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Introduction of software for patient dose assessment in computed tomography

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Abstract:

In recent years, there has been increasing concern about the radiation dose to patients undergoing radiological examinations, particularly computed tomography (CT), which has been reported to contribute the highest collective dose among X-ray diagnostic and interventional examinations. Regular monitoring and evaluating radiation doses for patients are essential to ensure quality assurance for all procedures. To address the inherent limitations of traditional dose assessment methods, an in-house software application named NTTU-SmartDose was developed to extract dose-related data from digital imaging and communications in medicine (DICOM) files. The software estimates the effective dose for each CT examination and reports the cumulative effective dose for each patient. A warning function, triggered when the cumulative dose exceeds a predefined threshold, has also been integrated into the software. Testing results indicated that the software provides accurate and reliable dose estimations, highlighting its potential as a valuable tool in diagnostic radiology departments. Implementing such tools is critical to healthcare systems aiming to comply with safety standards and optimise radiation-related procedures.

Keywords: **computed tomography, dose management, dose monitoring system, effective dose.**

Classification numbers: **1.2, 3.6**

1. Introduction

Since its invention in 1970, computed tomography (CT) has become one of the most widely used imaging modalities. Technological advancements now allow scanning to be completed in less than one second [1, 2]. Despite its benefits, the radiation dose to patients is a growing concern. According to the 2022 report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), CT accounted for only 9.6% of ionising radiation-related examinations but contributed up to 61.6% of the collective effective dose [3].

Numerous studies have explored the correlation between radiation exposure and cancer risks, providing evidence of a relationship between radiation from medical imaging and increased cancer risks, especially in children, who are more sensitive to radiation than adults [4, 5]. For instance, a 2012 study by M.S. Pearce, et al. (2012) [6] reported relative risks of leukaemia (cumulative dose of at least 30 mGy) and brain cancer (mean cumulative dose of 60.42 mGy) to be 3.18 and 2.82, respectively, compared to patients with an accumulated dose of no more than 5 mGy. Further studies on accumulated radiation doses in patients undergoing CT scans over five consecutive years revealed that approximately 1-1.33% of surveyed patients received an accumulated effective dose exceeding 100 mSv [7, 8] - a dose level associated with markedly increased radiation risks.

In some countries, the monitoring and analysis of dose-related data from radiological examinations are mandatory [9]. However, the perception of medical doctors regarding the radiation risks of radiological examinations remains relatively low. For instance, M.S. Pearce, et al. (2012) [6] found that approximately 53% of radiologists and 91% of emergency department physicians did not believe that CT scans could increase cancer risk [6]. This is concerning, as doctors are responsible for determining the necessity of examinations. Their knowledge of radiation doses is a key factor in ensuring the justification of such procedures.

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In Vietnam, although much modern imaging equipment has been installed in recent years, the issue of radiation dose to patients has not received adequate attention. There is currently no comprehensive statistical data on the number of CT examinations performed annually or the associated radiation doses [10]. This lack of complete statistics does not reflect the current status of medical exposure in Vietnam. Moreover, insufficient awareness of the importance of patient dose assessment increases risks to patients and creates additional challenges for administrators in managing radiation exposure.

Actions are urgently required to address patient dose management. Firstly, medical doctors must justify each examination by carefully considering the necessity of radiation-related procedures and potential alternative methods. Secondly, regular assessment of patient radiation doses is crucial. Since 2009, the International Atomic Energy Agency (IAEA) has implemented the Smart Card/SmartRad Track project to monitor patients' medical radiation doses in radiology [11, 12]. Many countries have adopted this initiative, yielding positive outcomes in ensuring justification, minimising unnecessary examinations, and optimising procedures to reduce ionising radiation doses [13].

Computed tomography provides dosimetric information, displayed on the examination room's computer, which can also be retrieved from the Picture Archiving and Communication System (PACS). Various methods are available to collect dose parameters from CT for radiation dose management. Traditionally, these parameters have been recorded manually from the CT room's computer or PACS. However, this method is time-consuming and prone to errors due to data entry mistakes. Another method involves using optical character recognition (OCR) on Dose Report images produced by CT systems. Depending on the manufacturer, dose parameters such as the volume computed tomography dose index ($CTDI_{vol}$), dose-length product (DLP), pitch, and scan range can be extracted from these images. Despite its accuracy, this approach is generally regarded as cumbersome [9].

A more efficient solution is the implementation of dose monitoring systems (DMS), which can be connected to scanners or PACS. Modern DMSs offer a range of features beyond dose monitoring [14]. However, their installation requires additional funding and qualified personnel, posing significant challenges in countries where patient dose assessment has not yet received adequate attention, and where more trained professionals are needed.

Given these limitations, in-house self-developed tools offer a viable alternative for assessing patient doses, providing clinicians and technologists with in situ information about examination doses, and assisting facility administrators in managing patient radiation exposure. These factors motivated the authors to develop NTTU-SmartDose, a software application designed to calculate effective doses in CT examinations based on metadata contained in Digital Imaging and Communications in Medicine (DICOM) images - the most commonly used image format in the medical field. The software also integrates a cumulative effective dose calculator and a warning function that activates when the cumulative dose exceeds a predefined threshold.

2. Subjects and methodology

NTTU-SmartDose is a MATLAB-based software application designed to estimate effective doses and cumulative effective doses for patients undergoing CT examinations. The input for the software consists of DICOM files, which generally comprise two components: DICOM headers: contain patient information, imaging equipment details, and technical parameters used to generate the images; Data sets: contain the medical images themselves.

DICOM attributes and tags used for information extraction are presented in Table 1.

Table 1. Parameters extracted from DICOM headers.

DICOM tag	Name
(0008,0020)	StudyDate
(0008,1030)	StudyDescription
(0010,0010)	PatientName
(0010,0020)	PatientID
(0010,0030)	PatientBirthDate
(0010,0040) (0010,1010)	PatientSex Patient's Age
(0018,0015)	BodyPartExamined
(0018,9345)	$CTDI_{vol}$
(0020,1041)	Scan Length

In diagnostic radiology, numerous dosimetric quantities are used to describe the radiation dose delivered to patients. In a 1990 publication, the International Commission on Radiation Protection (ICRP) introduced the concept of the effective dose to assess the health risks associated with ionising radiation [15].

The effective dose in CT can be calculated using the following formula:

$$E = DLP \times k \quad (1)$$

where DLP is the dose-length product, which can be obtained from the reported dose (in DICOM images) or calculated as the product of volume CT dose index ($CTDI_{vol}$) (DICOM tag: 0018,9345) and the scan length (DICOM tag: 0020,1041), and k is the conversion factor that converts dose length-product to the effective dose. The k-values used in this study (Table 2) were derived from tabulated data in Report No. 96 of the American Association of Physicists in Medicine (AAPM) TG 23 [16]. These values were selected based on the patient's age and the region of the body scanned, allowing for a more accurate dose assessment.

Table 2. *k*-values for converting dose-length product to effective dose.

Region of the scanned body	*k*-value (mSv/mGy.cm)				
	0-year-old	*1-year-old*	*5-year-old*	*10-year-old*	*Adult*
Head and neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen and Pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015
Others	0.044	0.028	0.019	0.014	0.015

The steps executed by the software are outlined in the flowchart in Fig. 1. The program was designed to extract DICOM information from a user-selected folder. Once the "read" command is issued, all DICOM studies in the folder are identified. The software searches within each DICOM study, extracting patient identification data as summarised in Table 1. All exposure sequences are then identified, and scout projections are filtered out. Importantly, the software does not modify any fields in the DICOM files.

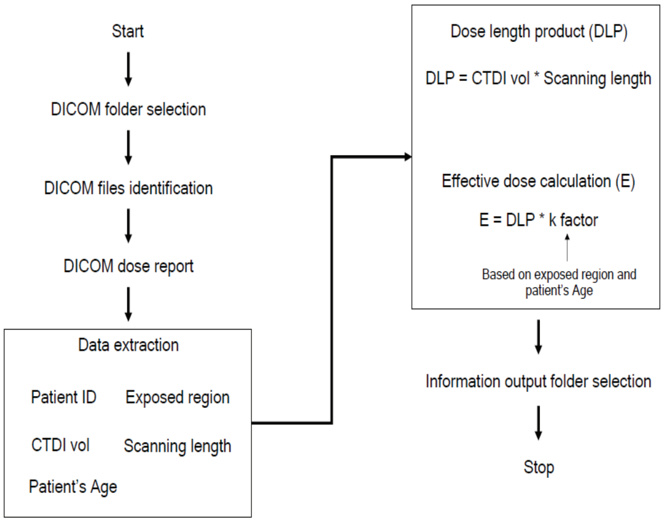


Fig. 1. Flowchart of the NTTU-SmartDose software.

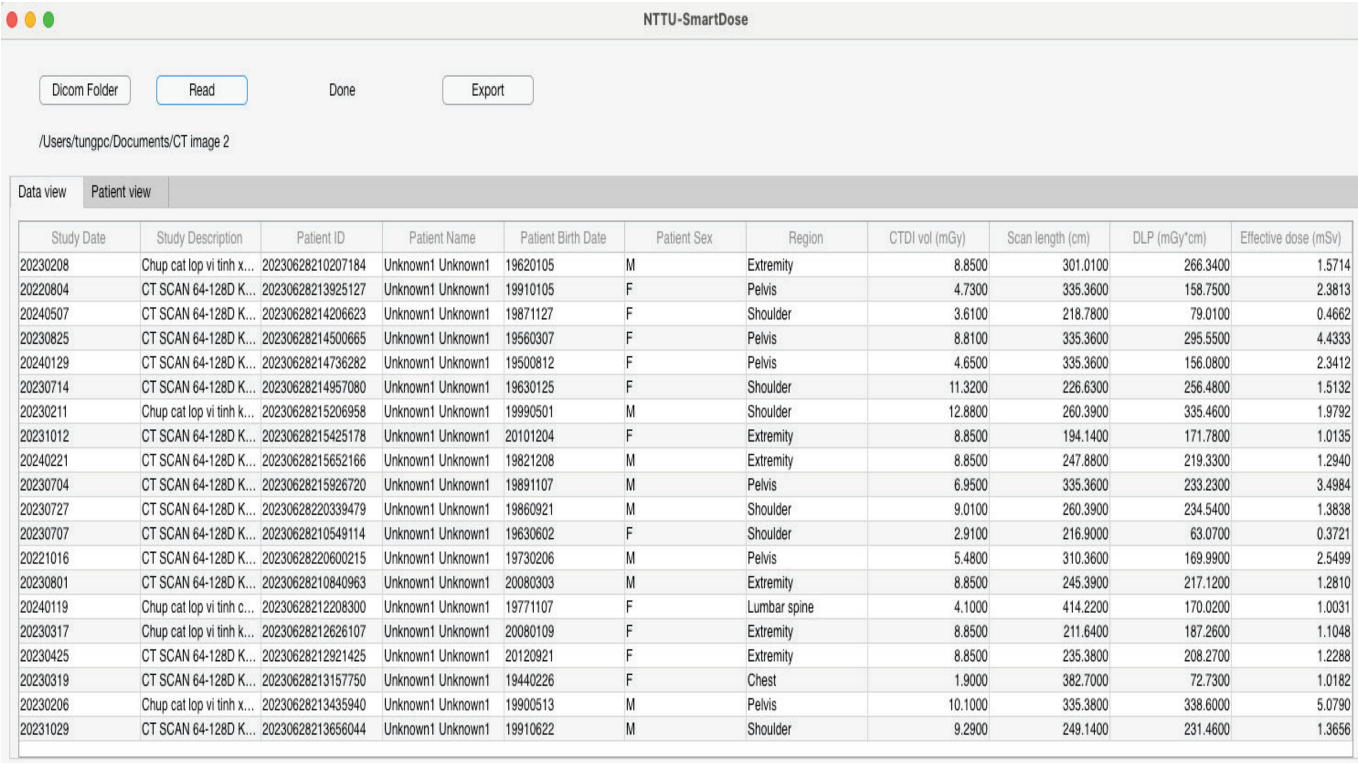
The $CTDI_{vol}$ and scan length are extracted from the CT exposures, and the DLP is calculated by multiplying $CTDI_{vol}$ and scan length. The effective dose is subsequently determined using the k-values listed in Table 2.

The software offers two display modes. The serial mode provides a general overview of the dose data from multiple examinations, serving as dose statistics. The individual mode allows users to monitor radiation doses for individual patients by displaying the effective dose for each examination and the cumulative effective dose. This mode also includes a warning feature, where an alert icon and message are displayed if the cumulative dose exceeds a predefined threshold, set at 100 mSv in this study.

To develop and validate the software, 40 DICOM files were retrieved from PACS. All personally identifiable information was anonymised, and the files were assigned ordinal numbers. The first 20 files were used for software development, and the remaining 20 were used for validation. During validation, a participant manually extracted DICOM attributes, tags, and values, performing simple dose calculations using Microsoft Excel. These results were then manually compared with those generated by the NTTU-SmartDose software to ensure accuracy.

3. Results and discussion

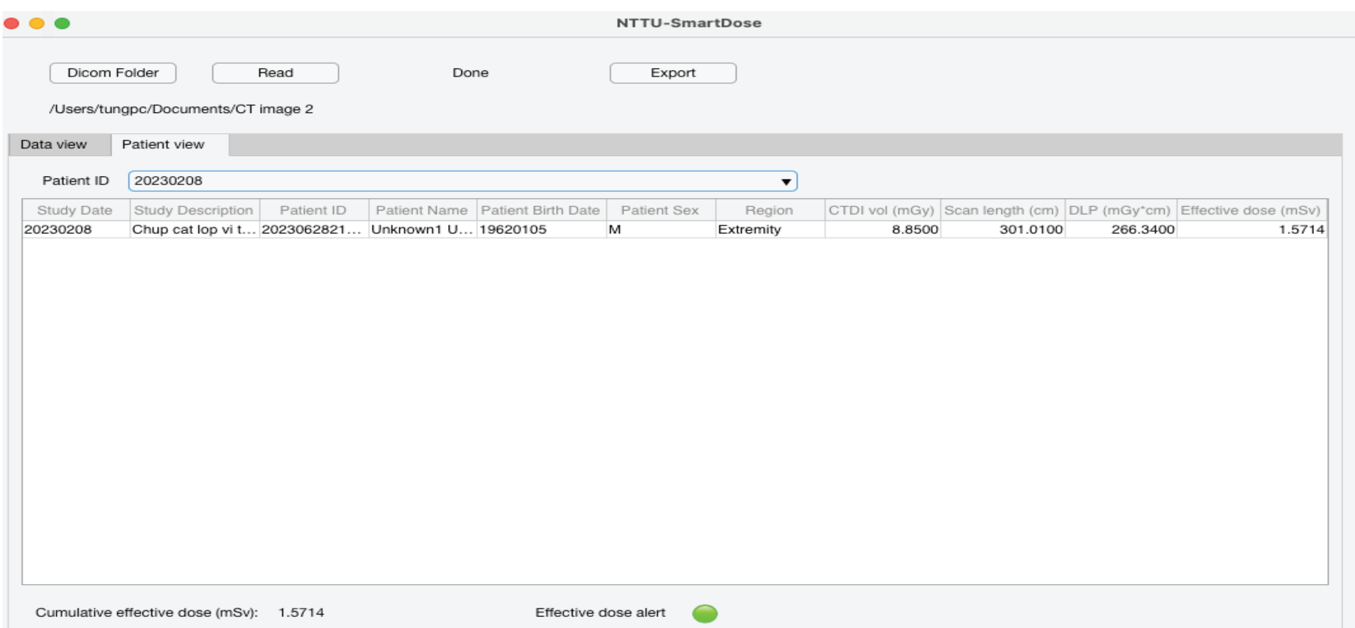
The NTTU-SmartDose software successfully extracts the required information for dose calculation by directly accessing the DICOM attributes. The calculated effective



Study Date	Study Description	Patient ID	Patient Name	Patient Birth Date	Patient Sex	Region	CTDI vol (mGy)	Scan length (cm)	DLP (mGy*cm)	Effective dose (mSv)
20230208	Chup cat lop vi tinh x...	20230628210207184	Unknown1 Unknown1	19620105	M	Extremity	8.8500	301.0100	266.3400	1.5714
20220804	CT SCAN 64-128D K...	20230628213925127	Unknown1 Unknown1	19910105	F	Pelvis	4.7300	335.3600	158.7500	2.3813
20240507	CT SCAN 64-128D K...	20230628214206623	Unknown1 Unknown1	19871127	F	Shoulder	3.6100	218.7800	79.0100	0.4662
20230825	CT SCAN 64-128D K...	20230628214500665	Unknown1 Unknown1	19560307	F	Pelvis	8.8100	335.3600	295.5500	4.4333
20240129	CT SCAN 64-128D K...	20230628214736282	Unknown1 Unknown1	19500812	F	Pelvis	4.6500	335.3600	156.0800	2.3412
20230714	CT SCAN 64-128D K...	20230628214957080	Unknown1 Unknown1	19630125	F	Shoulder	11.3200	226.6300	256.4800	1.5132
20230211	Chup cat lop vi tinh k...	20230628215206958	Unknown1 Unknown1	19990501	M	Shoulder	12.8800	260.3900	335.4600	1.9792
20231012	CT SCAN 64-128D K...	20230628215425178	Unknown1 Unknown1	20101204	F	Extremity	8.8500	194.1400	171.7800	1.0135
20240221	CT SCAN 64-128D K...	20230628215652166	Unknown1 Unknown1	19821208	M	Extremity	8.8500	247.8800	219.3300	1.2940
20230704	CT SCAN 64-128D K...	20230628215926720	Unknown1 Unknown1	19891107	M	Pelvis	6.9500	335.3600	233.2300	3.4984
20230727	CT SCAN 64-128D K...	20230628220339479	Unknown1 Unknown1	19860921	M	Shoulder	9.0100	260.3900	234.5400	1.3838
20230707	CT SCAN 64-128D K...	20230628210549114	Unknown1 Unknown1	19630602	F	Shoulder	2.9100	216.9000	63.0700	0.3721
20221016	CT SCAN 64-128D K...	20230628220600215	Unknown1 Unknown1	19730206	M	Pelvis	5.4800	310.3600	169.9900	2.5499
20230801	CT SCAN 64-128D K...	20230628210840963	Unknown1 Unknown1	20080303	M	Extremity	8.8500	245.3900	217.1200	1.2810
20240119	Chup cat lop vi tinh c...	20230628212208300	Unknown1 Unknown1	19771107	F	Lumbar spine	4.1000	414.2200	170.0200	1.0031
20230317	Chup cat lop vi tinh k...	20230628212626107	Unknown1 Unknown1	20080109	F	Extremity	8.8500	211.6400	187.2600	1.1048
20230425	CT SCAN 64-128D K...	20230628212921425	Unknown1 Unknown1	20120921	F	Extremity	8.8500	235.3800	208.2700	1.2288
20230319	CT SCAN 64-128D K...	20230628213157750	Unknown1 Unknown1	19440226	F	Chest	1.9000	382.7000	72.7300	1.0182
20230206	Chup cat lop vi tinh x...	20230628213435940	Unknown1 Unknown1	19900513	M	Pelvis	10.1000	335.3800	338.6000	5.0790
20231029	CT SCAN 64-128D K...	20230628213656044	Unknown1 Unknown1	19910622	M	Shoulder	9.2900	249.1400	231.4600	1.3656

Fig. 2. Screenshot of serial display mode.

dose is displayed within the software, as illustrated in Figs. 2 and 3, which demonstrate the serial and individual display modes, respectively. The software's performance was assessed by measuring the time required to process cases on a MacBook Pro (Processor: 2.3 GHz Quad-Core Intel Core i5, 8 GB RAM, macOS Sonoma 14.1.2). The running times were 59 seconds for two cases and 315 seconds for twenty cases. Approximately 12% of the processing time was allocated to information retrieval, with the remainder spent extracting DICOM headers.



Study Date	Study Description	Patient ID	Patient Name	Patient Birth Date	Patient Sex	Region	CTDI vol (mGy)	Scan length (cm)	DLP (mGy*cm)	Effective dose (mSv)
20230208	Chup cat lop vi t...	2023062821...	Unknown1 U...	19620105	M	Extremity	8.8500	301.0100	266.3400	1.5714

Fig. 3. Screenshot of individual display mode.

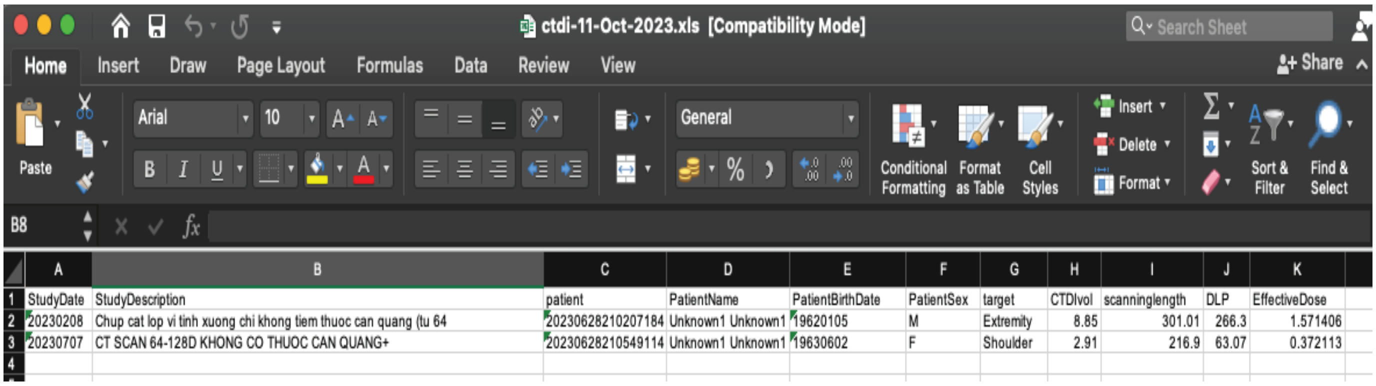


Fig. 4. Screenshot of data export.

In addition to displaying results, the software allows users to export data as Excel files, enabling further dose analysis and statistical evaluations (Fig. 4).

Compared to alternative methods for extracting dose-related data from CT examinations, the direct access and retrieval of information from DICOM files offered by this software is both convenient and efficient. For instance, in 2013, J.K. Dave, et al. (2013) [17] developed an automated program capable of extracting dosimetric information from DICOM files with 100% accuracy. Their software achieved an extraction duration of 4.5 seconds per CT study, which is shorter than the average 15.75 seconds per study achieved by NTTU-SmartDose. However, unlike NTTU-SmartDose, their program was limited to data extraction and did not calculate or report radiation doses [17].

The current version of NTTU-SmartDose reads DICOM files from a user-selected folder, making it particularly suited for retrospective dose collection. However, a limitation of this approach is the need to search for dose reports within numerous DICOM files, which increases processing time. Future development aims to enable communication with hospital PACS systems. This integration would significantly reduce processing times by allowing the PACS system to arrange and present dose reports directly to the software.

Another limitation of this study is the small dataset used for software testing, particularly the lack of paediatric patient data. Addressing this limitation in future research will enhance the software's utility and reliability.

Although the software provides convenience for radiologists and technologists, the involvement of medical physicists in diagnostic radiology remains indispensable. Medical physicists are uniquely qualified to interpret dosimetric values and apply them to optimise clinical workflows, improving efficiency and safety. Regular monitoring of patient doses is a critical step towards establishing consistent patient dose profiles across the country, contributing to improved radiation safety practices in the long term.

4. Conclusions

NTTU-SmartDose is a software application designed to assess the effective dose and cumulative effective dose of patients undergoing CT scans. By directly accessing DICOM attributes, the software accurately extracts the information required for dose calculations, ensuring precise results. The average time to extract and calculate the effective dose for a single CT study is approximately 15.75 seconds. These features make NTTU-SmartDose a valuable tool for medical doctors, aiding in clinical decision-making and helping to avoid unnecessary repeat scans, particularly for paediatric patients. Furthermore, the availability of dosimetric data supports the administration and optimisation of exposure procedures, promoting radiation safety for both patients and medical staff.

CRediT author statement

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] E.J. Kang (2019), "Clinical applications of wide-detector CT scanners for cardiothoracic imaging: An update", *Korean Journal of Radiology*, **20(12)**, pp.1583-1596, DOI: 10.3348/kjr.2019.0327.

[2] C.J. Garvey, R. Hanlon (2002), "Computed tomography in clinical practice", *BMJ*, **324(7345)**, pp.1077-1080, DOI: 10.1136/bmj.324.7345.1077.

[3] United Nations Scientific Committee on The Effects of Atomic Radiation (2022), *Volume I Report to The General Assembly Scientific Annex A: Evaluation of Medical Exposure to Ionizing Radiation*, 354pp.

[4] D.J. Brenner, C.D. Elliston, E.J. Hall, et al. (2001), "Estimated risks of radiation-induced fatal cancer from pediatric CT", *American Journal of Roentgenology*, **176(2)**, pp.289-296, DOI: 10.2214/ajr.176.2.1760289.

[5] D.J. Brenner, E.J. Hall (2007), "Computed tomography - An increasing source of radiation exposure", *New England Journal of Medicine*, **357(22)**, pp.2277-2284, DOI: 10.1056/NEJMra072149.

[6] M.S. Pearce, J.A. Salotti, M.P. Little, et al. (2012), "Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study", *The Lancet*, **380(9840)**, pp.499-505, DOI: 10.1016/S0140-6736(12)60815-0.

[7] M.M. Rehani, K. Yang, E.R. Melick, et al. (2020), "Patients undergoing recurrent CT scans: Assessing the magnitude", *European Radiology*, **30(4)**, pp.1828-1836, DOI: 10.1007/s00330-019-06523-y.

[8] C.R. Jeukens, H. Boere, B.A. Wagemans, et al. (2021), "Probability of receiving a high cumulative radiation dose and primary clinical indication of CT examinations: A 5-year observational cohort study", *BMJ Open*, **11(1)**, DOI: 10.1136/bmjopen-2020-041883.

[9] J. Boos, A. Meineke, O.T. Bethge, et al. (2016), "Dose monitoring in radiology departments: Status quo and future perspectives", *Rofo*, **188(5)**, pp.443-450, DOI: 10.1055/s-0041-109514.

[10] T.L. Dang (2021), "Patient dose in imaging diagnosis and radiation safety education and training for medical personnel, future directions", *International Atomic Energy Agency*, **69**, pp.18-25 (in Vietnamese).

[11] International Atomic Energy Agency (2009), "Summary of the first meeting of the Smart Card (Smart Access) Project of the IAEA held in VIC, IAEA, Vienna on 27-29 April 2009", https://www.iaea.org/sites/default/files/documents/rpop/smart-card-minutes.pdf, accessed 24 July 2023.

[12] M.M. Rehani, J.F. Kushi (2013), "A study of smart card for radiation exposure history of patient", *American Journal of Roentgenology*, **200(4)**, pp.780-782, DOI: 10.2214/AJR.12.10245.

[13] R. Seuri, M.M. Rehani, M. Kortesniemi (2013), "How tracking radiologic procedures and dose helps: Experience from Finland", *American Journal of Roentgenology*, **200(4)**, pp.771-775, DOI: 10.2214/AJR.12.10112.

[14] I.A. Tsalafoutas, M.H. Kharita, H.A. Naemi, et al. (2020), "Radiation dose monitoring in computed tomography: Status, options and limitations", *Physica Medica*, **79**, pp.1-15, DOI: 10.1016/j.ejmp.2020.08.020.

[15] International Commission on Radiological Protection (1991), "1990 recommendations of the International Commission on Radiological Protection", *Ann. ICRP*, **21(1-3)**, pp.1-201.

[16] C. McCollough, D. Cody, S. Edyvean, et al. (2008), "The measurement, reporting, and management of radiation dose in CT", *American Association of Physicists in Medicine*, DOI: 10.37206/97.

[17] J.K. Dave, E.L. Gingold (2013), "Extraction of CT dose information from DICOM metadata: Automated Matlab-based approach", *AJR Am. J. Roentgenol.*, **200(1)**, pp.142-145, DOI: 10.2214/AJR.12.8501.