Quality Control and Patient Dosimetry on line for Computed Tomography

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Abstract

The aim of this work is to present the functionalities and first results of an automatic system on quality control and patient dosimetry for diagnostic radiology, and its application to computed tomography (CT) in a big university hospital. The system is directly connected to the PACS (Picture Archive an Communication System) of the hospital and extracts useful information contained in the DICOM headers and Radiation Dose Structured Reports (RDSRs). The full process is automatic and was tested during the past 6 months for 11,500 procedures in three CT units. The system allows not only to extract, archive and process the parameters contained in the DICOM headers and RDSRs, but also to manage all the additional information contained in such headers for a quality control "on line". With all this information, several trigger conditions can be implemented to generate alarms and to launch corrective actions in cases such as individual dose values per examination higher than 3 times the diagnostic reference level (DRL), median values of the last 30 procedures higher than the DRL, etc. For other modalities, trigger conditions like low compression in mammography or low kV in chest images can also be used. The system allows export of data for statistical process. A personal patient dose record can be built, initially limited to the examinations performed at the hospital, but with the capability of further connection with other hospitals and outpatient centers using the same system. Mean and median Dose Length Product (DLP) values for the most common CT procedures are presented and compared with the existing references available, to decide if optimization actions are required to refine some clinical protocols. Effective doses have also been estimated from the DLP values, using the conversion factors based on the current Dose Datamed European Guidelines.

Keywords: radiation protection, computed tomography, patient doses, quality control, PACS

1. INTRODUCTION

According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), medical applications of ionizing radiation represent the man-made source of ionizing radiation exposure. Computed tomography (CT) and interventional procedures are the main contributors (UNSCEAR 2008). The National Council on Radiation Protection and Measurements (NCRP) in USA has determined that medical imaging contributes nearly half of the overall exposure to ionizing radiation in the U.S, identifying CT, nuclear medicine and interventional radiology procedures as the largest contributors to collective dose (NCRP 2009). Between 1993 and 2009 the use of computed tomographic (CT) scans in the United States (US) has increased more than 3-fold.

Around 70 million scans are performed annually in USA. Despite the great medical benefits, there is concern about the potential radiation-related cancer risk and patient dose records and analysis are

recommended. Berrington et al. estimated that approximately 29,000 future cancers could be related to CT scans performed in the US in 2007. The largest contributions were from scans of the abdomen and pelvis (n = 14,000), chest (n = 4,100), and head (n = 4000), as well as from chest CT angiography (n = 2700). One-third of the projected cancers were due to scans performed at the ages of 35 to 54 years compared with 15% due to scans performed at ages younger than 18 years, and 66% were in females (Berrington et al 2009).

The European Directive on Medical Exposures 97/43/Euratom (EC 2007) requires Member States of the European Union (art. 9) to use appropriate radiological equipment submitted to quality assurance programmes and to assess patient doses. This requirement has been reinforced in the coming new European directive on Basic Safety Standards for CT procedures (EC 2011): patient doses must now be assessed for all the CT procedures and the radiation dose should be part of the report of the examination (art. 59).

Hospitals with high workloads of radiological examinations and a large number of digital x-ray units may use automatic systems to archive and process patient doses data (Vano et al. 2005). On line patient dosimetry audit is possible by comparing current mean or median values of dose quantities included in the DICOM header of the images (or series of images) with local and national diagnostic reference levels (DRLs) (Vano et. al. 2007). Mean or median values exceeding the established trigger levels, or individual doses much higher than the DRLs can send an alarm signal and an action on the technical parameters or operational procedures may then be considered. Typical alarms, in addition to the dosimetric parameters (patient entrance dose, kerma area product, dose length product, etc) can be caused by the lack of compression in mammography (the compression force is included in the DICOM header and can be audited), the use of low kV in chest projection images (kV values are also in the DICOM header), etc. (Vano et al. 2008, Chevalier et al. 2004, Ten et al 2011). These systems may also be used to audit the number of repeated images in digital departments (Prieto et al. 2009) in a semi-automatic way.

For CT there is special concern due to the large number of examinations and the relatively high effective doses involved in these procedures. Much of the attention in the scientific literature is focused on strategies to reduce radiation doses and to optimize protocols (Cynthia et al 2009). Since the introduction of the multi-detector CT, the clinical applications have considerably increased including newer cardiac CT (Mahnken et al. 2007) and dual energy CT (Johnson et al. 2007). CT software allows a wide range of pre-programmed protocols for different examination types, with values for tube potential, tube current, rotation time, slice width, etc. These protocols are generally set-up for an “average” sized patient. The radiographer can vary these parameters on a patient-by-patient basis, usually through modification of the tube current or rotation time changing the mAs (tube current – time product). The degree to which the

parameters are altered depends on the technician's experience and the radiologist's criteria, but in many cases, parameters are not properly fixed.

DICOM (Digital Imaging and Communications in Medicine) is a standard for handling, storing, printing, and transmitting information in medical imaging. It includes a file format definition and a network communications protocol. For the last few years, medical physicists have worked on the information encoded in the DICOM objects, hoping to find data that would permit patient dose evaluation. Different approaches have been used according to the availability and level of implementation of the DICOM standard: extracting technical information and other details of the clinical protocol describing the study acquisition from the DICOM Image headers, storing the detailed information of CT Radiation Dose Structured Report (RDSR) that contains accumulated dose over several irradiation events, analyzing the "Modality Performed Procedure Step" (MPPS) messages that the modalities sent to the Radiological Information Systems (RIS) in order to communicate the different study status, and some basic dose information and implementing optical character recognition (OCR) techniques on images that are saved screens containing the text of the delivered dose information. The implementation of the DICOM RDSR and the software to process the information contained in these reports are likely to improve all these options in the coming years.

This paper presents the functionalities and first results in a big university hospital, of an automatic system on quality control and patient dosimetry for diagnostic radiology, and its initial application to CT.

2. MATERIAL AND METHODS

Dose quantities appropriate for CT examinations

From the early days of CT, the Computed Tomography Dose Index (CTDI) (measured in mGy) has been used by physicists to describe the amount of radiation delivered from a series of contiguous irradiations to a pair of standardized acrylic phantoms. It is, however, measured from one axial CT scan (Jessens et al. 2000, AAPM, 1990). Clinical CT examinations involve exposures from multiple rotations of the x-ray source, so that the dose to the irradiated volume is the accumulated dose from the adjacent scans, therefore several variations of the CTDI have been defined. For example, the CTDI-100 reflects the dose contribution from a 100-mm range centered on the index slice. The weighted CTDI (CTDIw) reflects the weighted sum of two-thirds peripheral dose and one-third central dose in a 100-mm range in acrylic phantom. The volume CTDI (CTDIvol), defined as CTDIw divided by the beam pitch factor, is the most commonly cited index for modern CT equipment. CTDIvol describes the radiation delivered to the scan volume for a standardized (CTDI) phantom (IEC 2002), accounts for gaps or overlaps between the x-ray

beams from consecutive rotations of the x-ray source and variations in dose across the "Field of View" (FOV). Although CTDIvol is a useful indicator of the radiation output for a specific exam protocol, (it takes into account protocol-specific information such as pitch, collimation, etc.), it is not a direct measurement of dose; it is a standardized measure of radiation output in the CT environment (Boone 2007).

The CTDIvol can be integrated along the scan length to compute the "Dose-Length Product" (DLP) (in mGy.cm) representing the overall energy delivered by a given scan protocol. The DLP reflects the integrated radiation output (and thus it can be correlated to the potential biological effect) attributable to the complete scan acquisition.

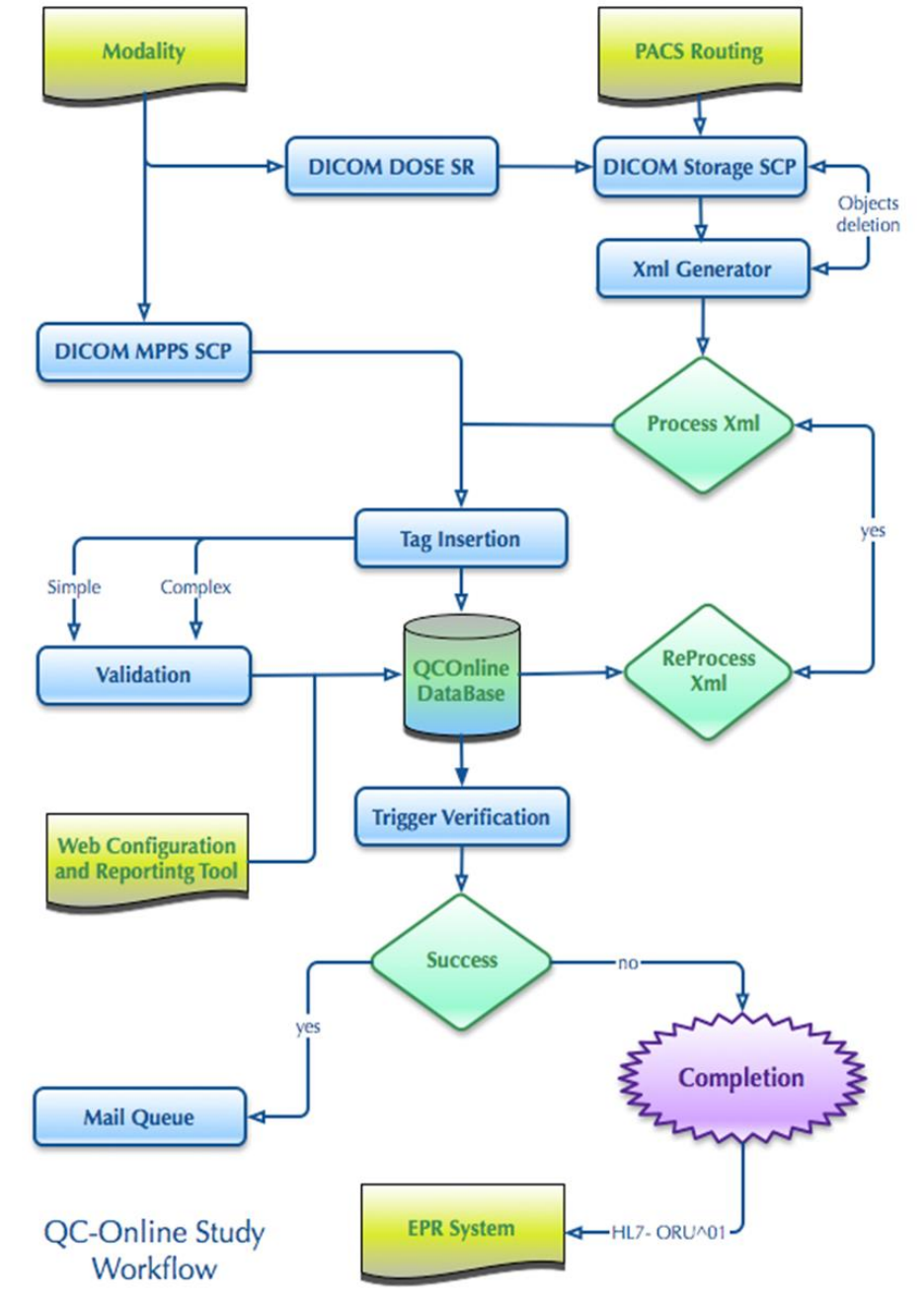
To estimate the stochastic risk from the exposure to ionizing radiation (ICRP 2007, McCollough et al. 2000) Effective Dose (E) (in mSv) is commonly used, although it cannot be used to estimate individual detriment. Typically, it is used to facilitate the comparison of radiation risks between diagnostic exams of different types or having different acquisition parameters when the gender and age of the patients are similar. Mathematical models for a "standard" body have been developed to calculate a set of coefficients k (dependent only on the region of the body) to relate the DLP and E. The use of DLP to estimate E appears to be a reasonable method to estimate effective dose (McCollough 2003), with a maximum deviation from the mean of approximately 10% to 15%.

System Design

The study has been made in a Diagnostic Radiology Department with three 64 slices CT´s units (one Philips Brilliance, and two GE Optima CT660). From the Philips CT, the dose information can be extracted from the DICOM header of the localizer image at the Philips proprietary Standard Extended Service-Object Pair (SOP) Exposure Dose Sequence information. When the procedure has been completed, doses information can be found on the RDSRs generated by the modality from the GE CT device. To automate the collection of information studies, we have developed a software module integrated in our already developed quality control "online" system (Vano et al. 2008). This system consists (see figure 1) of a DICOM Storage Service Class Provider that receives the images of both studies as RDSR routing directly from the PACS, but that is also prepared to receive information directly from the modality that generates the image. Alternatively, a module MPPS has also been developed to analyze DICOM MPPS messaging when available. When the system receives images, it automatically generates a structured file containing the complete contents of the DICOM header of each study, as well as the information extracted from the RDSR. When the reception of the study is over, the structured file is processed and the software performs calculations to store the desired information in the database. Table 1 shows the basic fields stored for CT procedures. The system provides a tool to establish levels of alert to

detect anomalous situations, and it can communicate alarms automatically via intranet by e-mail. Finally, our QCONLINE makes an estimation of the effective dose derived from the procedure according to the generic estimation method proposed by the European Guidelines on Estimating Population Doses from Medical X-Ray Procedures (EC 2008) and exports it to the Hospital Information System (HIS).

Figure 1. QCONLINE data workflow.



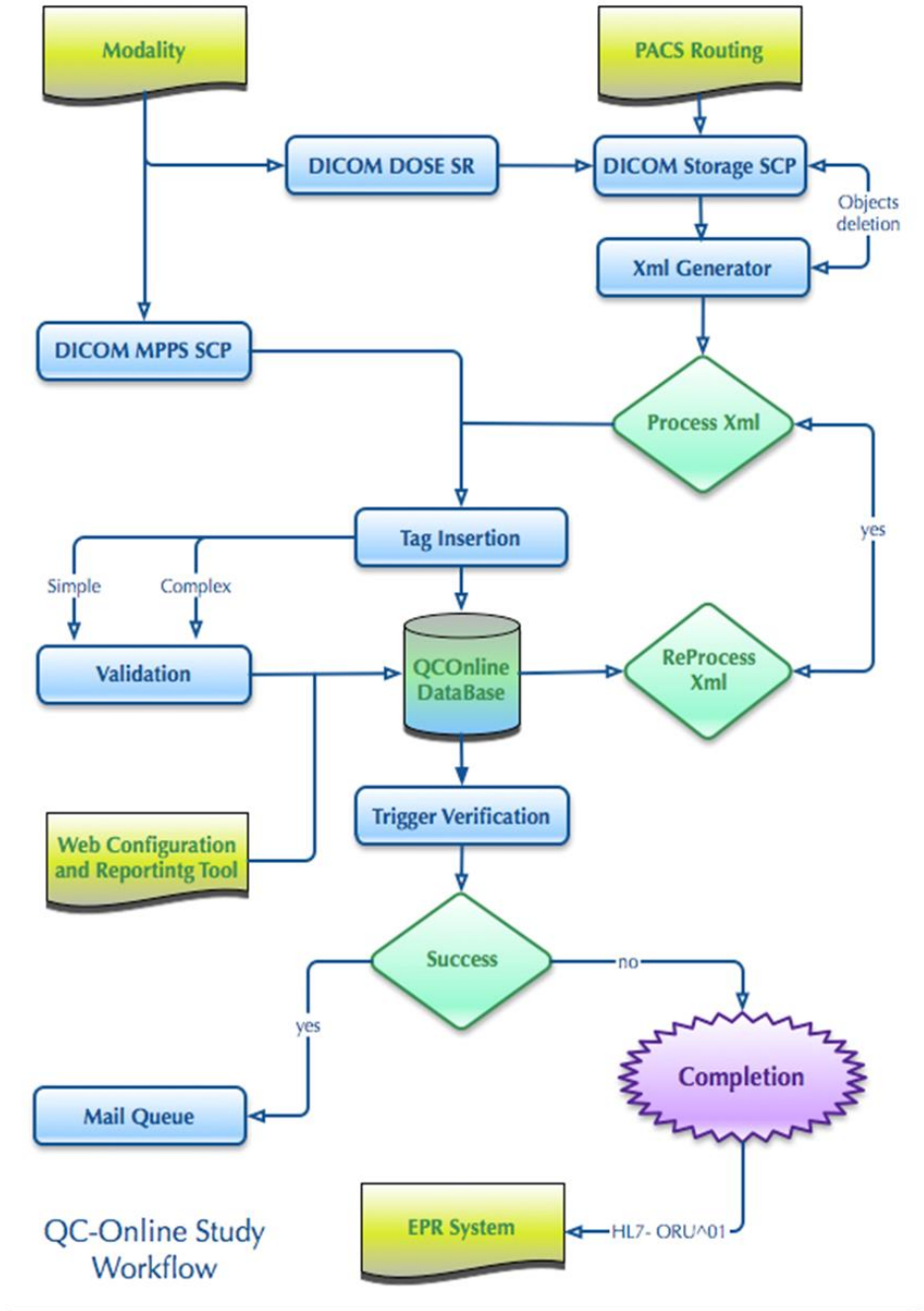


Table 1. Relevant Information saved onto the QCONLINE database

Patient level	**Study level**	**Series level**	**Image level**
Name, Date of birth, Gender, Number of previous procedures	Study description, Station name, date and time, DLP, effective dose.	Body part, Series Description Scan Options, Slice Thickness, Data Collection Diameter, Protocol Name	kVp, X-ray tube current, Exposure time, Estimated dose saving with intensity modulation,Table speed,Table feed per

	Rotation Direction, Total Collimation Width,Acquisition Type, Spiral Pitch Factor CTDIvol,DLP, etc.	rotation,Slice location, etc.

3. RESULTS AND DISCUSSION

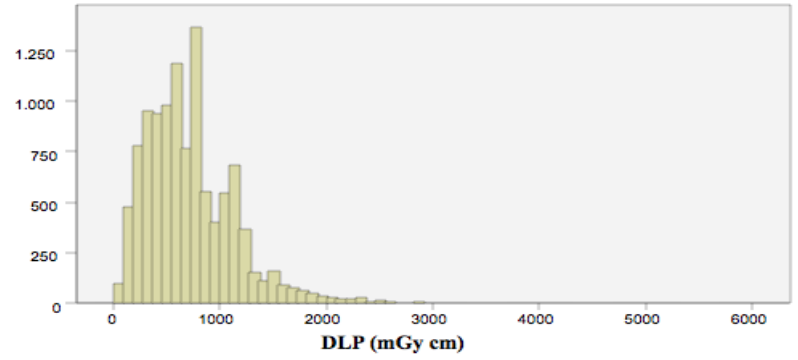
A total of 11097 CT procedures (grouped under: abdomen and pelvis, chest, head, neck and trunk) were performed between June 2011 and December 2011 at the Department of Diagnostic Radiology. Automated acquisition and dose data were correctly processed in 97% of the procedures (10754). The sample size allowed to set reference values in DLP and to estimate E values for all CT studies in our department (Table 2). Further analysis must be performed to analyze the different complexity of the procedures and its effect on DLP and E in each group.

Table 2. Mean, STD and Diagnostic Reference Levels for DLP (mGy.cm) and estimated E (mSv)

	Sample	Mean		STD		DRL	
		DLP	E	DLP	E	DLP	E (no DRLs)
Abdomen & Pelvis	2262	759	11,4	530	7,9	969	14,5
Chest	1336	447	6,3	338	4,7	505	7,1
Head	3633	857	1,8	445	0,9	1141	2,4
Neck	167	477	2,8	266	1,6	543	3,2
Trunk	3356	717	10,8	404	6,1	898	13,5
Total	10754	727	7,2	459	6,7	949	10,2

Figures 2a and 2b show the histograms of DLP and E for our sample. The analysis of the quartile values of our distributions allows discriminating priorities to optimize the protocols in some types of procedures. An audit will have to be carried out to verify if image quality and the body part examined in procedures in the first quartile of the doses distribution are sufficient. Examinations in the fourth quartile could also require some audit to explore the possibility of reducing the DLP and effective dose values.

Figures 2a and 2b show the distribution of DLP and E frequencies for our sample.



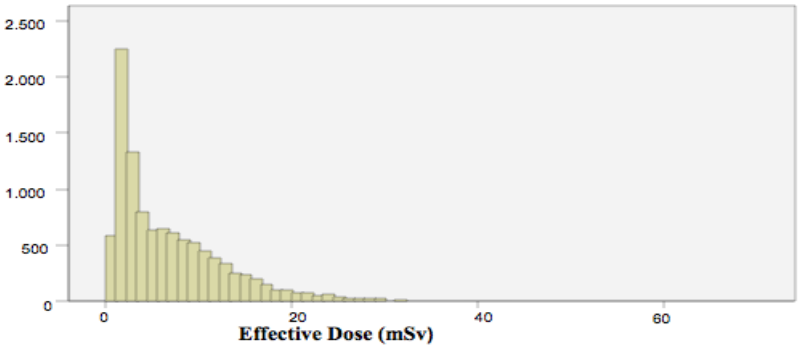


Table 3 shows the contents in each of the quartiles of the distribution (% of the full sample), e.g. in the case of the fourth quartile of DLP (studies that are above the DLP diagnostic reference level) the quartile value includes 21,4% of abdomen and pelvis studies, 4,2% of chest studies, 48,3% of head studies, 0,3% of neck studies and 25,8% of trunk studies, representing 25,8% of the total sample of the abdomen and pelvis studies, 8,5% of chest studies, 36,3% of the studies of head, 4,8% of the neck and 21,0% of the studies of trunk. Regarding the fourth quartile of effective dose, the results show that the quartile contains 36,6% of abdomen and pelvis studies, 5,7% of chest studies , 0% of head studies, 0.1% of neck studies and 57,6% of trunk studies, representing 43,5% of the total sample of studies of the abdomen and pelvis, 11,5% of chest studies, 0% of the studies of head, 0,1% of the of neck and 46,2% of the studies of trunk. As expected, the studies of the abdomen-pelvis and trunk are those that required most special attention to optimize the acquisition protocols at the time of the study.

Some triggers have been fixed in the database to detect different situations (such as studies with twice DLP than the diagnostic reference levels, patients with several studies in a short time, pediatric patients, etc.) . All these situations can be sent automatically via email to the person in charge of the clinical audit.

Table 3 Contents of the quartiles of the DLP and Effective Dose distributions

		DLP				
		Abdomen & Pelvis	**Chest**	**Head**	**Neck**	**Trunk**
1 Q	**Sample**	598	806	372	82	708
	% Sample	23,3%	31,4%	14,5%	3,2%	27,6%
	% Body Part	26,4%	60,3%	10,2%	49,1%	21,1%
2 Q	**Sample**	594	333	769	63	962
	% Sample	21,8%	12,2%	28,3%	2,3%	35,4%
	% Body Part	26,3%	24,9%	21,2%	37,7%	28,7%
3 Q	**Sample**	487	83	1174	14	981
	% Sample	17,8%	3,0%	42,9%	0,5%	35,8%
	% Body Part	21,5%	6,2%	32,3%	8,4%	29,2%
4 Q	**Sample**	583	114	1318	8	705
	% Sample	21,4%	4,2%	48,3%	0,3%	25,8%
	% Body Part	25,8%	8,5%	36,3%	4,8%	21,0%
Total	**Sample**	2262	1336	3633	167	3356
	% Body Part	21,0%	12,4%	33,8%	1,6%	31,2%
		Effective Dose				
		Abdomen & Pelvis	**Chest**	**Head**	**Neck**	**Trunk**
1 Q	**Sample**	35	90	2463	57	43
	% Sample	1,3%	3,3%	91,6%	2,1%	1,6%
	% Body Part	1,5%	6,7%	67,8%	34,1%	1,3%
2 Q	**Sample**	401	627	1131	101	428
	% Sample	14,9%	23,3%	42,1%	3,8%	15,9%
	% Body Part	17,7%	46,9%	31,1%	60,5%	12,8%
3 Q	**Sample**	843	466	36	7	1335
	% Sample	31,4%	17,3%	1,3%	0,3%	49,7%
	% Body Part	37,3%	34,9%	1,0%	4,2%	39,8%
4 Q	**Sample**	983	153	1	2	1549
	% Sample	36,6%	5,7%	0,0%	0,1%	57,6%
	% Body Part	43,5%	11,5%	0,0%	1,2%	46,2%
Total	**Sample**	2262	1336	3633	167	3356
	% Body Part	21,0%	12,4%	33,8%	1,6%	31,2%

5. CONCLUSIONS

Hospitals with a high workload in diagnostic radiology are likely to carry out procedures with high patient dose values in CT. Automatic systems receiving and processing patient dose values in real time allow to initiate corrective actions in a short time.

The coming European Directive on Basic Safety Standards will require archiving individual patient dose values for CT. The QCONLINE system presented here allows such archiving as well as the use of the database for optimization purposes auditing the procedures with low and high doses (e.g. the first and fourth quartile of the dose distributions).

One problem to solve is the frequent mistakes occurring in the identification and classification of some procedures when introduced into the PACS.

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