原 著

MiSDO: The Open-source Radiation Dose Management System

MiSDO：オープンソースの被ばく線量管理システム

SUGIMOTO Kohei[1),]**MATSUMOTO Masaki**[2)], **OITA Masataka**[3)], **FUJIWARA Yuta**[4)], **NAGASAKI Ryota**[5)], **SHODA Takashi**[6)], **KURODA Masahiro**[7)]

1) Graduate School of Interdisciplinary Science and Engineering in Health Systems, Okayama University/ Division of Imaging Technology, Okayama Diagnostic Imaging Center
2) Graduate School of Interdisciplinary Science and Engineering in Health Systems, Okayama University/ Department of Radiological Technology, Ehime University Hospital
3) Faculty of Interdisciplinary Science and Engineering in Health Systems, Okayama University
4) Division of Clinical Radiology Service, Okayama Central Hospital
5) Department of Radiology Diagnosis, Aoki Internist and Pediatrics Clinic
6) Department of Radiology, Kawasaki Medical School General Medical Center
7) Department of Radiological Technology, Faculty of Health Sciences, Okayama University

Key words: dose management system, open-source, digital imaging and communications in medicine, radiation dose structured report

【Abstract】
All medical facilities with diagnostic imaging equipment in Japan must recently record and manage radiation doses. Accordingly, a radiation dose management system (DMS) is essential for recording and managing radiation doses, and it is difficult to introduce in all medical facilities because of its high cost. In this study, we developed an open-source DMS called "MiSDO" and verified its capability through simulations. The results showed that it could record and manage radiation doses quickly and accurately. "MiSDO" is promising as free software to record and manage radiation doses that anyone can use.

【要 旨】
日本では画像診断装置を有する全ての医療施設において，放射線量の記録と管理が義務付けられている．被ばく線量の記録・管理には，放射線量管理システム（DMS）が不可欠であるが，高価なため全ての医療施設に導入することは困難である．そこで本研究では，オープンソースのDMSである「MiSDO」を開発し，シミュレーションによって性能を検証した．その結果，MiSDOは被ばく線量を迅速かつ正確に記録・管理できることが確認できた．MiSDOは，日本の全ての医療施設で使用できる，被ばく線量を記録・管理するためのフリーソフトウエアとして有望である．

1. Introduction

The International Commission on Radiological Protection recommends establishing diagnostic reference levels (DRLs) to optimize radiation dose for imaging procedure[1)]. Over the past decade, radiation dose optimization with DRLs has been implemented worldwide[2-8)]. Moreover, several reports suggest DRLs have contributed to reducing radiation dose in clinical practices[9, 10)]. The first step of radiation dose optimization is to obtain representative dose index values for each radiological examination in medical facilities. There are two principal approaches for collecting data: manual and automatic methods. Although manual data collection is simple, it has the problem of inaccurate data collection[11)]. Therefore, in recent years, a method that considers the value calculated from a dose management system (DMS)[12)], which can collectively manage radiation doses from radiological examinations, as the representative value of the medical facility and comparing the value with DRLs would be suitable for optimizing radiation doses[13)].

However, because commercially available

杉本 昂平[1)]，**松本 正輝**[2)]，**笈田 将皇**[3)]，**藤原 佑太**[4)]，**長崎 良太**[5)]，**正田 尊士**[6)]，**黒田 昌宏（医師）**[7)]

1）岡山大学大学院　ヘルスシステム統合科学研究科/医療法人　岡山画像診断センター　画像技術部
2）岡山大学大学院　ヘルスシステム統合科学研究科/愛媛大学医学部附属病院　診療支援部　診療放射線技術部門
3）岡山大学学術研究院　ヘルスシステム統合科学学域
4）社会医療法人　鴻仁会　岡山中央病院　診療技術部　診療放射線科
5）医療法人　青木内科小児科医院　放射線検査部
6）学校法人　川崎医科大学総合医療センター　中央放射線部
7）岡山大学学術研究院　保健学域

Received August 29, 2022; accepted May 24, 2023

DMSs are often expensive, there are problems with accelerating their introduction in all medical facilities. Under these circumstances, Japanese Enforcement Regulations on the Medical Care Act were revised in April 2020, making the recording and managing radiation doses mandatory for all medical facilities. Radiation dose recording is usually implemented by referring to the secondary capture output from the X-ray imaging modalities to the picture archiving and communications system (PACS). On the other hand, radiation dose management could be necessary to compare the representative dose index values of the facility with DRLs, and consider what to do if the representative values exceed one. As mentioned above, considering that manual recording of radiation doses is inaccurate[11] and comparing values calculated from DMS with DRLs as representative values are suitable[13], all medical facilities in Japan would be better to install DMS.

To achieve a possible solution, we have developed an open-source DMS called "MiSDO" that can record and manage radiation doses for the X-ray imaging modalities such as computed tomography (CT), angiography, and nuclear medicine examinations (URL: https://github.com/dose-mmasaki/MiSDO_release). Although there are several reports of developing in-house DMS systems for CT[14-21] and fluoroscopically guided intervention[20, 22-24] for referring to radiation dose information in digital imaging and communications in medicine (DICOM) format data. There has been no free DMS, including all modalities under the revised Enforcement Regulations on the Medical Care Act[14-24]. In this study, we verified the operation of "MiSDO" using DICOM files retrieved from diagnostic imaging modalities of several manufacturers. Then, we simulated the recording and management of radiation dose using "MiSDO" and clarified its usefulness.

2. Materials and Methods

2.1 Development environment and devices

The development environments were used Visual Studio 2019 (Microsoft Corporation, WA, USA) as the integrated development environment, Python (version 3.7.8; Python Software Foundation, DE, USA), and Visual C# (version 7.3; Microsoft Corporation, WA, USA) as the programming language, and SQLite as the database. Pydicom, a Python library, was used to process DICOM files, including radiation dose structured report (RDSR). A computer with Windows 10 education operating system (Microsoft Corporation, WA, USA), which has a single Intel core i5-3470S CPU 2.9-GHz processor and 4 GB RAM, was used to verify the software's operation. CT systems used were SOMATOM Sensation 64 (VB42B; Siemens, Munich, Germany), Discovery CT 750HD (17BW50.7B; GE Healthcare, WI, USA), Aquilion NEW PRIME TSX-303A/MW (7.0; Canon Medical Systems, Tochigi, Japan), and Aquilion 64 (3.10; Canon Medical Systems, Tochigi, Japan). Infinity Celeve-i INFX-8000C (N9; Canon Medical Systems, Tochigi, Japan), Symbia Dual Head System (VB10B; Siemens, Munich, Germany), and Biograph Horizon (VJ21B; Siemens, Munich, Germany) were used as angiography, single photon emission CT (SPECT) and positron emission tomography (PET)/CT systems, respectively.

2.2 Development of "MiSDO"

Figure 1A shows an overview of the system configuration of "MiSDO." It consists of two main modules for recording and managing radiation doses. The recording module consists of "DoNuTS," which extracts dose information from DICOM headers and RDSRs, and "ChuRROs," which automatically extracts dose information from secondary captures (only Aquilion 64) with an optical character reader (OCR). This OCR algorithm adds the image pixels in the column direction to obtain the

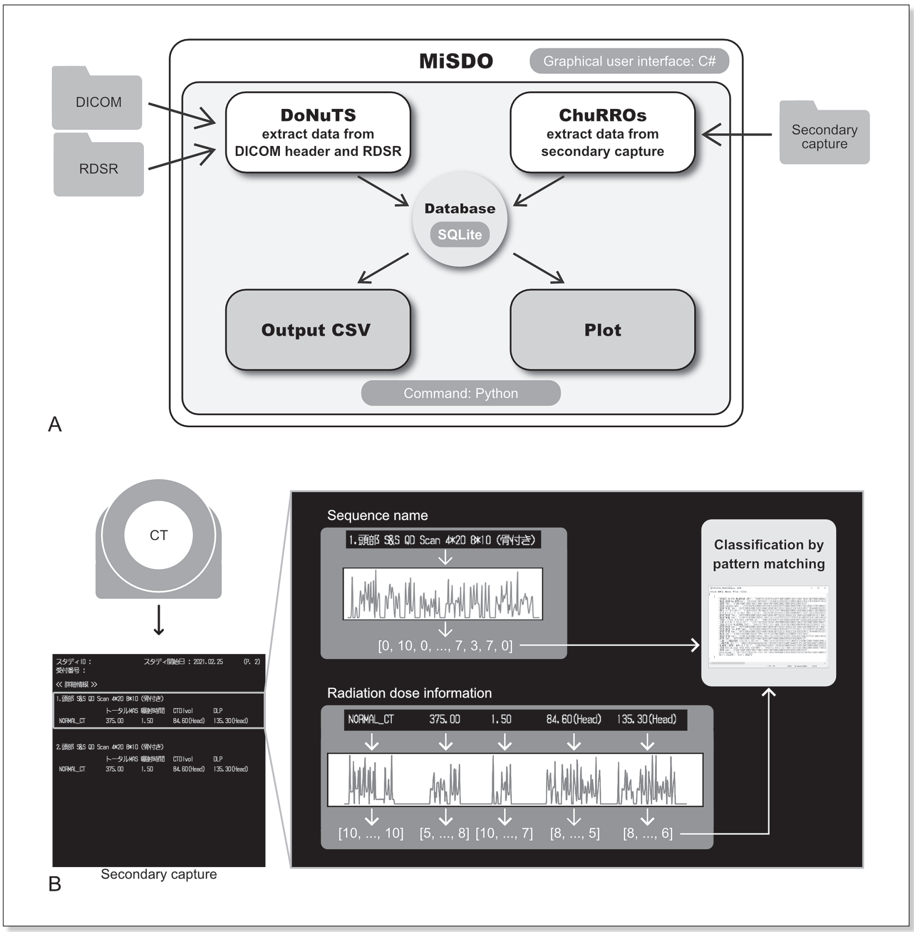

Fig.1 Overview and details of the developed radiation dose management system.

(A) An overview of the system configuration of "MiSDO."
(B) Details of the algorithm for the optical character reader function of "MiSDO." Character strings of secondary capture output from CT are acquired row by row, and the marginal distribution added in the column direction is used for character classification by pattern matching.

marginal distribution. Then, we performed the pattern matching classification between the marginal distribution and the previously registered information (Fig.1B). The radiation dose information of CT and X-ray angiography are extracted almost equivalently to the DEN Dose software[13]. Radiopharmaceutical dose is also extracted in nuclear medicine examinations, such as SPECT and PET. The management module consists of programs for visualization and output functions using data stored in the database. "MiSDO" was developed as a program that worked with these modules and could operate through a graphical user interface.

2.3 Operation validation of the developed DMS

The recording and management modules of "MiSDO" were operationally validated. A water phantom was scanned using one of the protocols routinely used in each imaging modality. Then, the RDSRs and secondary captures were retrieved from the CT, X-ray angiography, SPECT, and PET/CT devices in DICOM format. To verify the accuracy of OCR, randomly selected ten protocols from the protocols list used in clinical practice and scanned the phantom using the Aquilion 64. These DICOM files were imported using "MiSDO" to confirm that they were working correctly. Also, we simulated the recording and management of radiation dose from CT examinations. Referring to the report by Ogawa[25], the number of CT examinations per day was assumed to be 25. Then, the RDSR file outputs from Aquilion NEW PRIME TSX-303A/MW were duplicated for one day, one week, one month, six months, and one year, respectively. The number of these data were 25, 175, 700, 4,375, and 8,750, respectively. The volume CT dose index ($CTDI_{vol}$) and the dose length product (DLP) of the duplicated data were replaced with simulated data computed from regression equations created using patients' height and weight. "MiSDO" was used to store these data and measured the time required for analysis. The median values of the replicated one-year data were compared with the values of the routine chest CT scan for adults of the DRLs 2020 in Japan ($CTDI_{vol}$ = 13 mGy, DLP = 510 mGy·cm)[26].

3. Results

3.1 Operation validation

Figure 2 shows a screen capture of the developed DMS. All radiation dose information was extracted accurately without any errors from DICOM files of one scan for each of the six modalities (SOMATOM Sensation 64, Discovery CT 750HD, Aquilion NEW PRIME TSX-303A/MW, Infinity Celeve-i INFX-8000C, Symbia Dual Head System, and Biograph Horizon) and secondary captures of 10 scans for one modality (Aquilion 64).

3.2 Processing time

Figure 3 shows the time it took "MiSDO" to record the duplicated RDSR. The recording time increased as the number of data increased. The time required for 25 recordings for the number of daily examinations and

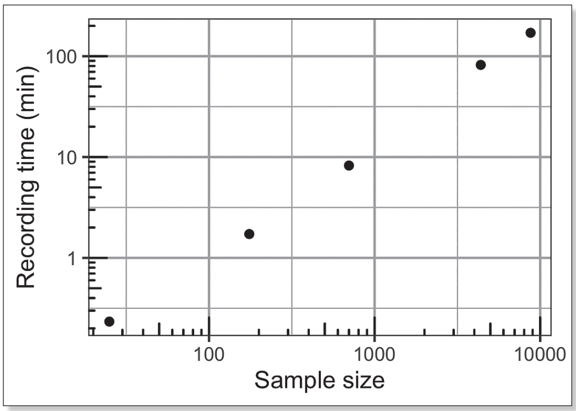

Fig.3 Double logarithmic plot of recording time for extracting information from duplicated radiation dose structured reports.

The time required for the Data analysis of 25 records for assuming some daily examinations, 175 records for weekly, 700 records for monthly, 4,375 records for semi-annually, and 8,750 records for annually were 14 seconds (0.23 min), 103 seconds (1.72 min), 494 seconds (8.23 min), 4,923 seconds (82.1 min), and 10,243 seconds (170.7 min), respectively.

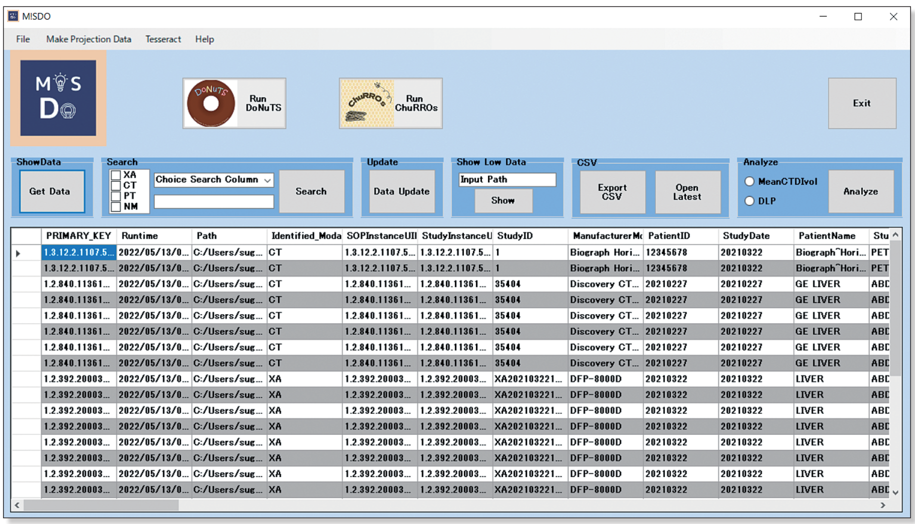

Fig.2 Screen capture of the developed radiation dose management system after extracting radiation dose information from multiple modalities.

8,750 recordings for annual examinations was 14 seconds (0.23 min) and 10,243 seconds (170.7 min), respectively.

3.3 Simulation of dose management

Figure 4 shows that the median $CTDI_{vol}$ and DLP of the standard body weight extracted from the duplicate RDSRs were 12.5 mGy and 487.2 mGy·cm, respectively. These data assume a routine chest CT scan for adults, and the corresponding values DRLs 2020 in Japan[26] are 13 mGy and 510 mGy·cm, respectively. The median values of the data simulated in this study were lower than those in DRLs.

4. Discussion

In this study, we verified that "MiSDO" could accurately extract data necessary for recording and managing radiation dose from multiple manufacturers' DICOM files retrieved from each modality. Furthermore, the extracted data were duplicated to simulate radiation dose management. "MiSDO" has been able to extract data quickly, revealing that it can accurately process large amounts of data generated in clinical practice. "MiSDO" can easily calculate representative dose index values and compare them with DRLs, suggesting that the system can be used as a tool to optimize radiation doses.

The developed DMS could extract information on one year of CT examination data (8,750 records) in less than three hours. The program that reads the data necessary for dose management only retrieves text data from the DICOM file so that the data can be extracted

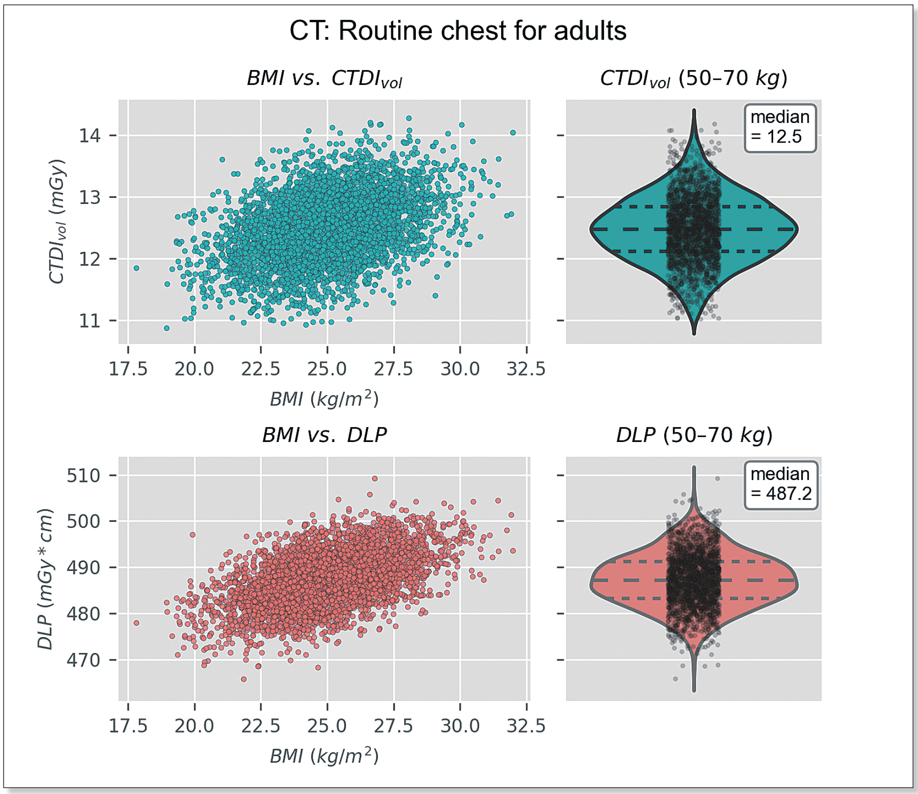

Fig.4 Scatter plots and violin plots for $CTDI_{vol}$ and DLP simulated routine chest CT scan for adults.

The left column shows the scatter plots, where the horizontal axis represents body mass index (BMI) and the vertical axis represents $CTDI_{vol}$ (first row) and DLP (second row). The right column shows violin plots of $CTDI_{vol}$ (first row) and DLP (second row) for standard body weight (50-70 kg). Strip plots are shown within the violin plots. The dotted lines in the violin plots are quartiles, representing the 25th, 50th, and 75th percentiles from the top, respectively. The median values of these data (12.5 and 487.2 mGy, respectively) are displayed in the upper right corner.

at high speed. The commercial DMS is designed to perform a DICOM query/retrieve on the PACS at night time to get the data into the DMS. "MiSDO" has been able to achieve short-time processing even on the local PC used for this simulation. Thus, we considered "MiSDO" acceptable enough for use in a clinical practice where data is expected to be extracted at night-time, similar to commercially available DMSs. Because there are many CT scanners in Japan[28], manual storage of radiation dose data is more time-consuming than in other countries. This issue may lead to prolonged work for radiological technologists. "MiSDO" could be an effective solution to this problem since the mechanical recording of radiation dose data can increase work efficiency and prevent human error.

"MiSDO" has the following two strengths compared to the previously reported in-house developed DMSs. The First is that all "MiSDO" source code is publicly available. Commercially available DMSs are guaranteed to work and are regularly inspected by the manufacturer. However, it is not possible with a free DMS. If the source code of the DMS is disclosed, the program errors can be addressed by reading the source code. RADIANCE[14] was a visionary open-source DMS; however, as of 2022, it is closed to the public. DEN Dose[20] is also a free DMS; however, the source code is not publicly available. Although there are several reports of other privately developed DMSs, the systems are private[19], or even if the source code is publicly available, only a limited number of systems[21] are available in the supported modalities. In other words, "MiSDO" is the only open-source DMS that supports many modalities.

The second is the ability to achieve accurate OCR for the Japanese. Compared to English, Japanese is more challenging to apply for OCR accurately due to the lack of spaces between words and the fact that it has more than 3,000 character types. Interestingly, "MiSDO" could read Japanese in secondary captured CT images with high accuracy. Since the secondary captured image is digital data, the marginal distribution of characters and phrases is uniquely determined. Therefore, it could be achieved with high accuracy by using a pattern-matching algorithm. To the best of our knowledge, the only language supported by the OCR functions of the free DMSs reported is English[14, 15, 17, 21], and this capability is an advantage when considering use in Japan.

A limitation of "MiSDO" is that it cannot connect with PACS. When using "MiSDO" to record dose information, it is necessary to read a DICOM file from the PACS system or to connect a workstation to the PACS and then process the data with "MiSDO". It is a significant drawback for fluoroscopically guided intervention, where the maximum skin dose needs to be calculated immediately; however, almost free DMSs also do not support this[27].

5. Conclusion

"MiSDO" is a DMS that can realize free and accurate recording and management of exposure doses. It is also the only free DMS compliant with the revised Japanese laws. "MiSDO" is expected to solve problems when manually recording and managing radiation doses.

Acknowledgments

We thank Mr. Eiji Ohnishi (Okayama Saiseikai General Hospital, Okayama, Japan) for his cooperation in obtaining image data.

Conflict of interest

The authors declare that they have no conflict of interest.

図の説明

Fig.1　開発した被ばく線量管理システムの概要と詳細.
（A）MiSDOのシステム構成の概要.
（B）MiSDOの光学式文字読取機能のアルゴリズムの詳細．CTから出力されたセカンダリキャプチャー画像の文字列を行ごとに取得し，列方向に加算された周辺分布を用いてパターンマッチングによる文字分類を行う.

Fig.2　複数のモダリティーから被ばく線量情報を抽出した後の，開発した被ばく線量管理システムの画面キャプチャー.

Fig.3　複製したradiation dose structured reportから情報を抽出したときの測定時間の両対数グラフ.
1日分25件，1週間分175件，1月分700件，半年分4,375件，そして1年間分8,750件のデータはそれぞれ14秒（0.23分），103秒（1.72分），494秒（8.23分），4,923秒（82.1分），そして10,243秒（170.7分）で測定された.

Fig.4　胸部1相の単純CT撮影を想定してシミュレーションされた$CTDI_{vol}$とDLPの散布図およびバイオリンプロット.
左列は散布図を示し，横軸はBody mass index，縦軸は$CTDI_{vol}$（1行目），DLP（2行目）を表す．右列は標準体型（50 kg ≤ weight ≤ 70 kg）の$CTDI_{vol}$（1行目），DLP（2行目）のバイオリンプロットを示す．バイオリンプロット内にはストリッププロットが表示されている．バイオリンプロット内の点線は四分位数であり，上から25パーセンタイル，50パーセンタイル，そして75パーセンタイルをそれぞれ表す．右上にはこれらのデータの中央値（それぞれ12.5，487.2 mGy）が示されている.

References

1) Vañó E, et al.: ICRP publication 135: Diagnostic reference levels in medical imaging. Ann ICRP, 46(1), 1-144, 2017.
2) Foley SJ, et al.: Establishment of CT diagnostic reference levels in Ireland. Br J Radiol, 85(1018), 1390-1397, 2012.
3) Fukushima Y, et al.: Diagnostic reference level of computed tomography (CT) in Japan. Radiat Prot Dosimetry, 151(1), 51-57, 2012.
4) Roch P, et al.: French diagnostic reference levels in diagnostic radiology, computed tomography and nuclear medicine: 2004-2008 review. Radiat Prot Dosimetry, 154(1), 52-75, 2012.
5) van der Molen AJ, et al.: A national survey on radiation dose in CT in The Netherlands. Insights Imaging, 4(3), 383-390, 2013.
6) Saeed MK, et al.: Regional survey of image quality and radiation dose in computed tomography examinations in Saudi Arabia. Australas Phys Eng Sci Med, 37(2), 279-283, 2014.
7) Sulieman A: Establishment of diagnostic reference levels in computed tomography for paediatric patients in Sudan: a pilot study. Radiat Prot Dosimetry, 165(1-4), 91-94, 2015.
8) Kanal KM, et al.: U.S. diagnostic reference levels and achievable doses for 10 adult CT examinations. Radiology, 284(1), 120-133, 2017.
9) Matsunaga Y, et al.: Diagnostic reference levels and achievable doses for common computed tomography examinations: Results from the Japanese nationwide dose survey. Br J Radiol, 92(1094), 20180290, 2019.
10) Katsari K, et al.: Implementation of a computed tomography dose management program across a multinational healthcare organization. Eur Radiol, 31(12), 9188-9197, 2021.
11) Dickinson N, et al.: A comparison of manually populated radiology information system digital radiographic data with electronic dose management systems. Br J Radiol, 93(1111), 20200055, 2020.
12) Gress DA, et al.: AAPM medical physics practice guideline 6.a.: Performance characteristics of radiation dose index monitoring systems. J Appl Clin Med Phys, 18(4), 12-22, 2017.
13) Osman ND, et al.: Radiation dose management in CT imaging: Initial experience with commercial dose watch software. J Phys Conf Ser, 1497(1), 012020, 2020.
14) Cook TS, et al.: Informatics in radiology: RADIANCE: An automated, enterprise-wide solution for archiving and reporting CT radiation dose estimates. Radiographics, 31(7), 1833-1846, 2011.
15) Shih G, et al.: Automated framework for digital radiation dose index reporting from CT dose reports. AJR Am J Roentgenol, 197(5). 1170-1174, 2011.
16) Christianson O, et al.: Automated size-specific CT dose monitoring program: Assessing variability in CT dose. Med Phys, 39(11), 7131-7139, 2012.
17) Sodickson A, et al.: Exposing exposure: Automated anatomy-specific CT radiation exposure extraction for quality assurance and radiation monitoring. Radiology, 264(2), 397-405, 2012.
18) Dave JK, et al.: Extraction of CT dose information from DICOM metadata: Automated Matlab-based approach. AJR Am J Roentgenol, 200(1), 142-145, 2013.
19) Nitrosi A, et al.: Patient dose management solution directly integrated in the RIS: “Gray Detector” software. J Digit Imaging, 27(6), 786-793, 2014.
20) Dendo Y, et al.: Development of computer code for dose management using DICOM radiation dose structured report in X-ray computed tomography. Medical Imaging and Information Sciences, 33(2), 43-47, 2016.
21) Weisenthal SJ, et al.: Open-source radiation exposure extraction engine (RE3) with patient-specific outlier detection. J Digit Imaging, 29(4), 406-419, 2016.
22) Johnson PB, et al.: Skin dose mapping for fluoroscopically guided interventions. Med Phys, 38(10), 5490-5499, 2011.
23) Borrego D, et al.: A hybrid phantom system for patient skin and organ dosimetry in fluoroscopically guided interventions. Med Phys, 44(9), 4928-4942, 2017.
24) Borrego D, et al.: Physical validation of UF-RIPSA: A rapid in-clinic peak skin dose mapping algorithm for fluoroscopically guided interventions. J Appl Clin Med Phys, 19(3), 343-350, 2018.
25) Ogawa K: Study on the running condition and the operation of CT in Saitama prefecture. Journal of JART, 60(8), 904-909, 2013.
26) Japan Network for Research and Information on Medical Exposure (J-RIME), et al. National diagnostic reference levels in Japan (2020) -Japan DRLs 2020-. [Accessed 21 May 2021] http://www.radher.jp/J-RIME/report/DRL2020_Engver.pdf
27) Malchair F, et al.: Review of skin dose calculation software in interventional cardiology. Phys Med, 80, 75-83, 2020.
28) OECD: Computed tomography (CT) scanners (indicator). [Accessed 26 December 2022]

06