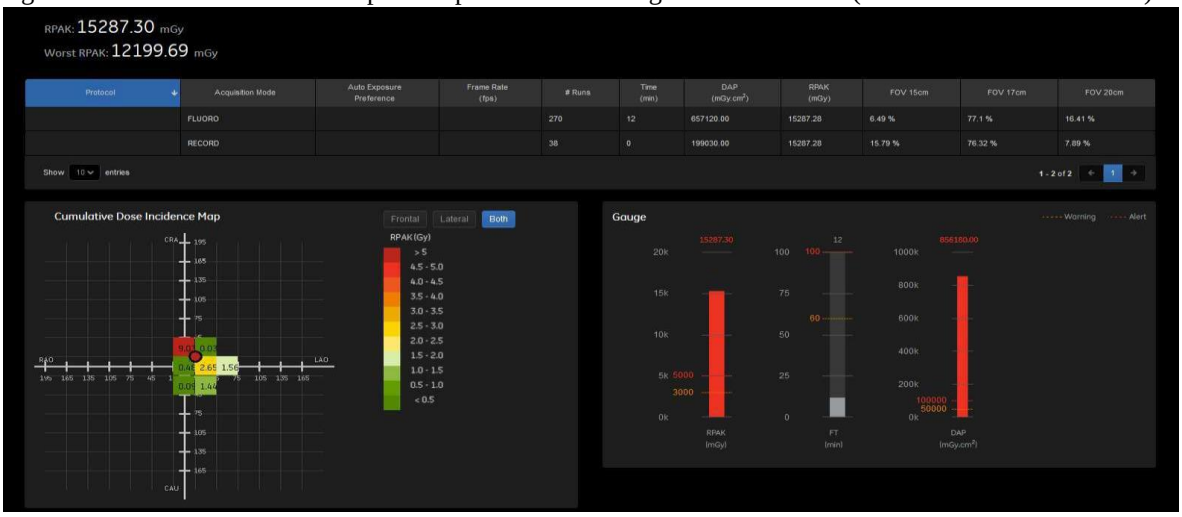
Table 1 Exam Codes with the Highest Dose Indices

NATIONAL EXAM CODE FROM NATIONAL PACS	No. of Studies (% of total)	RPAK* mGy	DAP $Gycm^2$	FT Minutes	Published RPAK* [7] mGy
IC PCI MULTI VESSEL CHRONIC TOTAL OCCLUSION	142 (2%)	Mean: 4019 Median: 2756 Range: 4 – 15287 P75: 4966	Mean: 240 Median: 170 Range:0.45-856 P75: 301	Mean: 42 Median: 38 Range: 0.65 – 141	Mean: 3985+/-3579 Median: 2729 Range: 132 – 24546 P75: 5779
IC PCI	514 (7%)	Mean: 1766 Median: 1086 Range: 31 – 12124 P75: 2112	Mean: 92 Median: 63 Range: 1.9 - 758	Mean: 18 Median: 13 Range: 0.35 - 96	Mean: 1024+/-1087 Median: 670 Range: 27 – 12015 P75: 1277
IC PCI MULTI -VESSEL	212 (3%)	Mean: 2341 Median: 1891 Range: 83 – 9719 P75: 2707	Mean:117 Median: 94 Range:4.9 - 504	Mean: 22 Median: 20 Range: 1.8 - 89	Median: 1501 Range: 928-2224 [1]
IC ANGIO CORONARY	4417 (62%)	Mean: 806 Median: 548 Range: 0.1 – 9056 P75: 928	Mean: 49 Median: 34 Range: 10 - 215	Mean: 7.7 Median: 5.4 Range:0.1 – 73	Mean:380+/-302 Median: 306 (Median:581 [1]) Range: 105 – 1507 P75:472

3.2. Patients with the highest RPAK

The Society of Interventional Radiology recommends that patients with RPAK >5000mGy, Peak Skin Dose (PSD)>3000mGy, DAP>500Gycm^2 or FT>60 minutes undergo post-procedure follow with their clinician [3]. In addition to providing user definable alerts for such dose metrics, DoseWatch® uses the X-ray gantry angular information in the DICOM RDSR to produce RPAK distribution maps which can be used by the clinician to support decisions around such follow-up. Figure 3 shows the RPAK distribution map of the patient who received the highest dose. This relates to the study at the top of the range of "IC PCI MULTI VESSEL CHRONIC TOTAL OCCLUSION" procedures in Table 1 i.e. RPAK of 15287.3mGy. Whilst this is a very high RPAK, the map in Figure 2 indicates that the dose is actually distributed over 7 projections and that the part of the skin that received the highest dose corresponds to an overlap of only 4 of these projections. Consequently the "Worst RPAK" is 12199.69mGy or 20% lower than the RPAK displayed on the imaging system. (Note the other information available in Figure 3 e.g. DAP, field size and proportion of the dose attributable to different acquisition modes (FLUORO or RECORD)).

Figure 3. The dose distribution map of the patient with the highest dose metrics (Taken from DoseWatch®)



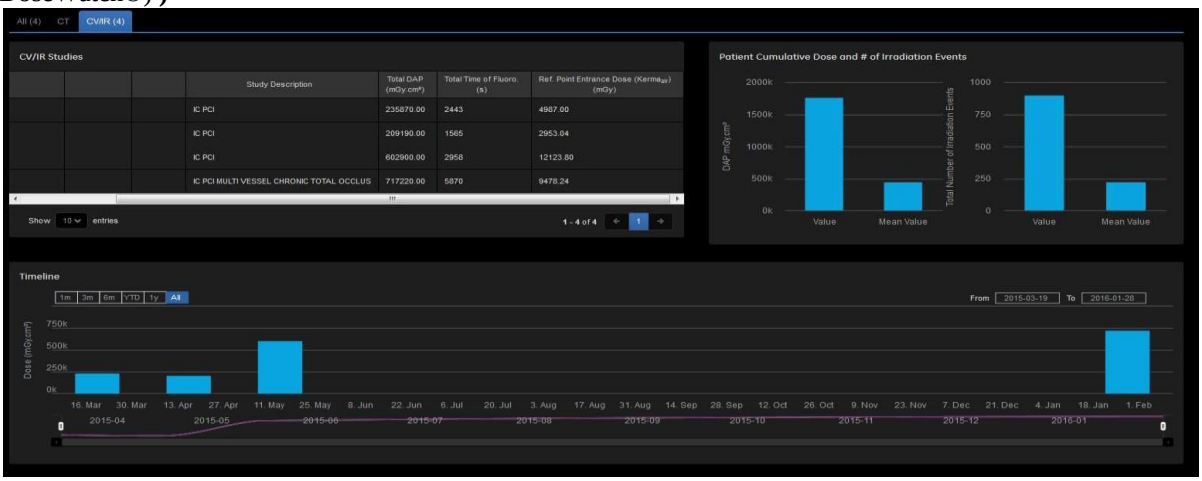
It is important to note that RPAK, like DAP and FT, is not skin dose. RPAK is a dose metric that corresponds to the dose in air at the IEC reference point, which is specified as a point in the centre of the X-ray beam 15cm below the isocentre of the interventional system [8]. The location of the isocentre relative to the x-ray source is different for different interventional systems/vendors. In the case of the Innova IGS 520, the isocentre and the reference point are located at 72cm and 57cm respectively from the focal spot, which corresponds with patient table vertical position of 0.0cm and -15cm respectively. Using the RDSR data captured by the dose tracking software it is possible to identify the vertical position of the patient table relative to the isocentre (and reference point) for any study if follow-up is required. For all the procedures carried out in the two labs it was found that the vertical table position is never below the isocentre (Average Vertical Table Position = +13.34cm range: +7.14cm to +24.18cm). Using this information together with other contributing factors (e.g. beam quality, table and mattress attenuation, field size, estimated back scatter, etc.), it is possible to estimate the skin dose and PSD of individual patients with high dose metrics [4], [5], [6].

3.3. Patients who undergo multiple high dose procedures

Patients who undergo multiple high dose IC procedures over a short period are at higher risk of developing skin injuries. Such patients are difficult to monitor in a busy clinical environment without dose tracking software. The Joint Commission classifies radiation overdose as a Reviewable Sentinel Event. In relation to fluoroscopy, the Joint Commission considers a Sentinel Event to be "prolonged fluoroscopy with cumulative dose >1500 RADS (15Gy) to a single field" and defines cumulative dose as a dose given within a period of six months to a year [9]. Figure 4 shows a screenshot from DoseWatch® providing the dose history of a patient who had 4 high dose procedures in a 12-month period. The cumulative dose for the four procedures is DAP= 1765Gycm^2 or

RPAK= 29.5Gy (DoseWatch® version 2.0 provides cumulative dose in terms of DAP only). Dose tracking software is useful at providing information about the cumulative radiation dose, which can be used to facilitate decisions about scheduling repeat procedures to minimise the risk of skin injuries and/or to facilitate regulatory investigation.

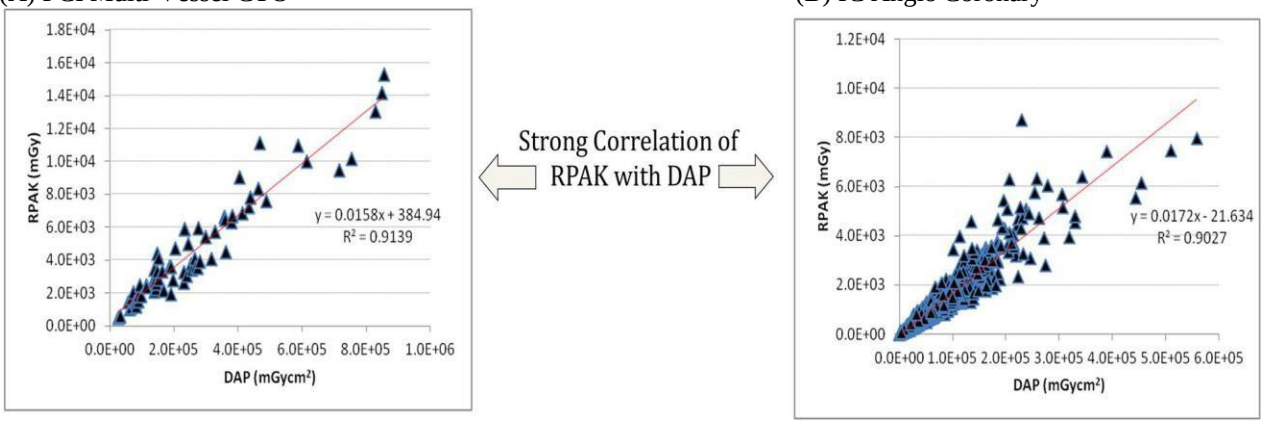
Figure 4 The cumulative dose (DAP) of a patient who underwent four procedures over 12 months (Taken from DoseWatch®) **)**



3.4. Reference Levels in Interventional Cardiology

In the absence of a widely available, quick and easy direct skin dose data capture methodology [10], DAP, RPAK and FT are commonly used indices for skin dose estimation [3]. Newer interventional systems provide both RPAK and DAP, which are essentially based on X-ray tube output. Figure 5 shows the strong correlation of RPAK and DAP for PCI Multi-Vessel CTO procedures (A) and for Coronary Angiograms (B) for the studies carried out on the two GE Innova IGS 520 systems. This strong correlation is unsurprising since the field size changes very little in dedicated interventional cardiology systems. In this lab the field size typically 17.5cm to 20.0 cm for most studies.

Figure 5 The Correlation of Reference Point Air KERMA (RPAK) with Dose Area Product (DAP)
(A) PCI Multi-Vessel CTO (B) IC Angio Coronary



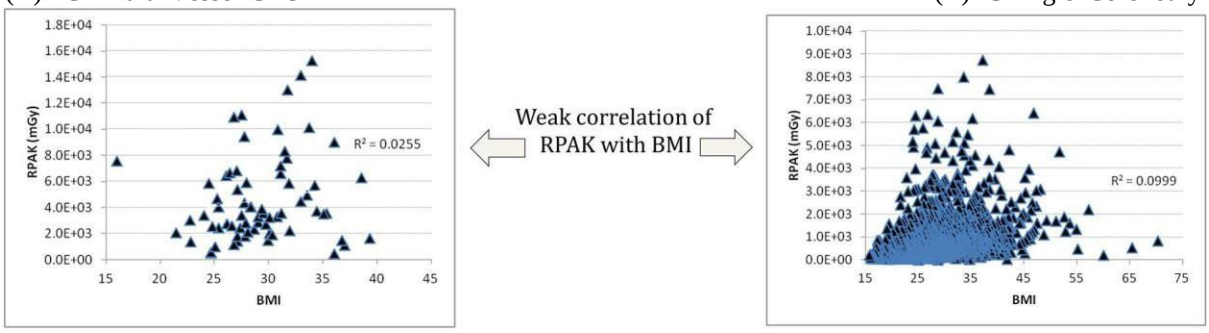
All patients who undergo interventional cardiac procedures have their height and weight taken at the time of the study, which is entered into the haemodynamic recording system. The DICOM RDSR facilitates the transmission of such information to DoseWatch®, which calculates the patient's body mass index (BMI).

The Correlation of RPAK with Body Mass Index (BMI) is plotted in Figure 6, showing that, for both high dose PCI Multi-Vessel CTO procedures (A) and relatively low dose Coronary Angiograms (B), there is a very poor correlation between RPAK and BMI. This suggests that for interventional procedures, unlike diagnostic

reference levels [11], complexity of the procedure is a better determinant of reference dose than the weight range of the patients.

Figure 6 The Correlation of Reference Point Air KERMA (RPAK) patient Body Mass Index (BMI)

(A) PCI Multi-Vessel CTO (B) IC Angio Coronoary



3.5. Comparison of Operators

The DICOM RDSR facilitates the transfer of information about the clinician/ practitioner operating the equipment. This requires either the manual entry of the operator's name or, preferably, the selection of their name from a predefined list of operators, at the acquisition console of the X-ray machine. If this feature is available and correctly used then it is possible to make a comparison between the dose metrics observed when different clinicians are carrying out similar procedure. This can be useful as a training resource in dose optimisation. Table 2 shows a comparison between two operators who carried out coronary angiograms and PCI multi-vessel CTO studies. From the table Consultant A produces higher mean RPAK doses per procedure than Consultant B. There may be any number of reasons for such a disparity, including the clinical complexity of the cases carried out by one operator compared to the other.

Table 2 Comparison of RPAK for similar studies carried out by Consultant a and Consultant B

	Consultant A		Consultant B	
Study Description	**No. of studies**	**RPAK (mGy)**	**No. of studies**	**RPAK (mGy)**
IC ANGIO CORONARY	178	Mean: 1091 Range: 61-7970	145	Mean: 657 Range: 19-6060
IC PCI MULTI VESSEL CHRONIC TOTAL OCCLUSION	16	Mean: 4787 Range:1488-13062	8	Mean: 3275 Range: 581-10960

4. CONCLUSIONS

The use of dose tracking software is a valuable tool in helping to track, monitor, and optimise patient doses in a busy interventional cardiology clinic. Analysis tools built into DoseWatch® are very useful but in cases where analysis tools were unavailable from within DoseWatch® (e.g. obtaining table height per procedure or the correlation between RPAK and BMI), it was possible to export the data and perform analysis in a spreadsheet. Overall dose tracking software has been successfully used to:

a) Identify the range of RPAK and DAP per procedure, which is useful for quick review, for developing local reference levels and for comparison with published data.

b) Demonstrate that there is weak correlation between dose metrics and patient BMI for both high and low dose procedures. This suggests that the use of patient weight ranges may not apply to interventional reference levels as they do to diagnostic reference levels (DRLs).
c) Identify the range of RPAK and DAP per procedure per operator, which can be useful in training and optimisation
d) Identify "Worst" RPAK from the dose distribution map, which is potentially a better indicator for patient peak skin dose (PSD) than RPAK or DAP alone.
e) Identify and generate alerts for patients with high skin doses for regulatory reporting, clinical follow-up or rescheduling as appropriate.

Based on the benefits derived from experience in interventional cardiology, the use of dose tracking has been extended to other interventional settings: general vascular, neuro-vascular and CT interventional. In future it is planned to derive staff doses per interventional procedure for each operator, using real-time personal dosimeters, and to correlate these with the patient dose metrics /workload to provide a fuller picture of radiation doses in our interventional suites.

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EFFICIENCY OF DOSE MONITORING SOFTWARE: CT PROTOCOL MANAGEMENT AND RAISED AWARENESS BETWEEN RADIOLOGY TECHNICIANS FOR REDUCED RADIATION EXPOSURE

Chang Hyun Lee[1], Park Margaret[1], Min Soo Lee[1], Eun Sung Kim[1],
Yong Hwan Shin[1], Eun Young Choi[1]

Chang Hyun Lee, MD., PhD, Park Margaret, PhD, Min Soo Lee, PhD, Eun Sung Kim, PhD, Yong Hwan Shin, PhD, Eun Young Choi, PhD.

Seoul National University College of Medicine, Seoul National University Hospital[1]
Department of Radiology
Seoul/Republic of Korea
Email: changhyun.lee@snu.ac.kr

Abstract

A survey from 25 radiology technicians questioned the pros and cons of the software as well as the most significant change that has occurred after using the dose monitoring software. A total of 77,736 patients from 34 CTprotocols were collected. The data, consisting of patients' effective dose(ED), CTDIvol, and DLP were retrieved. The greatest benefit from dose monitoring software was the ability to access statistical analysis of radiation dose (76%). The most notable change after the usage of dose monitoring software was the increase in interest in reducing dose exposure (40%) and the alteration of protocols in order to lower dose was the second largest change (28%). When analyzin the proportion of patients with dose above the diagnostic reference level by each quarter-year, themost recent quarter has the lowest proportion of such patients compared to the past quarters (6.02%, 7.16%, 5.38% in time order). With the use of dose monitoring systems, radiology technicians are now more aware of radiation dose in CT scans in numeric terms. Such interest has encouraged radiologists and technicians to search for causesand factors that may produce a relatively high radiation dose.

1. INTRODUCTION

CT scans now have become a popular and frequent method of medical imaging, replacing previous radiological imaging examinations [1]. While the number of CT scans in the United States was estimated to be around 3 million in 1980, the number has drastically elevated to approximately 85 million in 2011 [2]. However, increased usage of CT imaging also indicates and greater medical radiation exposure to ionizing radiation [3]. The average medical radiation effective dose (ED) to the U.S. population in 2006 was estimated at approximately 3.0 mSv, an increase of 600% in a single generation [4]. Computed tomography (CT) alone accounts for approximately half of this medical radiation dose [5].

With the increasing popularity of CT imaging though, the potential secondary dangers should also be taken into account [6]. Exposed radiation dose varies by the patients' size and age, but an average CT scan produces radiation around 100~400 times the exposure from a X-ray [7]. While direct connection with radiation dose exposure from CT imaging with secondary malignancy has not been proved, high rates of recurrent CT imaging suggested cumulative radiation exposure of over 100mSv, which is convincing evidence of increased risk [8]. Overlapping exposure in a particular organ from multiple CT protocol scans has also shown high possibilities in developing cancer and tumors [9]. Although only to be predicted, 1.5%~2.0% of all cancers in the U.S. to be caused by CT radiation exposure [10]. Several medical institutions have found it logical to perform only low-dose CT protocols for patients in early stages of cancer in order to prevent further development in cancer [11].

Secondary malignancy from CT imaging may be critical to underage children [12]. While approximately 7 million CT scans are performed on children yearly, with a growth rate around 10%, children are exposed to higher dangers as they show higher sensitivity to radiation due to growing tissues [13-14]. Many medical professionals predict that as many as 1 in 300 children who get a CT scan of the abdomen, chest or spine will eventually develop a tumor as a result of the radiation [15]. A single CT scan may not be significantly harmful for an individual patient, but concerns arise for the population in general, with elevating frequency in CT scanning in the medical field [16]. As certain populations, especially patients with repeated CT scanning,

patients in early stage of cancer, and children, are exposed to higher connection to secondary malignancy, regulation and control of radiation dose from CT scanning needs to be enacted.

In light of arousing controversy on dangers of CT scanning and its radiation exposure, dose monitoring in medical imaging is a newly introduced method to control radiation exposure [17]. The following study will observe the effects of a dose-monitoring program installed in a single institution and observe whether the monitoring program has brought positive changes in radiation dose as well as awareness among radiology technologists [Fig 1].

FIG 1. Dose monitoring system showing cumulative radiation dose in the patient who had multiple radiologic examinations in the hospital (left) and studies which were above the diagnostic reference level set for the dose monitoring in a year (right) (Dose M, Infinitt Healthcare, Seoul, Republic of Korea).

2. Materials and methods

A survey of the effects and efficiency of the dose monitoring software (Dose M, Infinitt Healthcare, Seoul, Republic of Korea) were completed from 25 radiology technicians who have been previously introduced to the software within a single institution. The questionnaire asked for opinions on the pros and cons of the software, the most significant change that has occurred after using the dose monitoring software, and the period and frequency of use of the software. Furthermore, a total of 77,736 patients from 30 CT study protocols were collected in an 18-month study period, extracted from the dose-monitoring program, to observe the changes in dose in the institution. The protocols were each selected based on frequency of scans within each body part section (chest, abdomen, neurology, genitourinary, cardiovascular, bone). The data consists of the patients' effective dose (ED), CTDIvol, Dose-Length Product, CT scanner, protocol type, as well as whether or not the patients' doses are higher than the standard dose for each protocol, which is the 75th percentile of the dose in the particular protocol from previous years. Information regarding the patients' demographics, such as age, gender, scan date, are also included. Table 1 and 2 display the types of CT scanner and protocol types used in the study.

TABLE 1. CT PROTOCOLS COLLECTED ACCORDING TO THE BODY PARTS

Body Part	Protocol	Frequency
Abdomen	CT Abdomen+Pelvis (contrast)	11439
Abdomen	CT Abdomen+Pelvis Arterial+Portal (contrast)	16444
Abdomen	CT Liver (contrast)	15356
Abdomen	CT Liver 3D (contrast)	7127
Abdomen	CT Pancreatobiliary Postop 2D (contrast)	4296
Bone	CT (Metal) Knee + 3D (noncontrast)	452
Bone	CT Ankle + 3D (noncontrast)	362
Bone	CT C-Spine + 3D (noncontrast)	930
Bone	CT L-Spine + 3D (noncontrast)	1221
Bone	CT Wrist + 3D (noncontrast)	343
Chest	CT Chest + 3D (contrast)	3503
Chest	CT Chest Breast Cancer (contrast)	9238
Chest	CT Chest Low Dose + 3D (noncontrast)	24820
Chest	CT Chest Lung cancer+3D(contrast)	6217
Chest	CT Chest Routine (contrast)	5903
CV	CT Angio + 3D Aorta (abdominal)(contrast)	919
CV	CT Angio + 3D Aorta (EKG gated thoracic) (contrast)	1946
CV	CT Angio + 3D Aorta (thoracoabdominal)(contrast)	1994
CV	CT Angio + 3D Heart (EKG gated)(contrast)	3174
CV	CT Angio + 3D Lower Extremity artery (contrast)	869
GU	CT Adrenal (4P) + 3D (contrast)	300
GU	CT Kidney (3P) + 3D (contrast)	3164
GU	CT Kidney (noncontrast)	2686
GU	CT Pelvis & Abdomen (Uro & GY) + 3D (contrast)	4310
GU	CT Urography (3P) + 3D (contrast)	3573
Neuro	CT Brain Trauma + 3D (noncontrast)	1827
Neuro	CT Neck (contrast)	3053
Neuro	CT OMU (noncontrast)	2966
Neuro	CT Routine Brain (Pre contrast)	11093
Neuro	CT Thyroid (contrast)	1371

TABLE 2. CT SCANNER TYPES

CT Scanner	Vendors	Frequency
Aquilion ONE	Toshiba	23882
Brilliance 64	Philips	20278
Brilliance 64 (ER located)	Philips	7169
Discovery CT750 HD	GE	12846
iCT 256	Philips	14724
Ingenuity CT	Philips	13407
LightSpeed Ultra	GE	6919
Sensation 16	Siemens	26577
SOMATOM Definition	Siemens	22064

SOMATOM Definition Flash	Siemens	2633
IQon - Spectral CT	Philips	397

Survey results were analyzed with the Chi-Square test of independence to determine significance in a certain answer selection compared to others. To fully grasp the changes and patterns in radiation dose occurring within the institution, the observational study was conducted on the entire collection of patients rather than sampling within each protocol. Comparisons of dose by quarter, device, and age group were conducted with the analysis of variance test (ANOVA) along with Tukey's post-hoc test. Yearly comparison of radiation dose was completed with student's independent t-test. All statistical analyses were performed using R Statistical Software (version 2.14.0; R Foundation for Statistical Computing, Vienna, Austria).

3. RESULTS

The greatest benefit from dose monitoring software was the ability to access statistical analysis of radiation dose (76%, 19 out of 25 radiology technicians) [Fig 2-3]. The downside of the dose monitoring software as of now was the process speed of the program itself (54.17%, 13 out of 25 radiology technicians). The most notable change after the usage of dose monitoring software was the increase in interest in reducing dose exposure (40%, 10 out of 25 radiologists) and the alteration of protocols in order to lower dose was the second largest change (28%, 7 out of 25 radiology technicians). However, only 1/3 of the respondents have used the monitoring program for more than 6 months and around 1/3 of the respondents said to have used the program regularly.

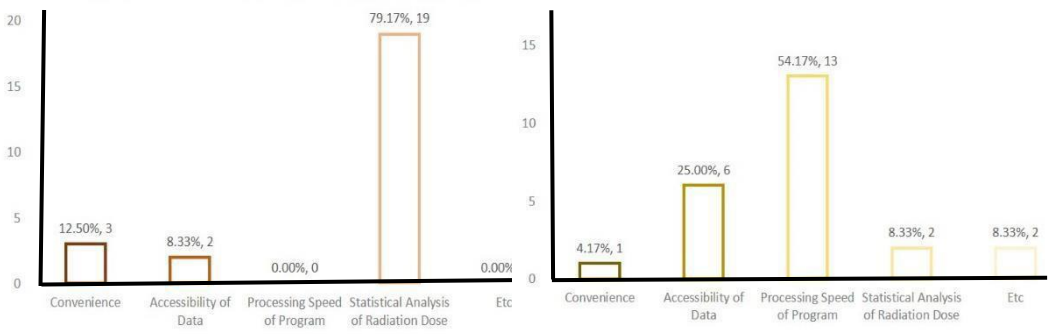


FIG 2. Number of response for Pros (left) and Cons (right) of dose monitoring system

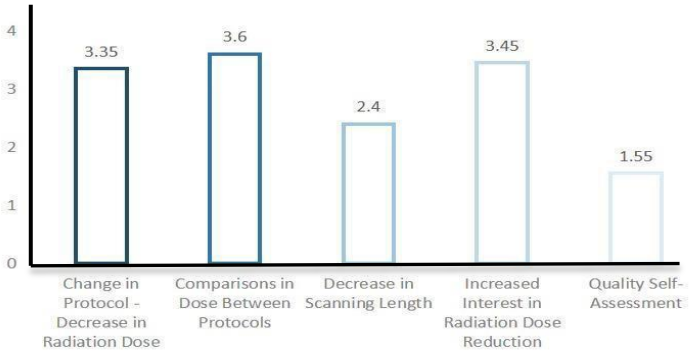
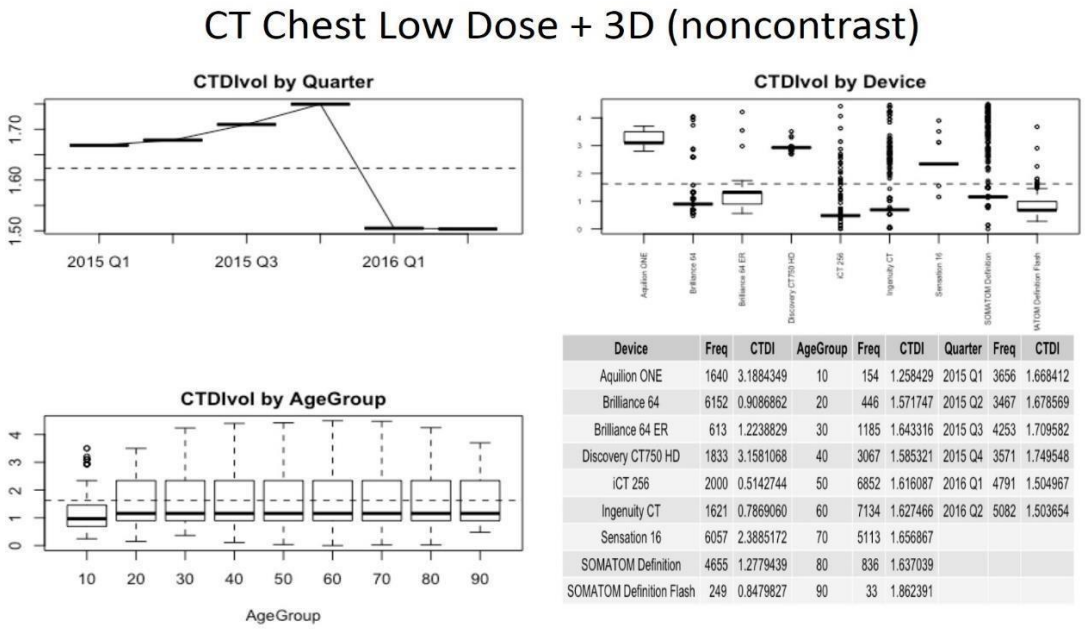


FIG 3. Survey results for radiology technicians: changes in practice after using dose monitoring system (higher average ranking indicates a greater change in practice).

Using the radiation dose data of the patients within the institution, in-depth statistical analysis was provided for each protocol at the end of each quarter-year in report formats so that radiology technicians and radiologists could observe the characteristics in each protocol [Fig 4].



Device	Freq	CTDI	AgeGroup	Freq	CTDI	Quarter	Freq	CTDI
Aquilion ONE	1640	3.1884349	10	154	1.258429	2015 Q1	3656	1.668412
Brilliance 64	6152	0.9086862	20	446	1.571747	2015 Q2	3467	1.678569
Brilliance 64 ER	613	1.2238829	30	1185	1.643316	2015 Q3	4253	1.709582
Discovery CT750 HD	1833	3.1581068	40	3067	1.585321	2015 Q4	3571	1.749548
iCT 256	2000	0.5142744	50	6852	1.616087	2016 Q1	4791	1.504967
Ingenuity CT	1621	0.7869060	60	7134	1.627466	2016 Q2	5082	1.503654
Sensation 16	6057	2.3885172	70	5113	1.656867			
SOMATOM Definition	4655	1.2779439	80	836	1.637039			
SOMATOM Definition Flash	249	0.8479827	90	33	1.862391			

FIG 4. Example of quarterly dose monitoring report.

In terms of CTDIvol, 27 out of 30 protocols have decreased significantly in 2016 compared to 2015 [Fig 5]. Two additional protocols have shown a decrease in CTDIvol compared to the previous year, the change was not statistically significant. While only 1 out of 30 protocols have increased significantly in CTDIvol, the particular protocol has gone through a deliberate change in protocol, which may be a cause in the increase in radiation dose [TABLE 3].

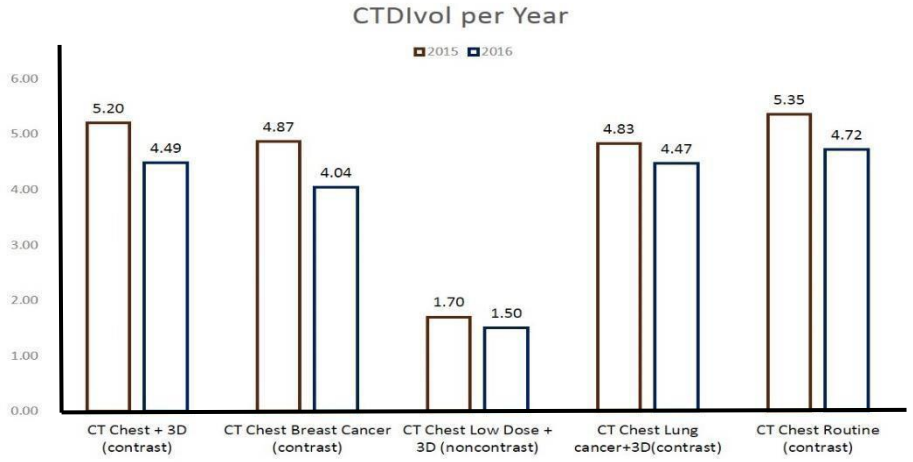


FIG 5. Changes in CTDIvol for chest CT protocols.

TABLE 3. CHANGES IN CTDI BY STUDY PROTOCOL AND ITS STATISTICAL SIGNIFICANCE

Study	Mean CTDIvol		Differences ($p<0.05$) *
	2015	2016	
CT (Metal) Knee + 3D (noncontrast)	3.33	3.73	-0.41*
CT Abdomen+Pelvis (contrast)	6.69	5.27	1.42*
CT Abdomen+Pelvis Arterial+Portal (contrast)	6.48	5.18	1.29*
CT Adrenal (4P) + 3D (contrast)	7.27	6.22	1.04*
CT Angio + 3D Aorta (abdominal)(contrast)	5.48	4.61	0.87*
CT Angio + 3D Aorta (EKG gated thoracic) (contrast)	13.87	9.87	4.00*
CT Angio + 3D Aorta (thoracoabdominal)(contrast)	6.04	5.47	0.57*
CT Angio + 3D Heart (EKG gated)(contrast)	11.24	9.94	1.29*
CT Angio + 3D Lower Extremity artery (contrast)	5.06	4.69	0.37
CT Ankle + 3D (noncontrast)	7.14	5.81	1.34*
CT Brain Trauma + 3D (noncontrast)	38.95	33.64	5.31*
CT C-Spine + 3D (noncontrast)	14.02	11.89	2.12*
CT Chest + 3D (contrast)	5.20	4.49	0.71*
CT Chest Breast Cancer (contrast)	4.87	4.04	0.83*
CT Chest Low Dose + 3D (noncontrast)	1.70	1.50	0.20*
CT Chest Lung cancer+3D(contrast)	4.83	4.47	0.36*
CT Chest Routine (contrast)	5.35	4.72	0.63*
CT Kidney (3P) + 3D (contrast)	6.03	5.26	0.77*
CT Kidney (noncontrast)	6.16	4.38	1.78*
CT L-Spine + 3D (noncontrast)	12.80	11.48	1.32*
CT Liver (contrast)	6.43	5.61	0.83*
CT Liver 3D (contrast)	6.27	5.36	0.91*
CT Neck (contrast)	7.57	5.99	1.58*
CT OMU (noncontrast)	25.51	19.14	6.36*
CT Pancreatobiliary Postop 2D (contrast)	6.68	5.79	0.89*
CT Pelvis & Abdomen (Uro & GY) + 3D (contrast)	6.91	6.12	0.79*
CT Routine Brain (Pre contrast)	38.48	36.28	2.20*
CT Thyroid (contrast)	7.12	6.09	1.03*
CT Urography (3P) + 3D (contrast)	6.47	5.65	0.82*
CT Wrist + 3D (noncontrast)	7.07	6.38	0.69

When analyzing the proportion of patients with dose above the diagnostic reference level by each quarter-year, the most recent quarter has the lowest proportion of such patients compared to the past quarters (6.02%, 7.16%, 5.38% in time order).

4. DISCUSSION

Radiology technicians are now more aware of radiation dose in CT scans in numeric terms. Not many were acknowledging the dangers of radiation dose from medical imaging. Such interest encouraged radiologists and technicians to search for causes and factors that may produce a relatively high radiation dose. Radiologists now also attempt to reduce dose by altering protocols and techniques such as dose modulation or iterative reconstruction [18-19]. In numeric terms, the radiation dose in 29 out of 30 protocols have decreased, in which

27 protocols showed statistically significant decrease ($p<0.05$) in yearly comparison. The following results would suggest that dose-monitoring software aroused radiology faculty's awareness and efforts in reducing dose and reviewing individual protocols have been beneficial.

This study has a relatively short follow-up period from the introduction of the dose monitoring software, further monitoring may be required to determine long-term efficiency and effects from dose monitoring. Furthermore, a higher rate of frequency and period of use among radiology technicians may be required in order to fully analyze the effects of dose monitoring program. With appropriate monitoring and follow-up reports on radiation dose in a systemized manner, radiologists and radiology technicians will be able to reduce and/or monitoring excess radiation dose occurring from CT scans.

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CHALLENGES IN THE IMPLEMENTATION OF INFORMATION TECHNOLOGY ON THE DOSE PATIENT DATA RECORDING ONLINE IN INDONESIA

SURYANTI, R
Indonesia Nuclear Energy Regulatory Agency (BAPETEN)
Jakarta, Indonesia
r.suryanti@bapeten.go.id

SYAHRIR, S
Indonesia Nuclear Energy Regulatory Agency (BAPETEN)
Jakarta, Indonesia

RUSMANTO, R
Indonesia Nuclear Energy Regulatory Agency (BAPETEN)
Jakarta, Indonesia

Abstract

Medical exposure to patients is a part of the medical treatment using ionizing radiation sources and the doses to the patients should be justified and optimized to prevent unnecessary exposure. One of the BAPETEN national priority program, as a regulatory body in Indonesia, is related to the issue of Strengthening of Radiological Patient Safety Protection Assurance. The program is in line with the IAEA and WHO recommendation in 2012 in the International Conference on Radiation Protection in Medicine in Bonn, Germany, in December of 2012 with declaration of "Bonn Call-for-Action". In 2014, BAPETEN provides a web-based application called "**Si**stem **IN**formasi da**TA** dosis pasie**N** (Si-INTAN) or "Data Dose Patient Information System"; an online system to input data of patient dose for each examination on each modality. The aim of the paper is to provide description of the application, its challenges and efforts that have been made and will be conducted. The methodology of the paper is a study literature, analysis of regulation in Indonesia related to radiation protection and safety to patients and evaluation of field activity results. As a web-based database application, Si-INTAN is implemented to input patient doses online for different modalities, i.e. CT-Scan (2014), Fluoroscopy (2016), Nuclear Medicine and Conventional X-ray (radiographs) (2017, in progress) and Mammography and Dental (2018, later). Recording of patient dose data prioritizes which ones are easy to identifies or measures; in that way, the dose data recording is taken on modalities that have dose indicators such as CTDI for CT-Scan or DAP for Fluoroscopy and Conventional X-ray (radiographs). The evaluation of this application from 2015 to May 2017 shows that only 32 hospitals out of 115 (28%) have input dose patient data since the introduction and trial of Si-INTAN. 32 hospitals are located in DKI Jakarta, Bandung, DI. Yogyakarta, Padang, and Semarang. These figures show that most hospitals are less interested in recording of patient data dose, in addition to the reasons for the lack of dose indicator for moderate fluoroscopy equipment. The challenges in the implementation of the application are (1) lack of awareness on recording patient doses, (2) lack of knowledge related to optimization of patient protection and safety, (3) unfamiliarity to the regulation related to the implementation of radiation protection and (4) incompleteness in the regulatory infrastructure. In responding to the challenges, BAPETEN has been provided a guideline to explain of the purpose and function of recording patient dose data for patient dose optimization. BAPETEN has been coordinating with professional associations to cultivate the interest of their members and conducting workshops related to optimization of radiation protection to patients and coordinating with Ministry of Health. Later, BAPETEN will collaborate with the Committee of Hospital Accreditation. BAPETEN will improve and make detail regulation related to recording dose patient data and improve inspection system which is making the recording of patient dose data to be one of the parameters of facility safety assessment. The implementation of information technology on the patient dose data recording online in Indonesia is a new information system introduced by BAPETEN to the users or operators in the hospital so it requires more effort and support from all related parties including assistance from experienced countries.

1. INTRODUCTION

The utilization of radiation for medical in Indonesia shows a significant increase, it can be known from the increasing number of modalities of ionizing radiation source used and the types of medical examination performed with the radiation. The use of such radiation shall be supervised to ensure the protection and safety of workers, patients and the public. Medical exposure to patients is a part of the medical treatment using ionizing

radiation and should be justified and optimized to prevent unnecessary exposure. Because of this, patient dose data recording becomes important as a basis in evaluating optimization.

BAPETEN as a regulatory body in Indonesia has 3 national priority programs, related to the issue Strengthening of Radiological Safety Protection Assurance. The program is in line with the IAEA and WHO recommendation in 2012 in the International Conference on Radiation Protection in Medicine in Bonn, Germany, in December of 2012 resulting in ten main actions Called "Bonn Call-for-Action." One of its actions is to improve the optimization of protection and safety by developing and implementing technology solutions to record patients, aligning the dose data formats provided by imaging equipment, and increasing the benefits of electronic health records [1].

Following up the "Bonn Call-for-Action", on 2014 BAPETEN developed a web-based application called "**Si**stem **IN**formasi da**TA** dosis pasie**N** (Si-INTAN) or "Data Dose Patient Information System"; an online system to input data of patient dose for each examination on each modality. The application is used for recording patient dose data and in turn the National Diagnostic Reference Level (DRL). The application is similar with an applications owned by ARPANSA Australia and IAEA in Radiation Protection of Patients (RPOP). The outcome of the Si-INTAN are to establish a sustainable system on the management of patients dose in diagnostic and interventional radiology that allow frequent improvements and reviews; Indonesia has a patient dose profile for each examination on each modality for better controlling needs; by having this, hospital have a tool for optimization protection and safety for patient as effort for the management of patient dose; hospital can have its own DRL and Indonesia have National DRL according to condition in Indonesia [2].

Although the expected outcome is ideal, there are several obstacles in the field must be solved. The paper will explain the Si-INTAN application, its challenges and efforts that have been made and will be conducted by BAPETEN.

2. METHODS

The methodology of the paper is a study literature, analysis of regulation in Indonesia related to radiation protection and safety to patients and evaluation of field activity results. The paper specially describe the action of the Bone Call-for-Action number 2, the action is the enhance the implementation of the principle of optimization of protection and safety, more precisely for develop and apply technological solutions for patient exposure records, harmonize the dose data formats provided by imaging equipment, and increase utilization of electronic health records [1]. The important of patients dose data recording is for study of radiological risk potential, reference level arrangement and radiologic quality assurance indicator. This is in accordance with the Chairman Regulation Number 8 Year 2011, in this regulation mention that the licensee must make up and submit a report on radiation protection and safety program to BAPETEN, one of which is the recording of patient dose monitoring [3]. And also according to Government Regulation Number 33 Year 2007 Article 6 paragraph (2) letter d stating that the licensee is responsible for creating and maintaining Records related to Radiation Safety Furthermore in Article 21 states that the licensee in utilizing ionizing radiation shall fulfill the radiation protection requirement which includes one of them is the optimization of radiation protection and safety. Application of optimization through the guidance level of medical exposure known as Diagnostic Reference Level (DRL) [4].

Recording of patient dose data, prioritizing which is easy to identify or measure, so that the dose data recording is done on modalities that have resultant patient doses (dose indicator) [5]. The dose indicator feature mounted on an X-ray plane is prioritized for which provides the high risk for radiation exposure to the patient. So it can be understood, that the dose indicator is on CT Scan, angiography, and fluoroscopy. For this reason then BAPETEN started with the recording of patient dose data for Ct-Scan in 2014 and Fluoroscopy in 2016 In recording of patient dose data through Si-INTAN, the users and operators in hospital shall include some information for registration, such as the information about institution, data of radiologist, person in charge, and type of modality the equipment (see Fig.1.). Data of modality covers brand, models and location (room) of the equipment.

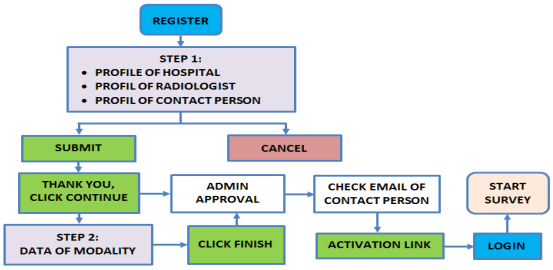

FIG.1. Registration steps for access to Si-INTAN web aplication

Before the users or operators in hospital entered data, they shall select the age group and type of examination. In Si-INTAN there is 3 age groups ie baby (infant): 0-4 years old; child: 5-14 years old; and adult: ≥ 15 years old [6]. Whereas the type of examination for CT-Scan consist of 9 type examinations: Head, Neck, Chest, Pelvis, Abdopelvis, Chestabdopelvis, Extremities, cardiac study, and lumber spine. Meanwhile for fluoroscopy consist of 5 type examination: coronary angiogram, cerebral angiogram (1-3 vessels), cerebral angiogram (≥ 4 vessels), abdominal angiogram, and endoscopic retrograde Cholangiopancreatography (ECRP). Besides that, they shall enter information related to weight and sex of patients. Then the users or operators entered the patient dose data, the input data of CT-Scan consist of exposure setting (kV, mAs), using contras or no, pitch, using dose modulation or no, type of CTDI (vol or w), DLP, rotating time, Helical or axial and iterative reconstruction. While the input data of fluoroscopy consist of exposure setting (kV, mA/mAs), field of View (FOV) for fluoroscopy and radiography mode and DAP (see Fig.2. for CT-Scan and Fig.3. for Fluoroscopy modality). After completing the data, the users or operators can see the result in table or scatter gram of their own data which have input data, and they can receive information about the minimum value, quartile 1, quartile 2, quartile 3 and maximum value of their data. And they can determine their own DRL values and from the data can be analysed for optimization action.

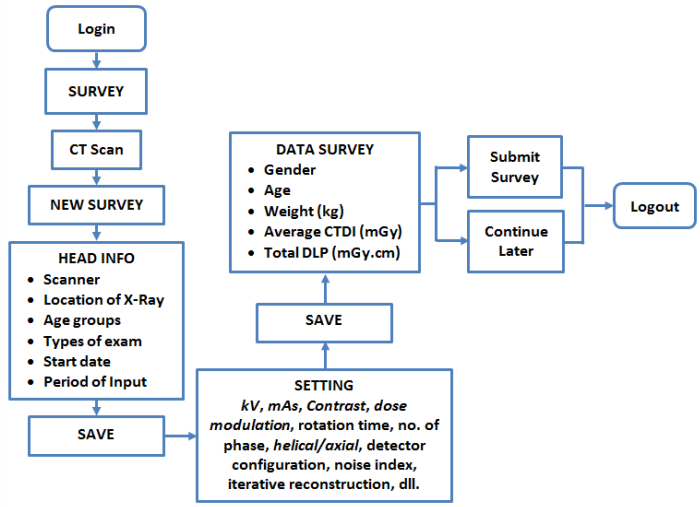

FIG. 2. The steps of patient dose data input for CT-Scan modality

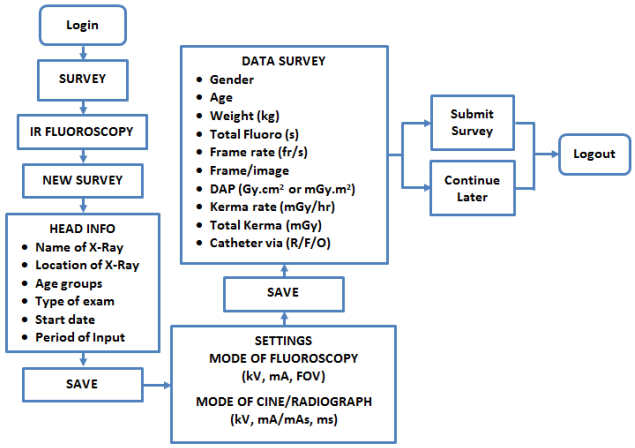

FIG. 3. The steps of patient dose data input for Fluoroscopy modality

We do introducing and trial of Si-INTAN to hospital with invite the users or operators for explain about the Si-INTAN application, what the purpose of the recording of patient dose data and trial using Si-INTAN with entered sample of their patient dose data. The users or operators invited consist of Radiation Protection Officer and Medical Physics, and BAPETEN expects each hospital to enter minimal 10 data for each examination on

modalities. The introduction and trial started in 2015 for CT-Scan and in 2017 for Fluoroscopy and we do analysed for the program.

3. RESULTS

In 2014, BAPETEN executed the development of a web-based database application called "**Si**stem **IN**formasi da**TA** dosis pasie**N** (Si-INTAN) or "Data Dose Patient Information System", starting from patient dose data recording for CT-Scan modalities. The reason is they deliver higher doses of radiation to patients in comparison to conventional X-rays (radiographs). It's been estimated that the average radiation dose of one CT scan is equal to roughly 500 chest X-rays [7] and the second is almost all CT-Scan equipment in Indonesia already has a dose indicator, making it easier for users or operator in hospital to enter patient dose data recording online via Si-INTAN.

The activity continues in 2015 by introducing and trial Si-INTAN for CT-Scan that have been built and by 2016 developing for patient dose data records of Fluoroscopy. Furthermore, in 2017 Si-INTAN was developed to patient doses data records on conventional X-ray (radiographs) and nuclear medicine and by 2018 Si-INTAN will be developed the patient dose data records for mammography and dental.

Introduction and trial activities were performed for several hospitals with CT-Scan and Fluoroscopy modalities, including fluoroscopy with moderate technology and high-tech fluoroscopy known as interventional fluoroscopy such as equipment for angiography. Execution of the introduction and trial of Si-INTAN in detail can be seen in TABLE 1.

TABLE 1. EXECUTION OF THE INTRODUCTION AND TRIAL OF SI-INTAN SINCE YEAR 2015 – 2017 [8]

Year	City of Execution	Number of Hospitals Invited	Other Information
2015	DKI Jakarta I DKI Jakarta II Bandung DKI Jakarta III	12 12 10 9	Introduction and trial for CT-Scan Modalities
2016	DKI Jakarta DI. Yogyakarta Surabaya	16 15 17	• Introduction and trial for CT-Scan modalities • For DKI Jakarta, of the 16 hospitals invited there are 12 hospitals that have been invited in 2015.
2017	Padang Makasar Semarang Malang	13 11 7 7	Introduction and trial for CT-Scan and Fluoroscopy Modalities

In TABLE 1, it is seen that in 2015 and 2016, the introduction and trial to the existing hospitals on the island of Java are Jakarta, Bandung, Yogyakarta and Surabaya for CT-Scan, as most CT-Scan are located in Java Island. While the year 2017 conducted introduction and trial to hospitals located in Makasar, Padang, Semarang and Malang for CT-Scan and Fluoroscopy modalities.

The results of the evaluation of Si-INTAN introduction and trial from 2015 to May 2017 show that of the 115 different hospitals involved in the introduction and trials there were 32 hospitals that had conducted patient dose data inputs that were mostly patient dose data from CT-Scan modalities, while patient dose data for interventional fluoroscopy modalities is angiography only two hospitals. The results of the evaluation can be seen in TABLE 2.

TABLE 2. EVALUATION RESULT OF EXECUTION OF INTRODUCTION AND TRIAL Si-INTAN SINCE 2015 – 2017 [8]

City	Number of Hospitals Invited	Number of Hospital Which performs data input	Percentage (%)
DKI Jakarta	35	15	43
Bandung	10	8	80
DI. Yogyakarta	15	4	27
Surabaya	17	0	0
Padang	13	3	23
Makasar	11	0	0
Semarang	7	2	29
Malang	7	0	0
Total Number	**115**	**32**	**28**

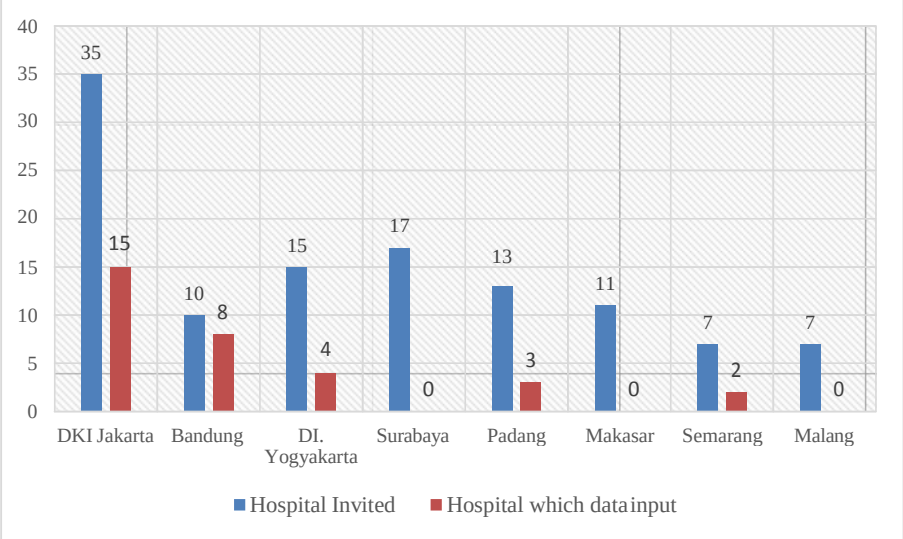

FIG. 4. Evaluation result of execution of introduction and trial Si-INTAN since 2015-2017 [8]

In TABLE 2 it is seen that only 32 hospitals of out 115 hospitals have been given introduction and trial of Si-INTAN (28 percent) which has entered the patient dose data into Si-INTAN by online. The 32 hospitals pread across DKI Jakarta, Bandung, DI. Yogyakarta, Padang, and Semarang. Meanwhile for Makassar, and Malang have not done data input because they have just done introduction and trial in April and May 2017.

4. DISCUSSION

With the a web-based database application for online patient dose data recording, the licensee can easily record the patient's dose data and determine their own DRL according to the conditions of each hospital. The DRL values that appears in the account of each hospital is the DRL value obtained based on the patient's dose data already entered by the hospital so that the hospital can perform the dose management in order to get the lowest possible dose without reducing the image quality for diagnosis. The patient dose data recording in Indonesia is done gradually, until 2017 Indonesia has done introduction and trial for patient dose data recording for CT-Scan and Fluoroscopy modalities. From TABLE 2 it was shown that only 32 hospitals out of 115 hospitals given Si-INTAN introduction and trials (28 percent) have input data of patient dose patient since the introduction and trial of Si-INTAN, these figures show that most hospitals are less interested in recording of patient dose data. This is an fact to be faced despite the legal basis for patient dose data recording as an optimization effort is available but user or operators have not realized it yet.

During the introduction and trial, there are several factors that influence the less of interested of users or operator in recording of patient dose data. These factors become challenges that must be faced in achieving the purpose of providing Si-INTAN. The challenges in the implementation of the application are (1) lack of awareness on recording patient doses, (2) lack of knowledge related to optimization of patient protection and safety, (3) unfamiliarity to the regulation related to the implementation of radiation protection and (4) incompleteness in the regulatory infrastructure.

In addition to the above factors, there are other factors particularly for patient dose data recording for fluoroscopy modalities is that there is no dose indicator for moderate fluoroscopy modalities and for high-tech fluoroscopy only few major hospitals have such equipment.

In responding to the challenges, BAPETEN has been provided a guideline to explain of the purpose and function of patient dose data recording for patient dose optimization. The guideline can be downloaded by user or operator through Si-INTAN and also given at the time of the introduction and trial of Si-INTAN by inviting Radiation Protection Officer (RPO) and medical physicist. The medical physicist can evaluated the patient dose data to produce a standard procedure and standard protocol of exposure conditions so that patients receive a low dose but the image quality still good.

BAPETEN has been coordinating with professional associations to cultivate the interest of their members and conducting workshops related to optimization of radiation protection to patients. Professional associations involved in the implementation of Si-INTAN are AFMI (association of medical physicist) and PARI (association of radiographer). BAPETEN also coordinating with Ministry of Health (MOH) to synergize the radiology facility quality assurance activities of MOH with web based application Si-INTAN of BAPETEN.

Later, BAPETEN will collaborate with the Committee of Hospital Accreditation to synergize the recording of patient dose data into its accreditation program. Then BAPETEN will improve and make detail regulation related to recording of dose patient data and improve inspection system which is making the patient dose data recording to be one of the parameters of facility safety assessment

In addition BAPETEN also makes efforts to encourage the purchase of X-ray equipped with dose indicators such as CTDI for CT Scan, and DAP for fluoroscopy and conventional X-ray (radiographs) by incorporating into regulation related technical requirements specific to CT-Scan and Fluoroscopy equipment such as mentioned in the Chairman Regulation Number 15 Year 2014 on Radiation Safety in the Production of X-Ray Diagnostic and Interventional Radiology. BAPETEN also expects consultation with other countries that already have experience so we can learn together and can further improve the program for the better.

5. CONCLUSION

The Implementation of information technology in online patient dose data recording in Indonesia is a new information system introduced by BAPETEN to users or operators in hospitals in improving the effectiveness of utilization of ionising radiation controlled related to optimization of protection and radiation safety to patients. In its implementation, serious efforts are needed such as provided a guideline to explain of the purpose and function of patient dose data recording for patient dose optimization, providing the adequate regulatory infrastructure, improving the inspection system and involve all stakeholders, including other regulatory authorities such as Ministry of Health, Committee of Hospital Accreditation, Professional Associations such as AFMI for medical physicists and PARI for radiographers. The effort and the coordination are expected to achieving the purpose of provided Si-INTAN an online system to input data of patient dose. This program needed consultation with the experienced countries.

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AUSTRALIA'S NATIONAL DIAGNOSTIC REFERENCE LEVEL SERVICE

P.D. THOMAS
Australian Radiation Protection and Nuclear Safety Agency
Yallambie, Australia
Email: Peter.Thomas@arpansa.gov.au

T.E. BEVERIDGE
Australian Radiation Protection and Nuclear Safety Agency
Yallambie, Australia

Abstract

The National Diagnostic Reference Level Service (NDRLS) operated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) collects data on radiation dose metrics for common procedures in computed tomography (CT), nuclear medicine, including positron emission tomography (PET), and image-guided interventional procedures (IGIP). The data is used to establish and review national diagnostic reference levels (DRLs) for Australia. DRLs have been established for six common adult CT protocols and three protocols for CT in children and infants. A total of 80 DRLs have been established for nuclear medicine and PET, including DRLs for CT scans conducted for attenuation correction or anatomical localization. DRLs are still in development for IGIP. A downward trend is observed in CT dose metrics over time and doses in CT are 20%-30% lower with the use of iterative reconstruction (IR). The data collected by the NDRLS will continue to be used to review and revise the national DRLs over time. The NDRLS has contributed to a greater awareness of radiation dose in medical imaging and has established benchmarks that guide optimisationefforts.

1. INTRODUCTION

Among the objectives outlined in the Bonn Call for Action is enhancement of the principle of optimisation in medical radiation and in particular ensuring the establishment, use and regular review of diagnostic reference levels (DRLs). DRLs are a form of investigation level intended for use as a simple test for identifying situations where the levels of patient dose or administered activity are unusually high or low [1]. The establishment of DRLs has proven to be a useful tool in the standardisation and optimisation of radiation doses received from common medical imaging protocols [2-4].

In Australia the greatest source of patient dose in diagnostic imaging is from Multi-Detector Computed Tomography (MDCT) [5]. Growth in MDCT scans in Australia is approximately 7% per annum with over 3 million MDCT scans being performed in 2016 [6]. The National Diagnostic Reference Level Service (NDRLS) commenced an ongoing survey of common MDCT protocols in 2011. Additional surveys covering nuclear medicine and positron emission tomography (PET), and image-guided interventional procedures (IGIP) were added in 2014. The NDRLS is a free service that provides facilities with a tool for comparing dose metrics with the Australian national DRLs. It is a collaborative project, conducted in partnership with relevant government and professional organisations.

2. METHOD

2.1. Multi Detector Computed Tomography

The web based MDCT survey is an ongoing program that collects de-identified data on patient dose for six adult (15+ years) anatomical protocols and three child (5-14 years) and infant (0-4 years) anatomical protocols. The six adult protocols are: Head, Neck, Chest, Abdomen-Pelvis, Chest-Abdomen-Pelvis, and Lumbar Spine. The three child and infant protocols are: Head, Chest, and Abdomen-Pelvis. A single survey is a sample of data for up to 20 patients scanned with a particular protocol on a given scanner. Dose metrics are the volume computed tomography dose index ($CTDI_{vol}$) in mGy and the dose-length product (DLP) in mGy.cm. A Facility Reference Level (FRL) is calculated as the median value for each dose metric for each survey. The distribution of FRLs can be used to derive the DRLs.

2.2. Nuclear Medicine and PET

The Nuclear Medicine and PET survey was conducted in 2014/15 and reviewed radiopharmaceutical activities administered to nuclear medicine patients across Australia. Participating facilities were asked to report every dose delivered within their department over a four week period, from both radiopharmaceutical and CT sources. FRLs were calculated as the median of the doses delivered at each facility, for each protocol reported. If a facility conducted a procedure four or more times, the FRL was included in the DRL calculation. A DRL was calculated using the NDRLS survey data for all procedures with at least four FRLs.

2.3. Image Guided Interventional Procedures

The IGIP survey collects data for five interventional and diagnostic angiography fluoroscopic procedures: coronary angiogram, cerebral angiogram (1-3 vessels), cerebral angiogram (4+ vessels), selective abdominal angiogram, and endoscopic retrograde cholangiopancreatography (ERCP). Participants choose which protocols they wish to submit and a sample of 30 patients per procedure is requested. Dose metrics are the total dose-area product (DAP) and total air kerma at the reference point. FRLs are determined as the median of the dose metrics for each survey.

3. RESULTS

3.1. Multi Detector Computed Tomography

The number of completed MDCT DRL surveys for each patient category, body region and survey year is shown in Table 1. Participation in the NDRLS has grown over time. Paediatric data submission has been low, reflecting the fact that most facilities perform very few paediatric procedures. Most paediatric procedures are performed at dedicated paediatric facilities.

TABLE 1. NUMBER OF COMPLETED MDCT DRL SURVEYS BY PATIENT CATEGORY, BODY REGION AND SURVEY YEAR

AGE GROUP	BODY REGION	2011	2012	2013	2014	2015	2016
Adult (15+)	Head	56	113	166	147	202	284
	Neck	30	57	80	76	141	192
	Chest	44	78	112	113	177	258
	Lumbar Spine	34	75	116	105	156	237
	Abdomen-Pelvis	51	100	150	128	194	274
	Chest-Abdo-Pelvis	40	68	100	93	135	200
Child (5-14 y)	Head	0	28	26	19	22	22
	Chest	0	7	8	7	8	9
	Abdomen-Pelvis	0	3	6	4	6	5
Baby (0-4 y)	Head	0	20	23	18	17	20
	Chest	0	3	5	4	3	4
	Abdomen-Pelvis	0	0	2	2	1	2

Initial Australian DRLs for adult MDCT were determined from the third quartile of the FRLs submitted in 2011 [7]. DRLs for paediatric scans were derived from data gathered by the Royal Australian and New Zealand College of Radiologists (RANZCR) under the Quality Use of Diagnostic Imaging (QUDI) initiative [8].

Fig. 1 traces the third quartiles of the FRL distributions for DLP for single-phase adult abdomen-pelvis scans as a function of survey year and the use of iterative reconstruction (IR). The DRL is displayed as a solid line. IR categories are: without IR (IR = 0), with IR (IR = 1), and unknown (IR = -1) as data on the use of IR was only collected after April 2013. The data show a general downward trend over time, with the third quartile of the 2016 data without IR showing a clear reduction compared to the DRL. Doses with IR are typically 20%-30% lower [9]. The general pattern of results is similar for the other adult protocols.

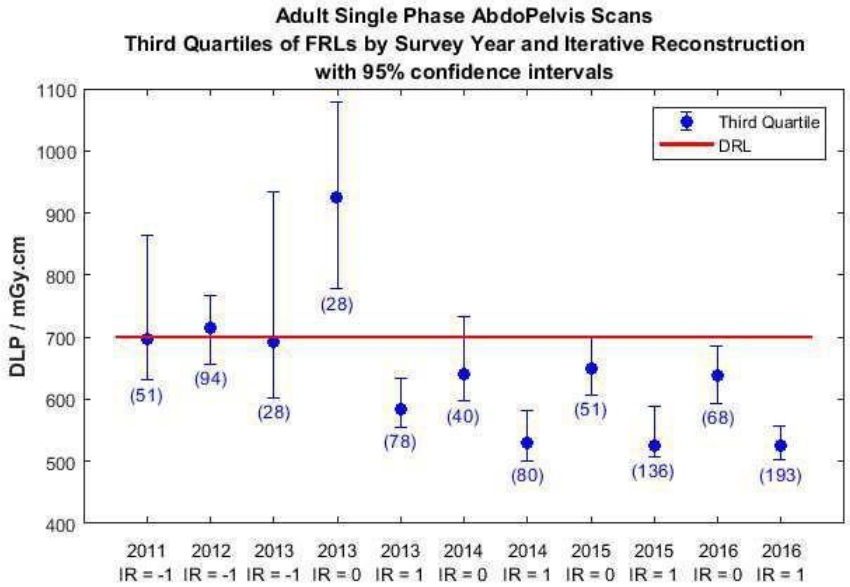

FIG. 1. Chart showing the third quartiles of the FRL distributions for DLP and the associated 95% confidence intervals for single-phase adult abdomen-pelvis scans categorised by survey year and the use of iterative reconstruction. The number of FRLs in each category is shown in parentheses. The confidence interval was calculated using the method described by Conover [10].

3.2. Nuclear Medicine and PET

Seventy-eight facilities participated in the survey, approximately a third of all nuclear medicine facilities within Australia. From this data, DRLs for fifteen general nuclear medicine procedures, three PET protocols, three PET/CT scan regions and seven SPECT/CT scan regions were defined. For less common procedures, the data collected in a survey of administration protocols in 2008 [11] was analysed to derive DRLs. In all, a total of 80 DRLs have been established for nuclear medicine and PET, including DRLs for CT scans conducted for attenuation correction or anatomical localisation. Fig. 2 shows the distribution of FRLs for bone scans using ^{99m}Tc MDP or HDP. The shaded region marks the range from the first quartile to the third quartile. The third quartile is also marked as the DRL with a solid line. The white dashed line within the shaded region marks the median. Data for all three quartiles have been published to give comprehensive guidance for optimisation.

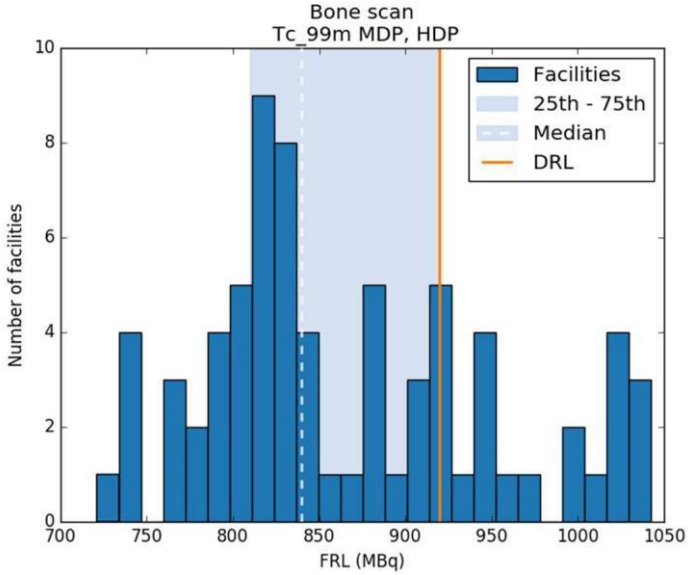

FIG. 2. Distribution of FRLs for administered activity for ^{99m}Tc MDP and HDP bone scans. The shaded region marks the range from the first quartile to the third quartile. The third quartile is also marked as the DRL with a solid line. The white dashed line within the shaded region marks the median.

3.3. Image Guided Interventional Procedures

A total of 44 completed surveys were submitted to the IGIP survey through to the end of 2016. Of these, 31 were for diagnostic coronary angiograms. The third quartiles of the distributions of FRLs were 34 Gy.cm² for DAP and 0.51 Gy for cumulative air kerma at the reference point. Data collection is ongoing.

4. DISCUSSION

The downward trend in adult CT dose metrics indicates that review and revision of the national DRLs would be appropriate. The fact that this reduction has occurred while participation in the service has increased strengthens confidence that the data are sufficiently representative of typical practice. The markedly lower dose for iterative reconstruction suggests that it would be appropriate to set separate DRLs for scans with and without IR. Nuclear medicine DRLs were only established recently and no ongoing data collection is planned. Instead a repeat survey will be conducted in approximately five years to assess whether typical administered activities have changed. At present sufficient data has been collected to propose a national DRL for diagnostic coronary angiograms but further work is required before DRLs can be established for other image-guided interventional procedures.

It is important to understand that DRLs are not dose limits; they are indicators of common practice and are expected to vary over time depending upon changes in technology, acquisition protocols and clinical application. If a facility, after due consideration and optimisation, can justify a local FRL that is higher than the national benchmark then they have met the requirements of the DRL philosophy. By definition, at the time of DRL calculation there will always be 75% of facilities who are at or below the current DRL and 25% who will be using a higher value.

5. CONCLUSION

The ARPANSA NDRLS has contributed to a greater awareness of radiation dose in medical imaging and has established benchmarks that guide optimisation efforts.

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MEASURING, MONITORING, AND REPORTING EFFECTIVE DOSE ON AN HYBRID EQUIPMENT: ONE YEAR RESULTS AND CHALLENGES TO INTEGRATE WITH MDCT

GIOVANNI TOSI
Humanitas Research Hospital
Rozzano, Italy
Email: giovanni.tosi@humanitas.it

ARTURO CHITI
Humanitas Research Hospital
Rozzano, Italy
Email: arturo.chiti@hunimed.eu

KATIA MARZO
Humanitas Research Hospital
Rozzano, Italy
Email: katia.marzo@cancercenter.humanitas.it

Abstract

The aim of this study was to measure, monitor and report effective dose in diagnostic nuclear medicine with a PET/CT.

1. INTRODUCTION

The clinical applications of PET/CT have been expanding, mainly in oncologic diagnosis and management, leading to the increasing demand for PET/CT studies.

However, PET/CT examinations, especially those that include diagnostic CT, result in increased patient radiation exposure compared with stand-alone CT or PET examinations, as the effective dose is a combination of the dose from PET and the dose from CT.

To date, a few studies have been performed to estimate total effective dose associated with PET/CT examinations both in case of fixed administered activity or patient-adapted activity.

The effective dose has been used to calculate the whole-body dose arising from nonuniform dose irradiation and provides the possibility of comparing radiologic detriments from different radiation exposures; it is defined by the ICRP as the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the human body and represents the stochastic health risk to the whole body.

The purpose of this study was to retrospectively estimate patient effective dose of the most recurring PET/CT procedures carried out in our Nuclear Medicine department in order to optimize patient dose.

2. METHODS

In 2014 we connected a CT-PET to a dose tracking software (GE Dosewtach™) and started to collect dose data, in terms of DLP and effective dose, from CT modality; in late 2015 the software was upgraded to a version which includes a Nuclear Medicine module for dose tracking. Data from the PET part of the scanner, in terms of administered activity and effective dose, were also collected.

Examinations were performed with a GE Discovery 690 which has a 64-detector CT scanner; PET scan is performed in stop and go imaging mode.

The PET/CT protocol were as follows:

- Whole Body (WB) examination from the vertex to midthighs
- Head examination covering the head within one bedposition

Dosewatch™ solution automates the tracking and archiving of dosimetric data, provides integrated statistical analysis tool and connects with existing RIS and PACS systems.

For each patient, effective dose was evaluated using standard coefficients referring to a generic reference individual. Thus, effective dose (ED) from the CT examination was calculated using the conversion factors k (mSv/mGy cm) multiplied by the DLP [1], depending on the scanned region. The PET ED was calculated by multiplying the injected activity by the Γ dose coefficient for each radiopharmaceutical.

The Γ coefficients (mSv/MBq) were 0.019 for ^{18}F-FDG [2], 0.0084 for ^{11}C-Methionine [2], 0.0044 for ^{11}C-Choline [2], and 0.021 for ^{68}Ga-DOTATOC [3]. The total ED associated with the combined PET/CT examination was evaluated as the sum of the PET and CT ED values.

3. RESULTS

Data from 1125 patients were collected, mostly from (see table 1): Whole Body (WB) ^{18}F-FDG (63.2%), WB ^{11}C-Choline (12.8%), Head ^{11}C-Methionine (18.4%), WB ^{68}Ga-DOTATOC (5.5%). CT mean DLP (mGy*cm) data values were (range between brackets): WB ^{18}F-FDG 1486.3 (76.1-7700.9), WB ^{11}C-Choline 2451.9 (290.9-5023.1), WB ^{68}Ga-DOTATOC 1184.2 (41.0-3728.4) and Head ^{11}C-Methionine 766.7 (52.3-2326.9). Mean effective doses due to CT modality (mSv) were: WB ^{18}F-FDG 15.3 ± 4.7, WB ^{11}C-Choline 26.5 ± 5.6, WB ^{68}Ga-DOTATOC 13.4 ± 2.7 and Head ^{11}C-Methionine 1.2 ± 0.7 (see table 2). Mean administered activity (MBq) and effective doses (mSv) for radiopharmaceuticals used in PET were: WB ^{18}F-FDG 335.9-6.4, Head ^{11}C-Methionine 294.4.6-2.5, WB ^{68}Ga-DOTATOC 168.3-3.5 and WB ^{11}C-Choline 322.2-1.5 (see table 3). The mean total effective doses (mSv) due to both modality were: WB ^{18}F-FDG 21.7 ± 4.9, Head ^{11}C-Methionine 3.7 ± 0.8, WB ^{11}C-Choline 27.9 ± 5.6 and WB ^{68}Ga-DOTATOC 16.9 ± 2.8 (see table 4).

4. DISCUSSIONS

From data collected it is clear that in most cases CT contribution to the total effective dose is predominant as showed in table 5; it is therefore mandatory to optimize CT acquisition parameters in order to maintain effective dose as low as reasonableachievable.

5. CONCLUSIONS

The implementation of a dose tracking system to nuclear medicine is of great value for accurate and regular recording, reporting and analysis of patient's effective doses. It can help to improve and optimize the evaluation of radiation exposures in the clinical practice.

6. TABLES

TABLE 1. Frequency (%)

	(%)
WB ^{18}F-FDG	63
WB ^{11}C-Choline	13
WB ^{68}Ga-DOTATOC	6
Head ^{11}C-Methionine	18

TABLE 2. CT dose contribution

	Mean DLP (mGy*cm)	Effective dose (mSv)
WB ^{18}F-FDG	1486	15.3 ± 4.7
WB ^{11}C-Choline	2452	26.5 ± 5.6
WB ^{68}Ga-DOTATOC	1184	13.4 ± 2.7
Head ^{11}C-Methionine	767	1.2 ± 0.7

TABLE 3. PET dose contribution

	Mean Administered Activity (MBq)	Effective dose (mSv)
WB ^{18}F-FDG	335.9	6.4 ± 0.9
WB ^{11}C-Choline	322.2	1.5 ± 0.2
WB ^{68}Ga-DOTATOC	168.3	3.5 ± 0.4
Head ^{11}C-Methionine	294.4	2.5 ± 0.4

TABLE 4. Total effective dose

	Effective dose (mSv)
WB ^{18}F-FDG	21.7 ± 4.9
WB ^{11}C-Choline	27.9 ± 5.6
WB ^{68}Ga-DOTATOC	16.9 ± 2.8
Head ^{11}C-Methionine	3.7 ± 0.8

TABLE 5. Total % effective dose contribution

	CT (%)	PET (%)
WB ^{18}F-FDG	71	29
WB ^{11}C-Choline	95	5
WB ^{68}Ga-DOTATOC	79	21
Head ^{11}C-Methionine	40	60

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8. FURTHER INFORMATION

8.1. Author affiliation

GIOVANNI TOSI
Medical Physics Department
Humanitas Research Hospital
Rozzano, Italy
Email: giovanni.tosi@humanitas.it

ARTURO CHITI
Humanitas University
Rozzano, Italy
Email: arturo.chiti@hunimed.eu

KATIA MARZO
Nuclear Medicine Department
Humanitas Research Hospital
Rozzano, Italy
Email: katia.marzo@cancercenter.humanitas.it

MEDICAL EXPOSURES IN BRAZIL: EXPERIENCE AND BASELINES

SÁ, LIDIA V. DE; LIMA, GABRIELA I. O. A., RIBEIRO, JÚLIO CESAR.
Institute of Radiation Protection and Dosimetry/National Nuclear Energy Commission
Rio de Janeiro/RJ/Brazil
Email: lidia@ird.gov.br

Abstract

With the advancement of medical techniques that use ionizing radiation, it has been a scientific community concern the dose involved in each procedure in evaluating the efficacy of diagnosis and therapy, and issues related to the healthy organs protection. Therefore, the knowledge of these doses is a prerequisite for strategies to implement improvements. UNSCEAR has promoted a survey on medical exposures in member states also with the same objective and as a member of this Committee Brazil should present its results. However, the country does not have a database regarding these procedures and tools to obtain it are discussed in nuclear medicine, radiology and radiotherapy fields. For nuclear medicine, software was developed and applied to three hospitals at Rio de Janeiro in order to determine the frequencies, patient data and activities involved in each exam. In radiology, the survey was performed including mammography, conventional X-rays and computed tomography procedures. For radiotherapy, agreements with Ministry of Health are ongoing in order to improve the data available today at National Cancer Institute. The information obtained and the methodology used leads to believe that the development of specific software for the three areas would be the best way considering the difficulties encountered.

1. INTRODUCTION

It is well known that with the advancement of science new technologies for early detection of diseases and treatment of neoplasia has been arise. The use of ionizing radiation in medicine has been increased in the last decades, with applications of radioactive materials capable of evaluating metabolic alterations, producing images and also treating diseases by new therapy procedures. However, the potential side effects that may occur due to exposure to such diagnostic and therapeutic technologies [1], as well as the consequent increase in the collective dose resulting in the world population has been a concern in the scientific community [2].

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was established to assess and report on the effects of ionizing radiation sources in all practices. The Committee conducts regular global surveys of the medical use of radiation and resulting exposures in order to identify trends and to estimate exposure levels worldwide. Surveys are also used to identify gaps in treatment capacities and possible unjustified dose variations for the same radiological procedure between many countries [3,4,5]. This requires the frequency and dose information for the major medical exams, procedures, or treatments. Ideally, the data presented should reflect the level of national practice as accurately as possible [3].

Brazil as member of UNSCEAR should provide national data. However, little information on this subject can be obtained, either through Ministry of Health (MS) or CNEN (National Nuclear Energy Commission), both regulatory bodies of practices involving radiation. The paper addresses the efforts and rationale introduced by Institute of Radiation Protection and Dosimetry IRD/CNEN to collect this data, discuss local problems and presents some results obtained until now.

2. METHODOLOGY

The health system in the country is parted into public (SUS) and private, but the population served by each one is disproportionate, governed by the scarce individual financial resources. About 77% of the population is attended by the public system and only 23% have access to better care in private clinics and hospitals [6].

The number of equipment installed was obtained through the National Health Facilities Registration System, as well as frequencies of the examinations performed. However, the distribution by age and sex groups is not provided by this system. To address this restriction a survey in three large hospitals was carried out in order to obtain parameters of this distribution and effective doses received for the patient [6].

2.1. Radiology Procedures

For Conventional X-Ray, the incidences were: skull, sinus, chest, lumbar spine, thoracic spine, cervical spine, abdomen, basin, costal arches and unilateral hip. The parameters tube potential (KVp), current product by exposure time (mAs), distance-focus-patient (DFP), X-ray tube yield and the backscatter factor (1.54 fixed) were noted to calculate entrance dose to skin. For Mammography, craniocaudal, and mid-lateral-oblique left and right incidences were considered to access glandular dose (Dg) based in the tube potential (KVp), current product exposure time (mAs), distance-focus-patient (DFP), and compressed breast thickness of the selected patients. For Computed Tomography (CT), Volume Computed Tomography Dose Index (CTDIvol) and Dose Length Product (DLP) were noted for head, neck, chest, abdomen and pelvis exams.

2.2. Radiotherapy Procedures

The National Cancer Institute (INCA) manages cancer incidence data in Brazil. To address the frequency of treatments, the maximum number of fractions reimbursed by national health system was considered. Therefore, assuming that each diagnosed cancer was treated, or is under treatment in the evaluated period, the frequency of each treatment could be obtained.

2.3. Nuclear Medicine Procedures

The frequency of nuclear medicine procedures, the software NIREA was developed at Institute of Radiation Protection and Dosimetry (IRD) to collect frequencies and administered activity for each patient in the three hospitals. The dose factors from ICRP publications [7,8,9] were used and extrapolated for patients specificities as age, sex and body mass index to calculate effective doses and absorbed doses in critical organs. Some exams were analysed as pilot to run and validate the software.

3. RESULTS

The number of installed equipment was obtained by the National Register of Health Establishments and is presented in table 1.

Table 1: Number of equipment in use on public and private health systems - 2016.

	Equipment	Total	Public system	Private system
Nuclear medicine	Gama camera (Planar and SPECT)	912	438	474
	PET/CT	130	34	96
	SPECT/CT	10	2	8
Radiology	X-Rays	140	36	104
	Dental X-Ray	46432	8029	38403
	Mammography	46572	8065	38507
	Computed Tomography	4191	1993	2198
	Fluoroscopy X-Ray	1473	825	648
	Densitometry X-Ray	2112	735	1377
	Hemodynamic X-Ray	848	414	434
Radiotherapy	LINAC linear accelerators	230	NSD	NSD
	Stereotactic	3	NSD	NSD
	Telecobalt	84	NSD	NSD
	HDR/LDR - Brachytherapy	110	NSD	NSD
	Low energy X-ray	98	NSD	NSD
	Tomotherapy	4	NSD	NSD

NSD: No Specific Data

3.1 Radiology

For mammography and X-ray procedures the public system (SUS) can provide the frequency, but only for mammography it is possible to access the age of the patients, calculating medium glandular dose (Dg) for each age group and the results are show in table 2, as the related effective doses.

Table 2: Mammography: glandular dose (dg) and effective dose report calculated for frequencies per age group

Age group (years)	Frequency	Medium age (years)	Height (m)	Mass (kg)	Body Max Index	Medium Dg (mGy)	Effective dose (mSv)
29 a 39	350	36.44±2.80	1.60±0.09	72.31±14.23	28.51±6.14	5.89±2.62	0.71±0.31
40 a 49	2404	44.28±2.98	1.61±0.06	72.40±13.86	28.00±5.39	5.52±1.40	0.66±0.17
50 a 59	3893	54.32±3.01	1.59±0.06	66.86±12.04	26.45±4.52	5.07±1.29	0.61±0.15
60 a 69	2508	64.79±2.42	1.59±0.11	70.63±14.20	27.88±5.24	4.53±1.18	0.54±0.14
Above 70	1850	72.90±3.84	1.56±0.08	68.50±10.29	28.22±3.74	4.04±1.39	0.48±0.17

Considering X-rays procedures the same SUS system could not provide frequency by age or sex, only the total exams, as show in table 3. For computed tomography, the dose factors were determined for the patients in the three hospitals participating in this research and some results are show in table 4.

Table 3: X-ray (XR) and computed tomography (CT) procedures frequencies in public health system - 2016.

Exam		Skull	Cervical spine	Abdomen	Chest	Lumbar spine	Pelvis	Thorax column	Hip	Face
Frequency	XR	7589	4231	8412	42309	8618	5403	4199	4333	19283
	CT	7578	2201	5943	3879	1787	6530	3879	-	1991

Table 4: Dose factors and effective doses for some computed tomography exams

	ABDOMEN		**SKULL**	
	women	men	women	men
CTDIvol	22.89±10.25	22.84±7.14	77.01±15.31	68.60±24.18
DLP (mGy.cm)	838.72±409.31	734.88±273.05	1379.43±371.34	1282.10±450.38
Effective dose (mSv)	12.60±6.13	11.02±4.10	2.90±0.78	2.69±0.95
	TORAX		**SPINE**	
	women	**men**	**women**	**men**
CTDIvol	23.18±8.10	24.46±8.15	29.38±3.21	31.38±2.20
DLP (mGy.cm)	756.26±259.52	635.31±377.49	792.75±237.81	958.95±96.10
Effective dose (mSv)	10.60±3.63	8.90±5.28	11.89±3.57	14.39±1.44

3.2 Nuclear Medicine

The software NIREA was based on the interpolation of ICRP dose factors and the individual effective doses could be calculated. Some examples of the results are show in table 5 stratified by age groups and sex.

Table 5: Some administrated activities for nuclear medicine procedures obtained by software NIREA

Age (years)		0-4	4-9	9-14	14-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59
^{99m}Tc MDP	men	81.4	296.0	418.1	751.1	832.5	814.0	869.5	895.4	888.0	906.5	921.3	1102.6
	women	81.4	333.0	666.0	740.0	814.0	888.0	928.7	895.4	921.3	913.9	917.6	1106.3
^{99m}Tc MIBI rest	men	NSD	NSD	NSD	NSD	377.4	414.4	469.9	477.3	543.90	551.3	525.4	869.5
	women	NSD	NSD	NSD	NSD	444.0	714.1	444.0	455.1	714.1	543.9	551.3	832.5
^{99m}Tc MIBI stress	men	NSD	NSD	NSD	NSD	832.5	1061.9	1061.9	1217.3	1324.6	1198.8	1332.0	1191.4
	women	NSD	NSD	NSD	NSD	810.3	921.3	917.6	1476.3	1228.4	1176.6	1350.5	1250.6
^{99m}Tc DTPA	men	166.5	218.3	270.1	314.5	340.4	392.2	373.7	377.4	370.0	410.7	392.2	399.6
	women	166.5	218.3	270.1	314.5	340.4	392.2	373.7	321.9	329.3	355.5	407.0	399.6

NSD: No Specific Data to paediatric patients were not obtained because they did not perform the specific examination

3.3 Radiotherapy

The INCA database for cancer incidence and patients treated are available for some treatments, but there are no data about specific absorbed dose prescribed for a specific patient or disease. Agreements between institutions are taking place in order to improve the system for collecting information on radiotherapy in all the states of the country, and so far, only the number of treatments performed is show in table 7.

Table 7: Radiotherapy treatment - 2016

Treatment	Number of procedures per year
Total body irradiation (TBI)	787
Skin electron beam irradiation	1512
Benign diseases	5432
HDR procedures	32755

4. CONCLUSION

Data collection of medical exposures is still incipient in Brazil. The difficulties are enormous and there is still resistance from the medical community in having all patient data in a local database. Efforts have been made to implement a single individual health record, but this is not yet the case. However, the evaluations carried out so far have promoted improvements in protocols and also training medical team in dosimetry methods, risk analysis and standardization of protocols.

Facilitating this data collection in the services through the development of friendly software seems to be the solution, even more considering the continental dimensions and scarce resources in the country.

When compared to effective doses published by other countries, the values observed here for many exams have shown that some practices need optimization, one of the objectives of the evaluation.

This work is underway and specific software for radiology and radiotherapy fields are under development.

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ESTIMATION OF CONVERSION COEFFICIENTS FROM DOSE-AREA PRODUCT TO EFFECTIVE DOSE FOR BARIUM MEAL EXAMINATIONS FOR ADULT PATIENTS

A. V. VODOVATOV
St-Petersburg Research Institute of Radiation Hygiene
St-Petersburg, Russian Federation
Email: vodovatoff@gmail.com

V. YU. GOLIKOV
St-Petersburg Research Institute of Radiation Hygiene
St-Petersburg, Russian Federation

I. G, KAMYSHANSKAJA
FGBOU VO "Saint-Petersburg state University", Department of Oncology
St-Petersburg State Mariinsky Hospital
St-Petersburg, Russian Federation

C. BERNHARDSSON
Medical Radiation Physics, Department of Translational Medicine, Skåne University Hospital
Malmö, Sweden

Abstract

The aim of the current study was to establish conversion coefficients (CCs) from dose-area product to effective dose for most common barium meal (BM) fluoroscopic examination. The study was based on data collection in two X-ray rooms in a major university hospital in St-Petersburg, Russia that allowed evaluating a structure of BM fluoroscopic examinations and developing a computed model of effective dose estimation using PCXMC 2.0 software. Results indicate that effective doses and the CCs were mainly influenced by the structure (contribution of different projections) and by the parameters (field size and energy characteristics of the X-ray beam) of the fluoroscopic examination. Resulting values of CCs estimated in the study were comparable with the published data for BM examinations.

1. INTRODUCTION

Justification and optimization are necessary and efficient ways to reduce both individual patient and collective risk from fluoroscopic examinations, that are associated with relatively high patient doses. Barium meal examinations (BM) are among most common fluoroscopic examinations, corresponding to 38% contribution to the collective dose from fluoroscopic examinations in Russia [1]. It is necessary to assess and optimize the level of exposure of the patients from these types of examinations.

Effective dose (E, mSv) was selected as the most practically suitable dose quantity for the issues of justification and optimization. Effective dose is estimated using conversion coefficients (CCs) that relate effective dose with dose-area product (DAP, cGy*cm^2). CCs are highly dependent on the exposure conditions (energy spectra of an X-ray beam, exposure geometry and examined anatomic area) [2]. Usually only a limited set of CCs for certain exposure conditions is available [2].

Hence, the aim of the current study was to calculate conversion coefficients (CCs), relating E with DAP for BM fluoroscopic examinations. That required to evaluate the structure of the selected fluoroscopic examinations, to collect the relevant patient dose and clinical protocol data, and to develop a computational model of patient exposure.

2. MATERIALS AND METHODS

Data for E estimation was collected on the base of two X-ray rooms, belonging to surgical (SD) and therapy (TD) departments in St-Petersburg State Mariinsky hospital. Fluoroscopic protocols significantly varied between these X-ray rooms. Examination data was collected for two samples of 20 and 26 typical patients in SD and TD departments correspondingly.

All the examinations were performed on two digital KRT-Electron (JSC "NIPK "Electron", Russia) X-ray units. These remotely guided X-ray units with an over-couch X-ray tube and a CCD-matrix detector are commonly used for fluoroscopic examinations and compose up to 70% of all fluoroscopic X-ray units in St-Petersburg. Both X-ray units were installed in 2005-2007 period and have identical settings (focal-image distance 115 cm; grid 110 lines/inch, R=13:1, F=180 cm; total filtration of 5 mm Al), varying only by a detector size (12' and 16' for SD and TD departments correspondingly). Imaging was performed using default vendor protocols with automated brightness control (ABC) without the digital image intensification.

The preliminary structure of BM examinations was estimated based on the existing clinical protocols and information from the radiologists. Patient positioning, examination structure, irradiation speed and total time of irradiation were selected by the radiologists individually for each patient based on their personal experience or preferences, patient condition and preliminary diagnosis. Each examination was divided into a set of standardized fluoroscopy phases and X-ray images, specified by the examined anatomic region and the projection of patient exposure. The following data was collected for each fluoroscopy phase and for each X-ray image taken for each patient: patient position (standing, supine, prone, recumbent), projection, total fluoroscopy time (s), fluoroscopy speed (frames/s), field size (cm*cm), average tube voltage (kV), total DAP (cGy*cm^2). Data was collected manually by the authors using dedicated spreadsheets. All examinations were digitally recorded in a DICOM format and exported from PACS; these records were used for computational modelling the exposure of the patients.

Effective dose calculation was performed using a PCXMC 2.0 software (STUK, Finland) [3]. Each fluoroscopic phase, in turn, was described by a set of discrete irradiation fields, corresponding to the locations of the relevant organs and tissues. If there was no significant movement of an X-ray tube and only the single organ as irradiated (i.e. fluoroscopy of the stomach with contrast), the phase consisted of a single irradiation field. On the other hand, if different organs were exposed and the tube movement was significant (i.e. survey fluoroscopy of the oesophagus), the phase consisted of several irradiation fields, each corresponding to a certain relevant anatomic location. Exposure parameters for each irradiation field within a single phase were considered to be constant.

Coordinates for the selected irradiation fields were determined for each projection. A total of 8 projections were selected to describe the exposure of the patient: anteroposterior (AP), posteroanterior (PA), left lateral (LATL), right lateral (LATR), left posterior oblique (LPO), right posterior oblique (RPO), left anterior oblique (LAO), right anterior oblique (RAO). For the simplicity of modelling the exposure in oblique projections it was assumed that all of them were 45°-fold.

Effective doses and CCs for each geometry of exposure were estimated using the standard adult (PCXMC default, 178.6 cm height and 73.2 kg body mass) parameters. Effective dose per phase was calculated as a sum of effective doses for each irradiation field. CCs were estimated for each phase for all projections.

To estimate the CCs for the whole BM fluoroscopic examinations, the following method was used:

— Estimation of the effective doses and CCs for each fluoroscopic phase and X-ray image for each projection;
— Estimation of DAP contribution of each projection into the total DAP for the examination for the whole patient sample for BM fluoroscopic examination;
— Estimation of mean CC for the selected type of the fluoroscopic examination using the following equation:

$$CC_{60} = \sum^{\text{projection}} \frac{DAP_{\text{projection}}}{DAP_{\text{total}}} \times CC_{60\text{projection}}, \frac{\mu Sv}{cGy \cdot cm2}$$

where:

CC_{60} – mean CC for the selected type of the fluoroscopic examination estimated using tissue weighting coefficients from ICRP Publication 60;

$DAP_{projection}$ –DAP for all fluoroscopic phases and X-ray images for the selected projection for BM fluoroscopic examination, cGy·cm^2;

DAP_{total} –total DAP for all fluoroscopic phases and X-ray images for the whole patient sample for BM fluoroscopic examination, cGy·cm^2;

$CC_{60projection}$ – CC for the selected projection for the whole examination, estimated using tissue weighting coefficients from ICRP Publication 60.

3. RESULTS

Data on the structure, relevant examination parameters, total DAP and E for BM examinations in surgical and therapy departments is presented in Table 1.

TABLE 1. DATA ON BM EXAMINATIONS

Department	Number of fluoroscopic phases	Number of X-ray images	Tube voltage, kV	Typical irradiation field size, cm·cm	Total DAP for the examination, cGy·cm^2	Total E for the whole examination (ICRP Pub 60), mSv
Surgical department	8.7±3.4* (3-16)	7±4 (0-15)	89±10 (61-127)	28·28	3392±2340 (316-10309)	8.7±6.4 (0.7-27.5)
Therapy department	17±5.5 (6-28)	6.3±1.9 (4-12)	90±11 (59-125)	35·30; 15·25**	508±371 (228-2157)	1.9±1.4 (0.7-7.9)

* mean±SD (min-max).

** For all patients 35·30 field was used only for the survey of UGIT without contrast; 15·25 field was used for all other phases.

Data on the CCs for individual projections and the contribution of different projections to the BM examinations for two X-ray rooms is presented in Table 2.

TABLE 2. CONTRIBUTION OF DIFFERENT PROJECTIONS TO THE TOTAL DAP FOR BM EXAMINATION AND CONRRESPONDING MEAN CONVERSION COEFFICIENTS

Projection	AP	PA	LATL	LATR	LPO	RPO	LAO	RAO
Contribution for SD	52%	12%	13%	6%	-	-	8%	8%
Mean CC, SD	3.1	1.9	1.9	1.0	-	-	1.8	1.7
Contribution for TD	26%	10%	1%	1%	35%	26%	-	1%
Mean CC, TD	3.9	2.4	2.5	1.5	3.2	5.1	-	2.4

Resulting CCs for BM examinations for both departments and comparison with the existing CCs from other studies are presented in Table 3.

TABLE 3. COMPARISON OF THE CONVERSION COEFFICIENTS FROM DAP TO EFFECTIVE DOSE (ICRP 60) FOR BM EXAMINATIONS

	Current study	Methodical guidance 2.6.1.2944-11 [4]	Delichas et al. [5]	Geleijns et al. [6]	Hart et al. [7]	Ciraj et al.[8]	Gyekye et al. [9]
CC for BM examination, $\frac{\mu Sv}{c \cdot c}$	SD: 2.6 TD: 2.7	2.0	3.4	3.2	2.0	1.9-2.4	3.2

4. DISCUSSION

The proposed approach for the estimation of the effective dose considers important features of fluoroscopic examinations: non-uniform examination composition, significant movement of the X-ray tube within a single phase and the variety of exposure geometries. Using standardized structure of fluoroscopic examination allows a uniform approach to the effective dose estimation regardless of structure of the

examination. In the current study the differences in CC values between two X-ray rooms (Table 3) can be explained by two main factors: differences in irradiation field size and different contribution of different projections into a total DAP for examinations (see Table 1 and 2).

It is visible from Table 3, that estimated CCs (SD) are higher (up to 30%) compared to the existing Russian CCs [4] results published in [7,8], and comparable (TD) with the published CCs [5,6,9] for BM examinations.

To allow accurate effective dose estimation, CCs should consider the structure of the examination, geometry of patient exposure and the parameters of examinations. The use of single CC for a selected fluoroscopic examination would lead to over- or underestimation of the effective dose. Hence, it is proposed to establish sets of conversion coefficients for different exposure geometries and energy characteristics of the X-ray beam for each common fluoroscopic examination. In this case it would be possible to increase the accuracy of the effective dose estimation by applying a corresponding CC for each fluoroscopic phase of the complex examination, or establishing X-ray room specific CCs based on the relative contribution of different phases and projections into a total DAP for the examination.

5. CONCLUSIONS

Effective doses and the corresponding CCs relating effective dose with dose-area product for the BM fluoroscopic examinations were estimated by calculations using PCXMC 2.0 software based on the input data collected from two X-ray rooms in a major St-Petersburg university hospital. Effective doses and the CCs would be mainly influenced by the structure (number of fluoroscopic phases and selection of the projections of irradiation of the patient) and by the parameters of the fluoroscopic examinations (field size and energy characteristics of the X-ray beam).

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