A dose monitoring system for dental radiography

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ABSTRACT

Purpose: The current study investigates the feasibility of a platform for a nationwide dose monitoring system for dental radiography. The essential elements for an unerring system are also assessed.

Materials and Methods: An intraoral radiographic machine with 14 X-ray generators and five sensors, 45 panoramic radiographic machines, and 23 cone-beam computed tomography (CBCT) models used in Korean dental clinics were surveyed to investigate the type of dose report. A main server for storing the dose data from each radiographic machine was prepared. The dose report transfer pathways from the radiographic machine to the main sever were constructed. An effective dose calculation method was created based on the machine specifications and the exposure parameters of three intraoral radiographic machines, five panoramic radiographic machines, and four CBCTs. A viewing system was developed for both dentists and patients to view the calculated effective dose. Each procedure and the main server were integrated into one system.

Results: The dose data from each type of radiographic machine was successfully transferred to the main server and converted into an effective dose. The effective dose stored in the main server is automatically connected to a viewing program for dentist and patient access.

Conclusion: A patient radiation dose monitoring system is feasible for dental clinics. Future research in cooperation with clinicians, industry, and radiologists is needed to ensure format convertibility for an efficient dose monitoring system to monitor unexpected radiation dose. *(Imaging Sci Dent 2016; 46: 103-8)*

KEY WORDS: Protection; Radiation; Radiation Dosage; Radiography; Dental; Radiation monitoring

Introduction

Progress has been recently made in medical and dental imaging techniques. Diagnosis through x-ray imaging is a well-established trend in medicine with wide clinical use. Dental radiography is one of the most frequent types of radiological procedure that is routinely performed in dental clinics for new patients as well as established patients.[1] An intraoral x-ray examination is suggested for patients of all ages for regular screening to achieve a disease-free state.[2] The frequency of panoramic radiographic examination has also been greatly increased. According to a report in 2010, panoramic radiography examinations increased in Korea up to 112.6% in 2009 compared to 2006.[3]

However, the recent introduction of dental cone-beam computed tomography (CBCT) has raised the total patient dose in dental clinics. Even though the exposure dose from CBCT is relatively lower than that from conventional CT,

it is considerably higher than conventional dental radiography.[4,5] In addition, radiation dose varies greatly according to different models of CBCT with different fields-of-view (FOV). Ludlow et al.[6] measured the absorbed dose of three different CBCT models using full FOV. The result was striking in that it ranged from 2.5 mGy to 32.7 mGy. The effective dose with an ICRP2007 tissue weighting factor ranged from 58.9 μSv to 206.2 μSv when the FOV were changed in the same model.[4] Thus, radiation dose evaluation and management in dentistry has become a more important task for dental personnel.

A worldwide effort is ongoing to reduce patient radiation dose in diagnostic imaging. The principles of radiation protection, suggested by the International Commission for Radiation Protection (ICRP), consist of justification, optimization, and individual dose limitation. Under these principles, dose limitation in medicine is not specified by regulations. However, strict application of the principles of diagnostic imaging should be kept so that diagnostic image quality can be achieved with a minimal radiation dose. The United Kingdom builds and reviews the National Patient Dose Database every five years. Dental radiography was included in the latest review, and a Diagnostic Reference Level (DRL) was also suggested.[7] The Korean Ministry of Food and Drug Safety[8] reported the nationwide exposure dose of dental radiography including intraoral and panoramic radiography in 2009 and specifically for panoramic radiography in 2013.[9] DRLs were also recommended based on the data.

In the past, radiation protection focused on the nationwide collection and reduction of radiation dose. Now, the concept has shifted toward protecting individual patients from excessive radiation dose. In this concept, "exposure tracking" is defined as tracing the history of radiological examinations; "dose tracking" is applied when an individual dose is tracing.[10] Dose monitoring, including both exposure and dose tracking, supports the justification and optimization of an individual patient's radiologic procedure and radiation dose. Thus, many approaches have attempted to monitor and regulate the radiation dose of individual patients. The National Institutes of Health of the United States attempted to reduce the exposure radiation of patients by tracking individual patients. A radiation passport was developed in Canada to track radiation dose and estimate the associated cancer risks with a smart phone application.[11] In 2006, the International Atomic Energy Agency (IAEA) launched a smart card project aimed at developing a system for tracking the radiation dose of each individual. The IAEA meeting in 2013 stated that individual patient dose tracking with a smart card has been implemented in Estonia, Finland, Malta, and Sweden. Algeria, Bulgaria, Egypt, Macedonia, the Netherlands, Romania, South Korea, and Spain are currently working on constructing the foundation for such a system.[12]

In 2015, Rehani reported that the availability of a patient identification (ID) system with PACS connected to all hospitals would make it possible to construct a dose tracking system for the entire world.[13] Rehani and Berris surveyed 40 countries regarding the availability of a patient ID number to facilitate a radiologic examination dose tracking system.[14] They also investigated whether there were nationwide plans for the use of PACS networks to support a system. A total of 21 out of 40 counties answered that they had plans for establishing a national PACS. However, only six counties currently have a good network that connects most hospitals. They outlined several obstacles to stabilizing this system nationwide. One is keeping personal information safety. The other is a lack of technical support. However, an effort to overcome these difficulties continues worldwide.

The current study proposes a platform for a nationwide dose monitoring system for dental radiography. The essential elements for an unerring system are also assessed.

Materials and Methods

A survey was performed to investigate the type of dose report of various models of dental radiography including intraoral, panoramic radiography, and CBCT. A dose report was defined as any information related to the exposure dose of a radiographic examination, such as the exposure conditions (kVp, mA, and exposure seconds), entrance air kerma (EAK), entrance surface dose (ESD), or dose area product (DAP). A questionnaire was sent to the manufacturer or importer if the corresponding radiographic machine exported images were in a Digital Imaging and Communication in Medicine (DICOM) file. If so, the type of dose report included in the DICOM file was recorded. Intraoral radiographic machines (14 models of X-ray generators and five models of sensors), 45 models of panoramic radiographic machines, and 23 models of CBCT currently used in Korean dental clinics were included in the survey. The items in the questionnaire are listed in Figure 1.

A main server for integrating the dose report data from each radiographic machine was prepared. A dose report transfer method from each radiographic machine to the main server was established as there are three possible

pathways considering all types of dose reports. The first pathway is for radiographic machines that do not output DICOM files. The exposure conditions (kVp, mAs, and seconds) were manually inputted into the main server according to the type of radiographic examination that the patient had undergone. The other two pathways are for those machines that output DICOM file including a dose report (Fig. 2). One was for radiographic machines that have single output port and send the DICOM file only to the PACS. Then, the dose report was extracted from the DICOM file and sent to the main server. The other is for machines with multiple output port that send a dose report directly that send a dose report directly to the main server and an image to the PACS.

The dose report that is sent to the main server is converted into an effective dose and stored as an individual patient database. For converting various types of dose report into an effective dose, a new computer program was introduced. The machine specification and exposure parameters of frequently used models in Korean dental clinics (three intraoral radiographic machines, five panoramic radiographic machines, and four CBCTs) were investigated to develop a program called D-dose (Table 1). The calculated effective dose is stored in the main server of the individual patient database.

A viewing system where each patient can access his or her effective dose was constructed and synchronized with the main server. A radio frequency identification (RFID) card was provided to each patient with his or her resident registration number recorded in it. When the patient tags the card to the system, the effective dose of the latest examination that the patient has undergone is recalled from the main server and displayed on a monitor. For security, the patient is required to enter the first six numbers of their resident registration number, which matches the RFID

|	Intraoral radiography	Panoramic radiography	CBCT
1	X-ray generator Manufacturer: ( ) Model: ( ) Sensor / Film Manufacturer: ( ) Model: ( )	Manufacturer : ( ) Model : ( ) Type: ❑ CR ❑ DR ❑ Film	Manufacturer : ( ) Model : ( )
2	Available to output image as DICOM file? ❑ Yes ❑ No		
3	Choose one or more dose information reported in DICOM header. (Answer this question, if 'Yes' in #2) ❑ kVp, mA, and second ❑ ESD* ❑ EAK* ❑ DAP* ❑ None		

Fig. 1. Items in a questionnaire for dental radiographic machines. *ESD: entrance surface dose, EAK: entrance air kerma, DAP: dose area product.
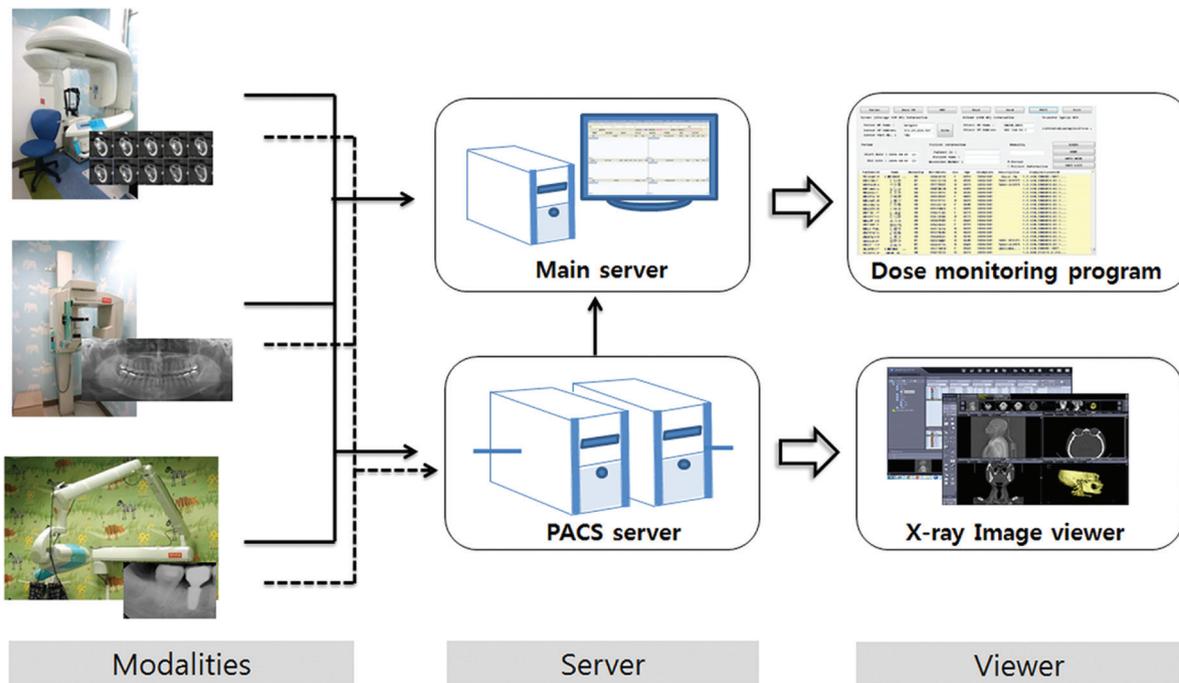
Fig. 2. Flows of the dose report and X-ray image obtained from different radiographic machines to the main server (--- single ouput port, — multiple output port).

Table 1. Specification and exposure parameters investigated for each modality.

Intraoral radiography	Exposure area	Exposure body part, area, angle, and collimator type (round)
	Exposure condition	kVp, mAs, filtration, FSD
	Measured dose type	ESD, DAP
Panoramic radiography	Exposure area	manufacturer, models
	Exposure condition	Rotational angle, rotational path, beam slit size (width x height)
	Measured dose type	kVp, mAs, filtration, SID
CBCT	Exposure area	Exposure area, rotational angle, FOV, shape of beam (full beam, half beam)
	Exposure condition	kVp, mAs, filtraiton, SID
	Measured dose type	EAK, DAP
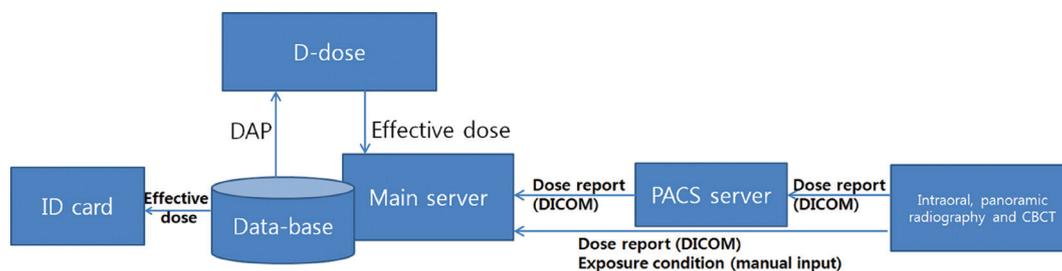
Fig. 3. Schematic view of the dose report transfer, conversion, and store process in the dose monitoring system.

card. This viewing system is also provided in administrator mode so clinicians can confirm each patient's history of radiographic examinations and cumulative effective dose.

The entire system was simulated with patients visiting Seoul National University Dental Hospital, and the overall system flow is described in Figure 3.

Results

The dose report from each modality of the radiographic machines was successfully transferred to the main server and converted into an effective dose via D-dose. The effective dose was then stored in the main server as well as in the patient RFID card without any errors. The exposure condition with the exposed region, which was manually inputted into the main server, was also safely converted into an effective dose by D-dose. There were no errors in storing the effective dose in the main server.

All of the models of the intraoral radiographic machines showed either no DICOM output or a DICOM output without a dose report. For those models that cannot output DICOM, manual input of kVp, mA, exposure seconds, and exposed area were performed. An image sending program for those machines that output DICOM without a dose report was modified to include the dose report (kVp, mA, exposure seconds, and exposed area) in a DICOM file.

The panoramic radiographic machines showed all types of dose report: with or without DICOM output, and single or multiple output port. As for the intraoral radiographic machine, manual input of kVp, mA, and exposure seconds was performed for models without DICOM output. For machines with single output port, a retrieve program from PACS server to dose server was established. All of the models of the CBCT were available to export the dose report to the main sever, either directly or to pass through PACS.

Discussion

The radiation dose of diagnostic radiography in dentistry is relatively low compared to that in medicine. However, regulation of radiation dose in dentistry is still an important issue since the frequency of examinations is higher than in medical radiography. In addition, radiation dose has shown a tendency to increase the DAP value of panoramic radiography. It showed an increase from 106.6 mGy cm^2 in 2006 to 143.8 mGy cm^2 in 2013.[8,9] To reduce noise in digital radiography, there is a tendency toward overexposure that has been called the "dose creep" phenomenon.[15] The recent introduction of CBCT has also increased total patient dose in dentistry. In particular, the radiation dose of CBCT varies greatly in different models. Evaluation of the radiation dose of dental radiography

is therefore required. Thus, the effort to reduce radiation dose in dental imaging is increasingly important.

Previous studies have attempted to recommend a DRL value based on a nationwide survey of dental radiation dose.[8,9] Researchers who study nationwide radiation dose have worked toward reducing radiation dose through measures such as investigating the causes of a high radiation dose when it is over the DRL value. In the present time, diagnostic radiation dose reduction has shifted focus toward individual dose tracking and monitoring. Seuri et al.[16] reported that individual patient dose tracking helps to justify and optimize the radiation dose of CT examinations in Finland. They introduced four cases of dose tracking that made it possible to avoid new CT examinations or adjust patient-specific exposure parameters. Based on the recent trend of individual patient dose tracking, the current study introduced a system to monitor the radiation dose of dental radiography.

Rehani and Berris stated in their 2013 report that PACS was essential to construct a dose tracking system.[14] In the current study, both a PACS and non-PACS environment were included. In the PACS environment, extraction of the dose report was required for effective dose calculation and monitoring. However, some image acquisition programs did not export the dose report within a DICOM file. For such cases, an image acquisition program was modified to include the dose report when exporting the DICOM file. An additional problem was that most local dental clinics in Korea are not in a PACS environment. Many intraoral and panoramic machines do not export an image as a DICOM file. For these machines, a manual input system of the exposure conditions was developed so that dose tracking would be possible even in non-PACS environments. However, manual input is a cumbersome procedure. Furthermore, the dose report transfer process becomes more complicated for some intraoral radiography machines that are a combination of an X-ray generator and a sensor from different manufacturers. Hence, future study is needed to ensure compatibility in transferring the dose report from each model of the radiographic machines with the cooperation of manufacturers. Furthermore, construction of a nationwide PACS infrastructure is essential for an efficient dose monitoring system. Radiographic machines with multiple output port are additional condition for unerring system flow.

For the present system, the resident registration number of individual patients was used so that the effective dose data could be updated even when the patient underwent an X-ray examination at a different dental clinic. Employing a unique patient ID number for radiologic examinations in hospitals is another essential factor for a dose tracking system along with PACS.[14] A unique patient ID number is crucial for dose monitoring system convertibility among different hospitals. For personal information protection, we coded the dose viewer system as two different modes, patient and administrator. In administrator mode, a supervisor can monitor and track each patient's effective dose data and examination history. However, individual patients are allowed to view his or her own effective dose via the patient mode of the viewer program. For personal security, the viewer system was only activated when the patient tagged the RFID card on the system and entered his or her birthdate.

However, there are some limitations of the research. There are a large number of panoramic radiography models from numerous manufacturers. This is problematic because different models from different manufacturers show numerous combinations of exposure parameters and diverse mechanical geometries that are sensitive to effective dose calculation. For the present study, five of the most common models in Korean dental clinics were selected, and their exposure parameters and mechanical geometry were studied to convert the dose report into the effective dose. The converting program, D-dose, may result in an error-prone effective dose when applied to other panoramic radiographic models rather than the five models used in this study. Therefore, to obtain the effective dose specific to a machine, the DAP value of the corresponding panoramic machine must be entered into D-dose when installing the program.

CBCT mostly shows the dose report in a DICOM file. Therefore, clinicians may recognize the values. However, unlike a multi-detector CT equipped with an ion chamber to measure dose, this is not the true measured value. Rather, the value is inputted by the manufacturer when initially produced. Thus, the value may differ from the actual radiation dose. It may be suggested for manufacturer to produce CBCT equipped with radiation dose meter, since the radiation dose of the machine may be differed with various conditions.

In order to reduce the radiation dose in dental diagnostic systems, nationwide radiation dose evaluation and data collection have been performed.[1,7-9,17,18] Based on this cumulative database, the present study introduces a monitoring system for the radiation dose of individual patients. Our goal is an attempt to develop a helpful aid for overall dose reduction.

However, overall dose reduction is the responsibility

of the entire dental community, including industry, dental clinicians, and radiologists. Clinicians should recognize the amount of a patient's radiation exposure and perform an examination only when the benefit is greater than the risk. Radiologists should minimize the dose while obtaining interpretable image quality. Manufacturers should produce machines equipped with a compatible or at least a convertible dose reporting system. Furthermore, all of these stakeholders must work together for the benefit of patients.

In conclusion, a patient radiation dose monitoring system is feasible for dental clinics. However, implementation would require further research and cooperation between clinicians, industry, and radiologists to create an efficient dose monitoring system that helps to unexpected patient radiation dose.

References

1. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 2008 report to the General Assembly, with scientific annexes. New York: United Nations: 2010.
2. American Dental Association. Updated ADA recommendations on dental x-rays. J Can Dent Assoc 2013; 79: d7.
3. Kim HJ. A study on investigation and analysis of medical radiation usage. Final report. Chungcheongbuk-do: Korean Ministry of Food and Drug Safety; 2010 Dec. Report no.10171Radiology457.
4. Roberts JA, Drage NA, Davies J, Thomas DW. Effective dose from cone beam CT examinations in dentistry. Br J Radiol 2009; 82: 35-40.
5. Loubele M, Bogaerts R, Van Dijck E, Pauwels R, Vanheusden S, Suetens P, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. Eur J Radiol 2009; 71: 461-8.
6. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. Dosimetry of 3 CBCT devices for oral and maxillofacial radiology: CB Mercuray, NewTom 3G and i-CAT. Dentomaxillofac Radiol 2006; 35: 219-26.
7. Hart D, Hillier MC, Wall BF. National reference doses for common radiographic, fluoroscopic and dental X-ray examinations in the UK. Br J Radiol 2009; 82: 1-12.
8. Kim EK. Development of diagnostic reference level in dental x-ray examination in Korea. Fianl report. Chungcheongbuk-do: Korean Ministry of Food and Drug Safety. 2009 Nov. Report no. 09142Radiology510.
9. Kim EK. Evaluation of patient dose for diagnostic reference levels in adult and pediatric dental panoramic radiography. Final report. Chungcheongbuk-do: Korean Ministry of Food and Drug Safety. 2014 Jul. Report no. 13172Radiology586.
10. Technical meeting on patient radition exposure tracking: progress assessment and development of further actions. Conference. Vienna: International Atomic Energy Agency. 2013 Sep. Conference code. 44107.
11. Baerlocher MO, Talanow R, Baerlocher AF. Radiation passport: an iPhone and iPod touch application to track radiation dose and estimate associated cancer risks. J Am Coll Radiol 2010; 7: 277-80.
12. Henriques S. A new way of thinking about patient radiation exposure. Division of public information. Vienna: International Atomic Energy Agency. 2013 Oct.
13. Rehani MM. Tracking of examination and dose: overview. Radiat Prot Dosimetry 2015; 165: 50-2.
14. Rehani MM, Berris T. Radiation exposure tracking: survey of unique patient identification number in 40 countries. AJR Am J Roentgenol 2013; 200: 776-9.
15. AlSuwaidi JS, AlMazrouei NK, Pottybindu S, Siraj M, Mathew D, Al Blooshi AA, et al. Patient dose monitoring in Dubai in radiography and interventional procedures. Ann ICRP 2015; 44(1 Suppl): 249-58.
16. Seuri R, Rehani MM, Kortesniemi M. How tracking radiologic procedures and dose helps: experience from Finland. AJR Am J Roentgenol 2013; 200: 771-5.
17. Hughes JS, Watson SJ, Jones AL, Oatway WB. Review of the radiation exposure of the UK population. J Radiol Prot 2005; 25: 493-6.
18. Hricak H, Brenner DJ, Adelstein SJ, Frush DP, Hall EJ, Howell RW, et al. Managing radiation use in medical imaging: a multifaceted challenge. Radiology 2011; 258: 889-905.