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**Development of an Online Automatic Diagnostic Reference Levels Management
System for Digital Radiography: A Pilot Experience**

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Abstract

The diagnostic reference levels (DRLs) concept is a methodology proposed by the International Commission on Radiological Protection (ICRP) for identifying any unusual high patient doses involved in radiological examinations. However, some

challenges are anticipated in the DRLs concept including resource demand for running the audit cycle by individual imaging departments and availability of DRLs. The objective of this study was to develop an online automatic DRLs management system for digital radiography (DR) with the aim of addressing the challenges of the DRLs obligation.

An online automatic DRLs management system for DR composed of freeware was developed. The system was tested with 75 DR images. This pilot experience shows that the system successfully addresses the challenges in the DRLs management, i.e. resource demand for running the audit cycle by individual imaging departments and availability of DRLs. It can provide at a low cost an efficient and effective solution to the implementation of regular audits of patient doses using DR in busy clinical departments. It can also contribute to the development of DRLs at local and national levels. In this way, any unacceptable radiological practice (examination used unjustified high radiation dose) can be identified.

Keywords

Diagnostic Reference Levels

Digital Radiography

Radiation Dose Monitoring

PACS

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1. Introduction

Patient dose monitoring in radiological examinations is not a new concept in radiation protection. Different ways have been suggested to achieve this purpose [1]. In 1996, the International Commission on Radiological Protection (ICRP) introduced the concept of diagnostic reference levels (DRLs) for use as a simple test to identify any unusual high patient doses involved in radiological examinations [2]. It is a quality audit cycle to evaluate patient doses of different examinations in an imaging department against DRLs. A DRL is a reference value of radiation dose set at the third quartile (Q3) of a number of measurements of entrance skin dose (ESD) or dose area product (DAP) of a type of examination or projection in normal situations. In this way, unacceptable radiological practice (examination used unjustified high radiation dose) can be identified [1,3]. This concept was adopted by influential bodies such as the European Commission (EC) [4] and the American College of Radiology (ACR) [3], and has been adopted as a legal requirement in some countries such as the United Kingdom (UK) [5-7].

However, some challenges are anticipated in the DRLs concept including resource demand for running the audit cycle by individual imaging departments and availability of DRLs [5,7]. Although some countries have established national DRLs determined by different dose surveys such as the five-yearly reviews of the National Patient Dose Database (NPDD) by National Radiological Protection Board (NRPB), UK [5,7,8], these only cover some of the common radiological examinations [1,7]. This requires individual imaging centres to determine their own local DRLs based on data obtained from their daily clinical practices to fill this gap [1,6,7].

Recently, more clinical centres have DAP meters installed for their imaging modalities [1]. For some products such as the Philips DigitalDiagnost digital radiography (DR) system, the measured DAP value is also recorded in the Digital Imaging and Communication in Medicine (DICOM) header (tag 0018-115E – image area dose product) of an image [9,10]. This creates an opportunity to adopt a data mining approach to extract this DAP value for an automatic audit process [11]. In this way, it is also feasible to feed the Q3 value of the result back to the audit system as the local DRL for future audit cycles. The objective of this study was to develop an online automatic DRLs management system for DR with the aim of addressing the challenges of the DRLs obligation.

2. Materials and Methods

As the proposed online automatic DRLs management system for DR aims at providing dose monitoring function against DRLs and setting local DRLs based on evaluated results, its nature is similar to a study conducted by Ng and Sun about development of an online automatic computed radiography (CR) dose data mining program [11]. The methodology of the development of the dose data mining program is therefore adapted into this study. Taking into consideration the possibility of low cost and easy implementation of the DRLs management system, the following softwares and hardware are used for the system including ConQuest DICOM server 1.4.15 freeware PACS [12], Microsoft SQL Server 2005 Express freeware database management system (DBMS), Microsoft Windows XP Professional operating system (OS) with Internet Information Services (IIS) 5.1 web server and Dell Latitude D630

laptop. A model of a DRLs management system for DR based on the model of the CR dose data mining program of Ng and Sun [11] is proposed (Fig. 1).

Fig. 1 – A model of a DRLs management system for DR.

In this model, all components of the DRLs management system such as a PACS, a web server for execution of Active Server Pages (ASP) scripts (ASP-VBScript) and a component object model (COM) object are installed into a laptop. The laptop can be connected to a DICOM-compliant imaging informatics infrastructure such as a clinical PACS which can initiate a push-mode operation (storage service class user (SCU)) to send DR DICOM images for evaluation to the PACS inside the laptop (storage service class provider (SCP)) (step 1). A web client such as a person in charge of dose monitoring can use a web browser to provide different evaluation parameters such as study period and DRLs of different examinations to the web server over the network such as internet or intranet (step 2). The web server executes appropriate ASP scripts, i.e. the DRLs management system to retrieve the file paths of DICOM images matching the search (evaluation) parameters from the local PACS database using structured query language (SQL) (step 3). These scripts then retrieve the DICOM files from the local image archive system (step 4) and execute a freeware COM object, ezDICOMax Library 1.0, ezDICOM [13], to extract header information from the DICOM images (step 5). The extracted headers are further processed by the ASP scripts to mine values of relevant tags including study date, patient's sex, patient's age, body part examined, view position, image area dose product (DAP), distance source to detector, kilovoltage peak (kVp), exposure (mAs), rectification type, filter type, grid, institution name, station name, patient's weight, patient's size,

body part thickness, exposure control mode, film size identifier (ID), manufacturer and plate type. The extracted information is exported to a comma separated values (CSV) file, providing a possibility for further Microsoft Excel manipulation such as for patient dose data submission to NRPB, UK [5,14].

The DAP is also analysed by the algorithms inside the ASP scripts to provide a series of descriptive statistics such as mean, standard deviation (SD), median, first quartile (Q1), Q3, interquartile range (IQR), minimum, maximum, range and percentage of images above DRLs. These results are then exported to a CSV file again and sent to the web browser for display. The user can also select Q3s or medians from the displayed results and save them into the system as local DRLs for future audit use, i.e. the feedback cycle (step 6) [7].

The extracted DICOM tag values from DR images, descriptive statistics displayed in the dose reports and local DRLs obtained from evaluated results were verified by comparing them with the figures obtained using a manual approach. If no discrepancy was found, this would indicate successful development of the system for the stated purposes [11].

3. Results

Using the proposed model shown in Fig. 1, an online automatic DRLs management system for DR which can provide dose monitoring function against DRLs and setting local DRLs based on evaluated results, was developed. There is a login page for authentication to secure the information. Other security measures include timestamp

to show the last login time and 'Logout' once finished using the system. A user is directed to the dose monitoring (DRLs management) system through the login page upon successful authentication (Fig. 2).

In Fig. 2, the first rectangle highlights the main menu for the user to input the evaluation parameters. The evaluation method can be either DRL or exposure index (EI). However, EI evaluation is not described in this paper due to its scope and the details can be found in our previous study [11]. DAP values of DR examinations in a chosen period can be compared against either national or local DRLs which are set in advance through the 'Settings' option noted in the second rectangle. The '% of Images above DRLs > ... % Considered as Unacceptable' field allows the user to select a criterion to determine unacceptable radiological practice (examination used unjustified high radiation dose). After the evaluation period and criteria are provided, and the 'Submit' button is clicked, the dose report for the selected period is generated automatically as shown in the fourth rectangle. This dose report lists the descriptive statistics of DAP of different regions of interest and the last row of the table displays the figures of all examinations taken in the selected period.

Fig. 2 – A snapshot of the online automatic DRLs management system for DR.

Rectangle 1: evaluation parameter input menu; rectangle 2: 'DRLs Settings', 'User Account Management' and logout buttons; rectangle 3: user name and last login time (timestamp); rectangle 4: dose report; rectangle 5: report, data and system log export buttons.

Provided that DRLs of projections under these regions have been made available to the system in advance, rows are highlighted in red if their corresponding ‘percentages of images above DRLs’ are greater than the inputted percentage in the evaluation parameter input menu, indicating unacceptable radiological practice (examination used unjustified high radiation dose) occurred. Asterisks after names of examinations indicate the DRLs of projections are absent and comparisons cannot be made. The user can view a detailed dose report of a region of interest through accessing the corresponding link under the ‘Examination’ column, i.e. clicking the region name. A new window is opened to show audit results for projections of the selected region undertaken in the chosen evaluation period as shown in the first rectangle of Fig. 3. Figures are highlighted in red if they are beyond the preset DRLs. The user can check boxes under the ‘As Local DRL?’ column for different projections and click the ‘Update’ button highlighted in the second rectangle if the use is required of the Q3 DAP values of the selected projections as local DRLs for future audit cycles. The third rectangle shows two ‘Export’ buttons, one for exporting the displayed summary and another for exporting extracted DICOM header information of DR images under the selected region and period in CSV format which is the information required by NRPB, UK (fourth rectangle) [5,14]. The CSV file export function also provides a possibility for further Microsoft Excel manipulation to suit different users’ needs such as for obtaining average values of kVp and mAs. The same buttons are also available in the system main page for exporting again the displayed summary and the corresponding extracted DICOM header information.

Fig. 3 – A snapshot of the detailed dose report. Rectangle 1: audit results for projections; rectangle 2: ‘Update’ button; rectangle 3: report and data export buttons;

rectangle 4: extracted DICOM header information exported into a CSV file for submission to NRPB, UK. The column headings noted in the CSV file are the same as the data fields used for NPDD although some headings cannot be shown in full in this illustration such as the column, 'Exposure settings' displayed as 'Exposure'. Further information can be obtained from Health Protection Agency, UK (http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1194947358851) [14].

In Fig. 4, the 'Settings' page for the DRLs maintenance is shown. The user can select appropriate parameters from the menus highlighted in the first and second rectangles to add, delete or change either national or local DRLs. The third rectangle shows the menu for changing the local DRL for a postero-anterior (PA) chest projection which was obtained from the previous audit result. 'Comparison Norm' is used to indicate either its Q3 ('Limit') or median will be used for comparison with DAP values of chest PA projections. The DRLs can also be exported into a CSV file (fifth rectangle) if the 'Export' button is clicked (fourth rectangle).

Fig. 4 – A snapshot of the 'DRLs Settings' page. Rectangle 1: action menu; rectangle 2: filter and search menu; rectangle 3: menu for adding / deleting / changing DRL information. 'Upper Limit' and 'Lower Limit' are the Q3 and Q1 values from a dose report respectively. However, either Q3 or median will be used for comparison; rectangle 4: DRLs export button; rectangle 5: DRLs exported into a CSV file.

This system has been tested with 75 Philips DR images. The extracted DICOM tag values, descriptive statistics displayed in the dose reports and local DRLs obtained

from evaluated results were verified by comparing them with the figures obtained using a manual approach. No discrepancy was found.

4. Discussion

This study suggests an online automatic DRLs management system for DR can be successfully developed and applied to the clinical environment. It addresses the challenges in the DRLs management, i.e. resource demand for running the audit cycle by individual imaging departments and availability of DRLs [5,7]. The system is composed of freeware except the OS. It can run on a typical OS such as Microsoft Windows XP Professional and a simple workstation such as a laptop. It can also be connected to a DICOM-compliant imaging informatics infrastructure such as a clinical PACS. In this way, the laptop can act as a mobile PACS application server for DRLs management which can be easily implemented at a low cost [15]. The use of web technology further increases the accessibility of the system. Most importantly, the audit process automation provided by the system relieves the demand on human resources, and efficiency (fast report generation) and effectiveness (elimination of human error) are assured [11].

The 'As Local DRL?' function provides a convenient way to set local DRLs based on evaluated results so as to form a quality improvement feedback cycle aligning with the requirements of DRLs practice [1,6,7]. In this way, the limited availability of DRLs can be addressed effortlessly. Although the DRLs should normally be set at Q3 which is the default setting of the system when the 'As Local DRL?' function is used for identifying any unacceptable radiological practice (examination used unjustified

high radiation dose), this system also provides the flexibility for selecting median values of evaluated results as local DRLs for comparison in the 'DRLs Settings' page [1,3]. The original concept of DRLs was for identification of unusual high patient doses involved in radiological examinations [2]. The doses of examinations undertaken in most clinical departments will be below or the same as the DRLs, i.e. reasonably justified if DRLs are set at Q3 [3]. In the studies conducted by Crawley and Rogers [16] and Pillai and Jain [7], they suggested the use of medians as DRLs in orthopaedic setting. It seems fewer dose values of practices will fall below the DRLs if DRLs are set at median. However, this arrangement may be able to promote use of a narrower range of radiation doses for examinations leading to a good practice [17]. Another aspect of the system that addresses the issue of limited availability of DRLs, is the export function of extracted DICOM header information in CSV format for submission to NRPB, UK. Although it is not a legal obligation to submit the dose data to NRPB by imaging centers in UK, NRPB encourages them to do this because the data are useful in its five-yearly reviews of the NPDD. In turn, this is used for the development of national DRLs [5].

Although some previous studies reported developments of computer programs to provide some degree of radiation dose audit automation for DR examinations [18-20], the system developed in this study can provide different or even better DRLs management experience to users. For example, Schuncke and Neitzel [19] suggested an approach to manually export a log file of examination parameters including DAP from a DR system console for a Microsoft Visual Basic program to execute an automatic analysis of radiation dose. However, involvement of manual procedures limits the potential of the system to generate real-time dynamic audit results because

it requires an individual to provide latest data to the program when an update report is required. This may also lead to human errors in the manual process which will affect the report accuracy [11]. In the studies conducted by Rampado et al. [18] and Vano et al. [20], their programs had direct access to DR DICOM header information which should provide a better degree of radiation dose audit automation. However, functionality for addressing availability of DRLs was not provided.

The limitation of this study is that the system has not been evaluated extensively (e.g. clinically) although it has been tested with Philips DR images at our institution. This then is a direction for further studies. Although it may appear that the data mining process may induce a risk to patient privacy, implementation of security measures could safeguard the patient confidentiality and prevent abuse by users. These include extraction of only dose-related information from DICOM headers and with user authentication [11,21]. Further protection can be achieved by restricting the system access such as being only available via intranet, i.e. within clinical departments or hospitals [11].

5. Conclusion

An online automatic DRLs management system which can be applied to DR systems was developed. Our pilot experience shows that the system successfully addresses the challenges of DRLs management. This provides a low cost, efficient and effective solution to the implementation of regular audits of patient doses of DR in busy clinical departments. It can also contribute to the development of DRLs at local and

national levels. In this way, any unacceptable radiological practice (examination used unjustified high radiation dose) can be identified.

Conflict of interest

None declared.

Acknowledgement

We gratefully acknowledge Dr. Janice C. McKay for the manuscript review.

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