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Analysis of the Data Consistency of Medical Imaging Information Systems: An Exploratory Study

Joana Almeida[a], Milton Santos[b,c*], Daniel Polónia[d], Nelson Pacheco Rocha[e,c]

[a]*Centro Hospitalar do Baixo Vouga, Aveiro 3810-193, Portugal*
[b]*School of Health Sciences (ESSUA), University of Aveiro, Aveiro 3810-193, Portugal*
[c]*Institute of Electronics and Informatics Engineering of Aveiro (IEETA) , Aveiro 3810-193, Portugal*
[d]*Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Aveiro 3810-193, Portugal*
[e]*Department of Medical Sciences, University of Aveiro, Aveiro 3810-193, Portugal*

Abstract

In the context of medical imaging, a considerable amount of data is created on daily basis, which are produced and managed by multiple medical imaging and information systems. The professional and department performance, as well as the respective characterization, are supported by these data, which makes their quality a critical aspect to take into account. The work developed had the objective of analysing the existence of nonconformities related to the consistency of the Radiology Information Systems (RIS) and Picture and Communication System (PACS) databases, as well as their precision, accuracy, integrity and associated risks for the healthcare practice. Data belonging to 1068 computed radiography studies were analysed and ten nonconformities were identified, related to the patient name, patient age, patient date of birth, patient gender, study date, study time, institution identification, radiologist identification, number of radiographic projections performed, and billing code. The work carried out allowed identifying some lack of data quality, sometimes evidenced in the absence of consistency, precision, accuracy and integrity.

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* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: mrs@ua.pt

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1. Introduction

The development of Information and Communication Technologies (ICT), and their use in clinical contexts made it possible to acquire and integrate patients' data resulting from multiple episodes/procedures. These data are acquired and managed by different information systems, namely electronic health records [1], with different functional, technological and architectural perspectives [2].

The use of ICT promotes improved healthcare delivery. This is particularly evident in developing countries where the implementation of clinical information systems improves communication between institutions, helps the organization and management of medicines, and allows monitoring and detecting patients who can abandon treatment, among other contributions [3]. For several decades now, the growing complexity and scope of ICT in clinical settings has been evident in different areas of healthcare provision, namely in the area of medical imaging, allowing the aggregation and availability of data to different stakeholders, which might be internal or external to the organizations [4].

Regarding medical imaging professionals, they access in a daily basis to multiple information systems, such as Hospital Information Systems (HIS), Radiology Information Systems (RIS) and Picture Archiving and Communication Systems (PACS). The networking of these systems promotes the collection, analysis, dissemination and archiving of patient's clinical information and also information related to the actors involved in the provision of healthcare over the time [5]. Concerning the requests for examinations managed by RIS, a critical process for carrying out medical imaging studies [6] that requires data to be shared with PACS databases, some authors have identified lack of data quality [7][8] which may undermine the provision of healthcare [9]. The healthcare provision as well as the professional and department performance characterization are supported by these data, which makes their quality a critical aspect to consider.

Therefore, the exploratory study being reported aimed to find out nonconformities related to the consistency of RIS and PACS databases, in terms of their integrity, precision and accuracy, as well as their risks for the clinical practice.

2. Background

The development, adoption, and implementation of new technological resources in a clinical context can promote better access to health data, with the potential to reduce attendance errors, increase collaboration between clinicians and improve communication between clinicians and patients, if adequate strategies are implemented to allow the exchange of correct and timely clinical data among the different stakeholders [3][11]. Usually, in a clinical context, the installed information systems were developed and are supported by different manufacturers and software vendors [12]. Consequently, the exchange of data often results in fragmented or even duplicate versions and, frequently, health institutions have the same data stored under different formats in different systems. This means that extra complexity is required to maintain consistency between different databases [13]. The quality of the clinical data has been object of study over the years, mainly due to the need to characterize the procedures supported by these data. For instance, Botsis et al. [10] found inconsistency, inaccuracy and lack of data in electronic health records databases. Moreover, Cruz Correia et al. [14] identified that 94.2% of all HL7 message traffic generated by healthcare institution presented nonconformities that jeopardized their quality, being the concept of quality considered as "suitability for use" (i.e. in accordance with the objectives of the messages' use). According to Muller and Freytag, [17] nonconformities detected in clinical data can be semantic (e.g. integrity constraint violations or contradictions), syntactical (e.g. lexical errors, domain format errors or irregularities), and coverage (e.g. missing values or tuples anomalies) nonconformities.

Botsis et al. [10] found that data inconsistencies result from two reasons: i) fragmentation caused by care records performed at different healthcare facilities; and ii) lack of contextual information caused by poor medical documentation. Since the quality of the data may be dependent on several factors, it can be analysed according to different dimensions. In particular, the data should be relevant, timely, accurate, complete, sufficiently detailed and consistent (i.e. appropriately represented), and should retain contextual information [15][16]. Therefore, some studies

were focused on the analysis of data quality in different dimensions in order to perform evaluations and comparisons, so that a set of guidelines were developed and proposed to consistently report and compare the results related to clinical data quality [10][18][19]. Moreover, it is necessary to ensure that data are consistent independently of being stored in multiple databases [20]. According to Mphatswe et al. [21], clinicians lifelong training and periodic data reviews and audits are processes that can promote the improvement of data quality.

In the scope of medical imaging, data nonconformities are related to incorrect patients' data records or studies' requests, which makes evident the importance of tools to allow the reconciliation of patients' data [22]. On the other hand, the existence of errors or non-compliance in the data registered in RIS and PACS databases often implies to process images and to correct the records in order to guarantee the right record of the patients and respective episodes [23]. In this context, Nissen-Meyer et al. [20] developed a tool to verify the correctness of a set of identification criteria associated with essential HIS, RIS and PACS data. The authors found discrepancies in the consistency of information ranging from 0.14% to 8.00%. Moreover, considering the data stored in PACS archives, Santos et al. [24] identified the existence of factors that could compromise their quality, namely the existence of fields related to Digital Imaging and Communications in Medicine (DICOM) metadata that were not filled or were incorrectly filled in. This lack of quality of the DICOM metadata, although residual, may be present in medical imaging studies aiming to characterize the exposure of a population to radiation [25] or medical imaging stakeholders, by using medical image repositories [26]. In the specific case of data reconciliation of RIS and PACS databases, Nitrosi et al. [27] highlighted four types of errors, each one with a respective degree of severity: i) incorrect fusion of different data regarding the same patient (moderate risk); ii) incorrect linking of an image or study to an episode or patient (high risk); iii) incorrect assignment of images or study to an event of the same patient (high risk); and iv) incorrect identification of projection/laterality (high risk).

3. Material and Methods

The data on computed radiography studies (i.e. "Chest - two projections", "Abdomen - one projection" and "Bilateral - two projections") performed for one month in a medium-sized hospital were analysed. The choice of these type of studies was based on the fact that they are among the most performed at National [28] and European levels [29]. The research study was authorized by the administration board and the ethics committee of the involved hospital, being assured that the data collected would be treated in a way that would maintain the confidentiality and privacy of the patients as well as of all those that performed and analysed the imaging studies. Moreover, the experimental work was developed in three phases. During phase one the RIS and PACS databases were analysed in order to collect information about existing fields and respective filling levels related to patients and requested studies. In turn, during phase two the collected information was structured to allow a comparative analysis of RIS and PACS databases fields (i.e. an intra-field and inter-field analysis). Finally, during phase three it was identified and characterized the existing nonconformities between RIS and PACS database data. The considered nonconformities were: i) consistency (i.e. comparative analysis of data representation); ii) precision (i.e. degree of correctness with which real-world data are represented); iii) accuracy (i.e. the extent to which data is recorded and updated); iv) integrity (i.e. the degree to which all relevant data are recorded and available); and associated risks to the patients (i.e. high, medium or low risk).

4. Results

4.1. The Study Sample

The analysis of the RIS and PACS databases allowed the collection of data related to 1068 imaging studies (Table 1), being 430 studies of the "Chest - two projections" (40.3%), 599 studies of the "Abdomen - one projection" (56.1%), and 39 studies of the "Bilateral Hips - two projections" (3,7%).

Table 1 - Sample of computed radiography studies

Study	N(%)
"Chest - two projections"	430 (40.3%)
"Abdomen - one projection"	599 (56.1%)
"Bilateral Hips - two projections"	39 (3.7%)
Total of studies	1068 (100.0%)

From the comparative analysis of the intra-field data (i.e. fields present in both information systems, RIS and PACS) and inter-field (i.e. fields that, although not having the same definition in both information systems are directly related) resulted the Table 2.

Table 2 – Comparison analysis of the RIS and PACS databases

Data Base				Base de dados			
Field	RIS	PACS	Common field	Field	RIS	PACS	Common field
Process no.	√	x		Complications	√	x	
Observations / comments on the study	√	x		Anaesthesia	√	x	
Name	√	√	@	Radiation dose	√	x	
Origin / Module	√	x		Technique	√	x	
Patient identification (ID)	√	√	@	Program	√	x	
Episode #	√	x		Notes / Study Comments	√	o	
Age	√	√	@	Study execution time	√	√	@
Date of birth	√	√	@	Execution start time	√	x	
Gender	√	√	@	End time of execution	√	x	
Address	√	x		Check-in time	√	x	
Telephone	√	x		Access No	√	√	@
Requisition number	√	x		Nº of study images	x	√	
Electronic request number	√	x		State	√	o	
Priority	√	x		Waiting time	√	x	
Requisition date	√	x		Module	√	x	
Requesting physician	√	o		Department	x	o	
Group of acts / scheduling	√	x		Requesting service	√	o	
Resource	√	x		HIS / RIS Verified	x	√	
Study schedule Date	√	x		Description of the study	√	√	@
Date of study	√	√	@	Billing code	√	x	
Start date of realization	√	x		Billing Amount	√	x	
End date of completion	√	x		Responsible for scheduling	√	x	
Location / Institution	√	√	@	Average Duration	√	x	
Doubts to clarify	√	x		Modality	x	√	
Clinical information on admission	√	x		Study Instance UID	√	x	
Operator	√	o		Office Supplies	√	x	
Radiologist	√	o		Contrast products used	√	x	
Observations / comments on the study	√	o					

√ - Existing field, x - non-existent field, o - existing field, but not used, @ - field common to both databases

Analyzing the Table 2 it is possible to identify that of the 55 fields, only ten are simultaneously present and properly filled in both RIS and PACS databases. On the other hand, there are eight PACS database fields that were not filled. Moreover, it is also possible to identify fields that, although with different designations in the RIS and PACS information systems, store equivalent information (e.g. the RIS Study Description field and the PACS Number of study images field), or even fields that store the same information within a same database such as, for example, the Study Description field and the Billing Code, both fields present in the RIS database.

4.2. Nonconformities between RIS/PACS Databases

When analysing the data present in the different fields of the RIS and PACS databases it was identified

nonconformities related to: i) patient name (NC1); ii) patient age (NC2); iii) patient date of birth (NC3); iv) patient gender (NC4); v) study date (NC5); vi) study time (NC6); vii) institution identification (NC7); viii) radiologist (NC8); ix) number of radiographic projections performed (NC9); and x) billing code/study performed (NC10). Table 3 shows the NCs that present the data quality dimensions that were analysed. Furthermore, the last column of the same table presents the respective degree of risk.

Table 3 - Characterization of the nonconformities present in the RIS and PACS databases

Nonconformity ID	*Description*	*RIS/PACS Consistency* (equal format/representation)	*Other data quality dimension affected*	*Risk*
NC1	Patient name (RIS ≠ PACS)	Present	Precision, Accuracy	High
NC2	Patient age (RIS ≠ PACS)	Absent	Precision, Accuracy	Low
NC3	Patient date of birth (RIS ≠ PACS)	Absent	Precision	Medium
NC4	Patient gender (RIS ≠ PACS)	Absent	Precision	Low
NC5	Study date (RIS ≠ PACS),	Absent	Precision, Accuracy	High
NC6	Study time (RIS ≠ PACS)	Absent	Precision, Accuracy	Low
NC7	Institution identification (RIS ≠ PACS)	Present	Precision, Accuracy	Medium
NC8	Radiologist identification (RIS)	Present	Precision, Integrity	Medium
NC9	Number of radiographic projections performed (RIS ≠ PACS)	Present	Precision, Accuracy	Medium
NC10	Billing code / study performed (RIS ≠ PACS).	Present	Precision, Accuracy	Medium

Analysing Table 3 it is possible to conclude that five of the ten NC identified are related to consistency deficits between the data stored in the two databases (consistency absent). Of these five nonconformities, three also present precision and accuracy deficits (two nonconformities classified with low risk and one with high risk), and one only present deficits of precision (classified with a medium risk).

Regarding the nonconformities that present consistency among the data, but present other data quality dimension deficits, they represent 40.0% of the nonconformities (four out of ten). Moreover, four nonconformities have precision and accuracy deficits (three were classified as medium risk and one with high risk) and one has only a precision deficit (classified as medium risk).

Table 4 - Nonconformities identified in the 1068 studies analyzed.

Study	**N**	***Nonconformity (n/%)***									
		NC1 N / %	NC2 N / %	NC3 N / %	NC4 N / %	NC5 N / %	NC6 N / %	NC7 N / %	NC8 N / %	NC9 N / %	NC10 N / %
"Chest - two projections"	430	2 / 0.5%	86 / 20.0%	1 / 0.2%	6 / 1.4%	20 / 4.7%	418 / 97.2%	28 / 6.5%	374 / 87.0%	220 / 51.2%	342 / 80.0%
"Abdomen - one projection"	599	7 / 1.2%	351 / 58.6%	0 / 0.0%	19 / 3.2%	11 / 1.8%	595 / 99.3%	1 / 0.2%	581 / 97.0%	89 / 14.9%	496 / 82.8%
"Bilateral Hips - two projections"	39	0 / 0.0%	20 / 51.3%	0 / 0.0%	0 / 0.0%	0 / 0.0%	38 / 97.4%	2 / 5.1%	31 / 79.5%	22 / 56.4%	37 / 94.9%

Finally, when analysing Table 4, it is possible to conclude that the NC6, NC8, NC9 and NC10 are the most identified (e.g. with 97.0% and 99.3% in abdominal studies and 56.4% and 94.9% of studies performed on the hips). Regarding NC2, this nonconformity appears in 58.6% of the abdomen studies and 51.3% of the bilateral hip studies. In contrast, NC1, NC3, NC4, NC5 and NC7 present low values, some of them almost residual, or even null (e.g. NC1 and NC3 in the abdomen and bilateral hip studies).

5. Discussion

5.1. Accuracy, Precision and Integrity Deficits

Nonconformities were identified in which, although there is consistency between the data from RIS and PACS databases, deficits related to the precision, accuracy and integrity dimensions were present (Table 4).

The patient name data field is always populated in both databases. However, it was possible to identify situations in which for the same study and patient, the patient name was not the same in both databases (NC1). For example, in several situations the complete name of the patient was stored in the PACS database, while in the RIS database the name was incomplete, and vice-versa. This nonconformity was detected in about 0.5% of the "Chest - two projections" studies and 1.2% of the "Abdomen - one projection" studies. One possible explanation might be that manual insertion of patients' data occurred when the information system was not accessible such, as, for example, in cases of urgency or lack of connection between information systems. This nonconformity can be considered as high risk, since the physician when using the patient name to query the information system, which is a very common practice, might select the wrong patient. Regarding the institution identification nonconformity (NC7), accuracy and precision deficits were identified (e.g. empty fields or fields with different contents appearing in the RIS database when compared to the PACS database) in 6.5% of the chest studies, and in residual percentages for the other studies. The same happens with nonconformities related to the identification of the radiologist who executes or validates the study (NC8). A high percentage of this type of nonconformities is present in the Abdomen studies (97.0%). Although the respective field exist in the PACS database, it was not populated, which means that it was not possible to compare the information stored in the databases of the two information systems. Similar situations were also identified in other studies when analysing medical image repositories [24]. When comparing the Radiologist field with the Operator field (both belonging to the RIS database), sometimes it was present the identification of the technician performing the procedure. The nonconformity of the both fields are considered to have medium risk since they do not endanger the health condition of the patients. However, in situations that is necessary to contact the technicians responsible for performing the studies, important information may be incorrect.

Regarding the number of projections made and stored in the PACS archives (NC9), the analysis fell into two distinct but directly linked fields. The Number of study images field belonging to the PACS database was compared with the Description of the study field belonging to the RIS database. In 51.0% of the "Chest - two projections" studies, a difference was notice between the number of stored images and the two projections that should be a part of the study. This percentage is higher (56.4%) in the "Bilateral Hips - two projections" studies. This can result from an incorrect request or change of procedures because of the characteristics of the patients. This nonconformity was considered to be of medium risk, however, it may eventually have repercussions when analysing the productivity of the medical imaging department, since this analysis is usually based on the data present in the RIS database and not on the data of the PACS database, irrespective of being the latter one the information system that effectively reports the procedures that were performed.

Concerning NC10, related to the coding of the procedures for later billing (Billing code field of the RIS database), once more it was not identified data consistency problems. However, it was identified deficits of accuracy and precision when compared to the field Number of study images of the PACS database. For example, in one situation, although a "Chest - two projections" study should have two images, the corresponding Billing code correspond to a study "Chest PA", which has only one projection. This type of nonconformity was detected in about 80.0% of the "Chest two projections" studies, in 94.9% of the "Bilateral Hips - two projections" studies and in 82.8% of the "Abdomen - one projection" studies. This type of nonconformity can be considered to have a medium risk because it has no severe consequences for the patients.

5.2. Data Inconsistency and its Accuracy and Precision

One of the nonconformities identified is relative to the age of the patient (NC2). The field destined to register the age of the patients was always filled in both RIS and PACS databases. However, it was possible to identify syntactical errors, namely lexical and domain [17]. For example, for a specific patient, the RIS database contained the value "20 Years", while the PACS database contained the value "19Y". In another situation the value "009M" was identified in

the PACS database while the value "1 year" was present in the RIS database. This type of nonconformities (NC2) was detected in 20.0% of the "Chest - two projections" studies and 51.3% of the "Bilateral Hips - two projection" studies. NC2 was also identified in 58.6% of the "Abdomen - one projection". Whenever NC2 was detected precision and accuracy deficits were also identified, but the age variations were always lower than one year.

In the scope of nonconformity related to the patient date of birth (NC3), different values were identified in the RIS and PACS databases for the same patient. For example, for a specific patient, it was found the value "05-12-1954" in the RIS database, while the value "12-05-1954" was found in the PACS database. This nonconformity is related to domain format errors and it was considered to have a medium risk because although it does not endanger the patients' health conditions but may raise doubts when analysing a study if it is really related to the specific patient being subject of care.

Regarding the nonconformity related to patient gender (NC4), it was possible to detect situations in which the gender of a given patient stored in the PACS is "O" (Other), while it is stored in the RIS as "Feminine". The same was observed for male patients. NC4 was detected in about 1.4% of the "Chest - two projections" studies and 3.2% of the "Abdomen - one projection" studies and, additionally, accuracy deficits were also identified. This nonconformity was classified as being of low risk because it does not endanger patients' health condition.

The data fields related to the date of execution of the study are present in both the RIS and PACS databases and were always filled. In terms of nonconformities (NC5), it was possible to identify studies that have different execution date on the RIS and PACS databases (e.g. 10/11/2015 on the RIS database and 03-11-2015 on the PACS database). NC5 was detected in 4.7% of the "Chest - two projections" studies and in 1.8% of the "Abdomen - one projection" studies. This type of situation can have different causes, such as, it was not possible to create the electronic request in the RIS, although the request exist in RIS, it did not go automatically to the image modality, or it was not possible to register the requisition in RIS when the study was performed. Regarding other dimensions of the quality of the affected data, deficits of precision and accuracy were identified.

The data fields related to the execution time of the study (NC6) are present in the RIS and PACS database and were always filled with information. From the analysis being performed it was possible to identify situations in which the information provided is not the same for the same study and patient. For instance, for a study, in the RIS database the execution time was "12:00" while in the PACS database it was stored "11:45:12". NC6 was detected in about 97.2% of the "Chest - two projections" studies, 97.4% of the "Bilateral Hips - two projections" and 99.3% of "Abdomen - one projection" studies. This type of nonconformities present deficits of precision and accuracy and it was considered to have a low risk, since in most situations it does not endanger the patients' health conditions.

Nonconformities were identified in the fields Location/Institution (NC7). NC7 was detected in 6.5% of the "Chest - two projections" studies, in 5.1% of the "Bilateral Hips - two projections" studies and in 0.2% of the "Abdomen - one projection" studies. The data field related to the institution identification where the study was performed, although it exists in both RIS and PACS databases, was not always completed in RIS. On the other hand, the identification of the institution is sometimes different in both databases, which can be erroneous interpreted as being in presence of two distinct institutions. Although it was evident the presence of precision and accuracy deficits, NC7 represents a medium risk because it does not have significant consequences for both patients and the normal functioning of the medical imaging department.

6. Conclusion

The quality of the stored data in RIS and PACS databases can be analysed to promote continuous quality improvements. The results of the experimental study reported in the present article allowed the identification of nonconformities and deficits of consistency, accuracy, precision and integrity of data stored in RIS and PACS databases. The correction of the identified problems may represent a point of improvement for the care delivery, both in terms of patients and professionals.

Nevertheless, the experimental study presented some limitations. Particularly, the sample was a small convenience sample and the collection of the data was confined to a short period of time. Therefore, it is not possible the generalization of the results, as well as to draw conclusions about the totality of the data stored in the databases under analysis.

As a future work it will be relevant the development of tools that automatically, and with little human intervention, might analyze the quality of the data stored on RIS and PACS databases. The rapid recognition of inappropriately recorded data would allow the implementation of corrective plans and, therefore, the improvement of medical imaging care.

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