Information Model for Radiology Performance Indicators based on DICOM

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Keywords: DICOM Data Mining, Health Care Quality, Quality Dimensions, Radiology Quality Indicators.

Abstract: The paper presents the information model of the DICOM - Radiology Performance Indicator (DICOM-RPI). This model can be used to aggregate information related to the characterization of medical imaging health care services, namely information incorporated in the studies according to the format of the Digital Imaging and Communication in Medicine (DICOM). The model comprises several components including the ones required to define the context of medical imaging health care services (*e.g.* the entities involved) and the context of use of the indicator (*e.g.* Quality Dimensions). For the validation of the proposed information model 51,277 Digital Radiography (DX) studies performed on 27,559 patients from a single health care facility were considered. The results of this validation within the scope of DX modality make possible to anticipate the DICOM-RPI relevance in other imaging modalities and its contribution for comprehensive analysis of medical imaging health care services.

1 INTRODUCTION

Whenever we seek to understand the concept of quality of health care we find several definitions (Piligrimiene and Buciuniené, 2008; Donabedian, 1988) which may vary over the course of time (Pisco, 2007).

For the World Health Organization (WHO), the quality of health care is understood as the extent to which the provision of care meets the existing professional standards which are thought to be important for the patient (WHO, 2004). The Organisation for Economic Cooperation and Development (OECD) (Kelley and Hurst, 2006) uses the definition of the Institute of Medicine (IOM) (Lohr and Schroeder, 1990). According to this definition, the quality of health care is defined as the extent to which the provision of health care to the individual or the population increases the probability of achieving the desired health results, consistent with the professional knowledge existing at the time.

The characterisation of the professional practice with regards to the quality of health care provided, may refer to the Structure, the Processes or the Outcomes of the provision of care (Donabedian, 1988) in different Quality Dimensions such as, for example, the ones recommended by the WHO (WHO, 2007): Clinical Effectiveness, Staff Orientation, Responsive, Efficiency, Safety, Governance and Patient Centeredness. These dimensions are also accepted in different countries, namely United Kingdom, Canada, Australia or United States of America, where other less common dimensions are also considered, *i.e.* Acceptability, Appropriateness, Competence or Capability, Continuity and Timeliness (Kelley and Hurst, 2006).

The six dimensions recommended by WHO are the bases of a conceptual model to allow health care providers to assess their performance and which is backed by a set of transversal and specific indicators. Transversal indicators may be used in every hospital and specific indicators are defined according to the characteristics and the reality of each health care facility (WHO, 2007). Furthermore, the WHO conceptual model and the respective indicators allow comparative characterisations of the performances of different health care facilities (WHO, 2007).

The OECD also has a long-term objective to develop a set of indicators to robustly reflect the quality of the provision of health care and to be

Santos M., Bastião L., Queirós A., Silva A. and Pacheco da Rocha N..
Information Model for Radiology Performance Indicators based on DICOM.
DOI: 10.5220/0005286201820190
In *Proceedings of the International Conference on Health Informatics* (HEALTHINF-2015), pages 182-190
ISBN: 978-989-758-068-0

disclosed in a reliable manner between different countries using comparable data (Kelley and Hurst, 2006).

With regard to the European Union, in the scope of the project Health Indicators for the European Community, generic indicators were recommended encompassing the major areas in public health, with the definition of the following categories: demography and socio-economic situation, health status, determinants of health and health interventions (Kramers, 2003).

In addition to enable the monitoring and comparison of the existing data, the indicators are used to develop policies (EC, 2013). Presently, there are more than 40 core health indicators in the European Union (EC, 2013). With regards to the International Quality Indicator Project (Associates, 2010), indicators were developed in the areas of emergency care, psychiatric care, continuing care and home health care.

2 BACKGROUND

Performance indicators can be used differently: either individually or in groups as part of an integrated and interdependent set of measures or as part of broader programmes. For instance, they can be part of performance analysis frameworks and certification programs developed by entities such as Kings Fund (Kings Fund, 2014) or Joint Commission International (Joint Commission, 2014).

With regards to medical imaging health care services and respective Quality Dimensions, Lau (2007) mentions the same dimensions that Kelley and Hurst (2006) had identified in their paper for the OECD. On the other hand, the definition of quality in Radiology proposed by Hillman *et al.* (Hillman *et al.*, 2004), quoted in (Rubin, 2011), comprises the dimensions related to Suitability of the Examination, Suitability of the Protocol for the Procedure, Acuity in Interpreting the Results, and Measurement and Monitoring of the Improvement of the Performance in Quality, Safety and Efficiency.

Also in the context of Radiology, Quality Dimensions such as Safety, Efficiency, Effectiveness, Opportunity or Focus on the Patient are clearly seen in the professional practice (Kruskal *et al.*, 2009), as well as the need for improving processes, professional performance and satisfaction of patients and health care professionals (Johnson *et al.*, 2009).

The development and use of specific performance indicators in Radiology may occur in several situations with different objectives according to the requirements of the stakeholders who use them and the Quality Dimensions being considered. Therefore, indicators may be required to analyse financial aspects, productivity, possibility to conduct studies, time spent doing and delivering medical reports and patient satisfaction or to provide information for continuous improvement of quality programmes (Ondategui-Parra *et al.*, 2004; Ondategui-Parra *et al.*, 2005; Ondategui-Parra *et al.*, 2006; Abujudeh *et al.*, 2010; Kruskal *et al.*, 2009).

In Radiology, the information concerning the results of imaging procedures may be found in medical reports, normally stored in the Radiology Information System (RIS), or in images stored at the Picture Archiving and Communication System (PACS). Indeed, images stored in the format Digital Imaging and Communication in Medicine (DICOM) include data that identify the entities involved in the studies as well the technical parameters used for the completion, identification and transmission of the images.

In general, PACS provide a limited set of search functions, *i.e.* we can only use a restricted number of DICOM fields to carry out queries. This means that it is only possible to perform inflexible queries to search DICOM data (Costa *et al.*, 2009; Källman *et al.*, 2009).

Therefore, to enable customized queryng some solutions have been developed to complement the standart search options provided by PACS-DICOM query and retrieve services (Vano *et al.*, 2002; Vano *et al.*, 2005; Vano and Fernandez, 2007; Vano *et al.*, 2008; Källman *et al.*, 2009; Stewart *et al.*, 2007). A solution that seeks to meet the requirements mentioned previously is the *Dicoogle* tool (Costa *et al.*, 2011).

The purpose of this paper is to define and validate an information model to support the definition of DICOM Radiology Performance Indicator (DICOM-RPI) taking into account the diversity of contexts arising from different professional situations such as those related to health care facilities with distinct health care profiles and providing different imaging modalities.

2 METHODOLOGY

The *Dicoogle* tool (Costa *et al.*, 2011) can be used to access and retrieve information included in the DICOM metadata. This tool has already been validated in hospital settings and allows data mining using DICOM metadata. Several initiatives involving pilot studies conducted in different health care facilities were implemented (Santos *et al.*, 2011, Santos *et al.*, 2013), such as the analysis of X-radiation exposure levels in mammograms (Santos *et al.*, 2014).

The access and retrieval of information included in the DICOM metadata and its use as statistical variables may occur in an isolated manner (*e.g.* analysing the variation of the value of an attribute throughout a certain period of time) or in combination with other attributes, depending on the goals to be attained. One way to promote its use is to develop standardized performance indicators to allow both intra-institutional and inter-institutional benchmarking taking into consideration the involving contexts. This means that a correct characterisation of the context, although complex, becomes the cornerstone for the assertiveness needed to develop, maintain and use DICOM-RPI.

Keeping this in mind, the definition of an information model that allows the characterisation of indicators and respective contexts was achieved by using the *Unified Modelling Language* (UML) (Booch *et al.*, 2001; Pender, 2004), in particular class diagrams. The classes may represent information objects from different sources, namely PACS.

In this context, the DICOM metadata that is relevant for DICOM-RPI can be obtained using *Dicoogle*, especially to identify the different stakeholders involved in the process of doing imaging studies, such as, for example, the patient, the health care facility or referring physician. This approach enables the inclusion of information which characterises the context in which the professional activity unfolds.

The methodological approach that was followed comprised two steps. First an information model was defined and, afterwards, the model was validated using data acquired by *Dicoogle* tool from 51,277 Digital Radiography (DX) studies of 27,559 patients that were selected from 7,525,275 images, belonging to 154,635 studies of 64,163 patients.

3 RESULTS

When defining the DICOM-RPI we consider that they should be relevant for the analysis of the quality of the professional practice in its different Quality Dimensions (*e.g.* Security or Efficiency). The Quality Dimensions may be included in different Areas of Performance (*i.e.* Structure, Processes and Outcomes). On the other hand, the Quality Dimensions and the Areas of Performance to be analysed rely on the context in which medical imaging health care occurs.

3.1 The Information Model Supporting DICOM-RPI

The DICOM-RPI comprises information that characterise different aspects relevant for the analysis of medical imaging health care provision. In Figure 1 some concepts that can be part of a DICOM-RPI and can characterise different levels of information are presented.

When we analyse Figure 1, we see that the definition of a DICOM-RPI requires the characterisation of: Intervening Entity/ies; Quality Dimensions; DICOM Metadata; Areas of Performance; and Contexts of Use (*e.g.* where the indicator was developed and used). On the other hand, the specification of the Areas of Performance is supported by information that identify the specific area (*i.e.* Structure, Process or Outcomes) and the respective sub-area (*e.g.* Use of Equipment, Exposure Factors or the Number of Studies Conducted by each Professional).

The information that characterises the Type of Entity may include the entity's address and is used to identify the intervening entity.

Finally, the characterisation of the DICOM Metadata includes the metric supporting the DICOM-RPI as well as the Metadata Origin and the Operational Definition.

Within the scope of the object-oriented information modelling, the different concepts presented in Figure 1 may represent different classes which are related. Therefore, the Intervening Entity, Quality Dimension, DICOM Metadata, Context of Use and Area of Performance classes are related to the DICOM-RPI class.

Keeping in mind the complexity of the information associated to the different classes, they must be divided into subclasses. This is the case of the Intervening Entities class, which must include a subclass supporting the identification of different types of entities (*e.g.* manager, developer, user or owner), or the Area of Performance class, which must include subclasses supporting the identification of the sub-area under analysis.

One way to generalise the information model that supports DICOM-RPI is to define structures that do not support only specific information, but also information that is transversal to all indicators. Within the scope of the model proposed in Figure 2,

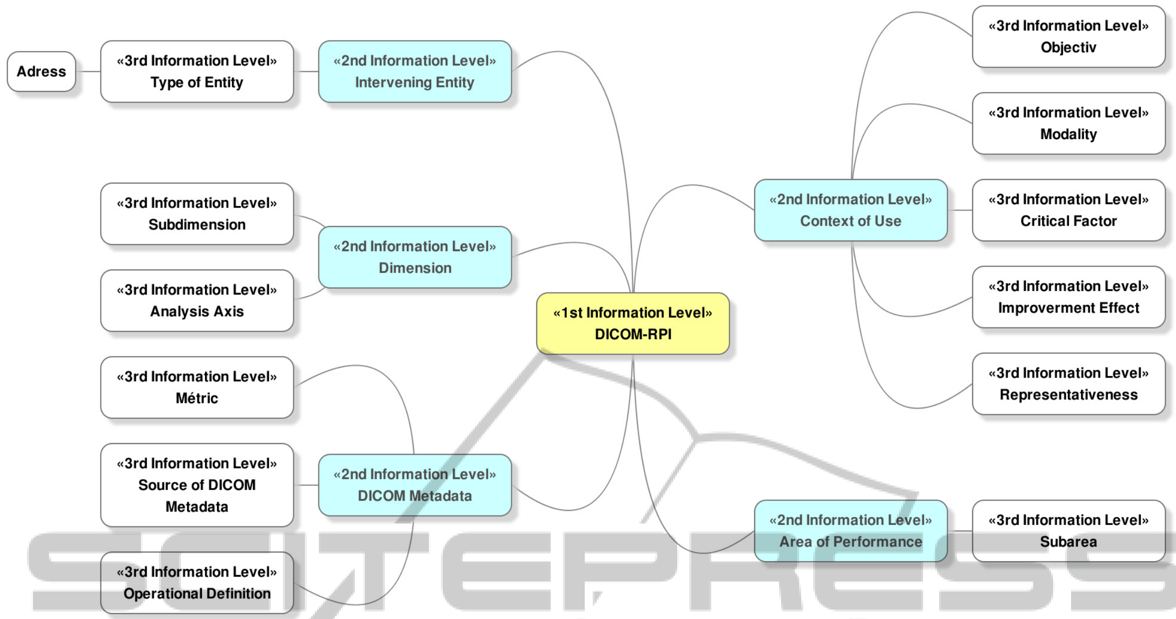

Figure 1: Different DICOM-RPI information levels (example).

the Modules and Collections are the elements responsible for the flexibility and expandability of the information structure. The possibility to use different Modules and Collections, with different structures, adapted to the reality under analysis, enables the use of the DICOM-RPI information model in different contexts and with different purposes.

Therefore, a high-level generic information model that supports the DICOM-RPI information may be described as follows: Each DICOM-RPI class (first level of detail) has one or more Module classes (information of a second level of detail). Each Module class has one or more Collection classes (information of a third level of detail). Each Collection class may or not include other Collection classes that are characterised by one or more items (Figure 2).

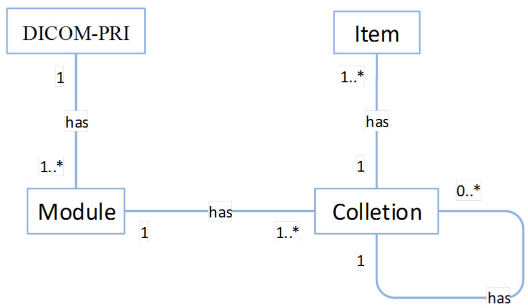

Figure 2: Generic information model supporting the DICOM-RPI.

The definition of a DICOM-RPI, supported by the information model being proposed always starts with a question concerning the medical imaging health care provision and access to the DICOM metadata.

Taking into account the specific characteristics of the different contexts in which the development of indicators may occur, the related information can be considered as persistent (*e.g.* the item Name or Identifier) and as dynamic, (*i.e.* items related to the specificity of each DICOM-RPI). The collected information may be structured in several different Collections of items belonging to different Modules (Figure 3).

3.2 Validation of the Model

The validation of the information model was based on data pertaining to the studies performed in a health unit of average size (400 beds) during the years 2011 and 2012. Data from 7 directories, forming part of the PACS archive, were analysed in a total volume of 4,152 TB of information. This process lasted for 648 hours and resulted in the collection of information on 7,525,275 images, belonging to 154,635 studies performed by 64,163 patients.

For example, in Figure 4 presents a DICOM-RPI related to the number of patients (based on the DICOM attribute Patient ID) with DX modality studies performed in the health care facility, as well

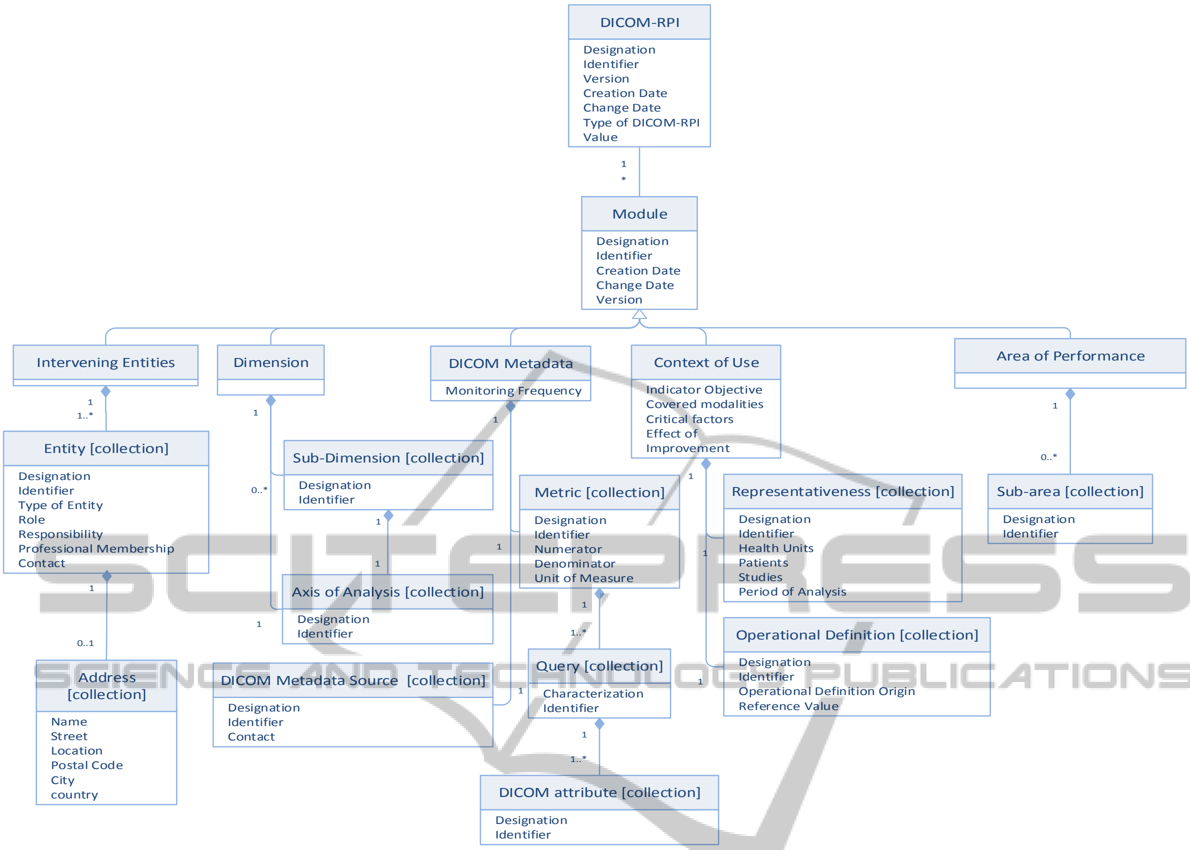

Figure 3: Example of the instantiation of the Generic Information Model that supports DICOM-RPI.

as related to the values pertaining to the number of patients with studies performed in a year (Macro DICOM-RPI type), month (Intermediate DICOM-RPI type), day (Elementary DICOM-RPI type), and the number of female patients with studies performed on that day (Sub-indicator DICOM-RPI type). With regards to the period of time covered by a DICOM-RPI, it arises from the query performed on the repository of imaging studies. In the example, the Analysis Axis is the number of patients. This Analysis Axis is used in the scope of the Radiological Security Sub-Dimension (with ID:SD.1) belonging to the Security Dimension (with ID:S.1), which in turn is part of the Area of Performance Results (with ID:AP.1) (Figure 4).

The model must support information that contributes to a better understanding of the DICOM-RPI. In Figure 5, and as an example, information is made available on the contextualisation of DICOM-RPI with ID: 1.1.1.1 and whose analysis must always take into account the intrinsic characteristics of the indicator (*e.g.* Area of Performance, Quality Dimension or Type of Indicator) as well as information about the imaging modalities included in each DICOM-RPI and the representativeness of the data sample from which the value of the indicator is obtained.

Particularly, the value for DICOM-RPI in Figure 5 is obtained from a sample of 27,559 patients and the corresponding 5.1277 studies of the health care facility throughout in 2011. The period covered by DICOM-RPI is a day (24h). With regards to the Operational Definition, it can be internal or external to the health care facility. Additionally, its reference value may be external or defined internally by the user.

In Figure 5 there is information regarding the number of patients with DX modality studies performed in the health care facility per year as well as the number of studies performed on those patients. These data contribute to the characterisation of the profile of health care provision and to the critical analysis of the value presented by DICOM-RPI (regarding the number of patients with studies performed on 11/11/2011). The characterisation of the entities intervening in the definition, use and maintenance of the DICOM-RPI, presented in Figure 6, is based on the role they take

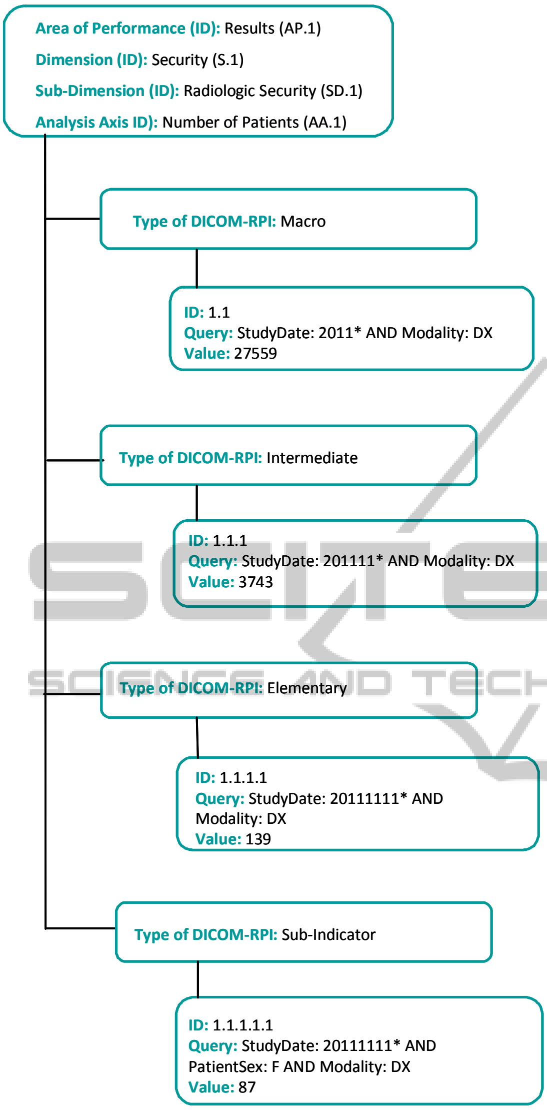

Figure 4: Example of DICOM-RPI types related to Area of Performance "Results".

DICOM-RPI designation			*ID:*
Number of patients with DX radiographic studies performed in one day			1.1.1.1
Creation Date	*Alteration Date*		*Version*
10/11/2013	12/11/2013		1
Type of DICOM-RPI	*Value*		
Elementary	139		
Module: Context of Use			
Designation	*ID*		*Version*
DICOM-RPI 1.1.1.1 contextualization	Context_1.1.1.1		V1
Creation Date	*Alteration Date*		
18/11/2013	--------------		
Objective			
Identify the number of patients with radiologic studies performed in one day			
Modalities			
Digital Radiology			
Critical Factors	*Effect of Improvement*		
DICOM metadata quality	Decrease of population exposure to X radiation		
Collection: Representativeness			
Designation	*Patients*		
Health Care Facility 1	27559 patients/year		
ID	*Studies*		
R.HD.HCF1.1.1.1.1	51277 studies/ year		
Health Units	*Period of Analysis*		
1	November 11 2011 (24h)		
Collection: Operational Definition			
Designation	*Origin*		
Number of studies performed during a day (24h)	Intern (Health Care Facility 1)		
ID	*Reference Value*		
DO.1.1.1.1	(to be establish by the user)		

Figure 5: Module "Context of Use".

Module: Intervening Entities (related with 1.1.1.1 DICOM-RPI)			
Designation:	DICOM-RPI 1.1.1 Intervening Entities	Version	V.1
ID:	*EI_1.1.1.1*	*Alteration Date* 19/11/2013	*Creation Date* 18/11/2013
Collection: Entity		**Collection: Entity**	
Type of Entity:	DICOM-RPI Manager	*Type of Entity:*	DICOM-RPI Manager
Name:	User A	*Name:*	User B
ID:	1234	*ID:*	2345
Role:	Responsible for Quality Improvement	*Role:*	Head of Department (MD)
Responsibility:	DICOM-RPI storage and management	*Responsibility:*	DICOM-RPI Definition
Professional Membership:	Health Care Facility 1 exclusivity (technologist)	*Professional Membership:*	Health Care Facility 1 exclusivity
Contact:	UserA@gmail.com	*Contact:*	UB@outlook.com
Collection: Entity		**Collection: Address**	
Type of Entity:	DICOM-RPI Proprietary	*Name:*	Health Care Facility 1
Name:	Health Care Facility 1	*Street:*	My street
ID:	3456	*Location:*	My city
Responsibility:	DICOM-RPI Proprietary	*Postal Code:*	1111-111 My city
Professional Membership:	State Department of Health	*City:*	My city
Contact:	HF1@ab.com	*Country:*	My country

Figure 6: Example of entities intervening in the definition and use of a DICOM-RPI.

on in the processes (Type of Entity). Here, we characterise the entities responsible for developing and managing a DICOM-RPI as well as the entity owning the indicator. In the example there is only information regarding the address of the DICOM-RPI Proprietary Entity.

From the analysis of Figure 6 it can be seen that all entities have an assigned responsibility, as well as a unique identifier to identify them in a repository of DICOM-RPI indicators.

The assertiveness of the use of DICOM-RPI depends on many factors such as, for example, the information that supports them, namely the Metric, the DICOM attributes that were accessed and the query method that was performed.

In Figure 7, and as an example, information is provided about the data that support the DICOM-RPI with ID: 1.1.1.1. With regards to the characterisation of the Metric that supports the indicator we verify that the denominator is 1.

However, this value may be different. For example, if we want to know the average number of patients with studies performed per hour, the numerator of the Metric would be the total number of studies performed during the day and the denominator would be the number of hours.

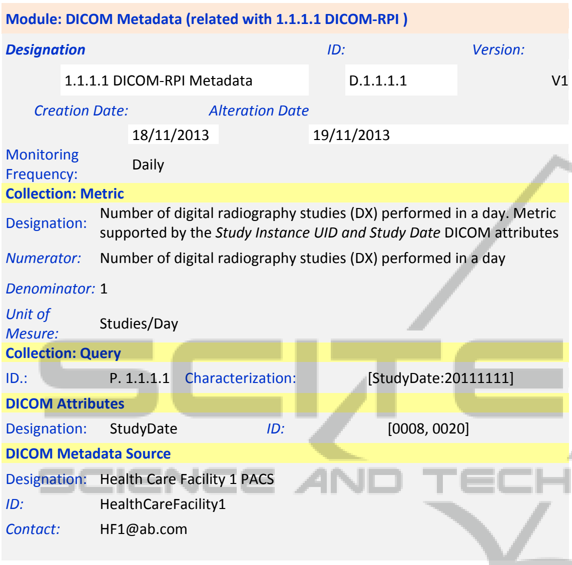

Figure 7: Example of the data characterisation which supports an DICOM-RPI.

As is the case with all information Modules, the DICOM Metadata Module also has the creation date (18/11/2013), the alteration date (19/11/2013), and information regarding the version (Version V1). The inclusion of the query that was used enables an easier identification of the DICOM Metadata that supports the DICOM-RPI.

In another aspect, the identification of the origin of the DICOM metadata, in particular through its naming, enables a faster communication between the different stakeholders interested in the analysis and use of DICOM-RPI.

4 DISCUSSION AND CONCLUSION

This study has highlighted its relevance in the definition of the DICOM-RPI. The information model presented allows the use of DICOM metadata to provide metrics as well the context of these metrics. The characterisation of the origin of the DICOM metadata that supports each indicator, as well as the context in which it emerges, promotes a better knowledge of the professional reality. Therefore, the resulting metrics can be analysed in accordance with the profile of provision of medical imaging health care of different health care facilities.

The definition of the Area of Performance and the Quality Dimension gives the information model that supports the DICOM-RPI the scalability it requires to be used in multiple professional settings. On the other hand, it considers the information pertaining to the different Quality Dimensions of health recommended by different international organizations (Kelley and Hurst, 2006; WHO, 2007) as well as those outlined in the framework of Radiology (Lau, 2007, Hillman *et al.*, 2004; Johnson *et al.*, 2009; Kruskal *et al.*, 2009; Rubin, 2011), which may be useful to identify areas for improvement in the provision of medical imaging health care.

The use of DICOM-RPI, based on the proposed information model, may contribute to the evaluation of the provision of medical imaging services.

The inclusion of DICOM metadata in a comprehensive structure of information that supports DICOM-RPI contributes to the characterisation of the quality of health care provision in Radiology. This characterisation can be made in different Areas of Performance and Quality Dimensions of medical imaging health care provision.

The DICOM-RPI related to the professional activity of the Radiology departments, supported by the access to DICOM metadata using *Dicoogle*, may become an important resource and valuable tool in the characterisation of the quality of medical imaging health care provision. However, the validation of the information model that supports the DICOM-RPI presented in this paper was only done at the level of DX modality. Therefore, in future work, it is relevant to develop strategies for the consolidation of the information model in the scope of other medical imaging modalities, as well as in the scope of broader studies for the characterisation of the professional practice in the Radiology departments. On the other hand, the success of the information model presented is dependent of the understanding by all users of the semantics being used and of the acceptance of a standardised methodology for the definition of DICOM-RPI that can be used by different stakeholders.

ACKNOWLEDGEMENTS

This work was partially supported by COMPETE - Sistema de Incentivos à Investigação e Desenvolvimento Tecnológico, Projectos de I&DT

Empresas em co-promoção, under QREN TICE.Healthy. LBS is funded by FCT, Fundação para a Ciência e a Tecnologia, under the grant agreement SFRH/BD/79389/ 2011.

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