Patient Dose Management Solution Directly Integrated in the RIS: “Gray Detector” Software

A. Nitrosi · A. Corazza · M. Bertolini · R. Sghedoni ·
P. Pattacini · M. Iori

Published online: 26 June 2014
© Society for Imaging Informatics in Medicine 2014

Abstract On X-ray modalities, the information concerning the dose delivered to the patient is usually available in image headers or in structured reports stored in the picture archiving and communication system (PACS). Sometimes this information is sent in the Modality Performed Procedure Step message. By saving the information inside the Radiological Information System, it can be linked to the patient and to his/her episode/request. A software, “Gray Detector,” implementing different and complementary extraction methods was developed. Query/retrieve on images header, Modality Performed Procedure Step message analysis, or the combination of the two methods were used. In order to avoid erroneous dose-protocol association, every accession number is linked to its unique report code, allowing multiple-protocols exam recognition. The adoption of different methods to extract dosimetric information makes it possible to integrate any kind of modality in a vendor/version neutral way. Linking the dosimetric information received from a modality to the patient and to the unique report code solves, for example, common problems in computed tomography exams, where the dosimetric value related to multiple segments/studies on the modality can be associated by the technician who performs the exam only to one accession number corresponding to a single study/segment. Analyses of dosimetric indexes’ dependence on modality type, patient age, technician, and radiologist were performed. Linking dosimetric

information to radiological information system data allows a contextualization of the former and helps to optimize the image-quality/dose ratio, thereby making it possible to take a clinical decision that is “patient-centered.”

Keywords Radiation dose · Radiology information systems (RIS) · Electronic medical record (EMR) · Medical informatics applications · Data collection · Information storage and retrieval · Information management

Background

In the current digital era, the registration and analysis of dosimetric values should be mandatory to regularly optimize examination protocols according to the ALARA [1] (as low as reasonably achievable) basic radiation protection principle. Many papers have highlighted this concept and described different solutions [2–7] even if few discuss the possibility to integrate it within the radiological information system (RIS) [8]. The RIS contains patients’ personal data and exams done, but it usually does not store dosimetric information about those exams. This information is sent through the modality performed procedure step (MPPS) or is stored in the image header in the picture archiving and communication system (PACS). By saving the information from modalities (MPPS or Digital Imaging and Communications in Medicine (DICOM) header) in RIS, we can correctly relate it to the patient, to the request/episode, and to his/her clinical data. This association will let us create a database containing the dosimetric history of patients and obtain that information to improve procedures and evaluate the compliance with the Italian diagnostic reference levels (DRLs) [9].

Linking dosimetric value to RIS will also solve problems common in CT such as the association of the dosimetric value related to multiple studies to the same protocol, when the

A. Nitrosi (✉) · A. Corazza · M. Bertolini · R. Sghedoni · M. Iori
Medical Physics Unit, Arcispedale Santa Maria Nuova Hospital
IRCCS, Reggio Emilia, Italy
e-mail: nitrosi.andrea@asmn.re.it

A. Corazza
Specialization School in Medical Physics, University of Bologna,
Bologna, Italy

P. Pattacini
Department of Diagnostic Imaging, Arcispedale Santa Maria Nuova
Hospital IRCCS, Reggio Emilia, Italy

name of this single protocol is used to describe the whole study.

In this paper, we will discuss our radiation management solution, which is directly integrated into the RIS, thus making it possible to contextualize these data and have a global vision of dose management and optimization. We called this solution “Gray Detector.”

Materials and Methods

Data Sources

The Reggio Emilia Province Diagnostic Imaging Department (REDID) includes six hospitals managed by two public health care institutions: the Azienda Ospedaliera S. Maria Nuova-IRCCS (ASMN-IRCCS) and the Azienda USL (AUSL) of Reggio Emilia. The former is a 900-bed regional acute hospital located in Reggio Emilia, while the latter includes five hospital facilities distributed throughout the province of Reggio Emilia (up to a radius of about 40 km), with a total of 800 beds. The ASMN-IRCCS is a tertiary-care-level hospital while AUSL facilities are secondary-care-level hospitals.

The two institutions perform about 410,000 examinations every year (about 190,000 and 220,000 examinations in ASMN-IRCCS and AUSL, respectively). For ASMN-IRCCS, outpatients account for 38 % of the workload, emergency patients for 28 %, inpatients and day hospital patients for 24 %, and breast screening patients for 10 %. For the AUSL, the workload is 61, 21, 9, and 9 %, respectively. About 60 % of these imaging exams of both ASMN-IRCCS and AUSL are 2D X-ray procedures (RX); the percentage of computed tomography (CT) procedures out of the whole workload in ASMN-IRCCS is over 15 % while in AUSL, this percentage is about 9 %.

In our region (Emilia Romagna), accreditation-specific requirements impose that each report include exam dosimetric values, thus making dosimetric value storage and correct exam contextualization necessary.

The Integrating the Healthcare Enterprise (IHE) Radiation Exposure Monitoring (REM) Profile [10] should be the upcoming standard for organizing and collecting exposure data in radiology. It requires that imaging modalities export radiation exposure details in a standard format; currently, however, most installed ones do not support this profile. For this reason, we adopted different solutions to register dosimetric values estimated/measured by the modality.

Quality Control Checks

All the radiological equipment of the REDID is regularly checked by the local Medical Physics Unit. The consistency between dosimetric values calculated by the system and transferred via

MPPS or in the header of the images and measured values is included in the periodic quality control checks, and this agreement must respect a reasonable limit tolerance (within 20 % considered as acceptable, within 10 %, desirable). For example, for CT systems, a calibrated RTI Piranha with a pencil Chamber CT Dose Profiler is used in order to control the DLP (dose length product—mGy cm) and CTDI (computed tomography dose index—mGy). For mammography, the same Piranha system equipped with an external solid state chamber or an electrometer UNIDOS-E PTW equipped with an ionization chamber model TW77337-0080 is used in order to verify that the entrance doses and relative average glandular dose (AGD) are correct. For angiographic or radiographic systems, a Wellhofer Scanditronix dose area product (DAP) meter—KermaX—plus DDP is used in order to check the DAP values coming from the modality-integrated DAP systems.

Gray Detector Software

Gray Detector software is a web-based application developed using Pentaho suite [11] (consisting in open source Business Intelligence). This solution is used to collect radiation dosimetric information directly from the radiological devices (CT scanners, angiography/vascular systems, mammography units, radiography systems, and so on). The dosimetric values/information are retrieved in multiple and flexible ways, as described in the followings paragraphs.

Gray Detector software is an add-on RIS module and is connected with the PACS as well. The dosimetric information collected by this module can be elaborated using a guided user interface designed as a group of tabs, each allowing a different elaboration. It is possible to consult all the data available for a patient or extract and build reports/graphs of the dosimetric information by modality, room, exam type, data range, operator, and so on. Figure 1 illustrates screenshots of the software dashboard. In addition, after its acquisition, the dosimetric information becomes an “attribute” of the single patient study on the RIS.

To extract dosimetric information from modalities, on Gray Detector, three automatic extraction methods were developed: MPPS message analysis, query/retrieve (Q/R) on the PACS, and a mix of these two methods.

In Table 1, modalities available in REDID are shown together with the extraction method implemented. The extraction method was not simultaneously configured on all the modalities, one reason why we collected different sample sizes from different diagnostic rooms.

The three methods implemented are described below.

1. MPPS

The MPPS message can be sent by the modality [5] (which acts as service class user, SCU) to the RIS (service class provider, SCP) at the end of an exam. This message contains the status of the exam (e.g., “completed”) and

Fig. 1 Screenshot from the Gray Detector dashboard page. **a** Gray Detector software main dashboard page. The page shows modalities, manufacturer name, number of studies, date of last data received, and the state of connection (green means connection is ok). **b** Example showing the patient AGD for the 11 REDID mammography units. Each point represents a study. Different symbols refer to different mammography units. The filter applied is on modality type (MG), exam description (bilateral mammography), and data range (1 month). With this selection, 4,633 studies are shown (clicking on a single point, a series of data are shown: among these are AGD value, patient name, accession number, operator, etc.). **c** Example showing the patient AGD for the

mammography unit as a function of operator. The point is the median, and the box includes values from the 25th to the 75th percentile. The filter applied is on mammography unit (SCMX2GE), exam description (bilateral mammography), and data range (4 months). Clicking on a single bar, a series of data are shown, including operator name, AGD median value, 25th and 75th AGD percentile, etc. **d** Example showing DLP values for a CT unit as a function of time. Each point represents a study. The filter applied is on modality type (CT), exam description (Head CT), and data range (8 months). After the protocol optimization (vertical line), an evident widespread reduction can be noticed.

Table 1 Modalities analyzed in the Gray Detector dose extraction module. Diagnostic room, device type, installed software version, and extraction method implemented are indicated for each modality examined

Modality	Diag. room	Manufacturer	Type	Software version	Extraction method
CT (8 units)	RE1 (D7)	Philips	Brilliance ICT 128	3.2.4	MPPS
	RE2 (D6)	Philips	MX8000 4 slice	2.64	N.A.
	RE3 (D8)	Philips	Brilliance 64 slice	2.6.2	MPPS
	CNM	PH	Brilliance 6	2.3.0	MPPS
	CO	GE	Lightspeed 16	07MW18.4	Q&R
	GU	GE	Brightspeed 16	qin.3	Q&R
	MO	GE	Brightspeed 16	qin.3	Q&R
	SC	Siemens	Emotion 16	syngo CT 2012E	Hybrid
MG (11 units)	ASMN/AUSL	GE	Senographe Essential	ADS_56.10	Hybrid
XA	RE4	Siemens	Axiom Artis	VB23J 100708	MPPS
	RE5	Philips	Integris Allura	7.6.1\5.3.1\3.3.1	MPPS
	RE6	Philips	Integris Allura Xper FD 10C	Allura Xper, 7.6.3	MPPS

other information such as patient data and dosimetric details.

In our system, the broker is the connecting element between RIS and modalities: it permits communication, moves the work list, and contains the status of the exam. Thus, the MPPS is the message that informs the broker that the modality has finished an exam. In our institution, this does not correspond to the status “exam completed” on the RIS, since access to the modality usually occurs with a generic user/operator without a personal user authentication mechanism (i.e., digital signature). To solve this problem, every exam is completed on the RIS by the technician who performed it and its actual execution is confirmed with the technician’s electronic signature. Each investigation is thus attributed only to the operator who actually performed it.

The information contained in the MPPS is matched with the information “completed” on the RIS and with the presence of at least one image on the PACS in order to avoid any reporting of exam loss. This is important for mammographic screening exams as the reporting process is carried out by two independent readers and can take place up to 2 weeks after image acquisition.

Data contained in MPPS messages are stored as a DICOM object composed of three elements: an alphanumeric coordinate made of eight digits (XXXX, XXXX) called DICOM tag, a description of the data shown, and the data itself.

Data sent via MPPS depend on the modality, on the manufacturer, on the equipment model, and for the same equipment, on the software version. However, it is possible to find some tags common to all modalities (compulsory tags) and others specific to a modality and common to all the manufacturers (optional tags).

From the data available, Gray Detector collects to its

database some DICOM tags by means of a specific query. Some examples of these tags are shown in Table 2.

2. Q/R on PACS

For those modalities which do not send any dosimetric values information via MPPS, we applied the second dosimetric values-extraction method: when the broker receives the status “completed” from the modality and the exam is completed on the RIS by the technician (usually after it has been archived on the PACS), the Gray Detector module performs automatically a query/retrieve on PACS using the common DICOM functions C-FIND and C-MOVE [8]. Gray Detector thus plays an active role and is not configured as a DICOM node to which the modality should send images and information. We thereby avoid a queue on the modality that otherwise could stop sending images to other DICOM nodes (PACS included) if the Gray Detector module goes out of service.

These queries on the PACS search the same tags extracted via MPPS, act on specific exam series (e.g., dose report series no. 999 for Siemens CTs), and are here shown in Table 2.

Table 2 DICOM tag extracted for each modality type and its physical meaning (i.e., dose length product (DLP), dose area product (DAP), average glandular dose (AGD), etc.)

Modality	Tag DICOM	Meaning
CT	00E1,1021	DLP (mGy cm)
XA	0018,115E	DAP (dGy cm ²)
	0040,0300	Total time of fluoroscopy (s)
MAMMO (MG)	0040,0316	AGD (dGy)
Common to all modalities	0040,0301	Number of exposure
	0018,1030	Protocol name

Fig. 2 Differences in DLP evaluation that can arise when no correction for wrong protocol-dose association is implemented. Report filtering for correct dose association to multiple accession numbers/exams (*ID-Ref filtering*) effect is shown in this figure for two of the most frequent CT exam protocols. Vertical lines represent the limit of the 90th and 99th percentile, the point is the 95th percentile, and the box includes values between 92.5 and 97.5 percentile. As the biggest difference is for high percentile values, only these values are shown here

3. “Hybrid” method

In addition to these methods, Gray Detector also implemented a “hybrid” method where information extracted via MPPS and data stored in the DICOM header are integrated. For example, in mammography (MG) modalities, the AGD, number of exposures, and protocol names are taken from the MPPS message, while information about breast thickness and glandularity is obtained from images header analysis.

For all the methods applied, the extracted data are then stored into the RIS database. Since Gray Detector is based on the same RIS database registry, it also allows real-time dosimetric values correction for wrong patient/exam association as soon as this error is recognized and found on the RIS/PACS [12].

Report Filtering for Correct Dosimetric Values Association to Multiple Accession Numbers/Exams (ID-Ref Filtering)

In REDID, each modality receives the worklist via DICOM worklist from the RIS. The operators can choose only those exams on the RIS that are recognized and reimbursed by the regional health care system. A study request may also contain more than one exam.

In CT, it is common to perform studies (requests) which are comprehensive of multiple exams (e.g., a study containing chest, abdomen, and pelvis CT examinations in staging/follow-up diseases for oncologic patients) corresponding to multiple accession numbers on the CT (RIS) worklist. On the worklist received by the CT, the

Table 3 Example of RIS information that can be linked to dose information and possible values these data can assume

RIS data associated	Possible values
Technician	Names or codes
Reporting physician	Names or codes
Sending unit	ER, inpatient, outpatient,...
Report	Positive or negative
Clinical task	–
Patient type	Age, BMI,...

technician can choose only one of these accession numbers to identify the whole study (although, on the CT unit, it would be possible to define custom protocols which include a number of anatomical parts/exams requested).

Finally, the MPPS message/image header seems to refer only to the chosen exam (corresponding to the accession number selected), potentially leading to an erroneous dosimetric values-study/protocol association (Fig. 2). To avoid this, every accession number in Gray Detector is linked to its report code (ID-Ref), which is linked to all the accession numbers referring to the exams in the study. In fact, all the exams of the same request/study are connected to a single ID-Ref (even in those cases where an exam is added in the worklist during the execution for clinical/diagnostic reasons).

Fig. 3 Percentile DLP values for abdomen CT examination, divided according to the diagnostic room where the exam was performed. Vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The horizontal line shows Italian DRL (920 mGy cm). The number under each candlestick indicates the size of the sample considered

Fig. 4 Percentile DLP values for head CT examination, divided according to the diagnostic room where the exam was performed. Vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The horizontal line shows Italian DRL (1,312 mGy cm). The number under each candlestick indicates the size of the sample considered

Example of Data Selection and Analysis

From the initial database, only CT data related to the head, abdomen, and chest were extracted to perform a preliminary analysis. The aim of this analysis was to give a “non-exhaustive” example of the potential of the Gray Detector extraction dosimetric values module.

For the three exam types (CT head, abdomen, and chest), the median and 10, 25, 75, and 90 percentiles DLP were calculated on the basis of diagnostic room, patient age, technician, and radiologist, considering single-protocol exams only (this selection was called “ID-Ref filtering”).

The DLP analysis dependent on patient age, technician, and radiologist was performed, limited to the RE1 diagnostic room examination to reduce inter-variability between different CT equipment.

Fig. 5 Percentile DLP values for head CT examination performed in the same diagnostic room (RE1), divided according to age groups. Vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The horizontal line shows Italian DRL (1,312 mGy cm). The number under each candlestick indicates the size of the sample considered

Ethics Committee Approval

The research project was approved by the Ethics Committee of the province of Reggio Emilia with disposal No. 64 on January 21, 2014.

Results

Figure 2 shows the differences in dosimetric value evaluation using and not using the ID-Ref filtering for two CT exams that oncological patients usually undergo, selecting only the RE1 diagnostic room (the most frequently used). Here, only high percentile values (vertical lines represent the limit of the 90th and 99th percentile, the point is the 95th percentile, and the box includes values between the 92.5th and 97.5th percentile) are shown to better appreciate the difference between the two ways of selection.

Filtered data can be analyzed and linked to information stored inside RIS. Table 3 shows some of the possible associations that can be made.

Some examples of the results of these associations are shown in the following figures and tables. In figures shown below, vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The number under each candlestick indicates the size of the sample considered.

Figures 3 and 4 illustrate the DLP measured in same-protocol CT exams (abdomen and head, respectively) done on different modalities, allowing us to compare absolute values and variations between these modalities, which can help to optimize the procedure. Figure 5 shows how DLPs in head CT exams vary according to patient age. Figure 6 shows the DLP differences for CT head examinations

performed on the RE1 diagnostic room according to the technician performing the exam. Figures 7 and 8 show how DLP can vary according to the physician who oversees the exam, for CT head and abdomen with contrast media exams, respectively.

Discussion

The adoption of three different methods to extract dosimetric information from modalities/images makes our system highly flexible and makes it possible to integrate any kind of modality, in a vendor/version neutral way. This feature could be adopted for any hospital environment.

The hybrid method lets us better understand the origin of high dosimetric values. In mammography, for example, it can explain whether a high AGD value may be related to a defect/calibration of the X-ray unit, to a technician, or to the patient's anatomical characteristics (i.e., breast thickness, glandularity).

The method of referring the dosimetric values to the unique report code identifier (a method we could not find in any previous commercial dosimetric values management module) allows us to group all the accession numbers/protocols of a patient study, then correctly manage the dosimetric values referring to single examination studies or “composite” ones [3].

In Fig. 2, it is worth noting that the spread distribution of DLP values is reduced, as we considered filtered exams instead of the unfiltered ones.

DLP values shown in Figs. 3, 4, and 5 should be compared with the DRL values indicated as horizontal lines (75th percentile of the DLP, Italian nationwide 2013 survey [9]). The 75th percentile DLP is below the reference for all

Fig. 6 Percentile DLP values for head CT examination performed in the same diagnostic room (RE1), divided according to the technician who performed the exam. Vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The number under each candlestick indicates the size of the sample considered

Fig. 7 Percentile DLP values for head CT examinations performed in the same diagnostic room (RE1), divided according to the radiologist who oversaw the exam. Vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The number under each candlestick indicates the size of the sample considered

examinations. It is worth noting the difference among different modalities in Figs. 3 and 4. This difference shows how our dosimetric tool can help to identify where protocols are probably not standardized and to suggest where further optimization actions should be taken.

In Fig. 3, the DLP values of modalities C and D are lower than all other modalities. This could depend on the availability of iterative reconstruction methods.

In Fig. 4, a further analysis of the CT protocol used in diagnostic rooms B and C shows that the two higher DLPs derive from a CT protocol that uses two different beam quality energies during the scan (140 and 120 kV).

In order to optimize and standardize the REDID protocols, a multidisciplinary team has been constituted. This team is composed of radiologists, medical physicists, technicians, and

Fig. 8 Percentile DLP values for abdomen with contrast media CT examinations performed in the same diagnostic room (RE1), divided according to the radiologist who oversaw the exam. Vertical lines represent the limit of the 10th and 90th percentile, the point is the median, and the box includes values between the 25th and 75th percentile. The number under each candlestick indicates the size of the sample considered

people from the administrative staff that is in charge of scheduling CT examinations.

The impact of decisions made by the working group to optimize and standardize the acquisition protocols is ongoing. The proposed actions will be easily verified thanks to the Gray Detector module, and they could be extensively discussed in a future paper.

Age dependence for the DLP CT examination was also investigated. In Fig. 5, the DLP for head exams according to patient age shows an increase of DLPs with age until the age of about 15. This should depend on the different protocols adopted (i.e., pediatric, automatic current modulation, 80/100 kV, etc.). For older patients, DLPs reached a median value between 760 and 780 mGy cm, with a maximum difference (defined as the ratio between the difference of maximum and minimum values over the minimum) of about 2.6 %.

Figure 6 shows that the median DLPs' maximum difference for head CTs performed in E room according to the technician is lower than 10 %. The use of standardized protocols in the same diagnostic room probably helps to standardize the DLPs.

Figure 7 shows a similar trend when considering median DLP values of CT head examinations according to the radiologist who oversaw the exam. The median DLPs' maximum difference is lower than 4 %. In Fig. 8, the median DLPs' maximum difference for abdomen CTs with contrast media became 48 %. This greater variability found in abdomen CT exams could depend on the decision of the radiologist to perform more consecutive series of different phases (basal/arterial/portal/delayed) on the basis of the patient/clinical task.

In addition to the comparison of dosimetric data for different rooms or diagnostic equipment, the activation of alerts if a single patient's dosimetric value limit is exceeded [1] is under development. However, there is no widespread consensus on the limits to apply [13]. When considering limits based on the effective dose, it should be necessary to estimate it by matching dosimetric information (DLP, AGD, etc.) with patient characteristics (e.g., BMI, age, etc.). It is worthy of note that integrating this dosimetric information on the RIS system will potentially enable even real-time alerts while planning or performing an exam.

Conclusion

In general, it makes no sense to evaluate the dose without associating it to a cost-benefit ratio for the patient, e.g., increase dose to have better image quality. The dose-image quality ratio (which is periodically analyzed in quality control protocols) in diagnostic procedures becomes the link between dose and clinical findings or clinical accuracy.

Dosimetric information, together with RIS information such as patient data, technician, radiologist, and most importantly, diagnostic task/diagnosis and report outcome, could "contextualize" the dose and consequently help in optimizing

the image-quality/dose ratio upon which it is possible to make a clinical decision. In addition, dosimetric value information will be stored in the patient's medical record, allowing further real "patient-centered" dosimetric value optimization and procedure selection such as "low-dose pathways" for patients undergoing many ionizing procedures.

Finally, extracting and storing dosimetric value within the RIS could be the first step toward the estimation of the effective dose given to single patients. This estimation could be done by considering the patient's personal and morphological characteristics, as well as the pathology progress, and adapting this information on known anthropomorphic phantoms.

Acknowledgments The authors gratefully acknowledge the collaboration of Michael Garollo, Sorin Virban, Fabio Capra, and all the staff of El.Co s.r.l. - Cairo Montenotte (SV).

References

1. Tsalaftoutas IA, Thalassinou S, Efstathopoulos EP: A Comprehensive Method for Calculating Patient Effective Dose and Other Dosimetric Quantities From CT DICOM Images. *Am J Roentgenol* 199:133–141, 2012
2. Cook TS, Zimmerman SL, Steingall SR, Maidment AD, Kim W, Boonn WW: RADIANCE: An automated, enterprise-wide solution for archiving and reporting CT radiation dose estimates. *Radiographics* 31(7):1833–1846, 2011
3. David G, Redden AE: Retrospective analysis of computed radiography exposure reporting. *Radiol Technol* 83(1):29–35, 2011
4. Seibert JA, Morin RL: The standardized exposure index for digital radiography: an opportunity for optimization of radiation dose to the pediatric population. *Pediatr Radiol* 41(5):573–581, 2011
5. Cook TS, Sundaram A, Boonn WW, Kim W: An interactive RADIANCE toolkit for customizable CT dose monitoring and reporting. *J Digit Imaging* 26(4):663–667, 2013
6. Robinson TJ, Robinson JD, Kanal KM: Implementation of the ACR dose index registry at a large academic institution: early experience. *J Digit Imaging* 26(2):309–315, 2013
7. Jungmann F, Pinto dos Santos D, Hempel J, Düber C, Mildenerberger P: Registration and monitoring of radiation exposure from radiological imaging. *Radiologie* 53(6):535–538, 2013 [Article in German]
8. Wilde R, Charnock P, McDonald S, Moores BM: Qualifying the use of RIS data for patient dose by comparison with DICOM header data. *Radiat Prot Dosim* 147(1–2):329–332, 2011
9. Palorini F, Origgi D, Granata C: Adult exposures from MDCT including multiphase studies: first Italian nationwide survey. *Eur Radiol* 24:469–483, 2014
10. Integrating the Healthcare Enterprise (IHE): Radiation Exposure Monitoring (REM). Available at http://wiki.ihe.net/index.php?title=Radiation_Exposure_Monitoring. Accessed 7 February 2014
11. Moody G: How Do You Make a Pentaho?. *Computerworld UK* May 5, 2010.
12. Nitrosi A, Bertolini M, Notari P, Botti A, Ginocchi V, Tondelli G, Iori M, Pattacini P: Efficiency and effectiveness of an innovative RIS function for patient information reconciliation directly integrated with PACS. *J Digit Imaging* 26(3):412–418, 2013
13. Wang S, Pavlicek W, Roberts CC, Langer SG, Zhang M, Hu M, Morin RL, Schueler BA, Wellnitz CV, Wu T: An automated DICOM database capable of arbitrary data mining (including radiation dose indicators) for quality monitoring. *J Digit Imaging* 24(2):223–233, 2011