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Medical Imaging Repository Contributions for Radiation Protection Key Performance Indicators

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Abstract

The data stored in the different information systems supporting the medical imaging departments are crucial for de development of Performance Key Indicators (KPI), namely in the radiation protection scope. One of the data sources pertinent for the development of these KPI, is the Digital Imaging and Communication in Medicine (DICOM) metadata related to medical imaging studies stored in Picture Archiving and Communications Systems (PACS). The study reported by this paper aimed to evaluate the adequacy of DICOM metadata stored in a healthcare institution PACS to implement some KPI related to radiological protection suggested by the European Society of Radiology and the European Federation of Radiographer Societies. Data produced by 30 medical imaging devices from different manufactures related to six medical modalities (i.e., Computed Tomography, Computed Radiography, Digital Radiography, X-Ray angiography, Radio Fluoroscopy and Mammography) were analyzed. Although, a significant number of KPI can be supported by DICOM metadata, the respective compliance depends on each modality image IOD. As future work, strategies must be defined to allow access and aggregation of public and private DICOM attributes as well as attributes of the Radiation Dose Structured Report and other hospital information systems for the development of KPI to reliably characterize the exposure to ionizing radiation during medical imaging studies.

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1. Introduction

In today's societies, the primary goals of healthcare provision are not possible to achieve without the use of information technologies to accurately collect, store, and process relevant healthcare information [1], whose quality can be guaranteed using diverse methods and tools [2].

In the field of medical imaging, both the clinical processes and technology used in daily practice have significantly changed during the last years, not only due to the improvement of the professional practice [3], but also due to the incorporation of new processes, namely by using huge amounts of data to recognize patterns that can be applied to medical images [4] or using machine learning algorithms to predict the risk of disease, diagnoses, prognoses and appropriate treatments [5][6].

The European Society of Radiology (ESR) and the American College of Radiology (ACR) consider that secondary use of information resulting from medical imaging procedures can represent an excellent opportunity for professionals to improve their practices, which may be translated into improved healthcare to the patients [7]. In a hospital context, the information produced in the radiology service is stored in Radiological Information Systems (RIS) and Picture Archiving and Communication Systems (PACS). These systems are designed to support administrative and clinical processes, allowing the management of medical imaging studies and all the information associated with them (e.g., involved actors, procedures, or exposure to ionizing radiation). Medical imaging studies and related metadata are stored in PACS using the Digital Imaging and Communication in Medicine (DICOM) format [8].

Within the scope of medical imaging, there are numerous aspects that should be considered when seeking to ensure that procedures are carried out according to best practices, namely in terms of radiation protection. One way to do this is using Key Performance Indicators (KPI). The use of KPI in medical imaging is not new, since they are being used to define and assess the organization's success, either in clinical or financial terms. KPI differ according to the nature and strategy of the organization and may relate to i) core functions of operations management, ii) financial management, iii) patient safety and quality of care, iv) management of external stakeholders, and v) management of internal stakeholders [9].

The ESR and the European Federation of Radiographer Societies (EFRS) have published a joint paper on Patient Safety in Medical Imaging [10], which mentions some critical categories related to the radiological protection of patients and medical imaging professionals, namely within the scope of the definition and use of KPI for radiation protection management, for the evaluation of study requests, procedures, and reports that may characterize the exposure to ionizing radiation to which patients and healthcare professionals may be subject during medical imaging studies [10].

The research study presented by this paper aimed to evaluate the contribution of the DICOM metadata, publicly available and belonging to medical imaging studies stored in a healthcare institution PACS, to support some KPI suggested by the ESR and EFRS in the scope of radiological protection.

The paper is organized as follows. In section two are addressed some issues related with the importance of the KPI in medical imaging context and the DICOM metadata for the development these KPI. In section three is presented the methods used for DICOM metadata analysis. The section four presents the results of the study and the respective discussion. Finally, the last section is reserved to draw a conclusion and future work initiatives.

2. Background

Strategies to ensure safety and quality of medical imaging practice can be focused on the patient, system, and processes. Independently of the methods to support these strategies (i.e., proactive, or reactive methods), the aims are the cost control and the improvement of the healthcare provision with impact in the satisfaction of patients and healthcare professionals. However, the quality improvement requires the contribution of several factors [11].

The success of any program focused in the quality of medical imaging depends on: i) the quality of the data produced; ii) the installed capacity to access these data; iii) the data analyses to assess relevant clinical processes; and iv) the ability to build KPI and respective metrics according to the policies of the medical imaging departments, which allows the preparation of adequate performance reports [12]. In this respect, the use of KPI is fundamental, since it is not possible to manage and improve what it is not possible to measure [13].

The need for quality auditing processes are recognized by National Radiological Societies in Europe; however, it is also unanimously recognized that an essential factor to take into account is the existence of technological and administrative infrastructures to support quality auditing processes [14].

The provision of medical imaging care has gradually become more patient-centered, which can be translated into significant advantages, namely in the quality and safety of procedures, reducing costs, improved outcomes and increased patient satisfaction [15]. On the other hand, the technological evolution in medical imaging has a significant impact on the level of quality of healthcare provided. For instance, within the scope of risk management, the use of data produced and stored within the scope of imaging modalities involving ionizing radiation (e.g., Computed Tomography, or Digital Radiology) can be essential for continuous improvement, namely for the optimization of the doses of ionizing radiation, which promotes the protection of patients and healthcare professionals as well as their trust in the healthcare provision [16].

As part of radiological safety and quality improvement programs, a study by Dick et al. [17] reported that a significant number of quality improvement initiatives in medical imaging departments focused on the studies appropriateness (92%) and on the recording of clinical information (92%), as well as on the use of KPI (83%). The accreditation of equipment and dose monitoring represented 75% of the initiatives.

The use of DICOM metadata may contribute to medical imaging quality programs. The DICOM standard defines an information model that intends to represent real-world objects logically grouped in different modules such as, for example, a medical image. Each image has its own Information Object Definition (IOD) composed by a set of attributes. In turn, each DICOM attribute is characterized by a designation and a unique identifier (tag), being the tag composed by two numbers (i.e., Group and Element) [18].

The DICOM standard also defines a set of Radiation Dose Structured Report (RDSR) data objects for recording and storing dose details of a medical imaging study [19]. These templates are prepared to incorporate dose metrics such as Computed Tomography (CT) Dose Index (CTDI), Dose Length Product (DLP), or Dose Area Product (DAP), along with other information types, including geometric and technical factors that can be used to estimate the radiation dose received by a patient and the adequacy of the imaging protocol being used. Some CT systems stored an image containing a screen capture of a dose report listing the CTDI and DLP values for each CT series, although the DICOM metadata of these images do not include CTDI and DLP values. In turn, some CT systems provide DLP value as a private attribute within such images or/and in the Modality Performed Procedure Step (MPPS) messages. Regarding the DICOM metadata, the headers of DICOM images may contain specific attribute tags with a subset of the dose information contained in an RDSR such as, for example, the CTDIvol (0018,9345) attribute.

In some healthcare facilities, the analysis of stored DICOM metadata is complex due to different implementations of medical imaging devices. Manufacturers often use their own interpretation of international standards for the data exchange and storage. However, the usage of DICOM private tags makes it practically impossible to extract pertinent metadata [19]. On the other hand, the data stored in the different information systems that support medical imaging activities (e.g., RIS and PACS) does not always reliably represent the procedures performed [20], which may be seen as an obstacle to the production and use of indicators, mainly in terms of consistency, precision, accuracy, and integrity. Although the quality of the data stored in the PACS is essential for patient exposure characterization during medical imaging studies there may be significant variability in the number of DICOM attributes made available by the different imaging modalities [21]. For example, in the context of mammographic studies, although it is possible to store values related to radiation exposure, it can sometimes be important to analyze the quality of the data stored [22].

In the medical imaging safety and protection context, one of the KPI identified as relevant for the patient exposure assessment/characterization is the analysis of the studies carried out to identify inappropriate studies request, which can be determine from the data stored in the RIS [23], or from the data stored in the PACS. Considering the PACS, the analysis can be performed based on evaluating the values of DICOM attributes, namely the KVp, mAs, and Exposure Time values, related to each patient (i.e., using the DICOM attribute PatientID) [4]. The access and use of

the metadata stored in the PACS can be done with different approaches, for example, they can be patient-oriented or study-oriented approaches [24]. The DICOM metadata that characterizes PACS stored studies can also help characterize the population with studies performed in different modalities [25][26] [27].

3. Materials and Methods

The DICOM attributes that are part of the imaging studies produced by the equipment (i.e., 30 different devices from various manufacturers) of a healthcare unit and stored in the respective PACS were analyzed. The confidentiality of patients and actors involved in the provision of healthcare was guaranteed. A search was performed over PACS archive to identify the studies stored for six months.

DICOM attributes related to the studies and made publicly available were identified according to the IOD of the imaging modalities CT, Computed Radiography (CR), Digital Radiography (DX), X-Ray angiography (XA), Radio Fluoroscopy (RF), Mammography (MG), and that could contribute to the definition of KPI related to radiation protection under the following workflows/topics: i) Exam Request (i.e., Inappropriate Orders, Inappropriate Orders Done); ii) Procedure (i.e., Study Oversampling, Study Over Phasing, Positioning, Study Clinical Indication, Dose Reference Levels - CDRL, Study Repeated Examinations, Studies Performed without Contrast Medium when Contrast was Required, Paediatric, Pregnant Women, Data Deleted before Image Review, Unintended Conceptus Exposure, Patient Skin Doses Managed - Interventional Radiology, Patient Threshold for Deterministic Effects - Interventional Radiology); Staff – Interventional Radiology; iii) Reporting (i.e., Dose Reporting); and iv) General (i.e., Over Exposure and Quality Control)

The IOD of images produced by different equipment were analyzed for each topic and modality, and the contribution of the DICOM attributes for KPI implementation was evaluated.

4. Results and Discussion

The IOD of the images of six modalities were identified and analyzed (Figure 1): i) CT modality with seven devices from three manufacturers; ii) CR modality with eleven devices from three manufacturers; iii) XA modality with five devices from two manufacturers; iv) RF modality with two devices from one manufacturer; v) DX modality with three devices from three manufacturers; and vi) MG modality with two devices from two manufacturers.

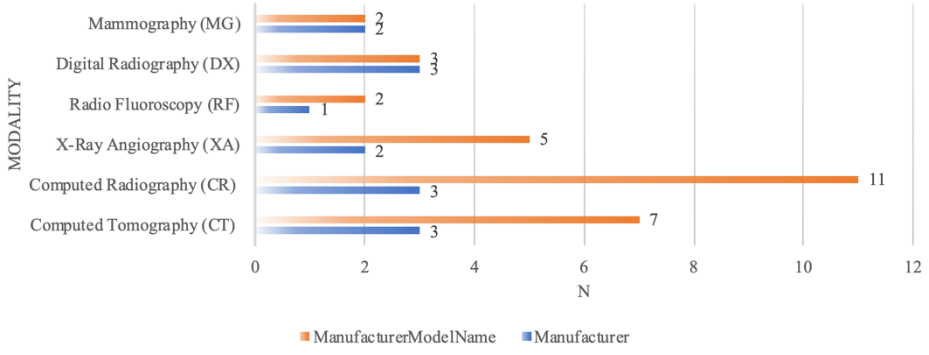

Figure 1 –– Modalities devices and respective manufactures

Table 1 presents some topics that, according to [10], are relevant to the definition of KPI in the scope of radiological protection, their definition as well as their feasibility in the scope of the analyzed imaging modalities. The Table 1 also contains the DICOM attributes that, whenever present, can be used in the definition of KPI. For each topic, and within each modality, it is indicated whether it is possible to define a KPI (+), if it is not possible (-) or if it is partially possible (±). In situations where it is partially possible, the DICOM attributes may partially contribute to the definition of the KPI, and the data of other information systems (e.g., RIS) should be used. Regarding the inappropriate request

for imaging studies, the information available in the IOD of the analyzed images does not allow any judgment, considering the need to access information stored in information systems such as the RIS for the definition and implementation of these indicators.

Regarding the topic of Study Oversampling, it is possible to define KPI based on DICOM attributes. In turn, considering the topic Study Over Phasing, it seems to be possible to analyze it based on the number of series associated with each study, namely within the scope of CT. For the other modalities, Over Exposure may, in specific contexts, be associated with the realization of a more significant number of series.

In what concerns the topics CDRL and Study Performed Without Contrast Medium when Contrast was Required, these KPI can be partially defined in the analyzed modalities, having to be complemented with data from the RIS. The exception is the RF modality that does not have DICOM attributes that can significantly contribute to these indicators (apart from the patient's demographic data). On the other hand, the XA modality provides the EPSR series but with an IOD that does not provide exposure-related metadata.

In the context of KPI related to patient positioning, the IODs of the analyzed modalities do not provide information regarding the positioning, except for the CT modality, which provides the PatientPosition (0018.5100) and TableHeight (0018.1130) attributes that can contribute to the evaluation of the positioning, but incompletely, requiring the analysis of the image/study by the healthcare professional. The KPI related to repeated studies can be developed in all modalities and can be supported by the attributes DICOM Modality (0008.0060), PatientID (0010.0020), StudyInstanceUID (0020,000D), StudyDate (0008.0020), StudyDescription (0008.1030) and BodyPartExamined (0018,0015)

Table 1 - Radiation protection-specific KPI listing topics and indicators for measurements and validation (partial table adapted from [10])

Workflow	Topic	Indicator	Definition/Metric	CR	CT	DX	MG	RF	XA	DICOM attributes for KPI support
1 - Order	1.1 - Inappropriate Orders	Nº of patients and %	a)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
	1.2 - Inappropriate Orders Done	Nº of pat. and %	a)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
2 – Procedure	2.1 - Study Over Sampling	Nº of pat.	b)	(+)	(+)	(+)	(+)	(+)	(+)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined
	2.2 - Study Over Phasing	Nº of pat.	b)	(-)	(+)	(-)	(-)	(-)	(-)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & SeriesInstanceUID & SeriesNumber OR SeriesDescription
	2.3 - Positioning	Nº of wrong positioning	b)	(-)	(±)	(-)	(-)	(-)	(-)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & PatientPosition & TableHeight
	2.4 – Study CDRL	% of pat. beyond 75%	c)	(±)	(±)	(±)	(±)	(-)	(±)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & *molatily specific atributes*
		% of pat. beyond 50%	c)	(±)	(±)	(±)	(±)	(-)	(±)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & *molatily specific atributes*
	2.5 - Study Repeated Examinations	Nº of patients with more than 5 modality studies in a year	c)	(+)	(+)	(+)	(+)	(+)	(+)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined
	2.6 – Studies Performed without Contrast	Number of patients	c)	(±)	(±)	(±)	(±)	(-)	(±)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & RequestedContrastAgent

			Medium when Contrast was Required							

(+) Possible; (-) Not possible; (±) Partially possible.
a) - If there is a CDS: data extraction If there is not an automatic data collection: retrospective review of 100 CT/mo st frequent indication (head, chest, abdomen, MSK) every year,
b) - Review of 100 patients for: head, chest, abdomen, MSK every year,
c) - If there is a dms: data extraction every 6 months. If there is not an automatic data collection: retrospective review: 100 for head, chest, abdomen, MSK, every year.

Analyzing Table 2, it is possible to define KPI that allow identifying wrong paediatrics protocols, which in the MG modality case does not seem to be applicable. Regarding the topics Pregnant Women and Unintended Conceptus Exposure, metadata can partially contribute to the creation of KPI, requiring information from other information systems besides the PACS. Concerning the topic Digital Radiography Data Deleted Prior to Image Review, the DICOM metadata supports this kind of KPI if it is not allowed to delete the acquired images (i.e., DICOM metadata contribution can be considered partial).

Table 2 - Radiation protection-specific KPI listing topics and indicators for measurements and validation (partial table adapted from [10])

Workflow	Topic	Indicator	Definition/Metric	CR	CT	DX	MG	RF	XA	DICOM attributes for KPI support
2 - Procedures (cont.)	2.7 - Paediatric	Number of wrong protocols	c)	(+)	(+)	(+)	n.a.	(+)	(+)	Modality & PatientID & Patient Age StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamine & KvP & mAs & *molatily specific atributes*
	2.8 - Pregnant Women	Number of misses	c)	(±)	(±)	(±)	(±)	(±)	(±)	Modality & PatientID & Patient Age StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamine & PatientSex & PregnancyStatus
	2.9 - Digital Radiography Data Deleted Prior to Image Review	Nº of patients	e)	n.a.	n.a.	(±)	n.a.	n.a.	n.a.	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined
	2.10 - Unintended Conceptus Exposure	Nºof misses	c)	(±)	(±)	(±)	(±)	(±)	(±)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & *molatily specific atributes*
	2.11 - Patient Skin Doses Managed	Nº of skin doses managed per year	g)	n.a.	n.a.	n.a.	n.a.	(±)	(±)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & *molatily specific atributes*
	2.12 - Patient Threshold for Deterministic Effects	Threshold for deterministic effects exceeded	f)	n.a.	(±)	n.a.	n.a.	(±)	(±)	Modality & PatientID & StudyInstanceUID & StudyDate & StudyDescription & BodyPartExamined & *molatily specific atributes*
	2.13 - Staff	Number of staff doses managed per year	h)	(-)	(-)	(-)	(-)	(-)	(-)	-

(+) Possible; (-) Not possible; (±) Partially Possible; n.a. – not applicable.
c) - If there is a DMS: data extraction every 6 months. If there is not an automatic data collection: retrospective review: 100 for head, chest, abdomen, MSK, every year; d) - Number of repeated exposures Retrospective review: 100 for chest, MSK, every year; e) - Review of patient examinations with data deleted every year; f) - Review of patient cases exceeding skin dose threshold every year; g) - Number of skin doses managed per year; h) - Number of staff doses managed per year

DICOM metadata seem to be able to partially support KPI related to intervention procedures in the modalities of XA, RF and TC. In these modalities, DICOM metadata must be complemented with data from RDSR, Exam Protocol Structured Report (EPSR) or RIS. On the other hand, KPI related to occupational exposure do not seem to be possible.

Within the scope of the analyzed modalities, the DICOM metadata that may contribute to the definition of KPI within the scope of radiation exposure characterization (e.g., dose descriptors) depend on the specific attributes of each modality.

Regarding KPI that allow evaluating the registration of exposure reports, the DICOM metadata does not seem to contribute, in a significative way, to definition and implementation of these KPI (Table 3).

Table 3 - Radiation protection-specific KPI listing topics and indicators for measurements and validation (partial table adapted from [10]

Workflow	Topic	Indicator	Definition/ Metric	CR	CT	DX	MG	RF	XA	DICOM attributes for KPI support
3 - Reporting	Dose Reporting	% of missed	i)	(-)	(-)	(-)	(-)	(-)	(-)	-
4 - General	General	4.1 - Over Exposure	j)	(-)	(-)	(-)	(-)	(-)	(-)	-
		4.2 - Quality Control	k)	(-)	(-)	(-)	(-)	(-)	(-)	-

(+) Possible; (-) Not possible; (±) Partially Possible.
i) - Data extraction from the RIS or from the PACS (check);
j) - Number of patient dose values managed per year,
k) - Number of QC per year (with written reports) and including the PACS and the patient dose management systems

5. Conclusion

The definition of KPI can contribute to continuous improvement of healthcare provision. Medical imaging studies involving patient exposure to ionizing radiation promotes the creation of pertinent data in different formats. Within the scope of radiological protection, part of important data that can support the definition of KPI are part of DICOM metadata.

The results of the study presented by this paper allowed to identify the contribution of the information stored in the DICOM metadata belonging to studies carried out in a hospital context, and stored at the PACS, to the definition of some KPI recommended in the literature, namely some advocated by the ESR and the EFRS. A significant number of KPI can be supported by DICOM metadata publicly available. However, their contribution depends on the images IOD of each modality. In some cases, DICOM metadata must be complemented with other data sources, including DICOM objects (e.g., RDSR or EPSR) and information systems (e.g., RIS).

As future work, it seems pertinent to define strategies that allow access and aggregation of information stored in DICOM private attributes as well as in RDSR or EPSR and other hospital information systems for the development of KPI able to reliably characterize the exposure to ionizing radiation during medical imaging studies.

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