



Universidade de Aveiro
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Departamento de Eletrónica, Telecomunicações
e Informática

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Santos Soares**

**Plataforma Web de Monitorização de Dose de
Radiação em Imagem Clínica**



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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Doutor Carlos Costa, Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro.

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o júri

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palavras-chave

Imagem Médica, PACS, DICOM, DICOM Data mining, Relatório de Dose.

resumo

A monitorização sistemática da exposição dos cidadãos à radiação ionizante associada aos procedimentos imagiológicos é fundamental para garantir a qualidade dos serviços clínicos. Esta atividade é importante no controlo de desempenho, na optimização de protocolos e na rápida rectificação das práticas erradas. Em teoria, os episódios de radiodiagnóstico devem sempre manter a exposição à radiação tão baixa quanto razoavelmente possível (princípio ALARA), preservando a qualidade de diagnóstico. Os sistemas de monitorização de dose automáticos podem ser úteis em todas as fases de procedimentos radiológicos, ajudando os profissionais de saúde a melhorar os seus comportamentos de dosimetria. Mais ainda, a exposição aplicada nos procedimentos deve ser planeada individualmente, o que significa que a monitorização da dose também deverá ser. Além disso, o acesso integrado à história imagiológica do paciente pode ser útil para efetuar um melhor tratamento. No entanto, muitos dos atuais sistemas de informação não permitem efetuar análise de dose e a sua monitorização contínua é rara. Neste contexto, o contributo desta dissertação é o Dose Center, uma ferramenta centrada no paciente que permite monitorizar e analisar a dose de radiação. Ela tem capacidade para extrair informação proveniente de diferentes fontes e permite uma visualização integrada de toda a informação relativa aos pacientes, quais os estudos realizados, a dose efetiva e cumulativa de radiação. A ferramenta permite ainda sinalizar os casos que excedam os limites pré-definidos de radiação, uma inequívoca contribuição para a melhoria da segurança do paciente.

Keywords

Medical Imaging, PACS, DICOM, DICOM Data mining, Dose Reporting.

Abstract

Systematic monitoring of radiation dose exposure is a key factor to increase the quality of radiological services. This activity may lead to performance control, protocol optimization and rapid rectification of wrong practices. Moreover, dose monitoring can help the healthcare professionals to improve their dosimetric behaviors. In theory, radiodiagnostic episodes should always keep the radiation exposure as low as reasonably achievable (ALARA), while preserving the quality of diagnosis. Hence, the applied exposure in the radiology departments shall be individually planned, which means that the dose monitoring should be performed individually to ensure an appropriate dose usage. Automatic dose monitoring systems may be helpful during all the phases of radiologic procedures and the integrated access to imagiologic history may be helpful to do a better patient treatment. However, many of actual healthcare information systems do not allow dose analysis and its continuous monitoring is rare. In this context, this document proposes the Dose Center, a software platform that provides a patient-centric radiation dose analysis and a monitoring system that was designed to automatically extract and analyze dose reports captured from distinct data sources. It provides several data analytics views like, for instance, by modality or patient, including the studies effective and cumulative dose radiation. Cases exceeding the radiation thresholds are signaling, contributing this way to improve the patient safety.

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Glossary

ACR American College of Radiology

AE Application Entity

ALARA As Low As Reasonably Achievable

CDA Clinical Document Architecture

CNEN Comissão Nacional de Energia Nuclear

CRUD Create, Read, Update and Delete

CSS Cascading Style Sheets

CT Computed Tomography

CTDI Computed Tomography Dose Index

CTDI_{vol} Computed Tomography Dose Index Volume

DAP Dose Area Product

DBMS Database Management System

DDM2 Dose DataMed 2

DICOM Digital Imaging and Communications in Medicine

DIMSE DICOM Message Service Element

DLP Dose Length Product

DML Data Manipulation Language

DR Digital Radiography

DRL Dose Reference Level

EC European Commission

ESD Entrance Surface Dose

HIS Hospital Information System

HL7 Health Level Seven International

HTML Hyper Text Markup Language

HTTP Hyper Text Transfer Protocol

HTTPS Hyper Text Transfer Protocol Secure

ICRP International Commission on Radiological Protection

ICRU International Commission on Radiation Units and Measurements

IE Information Entity

IHE Integrating the Healthcare Enterprise

IOD Information Object Definition

IT Information Technology

JPA Java Persistence API

JPQL Java Persistence Query Language

JSON JavaScript Object Notation

KAP Kerma Area Product

LDRL Local Dose Reference Level

MED Medical Exposure Directive

MPPS Modality Performed Procedure Step

MR Magnetic Resonance

MRI Magnetic Resonance Imaging

MVC Model, View, Controller

MWL Modality Worklist

NDRL National Dose Reference Level

OCR Optical Character Recognition

PACS Picture Archiving and Communications System

PET Positron Emission Tomography

PSD Peak Skin Dose

RBAC Role Based Access Control

RDSR Radiation Dose Structured Report

REM Radiation Exposure Monitoring

RIS Radiology Information System

SCP Service Class Provider

SCU Service Class User

SOP Service Object Pair

SQL Structured Query Language

SSL Secure Socket Layer

TLV Tag Length Value

UNSCEAR Scientific Committee of the United Nations for the Effects of Atomic Radiation

URI Uniform Resource Identifier

VL Value Length

VR Value Representation

WADO Web Access to DICOM Persistent Objects

1. Introduction

Nowadays, medical imaging departments have to contend with important challenges like, for instance, providing regulatory compliance, demonstrate good practice in the radiation dose management, reduce costs, optimize resources and ensure patient safety [1]. In particular, radiologists are interested in achieve a better balance between radiation dose and image quality. On other hand, healthcare managers are very interested in analysis software to help in risk management and in improving the services efficiency [1].

In order to ensure that the new MED (Medical Exposure Directive) guidelines are respected, health carers must continuously monitor radiation dose centred on the patient, independently where she/he receives care [2]. This associated inter-institutional scenario also touches the lack of interoperability problem in the healthcare domain. This new reality is promoting the development of dose monitoring tools, such as Dose Center. Those systems are used to capture, locate and automatically report the examinations radiation dose. This information may be obtained directly from imaging acquisition modalities or from the PACS (Picture Archiving and Communications System) archive [3]. These information technologies resources may be installed on hospital networks and are, in most cases, web-based, ensuring convenient access to all authorized users.

Automatic dose monitoring tools may be helpful during all the phases of radiologic procedures. Before the examination starts, radiologists may include in their assessment the dose information of the patients, and the access to the integrated imagiologic history may be helpful to do a better patient treatment.

Healthcare institutions and the scientific community itself have been working in the problem of monitoring the patient's effective radiation dose, applying the ALARA (As Low As Reasonably Achievable) principle to have a better and adequate treatment. This is a radiation safety principle [1, 2] for minimizing radiation doses and the health professionals can also monitor and optimize the individual modalities, ensuring that procedures protocols are correct. Moreover, they should have the maximum of information about their patients, such as aggregated information about the dose radiation data, the medical exams they have been submitted to and other facilities that allows simulating the possible impact of a specific exam.

This document proposes a new radiation dose monitoring tool, i.e. the Dose Center, that is compliant with DICOM standard and supports the IHE (Integrating the Healthcare Enterprise) radiation dose profile. It can be integrated with traditional PACS archives enabling a centralized access and dose analysis for the patient, study and population scopes. It is a crucial step for quality management of the medical imaging department by allowing systematic control of dose performances and supporting protocol optimization.

1.1 Thesis Structure

This document is divided into different sections in order to show the growth of knowledge as the complexity of the work has been gradually increasing. The chapters that will be addressed throughout this document as well as a brief description for each are as follows:

Chapter 2 introduces the common healthcare systems challenges in terms of interoperability and patient safety (IHE REM Profile). Some organizations like ICRP (International Commission on Radiological Protection) or standards like DICOM (Digital Imaging and Communications in Medicine) are very important in order to provide some guidelines of dose radiation protection or sharing information between institutions in order to reduce patient dose radiation when some dose values exceed the thresholds specified by Dose Reference Levels respecting the ALARA principle. Some medical physical concepts and calculation methods used to determine the effective / cumulative dose for a patient are also present here.

Chapter 3 represents the state of the art which addresses some examples of dose monitoring tools already exist and refer some of these features. It also presented a summary table (Table 10) which contains some pros / cons of each of these tools.

Chapter 4 shows in detail the overall system architecture and interaction with the PACS workflow. Essentially represents an overview of all steps from extraction to the display of dose data and statistical dashboards, not only in terms of dose but also in terms of productivity.

Chapter 5 addresses Dicoogle tool and its importance to developed work, explains the software architecture associated to the process of dose extraction (Dose Extractor) and describes the extraction methods used. It also explains the technologies adopted in the development of Dose Center.

Chapter 6 presents final results of all the features that have been implemented in the Dose Center and, for each of them, there is a brief explanation of its importance and impact on patient safety.

2. Background

2.1 Medical Image Network and Procedures

Medical image can be defined in various ways like, for instance, a *n-dimensional* map of a particular physical property of tissues (clinically relevant), a result of discerning an object with some form of steered energy or a result of many forms of tissue interactions and energy steering. In summary, it corresponds to a piece of information of about a certain patient [1, 2].

A good management and high-quality of medical imaging services provide patient care enhancement. Medical imaging assemble visual information about target organs of the human body, allowing assessment levels such as morphologic, metabolic, physiologic and functional; and support clinical decision making related to diagnosis, therapeutic and monitoring [1].

Nowadays, there are several applications that enable medical image processing, analysis and also visualization of different modalities (PET (Positron Emission Tomography), CT (Computed Tomography), or MRI (Magnetic Resonance Imaging)). Most of them supporting a standard user-interface and analysis tool via Web that can easily share research information to a better medical diagnosis, monitoring and treatment, like MIPAV application [4].

Most of the times, healthcare centers do not support all the modalities that are required to evaluate a patient (MR (Magnetic Resonance) or CT modalities, for instance) and a consequence of this is that patients need to move to another institutions that have required modalities. This can be critical because medical imaging data will be dispersed over different institutions and it needs to be exchange between healthcare institutions, a challenge due to interoperability and data access latency issues.

Medical images are very important in healthcare systems, representing an essential part for the delivery of high quality medical decisions. Digital images, patient data and studies are stored in local repositories addressing the concept of Picture Archiving and Communications System (PACS) [3].

PACS represent the technological core of a digital department that stores, distributes and displays digital medical images for interpretation or review. Moreover, it is usually integrated with hospital IT infrastructure, namely the HIS (Hospital Information System) and RIS (Radiology Information System) [3].

PACS facilitates also teleradiology, improves patient care and it is considered as an essential reference for radiologists and technologists as well as for imaging facility planners and support clinical staff.

2.2 Interoperability between Healthcare Systems

These days, there are many guidelines point that institutions need to estimate the procedures radiation dose to keep them as low as reasonably achievable (ALARA). For instance, the European legal framework 2013/59/EURATOM [5] states that health authorities will be more pervasive on inspecting the dose radiation applied to patients.

To support the sharing of dose information, healthcare systems must be interoperable at this level. The new IHE Radiation Exposure Monitoring (REM) Profile [6] allows the collection and distribution of the estimated patient dose radiation exposure values, providing a common language to discuss the integration needs and capabilities of healthcare infrastructures. IHE [7] has an important role in improving the way as healthcare information systems share information and in providing integration with established standards, such as DICOM (section 2.3) or HL7 (Health Level Seven International), to address clinical needs in order to optimize patient safety.

IHE improves interoperability in healthcare systems by providing services to develop, test and implement standards-based solutions. The main idea of this initiative is the interoperability of systems with regard to communication with each other, allowing that health care providers may use the information more effectively. These profiles offer an easy implementation for communication standards that are carefully documented (it documents how to support dose reporting using existing standards), reviewed and tested, reducing the complexity and costs of implementing interoperable applications [8].

2.3 DICOM Standard

DICOM (Digital Imaging and Communications in Medicine) is the international standard for the organization, communication protocols and management of medical imaging information, contributing to the exchange of information in a structured way.

DICOM “*is not just an image or file format*” [9], it provides all the necessary tools such a universal standard of digital medicine (a display protocol built and designed to cover all functional ways of medicine) in which all acquisition devices produce DICOM images and communicate through DICOM networks. The communication consists in two steps: negotiation phase – where many relevant aspects are agreed upon such as services supported and transfer syntaxes; effective data transfer – between the two hosts. It provides full support for several image acquisition parameters and different data types (DICOM defines 24 data types), complete encoding of medical information through numerous DICOM files and messages. It supports several message encoding syntaxes (including JPEG lossy or lossless), including multi-frames (movies) and multiple characters sets.

DICOM provides a set of recommendations and guidelines to allow the exchange of medical images between different digital equipment manufacturers, facilitating the development and expansion of PACS. PACS [3] are medical systems built to run digital medical images comprising the following components (Figure 1):

- Modality: Digital image acquisition device that produces DICOM files;
- Digital Image Archive: The local where the acquired images are stored;
- Workstation: The local where radiologists/medical physicians read the images.

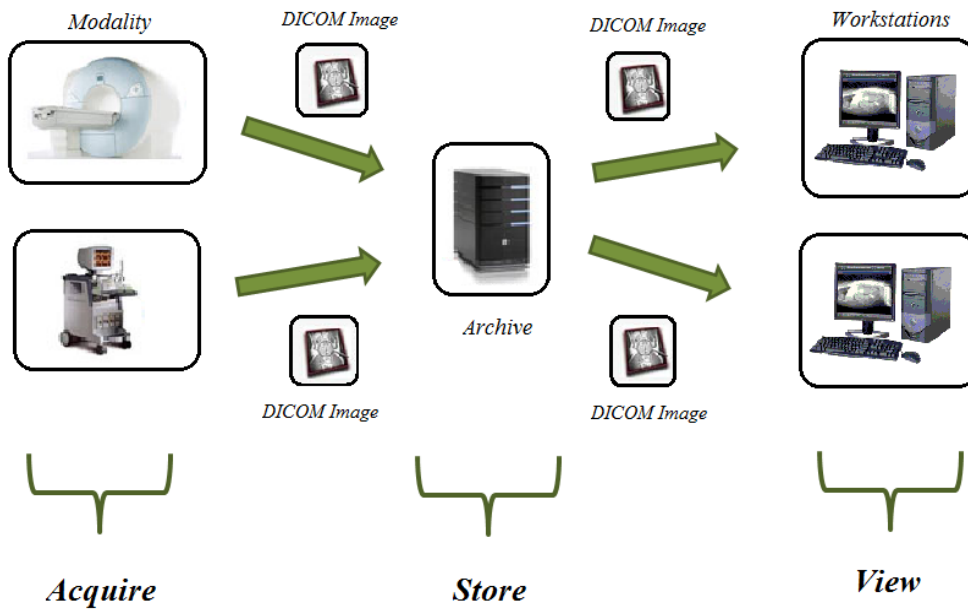


Figure 1. PACS Workflow: The PACS Components

The lead role of PACS consists in DICOM-driven which guarantees the interoperability between systems that process, store and transmit digital medical images. Modalities or image acquisition devices store the produced images on a digital archive (Image Manager & Archive) and from there images are accessed by healthcare professionals at the local viewing workstations (Figure 1).

2.3.1 DICOM Objects

All information data related to patients, studies, medical devices, images, reports, vital signals and others are considered as DICOM Objects and their format is defined in the DICOM Dictionary [10] to ensure consistency in formatting and processing, for instance. This dictionary corresponds to a unique identifier for an element composed by an ordered pair of numbers (a Group Number followed by an Element Number) and is used to identify attributes and data elements. DICOM is object-oriented and the information of each object and transfer syntaxes are identified by UID that starts always with 1.2.840.10008. The information related to the real-world objects is specified through the usage of an object-oriented data abstraction model called by IOD (Information Object Definition). For example, if we considered Study IOD then we can describe some tags related to the study level such as Study Date, Study Instance UID, Description, Modality, among others.

IOD Entity-Relationship model (E-R model) [11] provides the context (or relationships) between the different IE's (Information Entities). It means that this model explains how the composite instance information should be interpreted when exchanged between two DICOM AE's (Application Entities).

IE's represent real-life entities (study, series, patient, image, waveform, among others) which are comprised of one or more previous modules, consisting in reproducing objects that are manipulated in laboratories of images. Data elements correspond to the basic elements that are defined in dictionary. The organization of DICOM objects is the follow (Figure 2):

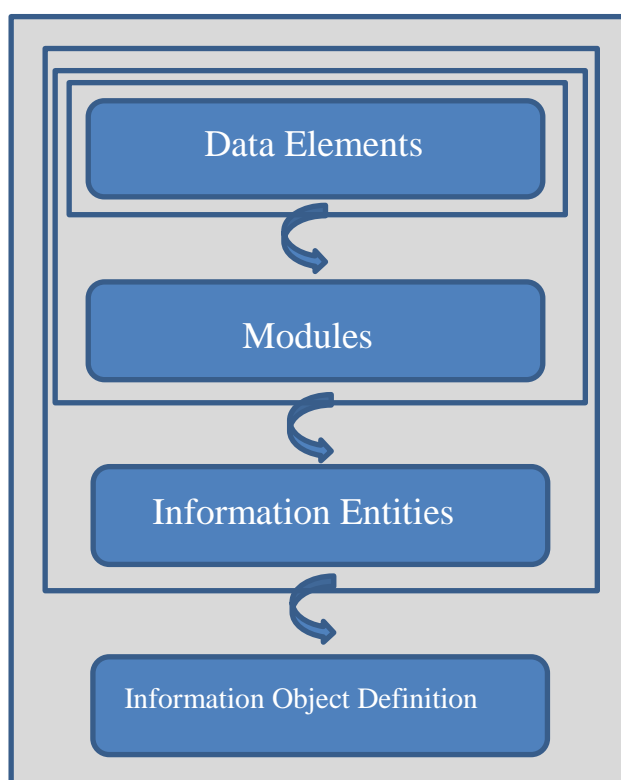


Figure 2. DICOM - Objects Organization

There are two DICOM Object types:

- Composite (NEMA v2 inherited): IOD's with multiple information entity;
- Normalized (DICOM v3 introduced): IOD's with only one information entity.

Figure 3 shows an example of composite image IOD with multiple information entities: Patient, Study, Series, Equipment and Image.

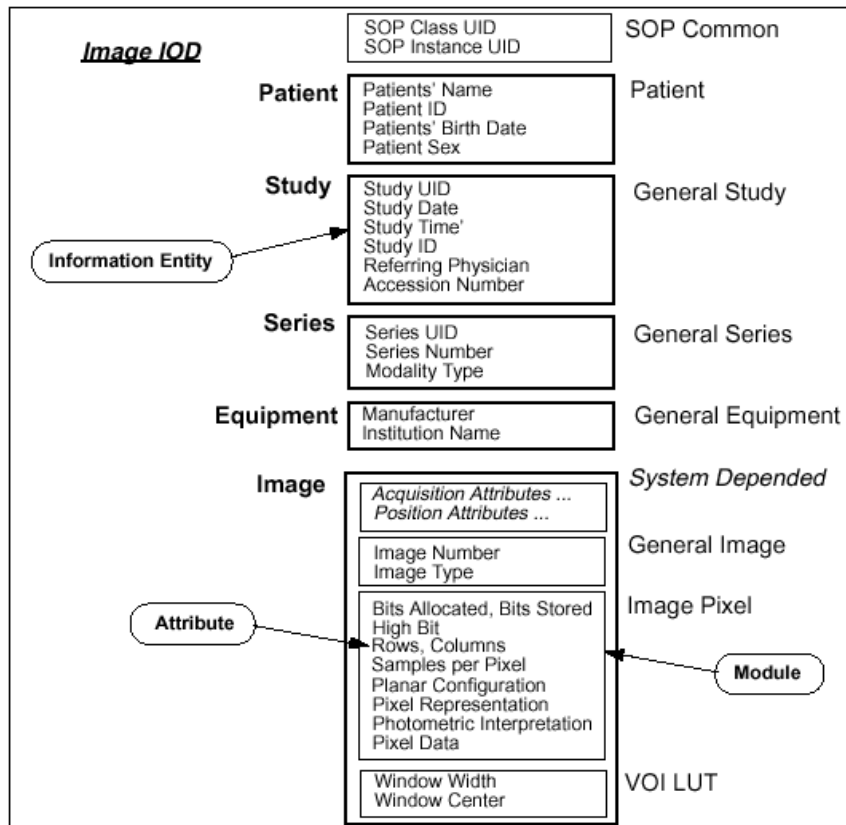


Figure 3. Image IOD, an example of Composite DICOM object [12]

2.3.2 DICOM File

Digital medical images are archived to the storage media as DICOM files. DICOM File [13] contains a file meta-information header and an image information object. The first one is composed of a file preamble (with 128 bytes) that corresponds to an empty region usually set to zero (sometimes applications will use it for proprietary data), a prefix “DICM”, all uppercase, that corresponds to the signature of the DICOM file and the file data elements with DICOM group 0002 (section 2.3.3). The header data is composed by clinical staff, patient demographics, image data, equipment’s data and others. The image data contains the encoding type (raw or compressed – RLE, JPEG lossy or lossless, MPEG2), the colour (RGB, Palette, Grayscale), among other relevant information.

PACS receives DICOM images from the acquisition modalities through DICOM services and then those files are created and well achieved.

The basic file structure can be seen in the following illustration (Figure 4):

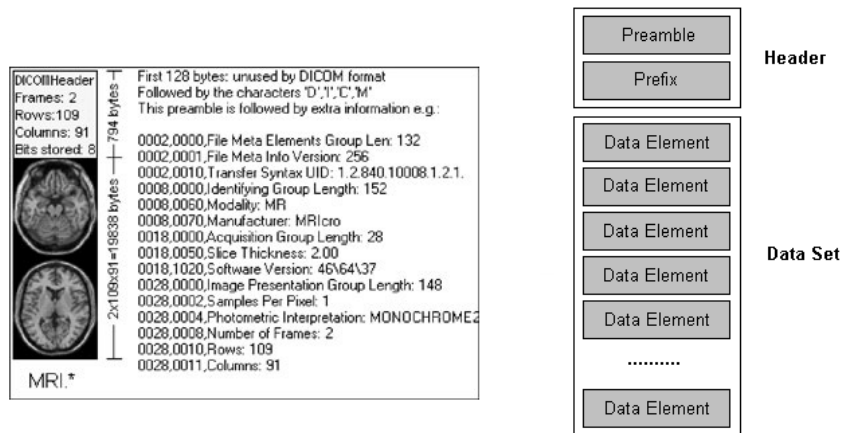


Figure 4. Basic DICOM File Structure [14, 15]

The information object should contain all mandatory data elements as specified in this standard and, to provide possibilities of encryption or compression data, the information object may be encapsulated based on meta-information.

This file format [16] is described by DICOM standard for communicate using offline media because most of the medical images are accessed as files stored in some offline scenario.

2.3.3 DICOM Data Structure

The DICOM data set is composed by numerous data elements or attributes that are sequentially stored (Figure 4). These elements are stored in a TLV (Tag / Length / Value) structure and organized in groups and subgroups. The next chapter will cover in a little more detail this structure.

2.3.3.1 TLV Structure

The tag identifies every data element and has a fixed length of 4 bytes (2 bytes for Group ID and another 2 bytes for Element ID). The representation of data elements follows a TLV data structure (Figure 5):

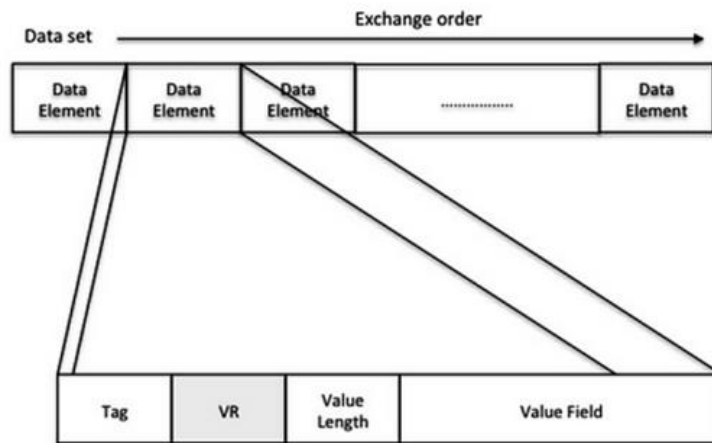


Figure 5. TLV format for data elements [17]

The tag (0010, 0010) means that group 0010 corresponds to the patient information and element 0010 corresponds to the patient name (Figure 6).

Value Representation [17] identifies the element data type (could be PN – Personal Name, UI – Unique Identifier, among others) and has the fixed length of 2 bytes (some VR have 4 bytes: 2 bytes for VR and another 2 bytes “0x0000”) and this attribute may be optional depending on transfer syntax.

Value Length is equivalent to the content field length and the length of this attribute could be 16 or 32 bits, it depends on transfer syntax, so if the transfer syntax is explicit (VR is included in TLV structure) the length could assume 16 or 32 bits but if the transfer syntax is implicit (VR is not included in TLV structure) then the total length is 32 bits (Figure 6).

Finally, the Value Field is the content field itself and may be a unique element or a subgroup of elements.

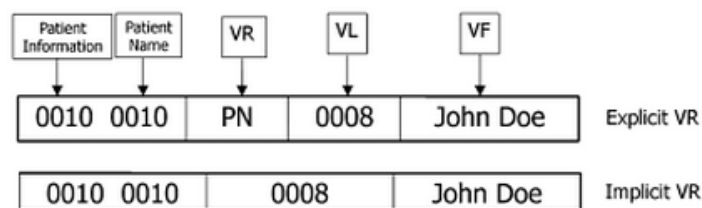


Figure 6. TLV structure for a Person Name [17]

The transfer syntax is one of the most important tags that allow verifying if the information is Little Endian / Big Endian, if it is a JPEG image lossy or lossless, essentially determines the type of object encoding.

By default, the tag transfer syntax is uncompressed (i.e. is raw by default), with Implicit VR and the information is Little Endian with the UID: 1.2.840.10008.1.2.

2.3.4 DICOM Communications

As mentioned before, the DICOM communication protocol consists of two phases: the negotiation phase where services supported or transfer syntaxes are agreed between two DICOM nodes and the effective data transfer phase between them, if the negotiation process was successful.

There are two classes of services in the DICOM communications [16]:

- Service Class User (SCU): entity that initiates the service communication (equivalent to client);
- Service Class Provider (SCP): entity that accepts the service request (equivalent to server).

During the negotiation process, the capacities of the services are defined as SOP (Service-Object Pair) Classes. These classes define services and their associated rules. SOP Class corresponds to the association of a DIMSE (DICOM Message Service Element) command with an IOD. There are several DIMSE commands like, for instance, Set, Get, Find and Move [16].

DIMSE Services are divided into two categories: DIMSE-C Services and DIMSE-N Services [16]. The first ones are applicable to Composite SOP Instances and the second ones are applicable to Normalized SOP Instances. The SOP Instance corresponds to the sum of SOP Class with the image object instance.

The operations for each of them will be addressed in more detail in the next two sub-chapters.

2.3.4.1 DIMSE-C Services

The DIMSE-C Operation Services [18] are: C-ECHO, C-STORE, C-FIND, C-GET and C-MOVE.

C-ECHO [16] is invoked to verify end-to-end communications, i.e. to verify the connectivity between two DICOM nodes. It is a DICOM Ping that in practice is used to see if some node is online or offline. Verification SCU send a C-ECHO-RQ command with no data set to the Verification SCP and this returns a C-ECHO-RSP command with success status indicating that connection between them was successful.

C-STORE is invoked to request the storage of Composite SOP Instance. Storage SCU sends the digital images to Storage SCP (push action) and it can send all objects using only an association or multiple associations [16].

Storage SCU sends a C-STORE-RQ command including metadata and pixel data to the Storage SCP and this one store the objects received (Image Archive) and sends a C-STORE-RSP with final status (Figure 7). The standard does not define how the Storage SCP stores the images received after push.

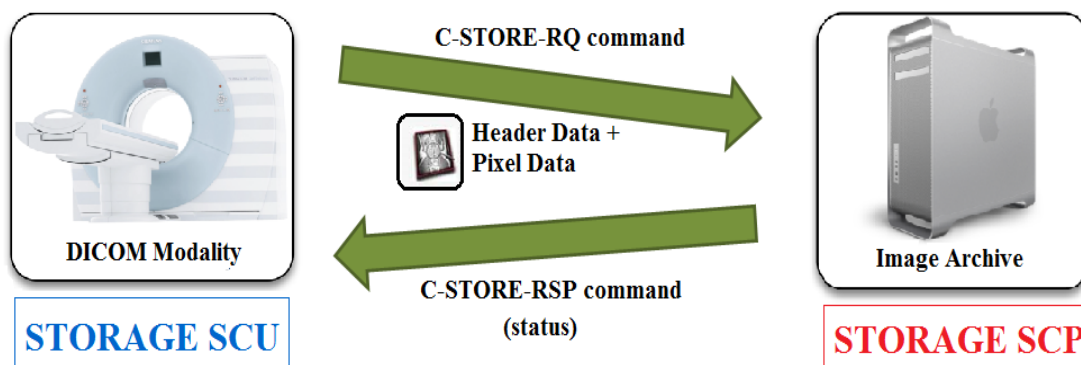


Figure 7. DICOM Storage Service

Query/Retrieve service is used by workstations for looking patients, studies, series or images and to obtain digital images from a certain file server (PACS Archive for instance).

C-FIND [16] is used to find a series of attributes of the set of SOP Instances and this service returns a list of attributes and their values. In a DICOM Query, the Query SCU sends a C-FIND-RQ command with query string (example of a query: Study=Today, give patient name and patient ID) to the Query SCP and this one sends a C-FIND-RSP command with the query response (example: Study=Today, Tiago Soares, 1234). But there may be more answers to the same query and if it happens then is sent as answer a pending status until finishing the query. For example, if today there are two patients who underwent studies, Tiago Soares and Carlos Costa, then the Query SCP will have to send it back another C-FIND-RSP command to the Query SCU with the query response: Study = Today, Carlos Costa, 5673, for instance. Finally, when the query response is finished, then the Query SCP will have to send another C-FIND-RSP command but now with the final status (success status) to notify the client.

C-GET [16] is invoked to fetch one or more Composite SOP Instances and C-MOVE service is invoked to move one or more Composite SOP Instances to a third party DIMSE-service-user peer. Both services are used in DICOM image retrieve, and the Figure 8 shows the interactions involved between Retrieve SCU and Retrieve SCP in this kind of DICOM service.

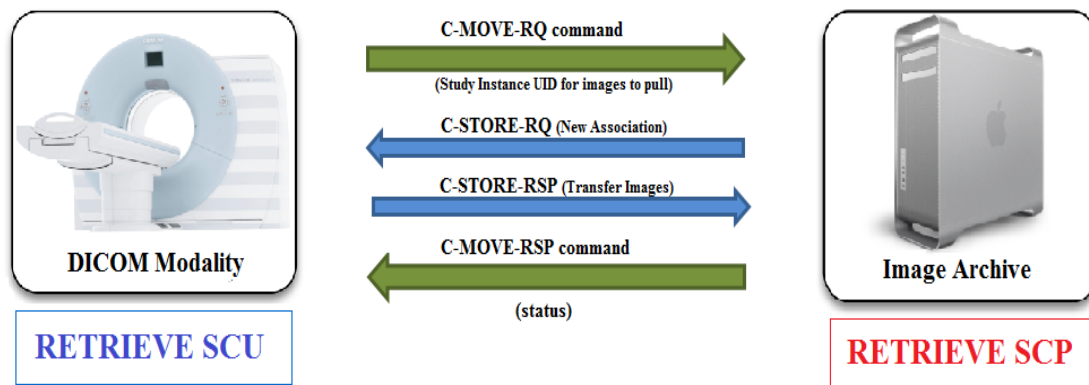


Figure 8. DICOM Image Retrieve Service

Figure 8 shows how DICOM Image Retrieve service works. Retrieve SCU initiates the service communication and sends to Retrieve SCP a C-MOVE-RQ command with the Study Instance UID for images to pull. Then the second peer opens a second Association to send the images (called by “Pull Model”) and sends a C-STORE-RQ command to the client and this one sends a C-STORE-RSP command to the SCP transferring all the multiple medical images. The SCP stores the images retrieved and to finalize the process send a C-MOVE-RSP command with the success status. C-MOVE operation could be also done with 3 devices: SCU, SCP and Storage SCP.

2.3.4.2 DIMSE-N Services

The DIMSE-N Operation Services [18] are: N-EVENT-REPORT, N-GET, N-SET, N-ACTION, N-CREATE and N-DELETE. DIMSE-N services provide not only the operations services for Normalized SOP Instances but also notification service.

N-EVENT-REPORT is invoked to report an event about SOP Instance to a peer DIMSE-service-user and corresponds to a confirmed service.

N-GET is invoked to request the retrieval of information from a DIMSE-service-user peer.

N-SET is invoked to request the change / adaptation of information by a DIMSE-service-user peer.

N-ACTION service is invoked to request a DIMSE-service-user to execute an action.

N-CREATE service is invoked to request a DIMSE-service-user to create an instance of an information object.

N-DELETE service is invoked to request a DIMSE-service-user to remove an instance of an information object.

N-ACTION and N-EVENT-REPORT are operations used in storage commitment service [16]. This happens because the C-STORE success status does not guarantee the storage of the medical images in SCP (server). So, to resolve that, storage commitment service verify if the images sent were well stored in the server and for that, Storage SCU sends an N-ACTION-RQ command to Storage SCP to know if the images were well stored and, in the affirmative case, Storage SCP sends an N-EVENT-REPORT with success status.

Another service that uses these operations is the basic print service [16] where the Print SCU sends an N-CREATE command to create the film sheet (after SOP Classes and Transfer Syntaxes being agreed) to the Print SCP, then sends an N-SET command to place the images on the film sheet created. N-ACTION command is sent to request the print of the film sheet and the SCP responds with an N-EVENT-REPORT command that includes the status of the printer.

2.3.4.3 Modality Worklist and MPPS

Modality Worklist (MWL) [9] uses also the C-FIND operation but with a different purpose. MWL is an important service because it is possible to healthcare professionals knows the actual list of patients to scan or to have the patient demographics information in the modality.

The Radiology Information System (RIS) [19] is designed to help professionals to control and document the work they do for patients and they used this system to add reports and images or retrieve / transmit this kind of information to specialists involved.

RIS performs scheduling exams for different modalities (Day, Hour, Room / Modality) and the MWL SOP schedule consumes this information coming from the RIS in DICOM format. The query is performed with C-FIND-RQ command using a special UID, the MWL SOP UID: 1.2.840.1008.5.1.4.31 in the (0000, 0002) tag. After that, MWL SCP sends a C-FIND-RSP command with the same MWL SOP UID to return the study data to each modality.

Some of the most data sources such as Modality Worklist are crucial in healthcare environments because it allows the automatically data transmission from RIS to modality, preventing replication tasks, transcription errors of operators and ensuring data consistency. MWL also allows efficient management of resources with regard to the planning performed by RIS and provides capacity of workflow adaptability of specific institution.

Modalities could be configured from two different modes: automatically (automatic query is sent with some periodicity) or manually (query is sent after operator request).

When the patient is scanned, data retrieved from MWL like, for instance, Patient Name, Patient ID or even Date/Time of Study is included in the DICOM images.

MWL has some advantages such as:

- There are no requirements in the modality about what is asked, this means that it could be adapted to the workflow defined by a certain entity;
- Efficient Resource Management that allows planning carried out by the RIS with automating assignment of patients to different modalities, human resource management and more efficient usage of device;
- Good ability to adapt to the specific workflow of institution.

Modality Performed Procedure Step (MPPS) [20] is a DICOM service that is responsible to send the information from Modality to RIS (typically) or to PACS Archive during or after the examination. This information could be patient data, clinical staff, performed protocols, consumed resources (time and material) and information produced such as a list of digital medical images.

Initially the modality sends an MPPS message indicating that the examination started and, at the end of the study, the modality sends another MPPS message to PACS Archive or RIS to inform that the examination was completed (Figure 9). This MPPS message contains a list of DICOM objects that were acquired during the examination.

Figure 9 shows the MPPS interaction between DICOM Modality and RIS / PACS Archive.

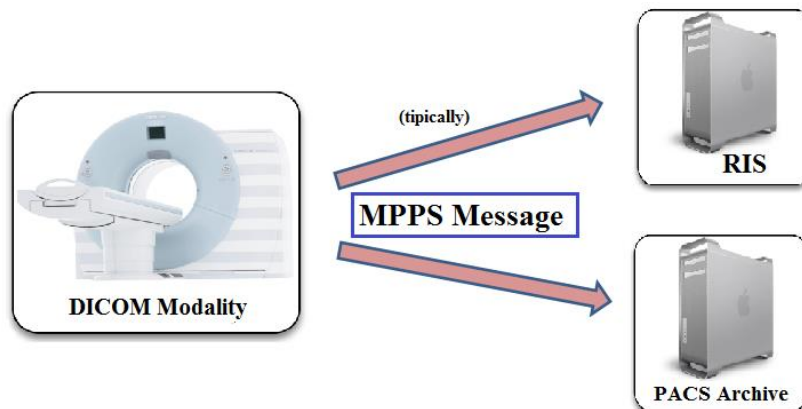


Figure 9. Modality Performed Procedure Step (MPPS)

Several advantages of the MPPS is that it allows to be used in billing providing procedures details, in procedure status monitoring (so that medical physicians could see if the order was started or canceled), in

workflow allowing healthcare professionals to see the pending exams or who are ready or even in patient tracking to know where the patient was at a certain moment, for instance.

2.4. Ionizing radiation dose

According to the Scientific Committee of the United Nations for the Effects of Atomic Radiation (UNSCEAR) [21], natural radiation exposes a person, on average, at a dose of 2400 μSv per year.

Although exposure to natural radiation depends on location, there are indications that many people are exposed to a dose between 10,000 and 20,000 μSv per year. A person is typically exposed to about 600 μSv in a survey of abdominal X-rays, and 6,900 μSv in a CT scan, for instance.

According to CNEN (“*Comissão Nacional de Energia Nuclear*”) [22] on March 15, 2011, a high dose radiation of 400 mSv (millisievert) per hour was measured in the Unit 3 area of Fukushima Dai-ichi, Japan. However, this is a value dose measured inside the nuclear central. The maximum value observed on the front gate of the nuclear central was 11, 93 μSv per hour in the same day.

Sievert (Sv) [22 - 23] is a unit used to measure the impact of radiation on the human body. This unit takes into account the relative biological effectiveness of ionizing radiation and it is inconveniently large for several applications, so the millisievert (mSv) unit [22] is frequently used instead for dose rate indications and concerns on radiological protection.

Sievert was recommended by ICRU (International Commission on Radiation Units and Measurements), in 1997.

The maximum exposure radiation value recommended by the International Commission on Radiological Protection (ICRP) for the individuals and for a professional who works with ionizing radiation is called dose limit.

The individual annual dose limit is 1 mSv (1000 μSv) and, for the workers, the dose limit is 20 mSv per year in an average of 5 years which cannot exceed the 50 mSv, per year.

It is important to note that the dose limit does not include the exposure to natural radiation. Although cancer risks increase proportionally with dose at any dose level received by a person below 100 mSv, it shows no significant increase in the risk of developing cancer sickness.

Dose Center was focused only on CT studies because CT radiation dose is potentially high and this modality should be considered. There are at least four reasons for CT should be considered as a modality with higher radiation dose: (1) there is no dose penalty for relatively high radiation dose examinations; (2) CT doses are intrinsically high radiation dose examinations; (3) there are "hidden" dose penalties that occur with CT; and (4) there is no binding regulation for CT practice.

CT radiation doses may be quite high, while doses, especially in pediatric CT, can be < 1.0 mSv, doses can be > 30 mSv as well [25]. The effective dose of a chest CT (e.g., 5 mSv) is nearly 100 times the effective dose from a frontal and lateral chest radiographic series (0.06 mSv) in an adult [26]. When settings are not adjusted for size, CT doses are higher in small children. Approximately 80% of all radiation exposure comes from background sources and 15% is from medical radiation, with up to 67% due to CT.

In conventional X-rays, the beam enters the body from one plane and the highest dose is at the entrance surface of the body. But in CT, the X-ray tube rotates around the patient's body and thus the radiation is deposited on all entrance points around the body and in addition there is contribution of radiation that penetrates the body from other directions and this result in overall higher radiation absorbed dose to the irradiated parts [25–27].

The effective dose (section 2.4.3) from CT scans may range from approximately 2 to 20 mSv, which is about the same as a person receives from background radiation in one (2.4 mSv global average) to eight years.

Table 1 shows the typical radiation doses associated with CT examinations, with mean effective dose values (in mSv) and the equivalent number of chest radiograph (each 0.02 mSv).

CT Examinations	Mean Effective Dose (mSv)	Equivalent number of chest radiograph (each 0.02 mSv)
Head	2	100
Neck	3	150
Calcium scoring	3	150
Pulmonary Angiography	5.2	260
Spine	6	300
Chest	8	400
Coronary Angiography	8.7	435
Abdomen	10	500
Pelvis	10	500
Chest (pulmonary embolism)	15	750

Table 1. Mean effective doses from CT examinations [29]

2.4.1 Justification and Optimization of Protection

The management and assessment of patient dose or even the measurement and calculation of radiation dose has become one of the most frequently discussed topics in Radiology. Information on patient dose depends on several parameters like patient-specific characteristics and technical parameters.

The International Commission on Radiation Protection (ICRP) is an independent and non-governmental organization that provides guidelines regarding radiation protection [30] This organization takes into account three fundamental principles of radiological protection, which are: justification, optimization and application of dose thresholds defined by the European regulations. The difference between the justification and optimization is not clear because justification concept relates to the practice itself (always do more than harm) while optimization is the process of establish the appropriate level of protection for that specific practice [31].

In order to avoid some constraints that may exist during optimization of protection, ICRP recommends dose limits that are received by individuals during practice operation and directed at doses from controlled sources of ionizing radiation.

At high doses, especially in emergency situations, radiation exposures may cause tissue reactions and occur above threshold doses. These deterministic effects depend on the absorbed dose, dose rate and also radiation quality as well as the sensitivity of the tissue [31].

The reporting of doses in medical procedures, the use of dose reference levels and the availability of dose indicating devices must be considered and also requires a “*high level of competence and a clear definition of responsibilities and tasks among all professionals*” [30], in order to ensure the adequate protection and safety of patients.

ICRP has introduced the concept of Effective Dose, which represents a risk-related quantity for the control of radiation exposure and optimization of protection. It cannot be measured directly, but rather is calculated using some kind of defined dosimetric models.

Quantities such as $CTDI_{vol}$, DLP and Effective Dose are important in medical institutions when they are used appropriately and should not be used to quantify higher radiation doses or to make decisions on the need for tissue reactions treatment.

2.4.2 Data sources and Metrics

The dose information may be obtained from the DICOM header or using the pixel data. Most of the dose calculation inputs may be obtained from studies metadata. However, most of them are not present in DICOM headers, such as beam collimation which is optional in the DICOM standard and not filled by the most modalities.

Monitoring radiation tools aim to automatically extracting the dose information from medical imaging repositories, providing a better control of dose performance and contributing, in this way, to get a better protocol optimization.

To do this, there are numerous DICOM tags [31 - 32] related to radiation dose that may be extracted directly from the DICOM header data such as: *Exposure Time* (corresponds to the total time that patient has received X-ray exposure during the irradiation event, measured in seconds), *Sensitivity* (detector sensitivity manufacturer in specific units), *KVP* (recorded by system, measured in kV), *Organ Dose* (corresponds to the average organ dose value measured in dGy (decigray) during the acquisition of that image), *Organ Exposed* (organ to which Organ Dose (0040,0316) applies and the defined terms are Bone Marrow, Gonads, Breast, Fetus and Lens), *Dose Calibration Factor* (the factor that was used to scale the image from counts /sec to Bq/ml using the dose calibrator and this value should be one if the calibration dose was applied) and *CTDI_{vol}* – *Computed Tomography Dose Index Volume*.

CTDI offers a more convenient method to estimating the dose values, requiring only a single scan acquisition and the early days of CT, saved a considerable amount of time.

CTDI_{vol} is a dose descriptor based on CTDI that corresponds to the measure of exposure per slice and is independent of scan length. It describes the average absorbed dose (based on sets of contiguous irradiation) for a specific frame for the selected CT conditions of operation within the scan volume for standardized phantoms and it is derived from the division between the *CTDI_w* and the pitch, where *CTDI_w* is the weighted computed tomography dose index 100 as defined in IEC 60601-2-44 that is used to account for the variation in the CTDI across the field [32].

$$CTDI_{vol} = \frac{CTDI_w}{pitch} (mGy)$$

Equation 1. CTDI_{vol} calculation [34]

CTDI_{vol} is an objective technical dose parameter based on a directly measured quantity and takes into account specific parameters (protocol information) being useful to estimate and compare different scan

protocols across several CT scanners of the same phantom. It is also considered as a useful indicator of dose for a specific test protocol.

However, usually most of these tags have no value and the manufacturers opt by save this information in the pixel data. The solution is to extract the dose information using Optical Character Recognition (OCR).

Nowadays, one of the main medical institutions challenges is in the monitoring of radiation dose. Concretely, exposure metrics have to be extracted "*from existing image repositories, stored, and organized in database that can be accessed*" (said Maj. Graham Warden, MD, from the U.S. Air Force Medical Corps, in his RSNA talk) [35]. So it is essential the development of dose radiation tool that automatically extracts this kind of information.

According to Graham Warden [35], "*institutions need to accumulate "large-scale, actionable" dose data, which can be done with open-source software and optical character recognition software*". Dose information from newer CT scanners is based on the 2007 DICOM CT Radiation Dose Structured Report (RDSR) standard for encoding CT dose, as well as the Integrating the Healthcare Enterprise (IHE) Radiation Exposure Monitoring (REM) profile.

CT (Computed Tomography) dosimetry makes use of two important radiation dose parameters: $CTDI_{vol}$ (discussed previously) and Dose Length Product (DLP). While the "*volume CTDI quantifies the intensity of the radiation used to perform CT examinations*", DLP "*quantifies the amount of radiation used*" (said Huda et al.) [36].

DLP is the measure for total radiation exposure for all the series of images and it is a convenient index for total dose radiation. While DLP is calculated for every irradiation event [32] (an irradiation event is one continuous irradiation procedure and defined through acquisition parameters), total DLP corresponds to the sum of the all DLP values.

It is important to mention that the radiation dose should always be stored at patient or study level. At the image level, they only contain information that will allow calculating the total DLP.

There are at least three ways of extract the DLP: 1) Calculate by our own based on the parameters stored in each image; 2) extract from the pixel data with an OCR and 3) extract from DICOM Radiation Dose Structured Report (RDSR).

For the first method, the DLP could be calculated depending on scanning type. For spiral scanning, DLP is calculated as follows:

$$DLP = CTDI_{vol} * Scanning Length (mGy \cdot cm)$$

Equation 2. DLP calculation for spiral scanning [31]

But if scanning type is sequenced, then DLP is obtained by:

$$DLP = CTDI_{vol} * Nominal Total Width * \frac{Cumulative Exposure Time}{Exposure Time per Rotation}$$

Equation 3. DLP calculation for sequential scanning [31]

For stationary and free scanning:

$$DLP = CTDI_{vol} * Nominal Total Collimation Width$$

Equation 4. DLP calculation for stationary and free scanning [31]

Scanning length, Nominal Total Width, Exposure Time, Exposure Time per rotation and $CTDI_{vol}$ are tags that could be extracted directly from metadata of DICOM objects.

These DLP calculation methods follow the IEC 60601-2-44 standard [32]. Unlike $CTDI_{vol}$, DLP is proportional to the size of the scan.

According to *Tsalafoutas* and *Metallidis*, DLP is “used to calculate the dose for a series of scans or a complete examination” and the equation is the following [37]:

$$DLP = \sum_{i=1}^N (CTDI_{vol})_i \cdot L_i$$

Equation 5. DLP calculation according *Tsalafoutas* and *Metallidis* [31]

where i represents each one of individual scans of the examination covering a length L_i of patient anatomy.

For the second method, we can extract the DLP values easily from the OCR and the total DLP value in mGy·cm directly, as shown in Figure 10.

AbdomenRoutine				Anlagenzentrum			
000000				SOMATOM Definition Flash			
*17-Sep-1960, O, 50Y				CT 2010A			
17-Sep-2010 13:44							
Ward:							
Physician:							
Operator:							
Total mAs 1365		Total DLP 274 mGycm					
Scan	kV	mAs / ref.	CTDIvol mGy	DLP mGycm	TI s	cSL mm	
Patient Position H-SP							
Topogram	1	120	35 mA				
Abdomen	2	120	190	12.71	274	5.3	0.6
PhantomType <a>32cm16cm							

Figure 10. DLP and CTDIvol extracted from Optical Character Recognition (OCR)

Figure 10 shows the dose values extracted from the OCR when a study (CT Abdomen example) is submitted, such as Total DLP amount equivalent to 274 mGy.cm (red colour), the total mAs (important value because it relates to how dark the radiograph will be) corresponding to the value of 1365 (red colour), the absorbed dose ($CTDI_{vol}$ in mGy – blue colour) and other dose relevant data such as the type of phantom (their diameters are 16 and 32 cm to approximate conditions for head and body examinations – orange colour), and even kV value (yellow colour). Increasing kV value reduces the skin dose, producing a better and satisfactory image in which kV is varied and mAs is adjusted to achieve balance [38].

The green rectangle shows the DLP values for Topogram and Abdomen, but the sum of all these values corresponds to the total DLP value which is in the second red rectangle, so it's the same information for DLP.

Before any calculations of effective dose, we must determine if the DLP value refers to a 32cm or 16cm CTDI phantom. If the DLP was already measured in the 16 cm phantom, like it is the case on new scanners, the conversion factors for effective dose calculation may be used directly without applying an additional factor (usually using a correction factor of 2.0 is sufficiently accurate for all scanners) [39].

When conversion coefficients are used for children and DLP value refers to a 32cm phantom type [40], in pediatric examinations, the DLP value should be multiplied by a factor of 2.0, as previously stated, in order to give a realistic estimate of the patient's dose.

Finally we also could extract the dose measures value from DICOM RDSR. DICOM SR uses to transmit and archive clinical documents and supports text-free reports and reports with structured information.

One of the advantages of SR is that it can "link" text with other elements such as images or even waveforms. It is used in print formatted text, archive and search for content of reports and in trans-code to another standards / formats that encode structure like HL7 CDA (Clinical Document Architecture) or home-grown XML [41].

In Figure 11 we could see that SR Content has the form of a tree where the content item corresponds to the SR node and all the nodes are linked by relationships.

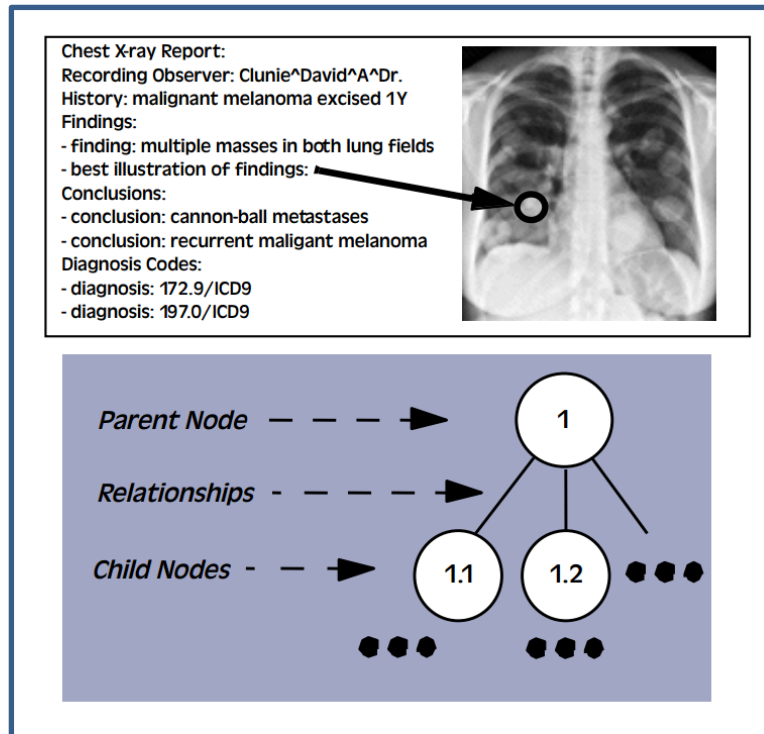


Figure 11. A "Structured Report" to encode as a DICOM SR [29]

Each SR node is a name-value pair (e.g. “finding” = “mass”), the “name” concept is always coded (e.g. (121071,DCM,”Finding”)) and the “value” concept may be one of multiple value types (such as TEXT, CODE, NUM, IMAGE, TIME, among others).

Basically SR works like a bridge to cross the traditional lack of interoperability between image and information systems and DICOM RDSR is used for modality dose information.

Figure 12 shows the total DLP information (red rectangle) extracted by DICOM RDSR using PixelMed™ Dose Utility™ [42], a free open source tool to query, retrieve, import, extract and report radiation dose information (purely written in Java).

```

cd C:\Users\Tiago\Desktop\Tese\Projeto Tese\TestOCR; "JAVA_HOME=C:\\Program Files\\Java\\jdk1.8.0_20" cmd /c "%C:\\Users\\Tiago\\AppData
Running NetBeans Compile On Save execution. Phase execution is skipped and output directories of dependency projects (with Compile on Save
Scanning for projects...

-----
Building TestOCR 1.0--SNAPSHOT
-----

--- exec-maven-plugin:1.2.1:exec (default-cli) @ TestOCR ---
1: : CONTAINER: X-Ray Radiation Dose Report [SEPARATE] (DCMR,10011)
1.1: HAS CONCEPT MOD: CODE: Procedure reported = Computed Tomography X-Ray
1.1.1: HAS CONCEPT MOD: CODE: Has Intent = Diagnostic Intent
1.2: HAS OBS CONTEXT: CODE: Observer Type = Device
1.3: HAS OBS CONTEXT: UIDREF: Device Observer UID = 2.25.140239934893842299456219560396856152356
1.4: HAS OBS CONTEXT: TEXT: Device Observer Name = ct54472
1.5: HAS OBS CONTEXT: TEXT: Device Observer Manufacturer = SIEMENS
1.6: HAS OBS CONTEXT: TEXT: Device Observer Model Name = Sensation 64
1.7: HAS OBS CONTEXT: TEXT: Device Observer Serial Number = 54472
1.8: HAS OBS CONTEXT: DATETIME: Start of X-Ray Irradiation = 20141022111422.531000
1.9: CONTAINS: CONTAINER: CT Accumulated Dose Data [SEPARATE] (DCMR,10012)
1.9.1: CONTAINS: NUM: Total Number of Irradiation Events = 1 events
1.9.2: CONTAINS: NUM: CT Dose Length Product Total = 212.46 mGy.cm
1.9.2.1: HAS PROPERTIES: CODE: CTDiw Phantom Type = IEC Body Dosimetry Phantom
1.10: CONTAINS: CONTAINER: CT Acquisition [SEPARATE] (DCMR,10013)
1.10.1: CONTAINS: CODE: Target Region = Internal Auditory Canal
1.10.2: CONTAINS: UIDREF: Irradiation Event UID = 1.3.6.1.4.1.5962.99.1.1067795482.1431992855.1431291937818.4.0
1.10.3: CONTAINS: TEXT: Irradiation Event Label = 3
1.10.3.1: HAS CONCEPT MOD: CODE: Label Type = Acquisition Number
1.10.4: CONTAINS: CONTAINER: CT Acquisition Parameters [SEPARATE]

```

Figure 12. X-Ray Radiation Dose Report

The code to use this tool is available in author website [42] and was quite helpful in this master work to support the extraction of several dose information through OCR and DICOM RDSR.

2.4.3 Effective Dose in CT

Effective Dose is a single parameter that aims to reflect the relative risk from exposure to ionizing radiation. This parameter is important to compare and optimize medical imaging procedures based on ionizing radiation, especially in comparison of examinations from different techniques like radiography, nuclear medicine and CT [43].

Concerning the quantification of radiation exposure dose, the Effective Dose [44] results from the weighted sum of equivalent radiation doses in all the human tissues and target organs of the body. If only a body portion is irradiated, then only these regions are used to calculate effective dose.

The effective dose concept was designed to estimate and compare the generic risks of exposure to different radiation fields and, more commonly, it is used to estimate radiation-induced cancer risks.

There are two common methods that are used to estimate effective dose for a CT diagnosis. The first one is based on organ dose estimates [44 - 45] that use tissue-weighting coefficients specified by ICRP and the second one is based on the DLP and DLP to E conversion coefficient, known as “*k* coefficient” or “*k*-factor”, and depends only on anatomic region examined [47], it is also considered as more simple method to calculate the effective dose (upper bound, the worst case scenario).

A powerful computational method for estimating organ and tissue doses is based on Monte Carlo simulation technique. With this technique, it is possible to simulate a CT scan and calculate the absorbed doses to all organs of the human body. Monte Carlo method may give accurate results such as deal with radiation transport in complex structure [48].

Next will be discussed in more detail the both possible methods of calculating the effective dose.

2.4.3.1 Calculation from Organ Doses

For partial body irradiation, Effective Dose is the weighted summation over all the organs and tissues of the body of the product of the equivalent dose, H_t , to the organ or tissue and a tissue weighting factor, W_t , for the same organ or tissue [41]. Tissue-weighting factors are defined by ICRP and represent the relative radiation sensitivity of each body tissue type.

This definition is related to first method in order to calculate the effective dose, using organ doses estimates and ICRP 26, 60 and 103 tissue-weighting factors [49].

$$E = \sum (W_t * H_t) \text{ (mSv)}$$

Equation 6. Effective dose calculation from Organ Doses [48]

E corresponds to the Effective Dose (in mSv), t corresponds to all ICRP-specified tissues and organs, W_t is the weighting factor for organ or tissue t or simply the ICRP-specified tissue weighting factor and corresponds to the measure of the energy deposited in a medium by ionizing radiation, and H_t is the tissue-specific equivalent dose in tissue t used in radiation protection and is not measurable in practice.

H_t is obtained by the following equation [50]:

$$H_t = W_r * D_{t,r}$$

Equation 7. Tissue-specific equivalent dose calculation [49]

where W_r is the radiation weighting factor defined by regulation (tabulated value according to ICRP 103 or ICRP 60) and $D_{t,r}$ is the absorbed dose in tissue t by radiation type r where CTDI is a measure of absorbed dose [51].

W_r only depends on the type and energy of the applied radiation. Table 2 provides all the radiation weighting factors for different types of radiation defined by ICRU 60 publication in 1991.

Radiation Type and Energy Range	Radiation Weighting Factor (W_r)
X and γ rays, all energies	1
Electrons positrons and muons, all energies	1
Neutrons:	
< 10 keV	5
10 eV to 100 keV	10
>100 keV to 2 MeV	20
> 2MeV to 20 MeV	10
> 20 MeV	5
Protons, (other than recoil protons) and energy > 2 MeV	2 - 5
α particles, fission fragments, heavy nuclei	20

Table 2. Radiation Weighting Factors (ICRU 60) [52]

The numerical values indicated above are valid legal EU-regulations for calculate the equivalent dose in an organ or tissue. The values for W_r in the 1991 recommendations were based on a review of the biological and other information available. These values have been developed in biological and dosimetric knowledge that demonstrates how they may be derived. We are dealing with ionizing radiation so that the value of W_r is 1 according Table 2, with X-Ray and γ -Ray radiation types.

If CTDI is the measure of absorbed dose [51] and $CTDI_{vol}$ is the measure of mean absorbed dose in mGy then $D_{t,r}$ corresponds to the $CTDI_{vol}$ value extracted, because $D_{t,r}$ is also the measure of absorbed dose and the unit is also mGy. Thus, multiply the value of W_r (which is the value 1 in this case – ionizing radiation) with $CTDI_{vol}$ value extracted (that corresponds to the $D_{t,r}$ variable) to give the final value H_t measured in Sievert.

Having the H_t value, simply multiply this by W_t value and thus obtain the effective dose value in millisievert (mSv). What remains now is how to get the value of W_t .

Like previously stated, tissue weighting factors have been defined by the ICRP 26, 60 and 103 publications with the aim of reflecting about the radiation sensitivity of several organs and tissues.

The tissue weighting factors are derived from the extrapolation of epidemiological evidence. They differ somewhat in calculation of effective dose, for example, in ICRP 26, organ doses are defined by a single point dose in the interest organ, but in ICRP 60 the mean organ dose is to be used [43]. The estimates of effective dose for the same CT study may differ substantially depending on which ICRP report was used.

The reasons for such variations are generally to do with improved knowledge about radiation risks and because different groups of experts had differing viewpoints. As such, the three ICRP publications provide a summary table with the Tissue-Weighting Factors values for each Tissue or Organ supported (Table 3)

Tissue or Organ	Publication		
	ICRP 26	ICRP 60	ICRP 103
Gonads	0.25	0.20	0.08
Red Bone Marrow	0.12	0.12	0.12
Lung	0.12	0.12	0.12
Colon		0.12	0.12
Stomach		0.12	0.12
Breast	0.15	0.05	0.12
Bladder		0.05	0.04
Liver		0.05	0.04
Esophagus		0.05	0.04
Thyroid	0.03	0.05	0.04
Skin		0.01	0.01
Bone Surface	0.03	0.01	0.01
Brain			0.01
Salivary Glands			0.01
Remainder	0.30	0.05	0.12
Total	1.00	1.00	1.00

Table 3. Tissue Weighting Factors for ICRP 26, 60 and 103 [43]

In each publication, W_t were primarily based on data information for the Japanese atomic bomb survivors and used data averaged over both genders and all ages. In all cases, the sum of the W_t over the specific set of sensitive tissues and organs equals 1 (Table 3). The specified tissues and organs, and methods used to determine W_t have changed over time. The relative importance of gonads was decreased, then the number of specified tissues and organs increased which decreases the remainder weighting factor and finally the breast weighting factor was decreased in the first time and then increased [30].

Effective dose will then be calculated using revised age and sex averaged tissue weighting factors, based on updated risk data and intended to apply as rounded values to a population of both sexes and all ages, and it is calculated for a reference person and not for an individual.

2.4.3.2 Calculation from DLP using Conversion Factors

As an alternative to the previous method, we may get the effective dose value but now using the DLP and k coefficients from the European Guidelines (EUR16262 Guidelines on Quality Criteria for CT [53]). This is considered one practical and simplest method to calculate effective dose.

The European Commission published in 2000 [53] a generic calculation method to estimate effective dose rapidly from CT studies, with publications updated in 2004 and 2005 [53–56]. With this, the effective dose (a first order effective dose estimate for mean population dose purposes) is calculated as follows:

$$E = k * DLP \text{ (mSv)}$$

Equation 8. Effective dose calculation from DLP using conversion factors [56]

Where k coefficient or conversion factor is related only to the anatomic region scanned, so depend only on the region of the body being scanned and Table 4 shows the values for conversion factor from DLP to Effective Dose in [mSv/ (mGy·cm)] for children and adults and for different body regions as published in [56 - 57].

Conversion Factor from DLP to Effective Dose [mSv / (mGy·cm)]					
Region of the Body	0-year-old	1-year-old	5-year-old	10-year-old	Adult
Head and Neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0032	0.0032	0.0021
Neck	0.017	0.012	0.0079	0.0079	0.0059
Chest	0.039	0.026	0.013	0.0013	0.014
Abdomen and Pelvis	0.049	0.030	0.015	0.0015	0.015
Trunk	0.044	0.028	0.014	0.0014	0.015

Table 4. Conversion Factors (*k* coefficients) from DLP to Effective Dose [39]

These conversion factors, for normalized effective dose per DLP value, were obtained from Monte Carlo calculations of effective dose for several examinations.

Because this method is widely used in general to calculate the effective dose, several manufacturers of CT scanners “*now compute and display DLP*” [43] counting with all irradiated length rather than the lesser prescribed scanning length.

Suppose that we want to calculate the effective dose using this method and a study was conducted (CT Abdomen, for example) whose DLP extracted value is: $DLP = 274 \text{ mGy}\cdot\text{cm}$. First, we have to determine if this DLP value refers to a 32 cm or 16 cm CTDI phantom type and if DLP is reported in the 32 cm CT dose phantom and is related to pediatric study, then this value has to be converted using a correction factor if pediatric conversion factors considered in Table 4 should be used to compute the effective dose: $DLP = 2.0 * 274 \text{ mGy}\cdot\text{cm} = 548 \text{ mGy}\cdot\text{cm}$.

Typical values of correction factors are between 2.0 and 2.4 in several scanners. Since the method of using conversion factors to determine the effective dose is a very rough method, usually using a correction factor of 2.0 is sufficiently accurate for all scanners. For a 5-year-old child, a factor of 0.015 mSv/(mGy·cm) for abdominal exams is used (Table 4) to estimate E. So the final value of effective dose is $E = 548 \text{ mGy}\cdot\text{cm} \cdot 0.015 \text{ mSv}/(\text{mGy}\cdot\text{cm}) = 8,2 \text{ mSv}$. If the DLP was already measured in the 16 cm CT phantom like in most new scanners, the conversion factors from Table 4 may be used directly without applying an additional factor of 2.0 to 2.4.

2.4.3.3 Comparison between calculation methods

The following figure (Figure 13) shows briefly the two possible methods to calculate the effective dose that were addressed in these last two sub-sections with intermediate steps necessary for the final calculation.

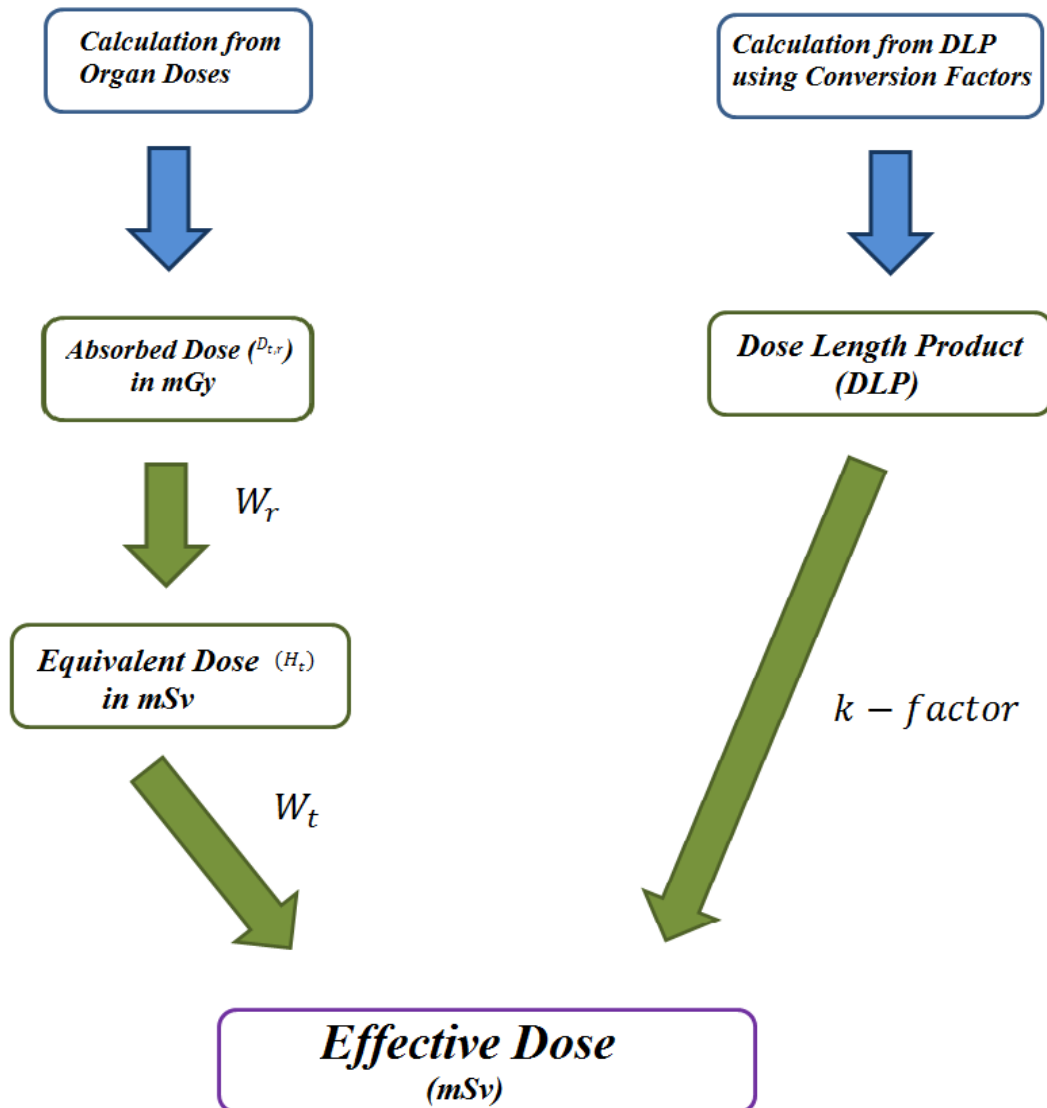


Figure 13. Methods of calculating the effective dose in CT procedures [57 - 58]

Calculating the effective dose using the second method may only be a rough estimate of effective dose because there are many parameters that influence this calculation that are not taken into account. The body size and the precise location of scanned area are two examples of those parameters.

Effective Dose was designed to allow comparisons of the risks associated with different non uniform exposures to ionizing radiation with the risks caused by uniform exposure of the whole body, from different imaging procedures or medical scenarios. This parameter has been defined and introduced by ICRP for risk management purposes and is used as a measure of risk in radiology (in ICRP 2009 [58 - 59]).

So, if there are two different dose distributions which result in the same radiation risk for adults, then would not result in same risks for children.

Effective dose is defined and estimated in a reference patient and provides a value that considers the exposure conditions but not the characteristics of a specific individual and represents only a mean dose value for humans averaged over all patient genders and age groups [60].

2.4.4 Cumulative Dose

The radiation effective dose from a CT technique may not differ a lot between equipment and if it is used repeatedly on the same individual, then it “*will increase the cumulative dose to the patient...*” [60 - 61]. If cumulative dose is increased, then the risk of chance effects (called by stochastic effects such cancer) with no threshold dose will increase too.

It is the responsibility of the radiologist ensures that the benefits provided by the data obtained from the CT procedure overbalance the risks associated with the effective dose.

Cumulative Dose is the total dose over a period of time that results from repeated exposures of ionizing radiation on multiple scanners to an exposed worker to the same portion of the body, or to the whole human body.

This is considered an important factor, since it is through this that it is possible to analyse the amount of risk applied in a certain study and, thus, may view, for instance, the historical cumulative dose applied to the patient in a given period of time.

The calculation of the cumulative dose boils down to the following equation:

$$Cumulative\ Dose_t = \sum (E_t) \ (mSv)$$

Equation 9. Cumulative Dose calculation

where t is the patient and E_t is the effective dose resulting in that patient t . Briefly, the Cumulative Dose in patient t is the sum of all the effective dose values (obtained for each medical study) that were applied to that person. The same calculation is applied to other modalities as well as CT (such as radiography and fluoroscopy), only effective dose (E_t) value varies from modality to modality.

The cumulative dose received by the patient may be highly elevated and it will increase in the future as the utilization of CT further increases. A consequence of this may be a significant increased incidence of radiation related cancer in the future [62 - 63].

Calculating the radiation dose in medical CT studies helped to establish dose reference levels for standard routine examinations.

2.4.5 Dose Reference Levels

Dose Reference Levels (DRLs) or Diagnostic Reference Levels means dose levels in medical radio-diagnostic practices or levels of activity in the case of radio-pharmaceuticals, typically for examinations of standardized groups of individuals or phantoms for widely types of medical equipment [64 - 65].

These levels depend on patient age or size, region of image and clinical indication in order to optimize the patient protection in CT procedures ensuring that the dose to each individual is as low as reasonably achievable for medical purposes (ALARA principle).

In order to reduce patient dose and initiate quality improvement, DRLs represent the appropriate dose level applied to medical exposure and they may provide the stimulus for monitoring practice to promote improvements in patient safety [67]. The usage of DRLs as an important and practical dose optimization tool is supported by many healthcare professionals and regulatory organizations such as ICRP. Some approaches to reference levels are used for medical imaging and usually, reference levels are used as quality guarantee tool in support of dose audit and practice review for promoting improvements in patient safety because they are used to help management of radiation dose to those patients [68].

There are two types of DRLs that need to be considered: National and Local.

National DRLs (NDRLs) [69] represent the typical practice for a patient group – children and adults with different sizes – at a range of numerous CT medical centers. They not represent optimum doses but they are very helpful in identifying potential dangerous practice. They are also important to promote awareness and dose comparison, improving the patient protection from dose radiation. It is the responsibility of health professionals to periodically revise and update them with the necessary changes.

DRLs have also local interest like, for instance, in a CT modality. Each institution should use the dose quantities for setting DRLs, which are $CTDI_{vol}$ and DLP for CT as the mean values observed for each patient group – children and adults with different size [70]. These mean doses should be compared with the

important NDRLs and may be set as Local DRLs (LDRLs) to also improve the patient security. LDRLs represent the local practice at a medical center and are used to compare practices in a hospital or between groups of hospitals. The LDRLs may be higher or lower than the NDRLs, it depends on image equipment available to them, providing feedback to ensure good practices in medical exposures.

Dose quantities mentioned before not reflect the radiation risk to individuals but shows the characteristics of radiation exposure for comparison of practice. Both NDRLs and LDRLs should be set for each study and each patient group in order to allow the facility of comparison of doses.

The comparison of DRLs with the mean effective doses may provide information for a country to evaluate the appropriateness of these DRLs, for instance, if the mean effective dose in a particular medical procedure is lower or equal then in another countries, but the DRL is higher, then may be a need to discover the main reasons for that and consequently update them.

Particular attention needs to be considered to establish the difference between DRLs for pediatrics according with ages. There are numerous published research articles on pediatric DRLs available, especially in Europe. The Table 5 shows the DRLs in terms of DLP applied to Brain and Abdomen / Pelvis pediatric examinations.

Examination Order Code (Pediatric CT)	Pediatric	
	Age	DLP (mGy·cm)
Brain	Newborn	340
	1-4 years	470
	5-9 years	620
	10-15 years	850
Abdomen / Pelvis	Newborn	130
	1-4 years	160
	5-9 years	230
	10-15 years	400

Table 5. Dose Reference Levels (DRLs) in terms of DLP (mGy.cm) on pediatric examinations [71]

The Table 6 and Table 7 show the DRLs in Europe given in terms of DLP and $CTDI_{vol}$ respectively, according to anatomical region [70 - 71] and identify which are the countries with the common higher and lower DRL. Remember that DRLs depending on the type of study and the patient's age.

Anatomical region	Most common value	DRL range	Countries with the most common DRL	Countries with higher DRL	Countries with lower DRL
Head, Brain	1000	760-1300	BG, CH, FI, LU, NO	AT, BE, DK, FR, IT, PL, SE, SI	DE, IE, LT, UK
Cervical Spine	-	400-600	CH, IE, LU, NO	-	-
Neck	500	440-500	DK, CH	-	LU
Chest	400	270-700	BE, CH, DE, NO	AT, BG, DK, FI, FR, IE, IT, LT, PL, SE	LU
Upper Abdomen	-	400-740	AT, CH, DE	-	-
Abdomen	800	460-1200	DK, IT, LU, NO	AT, BE, DE, LT	BG, CH, FI, IE, PL, SI, UK
Pelvis	550	450-650	BG, LT	AT, DK, IT, PL	CH, DE
Lumbar Spine	500	300-870	FI, DE, LU, NO	BE, FR, SE, CH	LT

Table 6. Dose Reference Levels (DRLs) in terms of DLP (mGy.cm) in Europe [72]

A more detailed description of the previous table, are present in page 7 of DDMD2 Project Report [72].

DDM2 project [61] estimates European population doses from radio diagnostic procedures based on data collection from different 36 European countries. From the adult DRLs, 71 % are based on own national dose surveys in Europe, and from the pediatric DRLs, 67 % are based on own national dose surveys, while the rest are based on published European guidelines or other publications.

The 75th percentile was adopted in order to report all countries to set DRLs that were given to normal size patients (70 kg \pm 15 kg) and to pediatric patients typically according to child's age or weight [61].

Anatomical region	Most common value	DRL range	Countries with the most common DRL	Countries with higher DRL	Countries with lower DRL
Head, Brain	60	50-75	BG, CZ, IT	CH, FI, FR, NO, SE, SI	HR, MD, UK
Chest	10	10-30	CH, UK	BG, FI, IT, NO, SE, SI	-
Abdomen	25	13-35	HR, MD, SE	BG, CZ, IT	CH, FI, NO, SI, UK
Lumbar Spine	35	30-55	CZ, H, MD	FI, SE	CH, NO

Table 7. Dose Reference Levels (DRLs) in terms of CTDIvol (mGy) in Europe [72]

These levels are expected not to be exceeded for standard procedures when good practice regarding diagnostic and medical technical performance is applied.

These are examples of DRLs applied to CT but there are also reference dose levels for other modalities (section 2.4.6) such as Fluoroscopy (in terms of DAP), Radiography (in terms of ESD), among others [72].

DRLs [73] are considered as an optimization process that need to be used and should be initiated in order to reduce the spread in dose and so contribute to the quality of medical imaging, reduce the radiation risk to the patient that is subjected and thus protect it safely.

2.4.6 Radiation Dose in other modalities

As there measures of dose in CT modalities, there are also measures of dose in another modalities, such as DAP (Dose Area Product), KAP (Kerma Area Product), PSD (Peak Skin Dose), among others. Each of these metrics will be addressed in this section.

DAP [74] corresponds to the amount used in the assessment of radiation risk of X-Ray diagnostic exams and interventional procedures. It is defined as the absorbed dose multiplied by the irradiated area and is expressed in gray square centimetres ($Gy \cdot cm^2$). DAP reflects not only the dose inside the radiation field but also the area of tissue irradiated. This value has the advantage of being easily measured with a permanent meter installation of a DAP in a given set of X-Ray types of exams.

KAP [75] is an easily calculated quantity which, for all practical purposes of radiation protection, is equal to the dose area product (DAP). However it is expressing mathematically by $DAP = KAP * (1-g)$ where g is the fraction power particle released that get lost in radiative processes and the dose is expressed in absorbed dose in the air.

PSD [76] is equal to the highest dose in a single area of the skin, which SI units is mGy . In practice, the PSD is difficult to measure but it is essential to estimate the PSD based on data available in making decisions in relation to the medical treatment of a patient. The total PSD is the sum of contributions from acquisitions of digital imaging and fluoroscopy to the PSD.

Fluoroscopy [77] is a type of medical imaging examination that shows a continuous X-Ray image on a monitor, which is used to treat patients showing the movement of a body part or even the passage of a contrast medium in the human body. The image is transmitted to a monitor so that the body and its movement may be seen in detail. The total fluoroscopy time is a major factor that determines the patient's exposure to fluoroscopy. If we consider a simple case in which the X-Ray beam was in the same location for five minutes, the absorbed dose to the skin in the beam may be obtained by multiplying the dose rate (mGy/min) by exposure time. Fluoroscopy depends on the sensitivity of the detector.

As in CT studies, it is also possible to calculate the effective dose for other modalities such as conventional X-Ray examinations in Radiography / Fluoroscopy.

Several of the Digital Radiography (DR) units at most of medical centres are equipped with DAP meters that append into the DICOM header of every image a DAP value. DAP may be used with conversion factors to determine the effective dose.

This is an X-Ray dose is measured in $dGy \cdot cm^2$ [33] to which the individual was exposed for the acquisition of the image and non-digital recording fluoroscopy performed and prepared for that acquisition. To calculate the effective dose, DAP must be converted in $mGy \cdot cm^2$, and applying the direct conversion: $1 dGy \cdot cm^2 = 100 mGy \cdot cm^2$, in order to use this value in the effective dose calculation. It is important to note that this value may be an estimated value based on assumptions about the body size of the patient and their habitus.

The DICOM group, element number used to reporting Dose Area Product is (0018, 115E) [32, 76].

The method for calculating the effective dose is based on the DAP [74] and DAP to E conversion coefficient for a radiograph or complete examination and is also based on the ESD (Entrance Surface Dose) and ESD to E conversion factor for a single radiograph procedures [47]. In the same manner that $CTDI_{vol}$ is used for each scan sequence and DLP for each scan sequence and complete examination in a CT procedure, the ESD is used for a single radiograph and DAP is used for a radiograph or complete examination for monitoring conventional X-Ray examinations.

ESD corresponds to the average entrance dose value at the surface of the patient during the acquisition of the image performed (Figure 14). This value may be extracted from DICOM header with the DICOM group, element number: (0040, 0302) if the value is measured in dGy or (0040, 8302) if the value is measured in mGy .

For Fluoroscopy, the effective dose is calculated as follow [77 - 85]:

$$E = E/DAP * DAP \text{ (mSv)}$$

Equation 10. Effective Dose for Radiography/Fluoroscopy

where E/DAP is the DAP to Effective Dose conversion factor and E is the effective dose in mSv. The E/DAP conversion factor depends of the age and sex of the patient and the type of examination performed. Table 8 shows the E/DAP values in relation to UK practice according to the exam.

The values of E/DAP were derived for each complete procedure making use of Monte Carlo calculated conversion factors for single static projections [79] using DAP value, irradiation geometry, exposure parameters and tissue weighting factors from the ICRP 60 publication. These conversion factors are used directly (reference levels obtained from ICRP 103) into the effective dose equation.

Exam	E/DAP (mSv / mGy·cm²)
Chest	0.16
Cervical Spine	0.19
Thoracic Spine	0.24
Abdomen	0.18
Pelvis	0.14
Cardiac Angiography	0.16

Table 8. E/DAP (mSv/mGy.cm²) conversion factors [80]

But for a single Radiography, the effective dose is calculated as follows [77 - 85]:

$$E = E/ESD * ESD \text{ (mSv)}$$

Equation 11. Effective Dose for single radiography

where E/ESD is the ESD to Effective Dose conversion factor and E is the effective dose in mSv. The E/ESD conversion factor depends of the age and sex of the patient and the type of examination performed. Table 9 shows the E/ESD values in relation to UK practice according to the exam.

Exam	E/ESD (mSv / mGy)
Chest	0.13
Cervical Spine	0.035
Thoracic Spine	0.094
Abdomen	0.13
Pelvis	0.10
Cardiac Angiography	-

Table 9. E/ESD (mSv/mGy) conversion factors [80]

Figure 14 shows the ESD and DAP dose measures for the calculation of the effective dose in conventional X-Ray examinations.

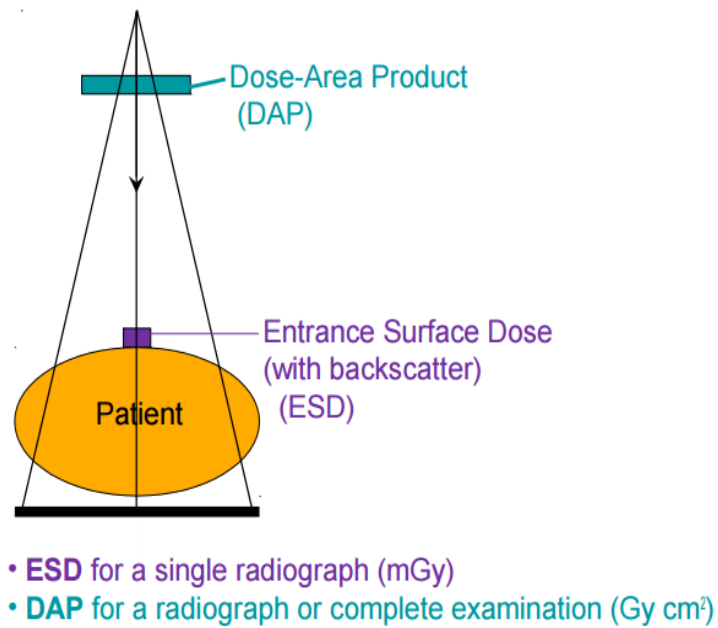


Figure 14. ESD and DAP measures in Interventional Radiology [80]

Dose monitoring tools, such as Dose Center, allows users to visualize scanning technique, patient positioning and also dose impact visualization to the technical parameters like scan length, tube voltage, among others. Thus dose monitoring tools simulate parameters to evaluate the balance between protocol parameters and estimated dose to the patient and receive alerts when the Dose Reference Level is breached or advice users of the scheduled review.

In the next section will address some of the examples of numerous competitors of dose monitoring tools and some advantages and disadvantages of each.

3. Related Work

There are numerous competitors in software management of radiation dose like, for instance: *Radimetrics*, *Sectra Dosetrack*, *DoseWatch*, *Nexo Dose*, *RADIANCE*, *Siemens Right Dose*. In this section, some of the most important solutions will be succinctly presented as well as their advantages/disadvantages.

3.1 Radimetrics™ – Platform Administration of the Radiation Dose

Bayer Healthcare provides Radimetrics™ [81], a complete and automated solution for monitoring and optimization of the radiation dose and management through imaging modalities. The purpose is to get dose information to improve patient's safety. It stores and automatically monitors relative dose information, reducing the risk of the patient being exposed to unnecessarily high doses of radiation and eliminating the human risk error. It is an important reference for hospitals centers and imaging services, being associated to the increase of productivity and service quality.

Radimetrics™ uses a Monte Carlo technique to calculate the effective dose. This technique of summary statistic corresponds to the evaluation of mathematical functions using random samples. This always involves some error, but the higher the number of samples random took, the more accurate will be the result.

This solution is compatible with multiple web browsers and provides integration with DICOM, HL7 and IHE standards for interoperability between protocols.

Radimetrics™ provides intelligent reporting that allows the creation of flexible statistics view and dashboard components such as pie charts, bar graphs and scatterplots. Among others, it permit a statistics analysis by institution, specialty and for specific patient populations using filters for age, gender, weight or diameter and view performance in preferred dose metrics. The reports, including the dashboards, can be exported too.

In what productivity concerns (Figure 15), it is possible to monitor dynamically studies of each modality and compare productivity and utilization of some resources like medical equipment.



Figure 15. Statistics and Reporting in Radimetrics [81]

3.2 Sectra Dose Track™ – Radiation Dose Monitoring

Sectra DoseTrack™ [82] is a web-based dose monitoring software similar to Radimetrics™, which allows users to monitor patient radiation doses ensuring that the dose applied to each patient is as low as reasonably achievable (ALARA principle) for the clinical purpose of image acquisition. It automatically stores and monitors radiation dose from different acquisition modalities, providing analysis and reporting functionalities. Users can track and compare the radiation dose levels on a specific acquisition modality or patient level and allows imaging protocol revisions to ensure the best use of equipment and staff members.

The system may provide automatic alerts when radiation dose levels exceed established thresholds. It could be configured using local and national DRL (section 2.4.5) to ensure performance within the expected limits, increasing patient safety. It supports both the IHE REM Profile and the DICOM MPPS standard allowing multi-modality support of almost any acquisition modality to obtain optimal monitoring solution.

3.3 Dose Watch™

DoseWatch™ [83] is a web-based patient radiation dose monitoring tool used to capture, monitor, track and report radiation dose. It helps health professionals to improve patient care by analyse radiation dose information across all modalities and track dosimetric data.

It works across health systems to evaluate radiation dose delivered to patients optimizing performance and enabling compliance. This software finds the right balance between image quality and dose information and helps users to improve patient care, minimizing risk error. It also provides customizable reports and alerts when dose levels exceed established thresholds.

3.4 Nexo Dose™

Nexo Dose™ [84] is a radiation dose monitoring software that measures multiple parameters, including acquisition modalities, devices, and patients for enterprise-wide results keeping safety and compliance. Enables a large hospital group with multiple facilities to easily understand and monitor radiation dose, permits the evaluation of radiation delivered during specific modality procedures and promotes the implementation of radiation reduction techniques, improving the quality of healthcare and patient safety. It provides a very flexible notification system that responds to notify multiple groups simultaneously.

This tool allows users to identify and address equipment, technologists and physicians to promote improved efficiency and performance. Also facilitates real-time analytics, letting users to maintain consistency and act rapidly in support of ALARA principle.

3.5 Radiance™



Radiance™ [85] is a free and open-source dose monitoring tool that automatically extracts and archive CT dose-related parameters. The main advantage of Radiance™ is the analyses of several dose reports that are written inside the pixel data of the image and the traditional systems do not recognize it.

This radiation dose intelligent analytics for CT examinations provides a set of web-based scripts that run and support real-time analytics dashboards. It has the ability to generate and parse RDSRs (Radiation Dose Structured Reports) and transmit it to the Dose Index Registry of the American College of Radiology (ACR), allowing this way the comparison of dose indices at regional/national level. The system was only designed to monitor the dose applied in CT modality and does not work to any other modality.

3.6 Siemens Right Dose™

Siemens Right Dose™ [86] is a dose monitoring tool that aims to protect patients and staff from high radiation doses. It is a dose management for a reasonable balance between image quality and applied radiation dose. This monitoring software is designed to help users getting the most information possible from a medical image, while managing and reducing dose for all stakeholders to a sensible minimum. It offers a set of features that enable users to identify and realize a balance between medical image quality and applied dose. This implies an exact targeting of emitted radiation at all times.

3.7 Summary Table (Main Features)

Radiation Dose Managing Tools	Main Features
	<ul style="list-style-type: none"> Capture data with a direct connection to the PACS and/or the modality; Support IHE compliance using integrated HL7 and DICOM standards; Maximize dose information available with capture from RDSRs (Radiation Dose Structured Reports), MPPS, and OCR; Migrate historical data from PACS to build patient history and dose data for setting meaningful Dose Reference Levels (DRLs); View summary of a patient’s system alerts based on exceeded-cumulative and exam thresholds; Review a detailed examination history and dosimetry details across imaging modalities; Customize display of patient cumulative dose record and educate technologists about the impact of scanning technique on patient dose and simulate protocol parameters before implementing clinically; Support multiple CT devices in a single protocol; Follow the ALARA principle;
	<ul style="list-style-type: none"> Easy to export data for reporting to regulatory authorities or for further analysis in Excel; Automatically collects, stores and monitors data from all connected modalities; Follow the ALARA principle; Increase patient safety; Allows staff training to optimize the use of modalities; Is a certified ACR software partner; Allows multi-modality support (IHE Radiation Exposure Monitoring profile and the DICOM MPPS standard);

	<p>Alerts when dose exceeds set thresholds;</p> <p>Automated reports by e-mail;</p> <p>Visualization of patient dose history;</p> <p>Positive financial and product performance;</p>
	<p>Is a multi-modality and vendor agnostic;</p> <p>Drive Awareness Across Modalities & Devices;</p> <p>Optimize Performance;</p> <p>Enable Compliance;</p> <p>Compatibility with DICOM SR & DICOM MPPS messages and OCR;</p> <p>Alert notification system when dose levels exceed predefined thresholds;</p> <p>Preconfigured and customizable reports;</p> <p>Easy to use dashboard provides quick access to patients' cumulative dose and medical history;</p> <p>Compare performance against national and local Dose Reference Levels (DRLs);</p> <p>Includes a variety of embedded analysis and optimization capabilities;</p>
	<p>Provides efficiency and performance;</p> <p>Is consistent with state and federal regulations;</p> <p>Single-server, fully automated system enables enterprise-wide data acquisition;</p> <p>Allows providers to track a patient's exposure history through PACS, departments, and facilities;</p> <p>Delivers customizable, real-time alerts that can be configured for any system parameter;</p> <p>Provides accurate analytics to determine real-time usage, create reports, measure trends, and take action;</p> <p>Customized alerts and notifications can be sent via email or HL-7;</p> <p>Follow the ALARA principle;</p>
	<p>Small footprint;</p> <p>Real-time PACS query to retrieve dose sheets;</p> <p>Dashboard (real-time) and scorecard (monthly) analytics;</p> <p>Support for four major CT vendors: Siemens, GE, Toshiba and Philips;</p> <p>Automated extraction of parameters from CT dose sheets and storage in a relational database;</p> <p>Follow the ALARA principle;</p>
	<p>Reasonable balance between image quality and applied dose;</p> <p>Valid quantification of results and dose values;</p> <p>Value orientation for tangible patient outcomes;</p>

Table 10. Summary table between dose monitoring software's with main features

The previous table (Table 10) shows the main features of each of the software that was previously referenced, allowing us to compare the different solutions and see what are the differences or similarities between them.

Based on each of the software features shown in the table, we can see that they all have a common goal: radiation dose monitoring solution to an individual patient, which complies with the ALARA principle in order to help service providers in a later analysis.

In fact, they all comply with the ALARA principle and obey the DRLs and they are compatible with some standards (IHE Profile, OCR). However, some of them provide better performance than others. In general, they all have the same features and allow the usage of dashboards for optimization and comparative analysis regarding the cumulative dose and the patient's historic alerting automatically the health care providers, ensuring patient safety.

Nevertheless, one of the major disadvantages of these systems is the lack of full integration with the other healthcare information systems. These kinds of systems should be able to integrate with third party information sources such as PACS, RIS (Radiology Information System) or any other potential source, as long as it follows the standards and can contribute to the patient's treatment enhancement and dose safety application. This should focus not only on patient, but also on population. Most of them was not focus on patient and not support cross institution.

To achieve this, the Dose Center arises and enables health care providers to perform radiation dose analysis that had been applied to a particular study. Dose Center allows dose information to be collected and occupied with patients' care.

4. System Architecture

One of the major disadvantages of already developed dose monitor systems is the lack of integration with the other healthcare information systems, like previously stated.

In order to help the healthcare professionals supply a better treatment, the information should be easily available in the user interface.

To achieve this, came the Dose Center, a system able to integrate with third party information sources such as PACS as long as it follows the DICOM standard. The dose information is collected and evaluated without imposing a significant administrative burden on staff. Typically, one dose object is created at the end of each procedure step performed on the modality. That object collects all radiation events from the procedure step and adds summary dose index values. The details include patient demographics, study information and typical dose metrics like $CTDI_{vol}$ and DLP.

4.1 System Wide Requirements

The provision of health care is often held in diagnostic imaging tools, for example, an X-ray or CT scans. This is performed in various institutions as from hospitals to small imaging centers. It's from knowledge that in many of these examinations we are subject to radiation ionizing, which is quite harmful to human health. The radiological protection has developed standards and rules that indicate the proper dose of radiation, and the maximum number of examinations that a patient must do in certain periods of time, according to patient characteristics that vary with the age, weight and gender.

The information associated with the dose applied in surveys, is found in medical imaging repositories, also referred as PACS. On the other hand, there are several devices that have the possibility of sending direct information to information systems through a protocol DICOM standard named. According to this standard, the stored files contain not only the image but also other information about the study and the state of the image that was acquired, for example, patient name, date, modality, the applied dose, exposure time, etc.

Dose Center is a web platform that allows the radiation dose monitoring in clinical imaging and allows extracting and storing the data on the dosage applied to each clinical examination with ionizing radiation. This should have multiple levels of access depending on the user profile, make comparison between different patients and populations and generating graphs with statistics.

The solution was thought to be developed as a plugin for Dicooogle Open Source PACS platform for aggregating the data extracted from the files stored in the repository. For proper operation of the software or to meet user needs, the next sections will present and analyses some requirements.

4.1.1 Functional Requirements

One of the main functional requirements of proposed application refers to the authentication functionality for all users as well as the capacity of extracting the dose information, storing it in a database, and finally visualization of this information effectively using graphs for a better comparison between different patients and populations.

Dose Center was initially developed to support three users associated to three different roles. The users are: Provider Dose Info, Administrator and Viewer (each one with username and password associated).

Provider Dose Info user has the objective of send all the dose information from Dose Extractor plugin to the Dose Center, in a secured way and it has the role name of Provider Dose Info. The Viewer has access to most of the features available in the Dose Center, yet this type of user cannot change the DRL or have access to productivity statistics associated with the physicians / operators. The Administrator user has access to all features included in this monitoring dose tool.

Figure 16 represent the use case model and show the functionalities that each of user / role may execute through Dose Center tool.

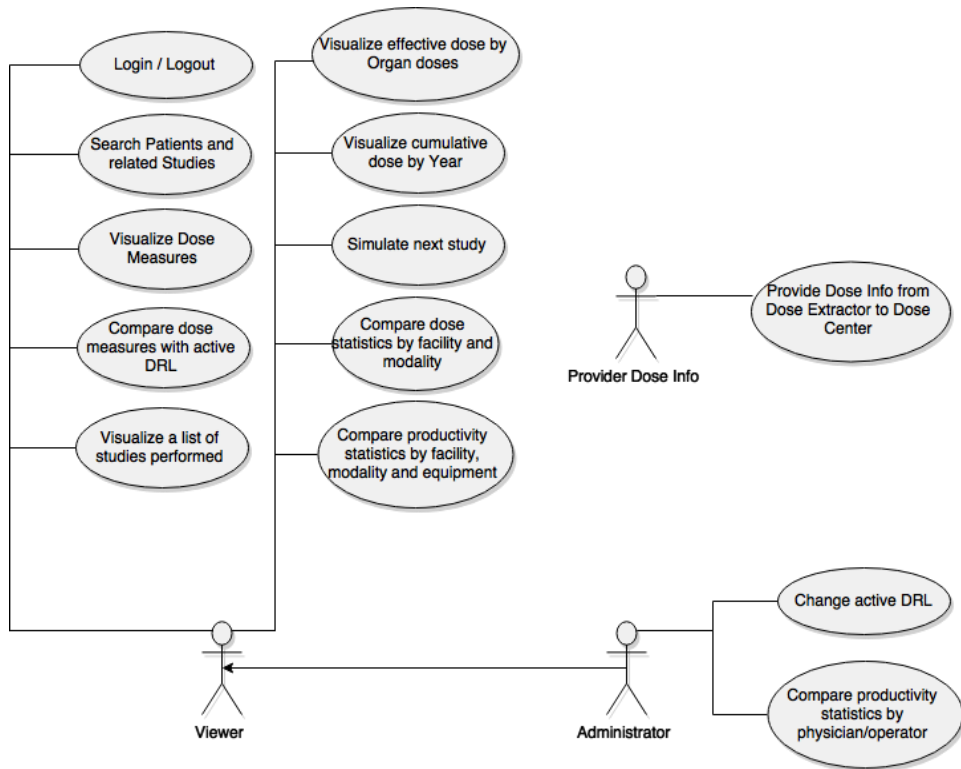


Figure 16. Dose Center - Use Case Model

Use Case Model (Figure 16) represents all the functionalities that users could performed in Dose Center and this diagram was also developed using the design tool Visual Paradigm [87].

Table 11 presents a brief description of each of functionality from use case model.

Functionality	Description	User / Actor
Login / Logout	User access to the Dose Center system by entering its credentials (username and password).	Viewer, Administrator
Search Patients and related Studies	User visualizes a list of patients that exist in Dose Center database as well as their attributes (Patient ID, Patient Sex, among others) and related studies.	Viewer, Administrator
Visualize Dose Measures	Visualization of CT dose measures such as $CTDI_{vol}$ and DLP, according to Dose Reference Levels.	Viewer, Administrator
Compare Dose Measures with the active DRL	User could compare CT dose measures with the active DRL (one DRL is active per time).	Viewer, Administrator
Visualize a list of studies performed	Visualization of studies history that is related to a specific patient as well as study attributes like Modality, Study Date, among others.	Viewer, Administrator
Visualize Effective Dose by Organ Doses method	Visualization of effective dose chart related to each study using the organ doses estimates method. The values of effective dose depend on ICRP publications (ICRP 26, 60 and 103) and vary according to the type of organ.	Viewer, Administrator
Visualize Cumulative Dose by Year	Visualization of cumulative dose values by progress bar and chart with the possibility to filter by last 7, 5 or 3 years.	Viewer, Administrator
Simulate Next Study	Allow user to simulate the next CT study using the following simulation options: choose simulated studies from Favorites list or simulate new study filling the study name, modality, dose measures values and conversion factor value. The new simulation study, after simulation, will be saved	Viewer, Administrator

	automatically and inserted dynamically in Favorites list.	
Compare Dose Statistics by Facility and Modality	Visualization of dose statistics by Facility and Modality with average cumulative dose charts in terms of age or even gender.	Viewer, Administrator
Compare Productivity statistics by Facility, Modality and Equipment	Visualization of productivity statistics by Facility, Modality and Equipment performance. For example: total number of DICOM Studies, Exposure Time (in ms), number of patients according to age or gender, among others.	Viewer, Administrator
Compare Productivity statistics by Physician/Operator	Visualization of productivity statistics by Physician/Operator. For example: total number of DICOM Studies, number of study time (in ms), among others.	Administrator
Change active DRL	Capability to change the active DRL, by default the active DRL is the first one from DRLs list in database. Dose measures colors are updated according to the reference levels selected.	Administrator
Provide Dose Information	This user has the responsibility to send the dose information, in a secure way, from Dose Extractor plugin to Dose Center (Information System).	Provider Dose Info

Table 11. Dose Center functionalities description for each user

The Viewer user could login or logout at Dose Center, may search for Patients and related studies, visualize dose measures like $CTDI_{vol}$ and DLP, compare these dose measures with the active DRL (it works like a traffic light), visualize a list of studies that were performed by a specific patient, visualize effective dose by organ doses method (effective dose applied to each organ), visualize cumulative dose by year (the user could filter by the last 7 years, or the last 5 years or even the last 3 years to comparison), simulate next study (by choose simulated studies from favorites or simulate a new one), compare dose statistical information by facility and modality and compare productivity statistics by facility, modality and equipment (by station name).

The Administrator could perform all features which have been mentioned above, but could also change the active DRL (one DRL is active per time, and the administrator could select a list of possible DRL's list that are stored in database) and compare productivity statistical data by physician / operator.

Provider Dose Info only has the functionality of providing, securely, dose information from Dose Extractor to Dose Center (section 5.1.2).

These requirements have been raised through meetings with ESSUA (“Escola Superior de Saúde da Universidade de Aveiro”) teachers who have experience and knowledge of medical physicist's theoretical concepts that were essential for Dose Center implementation and through some informal usability tests with them.

4.1.2 Non-functional Requirements

In addition to the functional requirements that define specific behavior or functions, there are also other requirements that specify criteria that may be used to judge the operation of the system, rather than specific behaviors. To these requirements we call non-functional requirements or simply qualities of the system.

Some of the non-functional requirements are: usability, reliability, performance and supportability.

For the web application, its use should be intuitive, i.e. no terms or confusing elements for all target users, and user-friendly interface via web browser. The user inserts their credentials and gain access to the platform. From there scroll through the various menus until reaching the desired option, then manipulate or simply research the data depending on what he wants to manage and visualize.

The system ensures both reliability of authentication as the transaction of information. The reliability of authentication is based on the Security Authenticator configured in Play Framework (section 5.2.5.1).

For the information of transactions (specifying here interactions with the database, both in terms of reading (get information) as written (submission changes)), the system should be consistent and have synchronization mechanisms, that will have some local storage based on dose information extracted.

The dose extraction values should be fairly faster so that the user feels transparency in the process, in a normal operation of the entire system. The insertion of data in the database follows the same rule.

The time of response of the web application (where information is exchange) should also obey this profile to ensure system quality.

The system should take into account the processing performance. The database must take account of multiple access as fast as possible, which it translates into an efficient architecture. The calculations (especially for calculating the effective and cumulative dose) and all processing of the program should also be efficient to avoid unnecessary latencies.

These requirements translate into a shorter response time, which makes the system effective, and in the user's point of view, faster and responsive.

The Dose Extractor module should be integrated in Dicoogle, as Dicoogle plugin for dose information extraction, which is already implemented. In the case of Dose Center, once it will run on web, a browser (Mozilla Firefox v27.0.1 +, Internet Explorer 8.0+, Google Chrome 33.0.x +) is required.

The architecture of the system should be maintainable without affecting existing Dicoogle services, since this plugin is a module added to it. If the module is being serviced then the Dicoogle remaining services should not be affected.

There are web services that were implemented to get information from Dose Center database and in some cases to submit information and save it automatically (when user do a new simulation study or apply another DRL).

It is even used the Entity Framework (section 5.2.2) to manage the database and to get information from it. The application is always running on the server and in constant contact with the database, which enables to use it at any time. This service will then be permanent with the exception of system maintenance times.

In addition to these requirements, it must also take into account some business rules:

- The access to the application may only be done by viewer or administrator. Provider Dose Info is only responsible to send dose information from Dose Extractor to Dose Center, without permissions to access it;
- Users who have permission to access to the Dose Center have an identification username and password. The user needs to insert its credentials to enter the system, only after the authentication process being correctly done;
- Viewer does not have permissions to change the active DRL or to see productivity statistics by physician / operator, unless he is the system administrator;
- For legal warnings or copyright, all content and functionality of these applications (Dose Center and Dose Extractor) cannot be copied by others for commercial use or distribution nor be modified and / or reposted to other websites, are subject to legal provisions on the protection of copyright (BMD software [88]) and intellectual property.

4.2 Software Wide Architecture

This section reports all decisions, significant elements and other general aspects of proposed system that modelling its design and subsequent implementation.

All these elements are based on specific system requirements (section 4.1) as well as the proposed objectives. This platform aims to allow the creation of a web solution that offers better dose monitoring in order to ensure a better optimization and consequently the safety of the patient when this is subjected to a medical examination from modality which emits radiation to its body.

The completion of the project is dependent on the technologies and languages chosen for its implementation. In this sense, it is important to implement a better solution with some common and important web technologies (section 5.2.4) and must always follow the iterative lifecycle software so that at each stage everything runs smoothly.

The proposed system automatically collects data and monitors the actual activity of each acquisition modality, providing resources usage indicators and comparing their productivity. Moreover, Dose Center provides an aggregated view of several information sources. For instance, it allows to have an integrated PACS frontend that includes visualization capabilities with dose analysis at different scopes (patient, imaging study and population) and chronologies. The continuously control of dose performances contributes to the reduction of wrong practices, and by supporting protocol optimization.

Figure 17 shows the Dose Center architecture that includes a centralized dose analysis tool and a Dose Extractor plugin module to extract all dose information. The demand for medical imaging studies was conducted by a plugin developed to Dicooogle PACS [89], an open-source archive that uses indexing technology. It is a HTML5 zero-footprint (pure web platform) for medical imaging allowing information analysis for managing the radiation dose according to the regulations.

In order to collect and extract this kind of information, there are two important components: the PACS feeder (1) and the Dose Extractor Plugin (2). The PACS feeder (1) supports the reception of medical exams from the acquisition modalities. In alternative, it is also possible to fetch studies from PACS archive using programmed routines. Then, the Dose Extractor plugin (2) is responsible to extracts all radiation information available from PACS Feeder (1) such as $CTDI_{vol}$ and DLP. This data can be extracted from DICOM objects meta-data (headers) or even through the OCR techniques applied to secondary capture images or in the latter case through the DICOM RDSR. With this functionality, the health care professional can be alerted to patients with a critical dose history, helping them to provide a better service. All collected radiation dose data is stored in the Dose Center database (Figure 17).

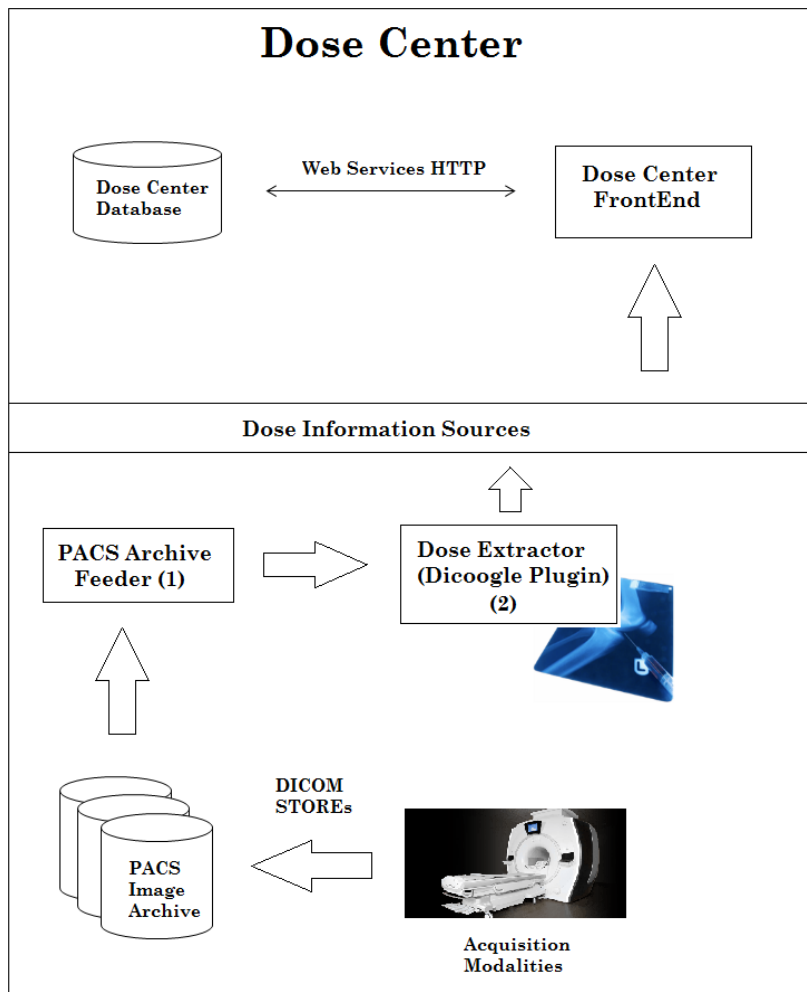


Figure 17. Dose Center system architecture: integrating multiple sources in PACS workflow

4.3 Database Model

Database is a collection of interrelated stored data that serves the needs of several users within one or more organizations, i.e. an interrelated collection of different tables. This concept allows the integration of data for easier access and update for complex transactions and less redundancy of data [90].

Database Management System (DBMS) [90] is a software system for manipulating databases. It supports a logical view – schema, a physical view – data cluster, access methods, data manipulation language, transaction management and concurrency control. Allows also data integrity, security and crash recovery which are very important utilities in nowadays.

An example of a database type is the relational database system, which is the dominant type of databases for business systems and provides a greater degree of data independence than other earlier database management systems. In a relational database, data item is called as *column* or *attribute*, a record is called as a *row* or *tuple* and a file is called as a *table*.

Data warehouse is a large repository of historical data that may be integrated for decision support and receives periodically these data in batches and grows over time and it enables the end user to make quick and sound decisions.

The context of data warehouse compels a different approach to know the real needs of the user. Data warehouses are organized with one large central “fact table” and many smaller “dimension tables”. Each “fact table” is composed by two types of attributes: “dimension attributes” (for example: CustomerID, JobID with dimension tables: Customer, Job) and “measures”. Most of “dimension attributes” have primary keys and foreign keys relationships. We call this model as *Star Schema*.

Star schema represent speed and simplicity concepts, because not only this schema yield quicker query response, but also it is easier for the end user understand when building queries and this is a very important factor that need to be considered in database management and design.

So, data warehouse favors the quick and simple access to data which in the case of Dose Center is an asset. For this reason, it was adopted this kind of database.

However, the selected data model is a hybrid solution because there is not a pure data warehouse or a pure relational database. Theoretically, Dose Center follows data warehouse patterns that were discussed earlier, however, in practical terms it is important to minimize data redundancy, thus making use of relational databases, using MySQL database type in this web application.

Figure 18 shows the Dose Center database model with all entities created as well as their attributes and relationships between them.

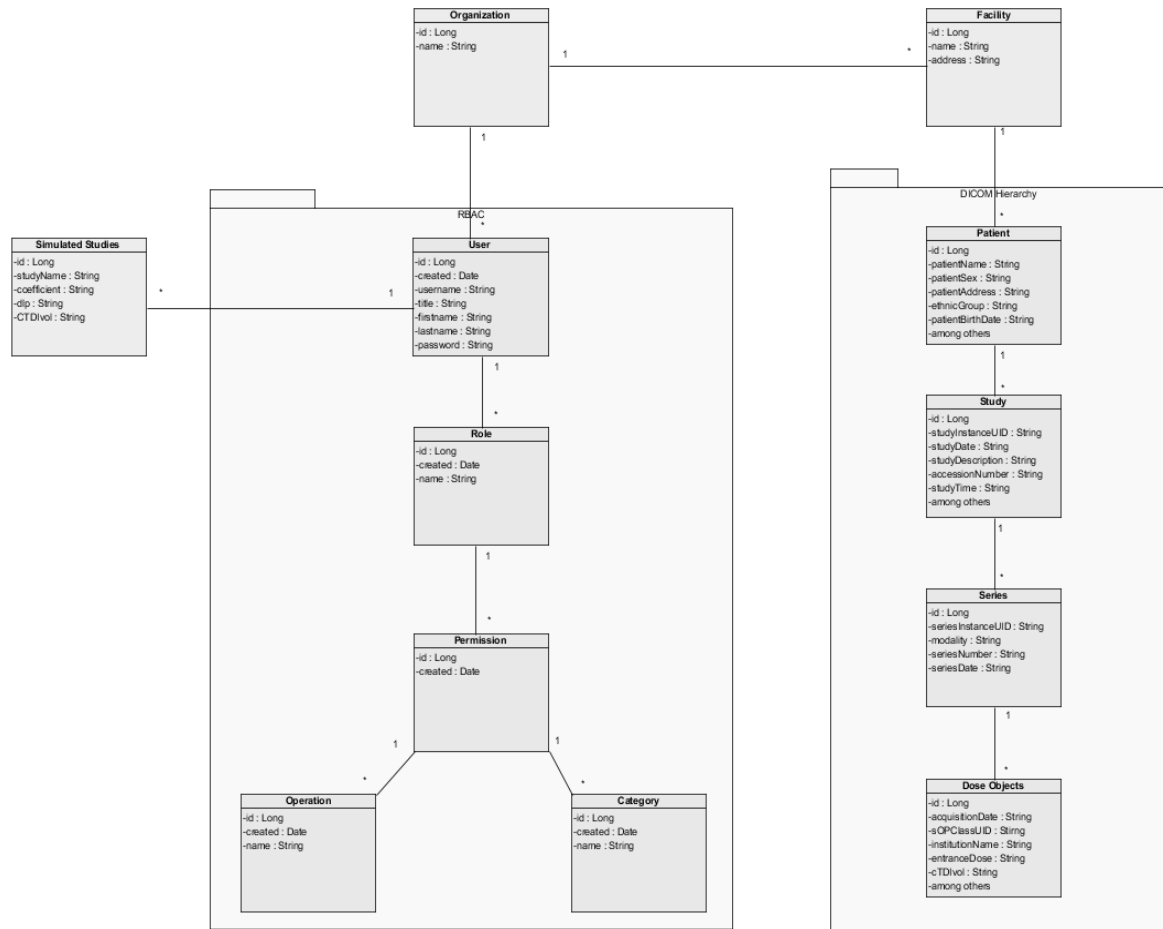


Figure 18. Dose Center Database Model: Class Diagram

The figure above shows the Dose Center database model organization, using a class diagram produced with the design & management software Visual Paradigm [87]. Each square represent an entity and inside of them there are the attributes and the data types associated to each related to that entity. The lines between each entity represent the relationships between them. The packages are represented with rectangles to specify different modules that entities belong.

In this database model, there are as entities or classes: User, Simulated Studies, Role, Permission, Operation, Category, Organization, Facility, Patient, Study, Series and Dose Object.

The Organization entity is the responsible to support the field of medical imaging and has the functionality to care about patient security through study, treatment and diagnosis. One Organization could have many users and many facilities, for example: Organization1 could have 2 different facilities (Institution1 and Institution2) which are located in different places. Organization is defined by an ID and its name.

Facility entity corresponds to the medical institution that is associated with a particular organization and it is composed by a numerous group of medical specialists created for the practice of medicine. This class has the

attributes: ID, name (Institution1, for instance) and address (Gaia, for example). One facility could have many patients.

The package named by “DICOM Hierarchy” represents the four hierarchical levels in DICOM standard, which are: PATIENT, STUDY, SERIES and IMAGE [91]. In this case, IMAGE level is substituted by Dose Object class that contains all dose information that were extracted at image level and saved from Dose Extractor plugin.

Each Patient may have several Studies, each Study could have many Series and each Series can have many Dose Objects.

The Patient entity has some relevant tag values as attributes such as Patient Name, Patient Sex, Patient Address, Ethnic Group, Patient Birth Date, among others, including the ID attribute as a unique identifier, of course.

The relevant tag values as attributes for the Study entity are: Study Instance UID, Study Date, Study Description, Accession Number, Study Time, among others, for the Series entity are: Series Instance UID, Modality, Series Number and Series Date and finally for the Dose Object class are: Acquisition Date, SOP Class UID, Institution Name, Entrance Dose, CTDIvol, among others.

It should be noted that attributes in Dose Object entity refers to tag values that have been extracted at the image level as well as dose values obtained using OCR or even RDSR (section 2.4.2).

“Raw Dose Object” entity is a class with the responsibility to get patient, study, series and dose objects and set those tag values to be manipulated by the information system and be available to the user.

One User could have several Simulated Studies or many roles. Simulated Studies entity represents all the studies resulting from the next CT study simulation (this is one of the most important features that Dose Center considers and is discussed in Chapter 6 with more detail). This class has the following attributes: ID, Study Name, Coefficient (this attribute represents the k-factor or conversion factor that was used to calculate the effective dose), DLP and CTDIvol values.

The package named by “RBAC” represents the RBAC module that was included this information system. It will be described in the section 5.2.5.2. Entities that are part of this package are as follows: User, Role, Permission, Operation and Category.

User entity could have many roles and their attributes are: ID, Created (date when was created), First Name, Last Name, Password, Title and Username, an example of a user (Viewer) as an entity in database is the follow:

2015-04-29 11:05:24 | Viewer | Viewer | 1234 | Mr. | viewer1

One Role is defined by its attributes: ID, Created and Name (for example: Provider Dose Info) and could have many permissions. One Permission has the following attributes: ID and Created and could have many operations or many categories.

Operation and Category entities are defined by ID, Created and Name (for example: “EDIT” for Operation name and “USER” for Category name) attributes.

There are two more entities that are isolated from above, they are: DRL and DRL Range. Figure 19 shows these entities and their attributes and how they are related to each other.



Figure 19. DRL and DRL Range entities: Class Diagram

The DRL entity has the following attributes: ID, Name (for example: NDRL) and a verification field called “Is Selected” that is responsible to ensure that one DRL, and only one DRL, is active each time. One DRL could have many DRL Ranges and this class has the ID, Age (age of patient that was submitted to a specific examination), Min Val DLP, Max Val DLP, Min Val CTDI and Max Val CTDI corresponding to the minimum value of DLP dose measure, maximum value of DLP measure, minimum value of $CTDI_{vol}$ measure and maximum value of $CTDI_{vol}$ measure, respectively.

These entities are very important in order to optimize the medical process and reduce the patient risk and thus contribute to the quality of medical imaging and for the security of these patients.

DRL and DRL Range are defined by administrator of the system, as well as some of the previous entities described, in a configuration file called by “*global.props*” and are triggered when Dose Center runs for the first time (section 6.1).

5. Implementation

This chapter introduces the technologies used and explains important implementation details regarding database model and the communication protocol in Dose Center, and how these components are integrated with implementing the interface of Dose Center Frontend.

It will be also addressed the web technologies used and which are the basis of its implementation as well as the decisions taken. The issue of security in authentication method and the usage of information system is also considered.

5.1 Dose Extractor

Dose Extractor allows the extraction of dose information from PACS Feeder that supports the reception of several medical images with ionizing radiation from acquisition modalities.

As such, a module needs to be created in order to execute that operation. In order to do that, Dicoogle was used to develop a plugin with the capabilities to extract dynamically this kind of information and send it to the information system. This module is called by “Dose Extractor plugin”.

First will be done a brief introduction to Dicoogle PACS system and explain his importance in this context, and then addressing the Dose Extractor plugin which was developed in order to extract the full dose information from the PACS Feeder.

5.1.1 Dicoogle

Dicoogle is a PACS system developed by Bioinformatics research group from IEETA (*Instituto de Engenharia Electrónica e Telemática de Aveiro*) under the project “*Dicoogle P2P Network*” [89].

It is a plugin based and a PACS engine that allows indexing and querying DICOM studies/files over a set of distributed repositories and accessible by web services allowing reduced installation and maintenance costs.

This architecture is P2P (peer to peer), distributed, interoperable and secure with a server/client architecture (RMI based). Dicoogle is a PACS Storage / Retrieve approach that provides storage services for whatever acquisition modality and the access to images is supported by DICOM Query and Retrieve or perhaps by the WADO (Web Access to DICOM Persistent Objects).

One of the main objectives of Dicoogle is the replacement of traditional databases by an indexing engine and data recovery.

Thus it is possible to search and organize the DICOM attributes but also their value without creating any new tables or relationships, unlike traditional databases.

Dicoogle is a data repository where any system may use it to make free text searches or retrieve data in other distributed repositories [92].

Dicoogle has two different interfaces, one that is related to the DICOM Storage SCP service to receive objects from the acquisition modalities and another one for configuring a service that allows monitoring of files and indexing service.

Figure 20 shows the Dicoogle interface based on indexing service.

Id	Name	Gender	Studies
	PNEUMATIX		1
	Pr22_0		2
1	patient 1		7
1.3.6.1.4.1.9328.50.4.0002	1.3.6.1.4.1.9328.50.4.0002		1
1.3.6.1.4.1.9328.50.4.0044	1.3.6.1.4.1.9328.50.4.0044		2
1.3.6.1.4.1.9328.50.4.0095	1.3.6.1.4.1.9328.50.4.0095		1
7DHDKDK	FELIX		1
Duet MIBI	Cardiac 2**Myo Perf		1
FU_1	Fusion 1**PET/CT WB		1

Figure 20. Dicoogle: Interface based on indexing service

Dicoogle operates two data indexing methods: free text indexing (or content based) and indexing metadata attributes. The first method has the functionality to build, for each word resulting from search, a list of files containing that word. The second method is the most important factor for establishing the association between DICOM attributes with their values [92].

Several key features regarding new approaches into metadata information for retrospective assessments are contained by this tool, and this is useful in statistical oriented management and reporting tasks or clinical studies requiring, such as dose metrics. Dicoogle can be used as DICOM data mining tool allowing the identification of data and process inconsistencies [93].

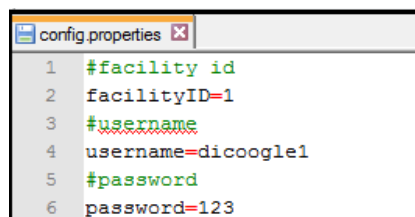
It may also be used to audit PACS information data and thus contribute to improvement of radiology department practices.

5.1.2 Dose Extractor Plugin

Dose Extractor is a Dicoogle plugin developed in Java [94], for the purpose of extracting the information dose associated with a medical examination as well as extract information associated to the study and patient. This plugin was developed using the NetBeans IDE [95], version 8.0 in Windows Operating System and generates a JAR file, which is included in “Dicoogle Plugins” folder and each time it runs, the plugin is triggered automatically.

As mentioned earlier, there are several dose extraction methods to consider. First, the plugin considers the extraction method by DICOM header metadata and, if the value in those tags is not supported, then the Dose Extractor uses the OCR to get dose values measured as is the case of $CTDI_{vol}$ or even the Total DLP (section 2.4.2). Some values like DLP or even Total DLP could also be extracted from Radiation Dose Structured Report.

It was necessary to create a configuration file named “*config.properties*” that was included in Dicoogle settings (Figure 21) in order to specify what is the facility identification, username and password that is associated to the Provider Dose Info that is responsible to send the dose information to the Dose Center where it will be saved in the database.



```
1 #facility id
2 facilityID=1
3 #username
4 username=dicoogle1
5 #password
6 password=123
```

Figure 21. Configuration file included in Dicoogle settings

Dose Extractor will extract dose information from DICOM metadata attributes using the class “*Tag*” provided by the dcm4che library [96]. This library is a collection of open source applications and utilities for clinical image organizations and object management. These applications have been developed also in the Java programming language. This framework provides also robust and scalable services such as DICOM Storage, DICOM Query / Retrieve, WADO, among others.

Dose Extractor will get not only the dose information at image level but also some data related to the patient, study and series level. There are numerous tags that contain relevant information that need to be considered. Annex 1 present all reference tags that were used to extract the necessary information at all DICOM levels.

If Dose Extractor cannot extract dose information from metadata attributes, then will get the essential CT Dose from OCR of Dose Screen. In this case, PixelMed™ open source dose tool is used, named DoseUtility™ [97]. It was developed for query, retrieve, import, extract and report radiation dose information from a GE or Siemens or Toshiba CT screen using OCR, for instance. It was used the PixelMed™ Toolkit [98] version 1 (pixelmed-1.0.jar).

Some dose information such as DLP, Total DLP, $CTDI_{vol}$, Start Date Time, End Date Time, Total Number of Irradiation Events, Total mAs, among others, are extracted using OCR. Figure 10 show these values extracted using OCR when a CT study is performed. The developed plugin will also get some dose values like DLP or Total DLP using the Structed Report whose information is made available by function “*getStructuredReport*” from PixelMed™ Toolkit.

Finally, Dose Extractor needs to read the configuration file (Figure 21) and get all the properties (Facility ID, Username and Password) from the Provider Dose Info and submit, according with these properties, all dose information extracted (Figure 22). It was created a function called “*submitDoseInfo*” that put the patient, study, series, dose (from DICOM header) and OCR dose information in a single JSON object with a collection of name / value pairs, to be more easily interpreted by the information system side.

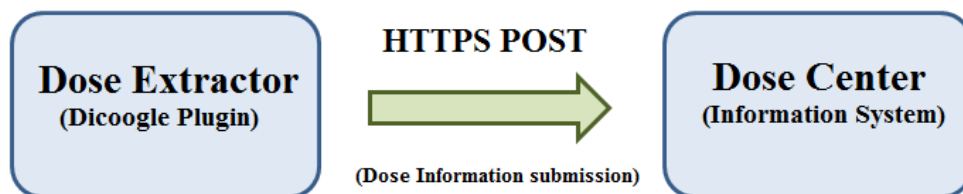


Figure 22. Dose Information submission from Dose Extractor to Dose Center

The JSON message will be sent to the Dose Center establishing a secure connection (*HttpsURLConnection*) with SSL (Secure Socket Layer) where authorization property is required. Dose information will be stored automatically in the Dose Center database to be available to the Frontend.

5.2 Dose Center – A New Monitoring Dose Paradigm

Dose Center is described as a dose information system integrated with PACS data sources and it is indispensable to the aimed provision at quality of radiological services to patients. It allows easy integration of legacy systems being convenient with regard to European law has changed, reinforcing the cinergy among all and thus can lead to performance control, protocol and optimization. Furthermore, Dose Center may increase risk awareness among hospital staff members.

Dose Center information system was developed using the Play Framework in Java [97 - 98], which is based on a lightweight, stateless and web-friendly architecture. It facilitates the development of web applications with Java and Scala programming languages.

In fact, Play Framework powers some of the most innovative web sites and it is reliable, simply and scalable and it is also developer friendly because what developers need is only a web browser (Google Chrome, Internet Explorer, Mozilla Firefox) and a text editor.

IntelliJ IDEA - Java IDE [101] was used because is considered as the most intelligent Java IDE and has some advantages like: IDE knows the code and helps developers by giving smart and relevant suggestions, instant code completion, easy project navigation and reliable refactoring tools for web development with Java and other programming languages (Scala, Groovy).

To install Play framework, it is necessary to download the latest Activator distribution and extract the archive to a location that have the access to reading and writing. After that, Play supports documentation guidelines [97 - 98] that explain in more detail the next steps to create an efficient web application.

Play application follows one of the most important patterns applied to the web architecture called by MVC architectural pattern. The following subsections explain with more detail this application model.

5.2.1 The MVC Application Model

The MVC (Model, View, and Controller) [102] application model splits the web application into different layers: Presentation layer and the Model layer. The first one is split into another two sublayers which are: View and Controller layer.

The description of each of these layers is the following:

- Model – is the domain-specific representation of the information on which the application operates. Several applications use a persistent mechanism of storage such as database to store data.

- View – renders the model into a form suitable for interactions, something like a user interface. In web applications, the view is a component rendered in a web format such as XML, HTML or JSON. Several views may exist for a single model and may have different purposes.
- Controller - responds to the user actions and processes them and could also invoke changes in the model. User actions represent, typically, HTTP Requests. So, the Controller listens for HTTP requests, extracts all relevant data (request headers, query parameters, for example) and applies changes on the model objects.

Figure 23 demonstrate how the MVC architecture works succinctly.

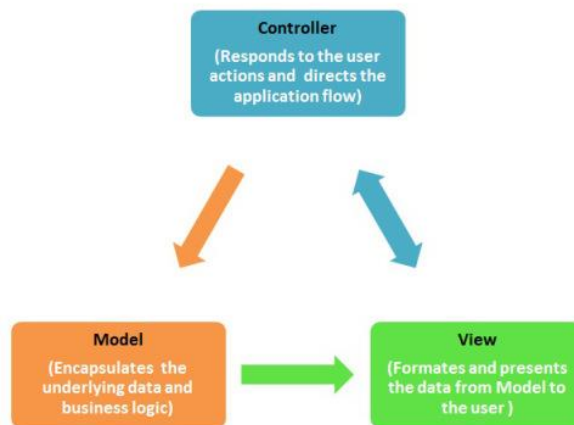


Figure 23. The MVC application model [102]

Play defines these three layers in the *app* directory, each one in a separate package: *app/controllers*, *app/models* and *app/views*.

The model object layer consists in a set of Java classes using all the object oriented features that are available from the Java language [94]. In this layer, we may find the operations and data structures that are part of web application. Java classes are the classes / entities that were addressed in the Dose Center database model (Figure 18 and Figure 19).

The Controller is a Java class where each method is an action invoked when HTTP Request is received. The action method will extract relevant data from those HTTP Requests and updates the model objects sending back a HTTP Response to the user actions.

Controller is also responsible for applying a template to decorate model objects and this packages contains some of web formats like XML, HTML and JSON template files that will be used to generate automatically the model representation.

These model objects are saved into a persistent storage, containing some JPA annotations or SQL statements.

5.2.2 Data Persistence

Dose Center entities/classes were developed based on Java Persistence API (JPA), thus constituting the Model layer from MVC application model.

JPA [103] is a specification of Java application programming interface that describes the management of data information in applications using Java platform.

Persistence Entity [103] corresponds to a grouping of state associated together as a unique unit. Some important characteristics of an object that has been transformed into an entity are: persistability, identity (where the entity identifier is the primary key in the database that stores the entity state), transactionality (create, update and delete operations that are normally done in the context of a transaction and this one is required for the changes to committed in the database) and granularity.

JPA also provides some annotations (JPA Annotations) that represent a convenient way to learn and use the API and they are co-locate the metadata with artifacts of the application and this way, it is only necessary to specify the metadata. JPA annotations are defined in the `javax.persistence` package and the implicit import is: `import javax.persistence.*;`

Each annotation always starts with the tag `@` and there are a lot of JPA annotations, including:

- **@Entity** – annotation that represents an Entity or Class (Organization, for example);
- **@Id** – annotation that specifies the primary key of an entity;
- **@OneToMany** – annotation that defines a many-valued association with one-to-many multiplicity;
- **@ManyToOne** – annotation that defines a single-valued association to another entity class that has many-to-one multiplicity;
- **@OneToOne** – annotation that defines a single-valued association to another entity class that has one-to-one multiplicity;
- **@CheckPermission** – annotation that indicates what are the specific permissions that roles had to perform a specific task;

Figure 24 show the Facility entity class with some of those JPA annotations.

```
1 package models;
2
3 import ...
4
5
6
7
8
9
10 /**
11  * Created by Tiago on 13/02/2015.
12  */
13 @Entity
14 public class Facility {
15
16     @Id
17     @GeneratedValue
18     private Long id;
19
20     private String name;
21
22     private String address;
23
24     @OneToMany(fetch = FetchType.LAZY, cascade = CascadeType.ALL, orphanRemoval = true)
25     @JoinColumn (name = "facility_id")
26     private List<Patient> patients = new ArrayList<>();
27
28     public Facility() {
29     }
30
31     public Facility(String name, String address)
32     {
33         this.name = name;
34         this.address = address;
35     }
36
37     public Long getId() { return id; }
38
39
40
41     public String getName() { return name; }
42
43
44
45     public void setName(String name) { this.name = name; }
46
47
48
49     public String getAddress() { return address; }
50
51
52
53     public void setAddress(String address) { this.address = address; }
54
55
56
57     public List<Patient> getPatients() { return patients; }
58
59
60
61     public void setPatients(List<Patient> patients) { this.patients = patients; }
62 }
```

Figure 24. Facility Java Class - a JPA Entity example

Facility class (entity from Dose Center) represents a JPA Entity example (annotation **@Entity**) and has some attributes such as *id* (annotation **@Id**) which value is automatically generated with annotation **@GeneratedValue**, *name* and *address*. It can also be noted that there is a many-valued association with one-to-many multiplicity (annotation **@OneToMany**) with Patient entity, because one Facility could have many patients associated (Figure 18).

Annotation **@JoinColumn** [104] specifies a column for joining an entity association and if this annotation is defined by default, then a single join column is assumed with default values applied.

In Facility class there are also two constructors created: *Facility()* and *Facility (String name, String address)*. The constructor method has the functionality of initialize an instance of an object to make sure that all the minimum amount of data required for a valid object state are provided at the creation time. The default constructor (*Facility()*) completes background plumbing which developers won't go into detail about it and it reserves also memory space in RAM, for instance.

The second constructor (*Facility (String name, String address)*) requires name and address because those things are what make the Facility object fully initialized.

Getters and setters are completely ordinary functions but the reason of using these methods instead of making members public is that it makes possible to change the implementation without changing the interface. Throughout the development of this project, there was always the concern to make the most possible model code.

5.2.2.1 EntityManager API

JPA uses the EntityManager API [104 - 105] for runtime usage that represents the application session or dialog with the database and for each request, EntityManager is used to access the database.

This API also represents a transaction context and typically for each transaction, a new EntityManager is created (in a stateless model). In a stateful model, an EntityManager could be matched with the lifecycle of a client's session.

EntityManager provides an API for all requires persistence operations including the following CRUD operations: Persist (insert), Merge (update), Remove (delete) and Find (select).

Persist operation (*EntityManager.persist()*) is used to insert a new object into the database but does not insert directly the object, it just registers it new transaction and when the transaction is committed, then the object will be correctly inserted into the database. It makes an entity instance managed and persistent. If the object uses a generated ID, then this ID will be assigned to the object when Persist operation is called, so this operation may also be used to support an object's ID assigned.

Once an entity is in the database, the next operation consists into find it again by primary key. For example, if we are looking for an instance of *Facility* class then this class and the id (or primary key) that identifies this particular entity need to be passed in the finding method. The code for this method is shown in Figure 25.

```

/* Get Facility by ID */
public static Facility findById(Long id) {

    //find facility by id
    return JPA.em().find(Facility.class, id);
}

```

Figure 25. Method for finding a Facility

With this method, the EntityManager will find the instance in the database and when the call completes, the facility that gets returned will be a managed entity. In the case of there are no facilities for the id passed, this method will return *null* value.

Merge operation is used to merge the changes made to a detached object into the current persistence context but does not update directly the object, it just merges the changes into the transaction and when the transaction is committed, then the object will be correctly updated into the database.

The method to update the name of a given facility will take the id and the new name, find the facility and change the name of it (Figure 26).

```

/* Update facility name by ID */
public static Facility updateFacilityName(Long id, String newName)
{
    //find facility by id
    Facility facility = JPA.em().find(Facility.class, id);

    //if facility exists
    if(facility != null)
    {
        //set facility name
        facility.setName(newName);
    }

    return facility;
}

```

Figure 26. Method for updating a Facility

If the facility is not found, then this method will return *null* value and so that, the caller will know that no changes could be made.

Remove operation is used to remove an object or entity instance from the database but does not delete directly the object from the database, it just select the object to be removed into the transaction and when the transaction is committed, then the object will be correctly deleted from the database.

In order to remove an entity instance, the entity must be managed itself so it means that the calling application should have already loaded the entity, issuing a command to remove it. In the application method

for deleting a facility, the problem may be fixed by checking for the existence of the facility before issuing the *remove()* call (Figure 27).

```
/* Delete facility with the given ID */
public static void removeFacility(Long id)
{
    //find facility by id
    Facility facility = JPA.em().find(Facility.class, id);

    //if facility exists
    if(facility != null)
    {
        //remove facility
        JPA.em().remove(facility);
    }
}
```

Figure 27. Method for removing a Facility

This method will ensure that the facility with the given id is removed from the database and it will return successfully whether the facility exists or not.

The same is done for the remaining entities that are part of the data model of Dose Center.

EntityManger is an object-oriented API, so does not map directly into SQL database or DML (Data Manipulation Language) operations. It is very useful to the developers, because to update an object, for example, the developer needs only to read that object and update its state through its *set* methods.

In JPA a query is similar to a database query, but instead of using SQL (Structured Query Language) to specify the query criteria, it uses JP QL (Java Persistence Query Language). The EntityManger interface supports a lot of API calls that return a new query (query is defined as Query object).

There are two ways to define the queries: statically or dynamically.

In a static way, the query is defined in either annotation or XML metadata and it must include the query criteria. A dynamic query may be issued at runtime supplying the JP QL query criteria or a criteria object and typically they are a little bit more expensive to execute but these queries are very simple to use and may be issued in response to user / program logic.

Figure 28 demonstrate an example of how to create a dynamic query and then execute it to get all the organizations that are saved into the database.

```

/* Get all organizations*/
public static List<Organization> findAllOrganizations() {

    //find organizations using JPA Query
    List<Organization> orgs = JPA.em()
        .createQuery("select o from Organization o", Organization.class)
        .getResultList();

    return orgs;
}

```

Figure 28. Method for issuing a query object

For executing the query, all we need is to invoke the *getResultList()* function and this method returns a *List<Organization>* containing all the *Organization* objects that matched the query criteria. The method *createQuery()* is used to inject the query and, in this case, this method, together with *getResultList()* method, returns all of the organizations.

5.2.3 Communication Process

HTTP (Hypertext Transfer Protocol) is the protocol programs to use to communicate over the World Wide Web [107] and there are several applications of this protocol, but HTTP is most famous for two-way conversation between web servers and browsers and it is considered as the common language of the modern global Internet.

It is essential to note that the web content lies on web servers, typically called by HTTP Servers. These servers have the responsibility to store the Internet's content and provide the data when it is requested by HTTP Clients. These ones send HTTP requests to the servers and the last one returns the requested data (in HTTP Responses) to the clients (Figure 29).

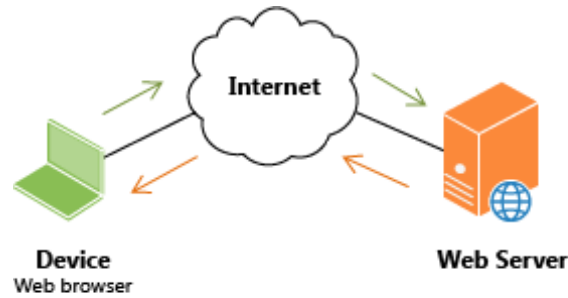


Figure 29. Web clients and Servers [106]

In Figure 29, the green arrows represent the HTTP Request message sent by Web Client, which is the Web Browser and the orange arrows represent the HTTP Response message sent by the Web Server returning the requested information to the client.

HTTP defines a set of methods that need to be considered in Dose Center application, the most important are: GET, PUT, POST and DELETE methods [107]. Each of these methods will be discussed next in more detail.

The GET method is used to ask a server to send a resource and it is considered as the most common method in HTTP. The client sends a request message (GET method) to the server and this one responds with sending a message containing the HTTP code (200 OK if succeeded, for example).

The PUT method is responsible to writes documents to a server instead of GET method. The client sends a request message with PUT method to the server and this one updates or creates the resource that is included in the HTTP Request, writes it to disk and responds with code 201 Created, for example.

If the resource already exists in server database, then server use the body to replace it. Because PUT allows changing the content, web servers require clients to authenticate with a secure password before PUT method being executed.

The POST method consists in sending input data to the server which decides where the information needs to go, for a server gateway program, for instance. This data is related to the filled-in form and it is the client the responsible to send this information to the server.

Finally the DELETE method asks the server to delete the resources that are specified by the request URL (Uniform Resource Locator) and the client application has not guaranteed that this method is carried out because HTTP allows the server to override the request without notifying the web client.

Play supports route files that are very useful in order to mapping the tuple of HTTP method and HTTP URL to certain actions. After creating the Dose Center application, a *conf/routes* [100] file is included. This file is considered as the central point of whatever is the application for every incoming HTTP request. In order to support a truly RESTful [108] based architecture, the combination of HTTP method and URL define an implicit action.

For every incoming HTTP Request, there is always a router component that is responsible to parse the routes file on startup and does the mapping to the Controller. Routes file is the configuration file used by the router component and contains a list of all routes needed by Dose Center application.

Each route consists of an HTTP method and URI patterns, both are associated with a call to an action generator, like was said before.

Each route starts with the HTTP method, followed by the URI pattern and the last element corresponds to the call definition. Figure 30 show the list of all routes that were used in Dose Center.

```

routes x
8 # Views
9 POST /login controllers.Application.login()
10 GET /logout controllers.Application.logout()
11 GET /search controllers.Application.search()
12 GET /effectiveDose/:patientID controllers.Application.effectiveDose(patientID:Long)
13 GET /statistics controllers.Application.statistics()
14 GET /facilityStatistics controllers.Application.facilityStatistics()
15 GET /equipmentStatistics controllers.Application.equipmentStatistics()
16 GET /physicianStatistics controllers.Application.physicianStatistics()
17
18 #Provider Dose Info
19 POST /facility/:facilityID/rawDoseObject controllers.DoseObjects.importDoseObject(facilityID:Long)
20
21 #DRIs
22 GET /drls controllers.DRLs.getAll()
23 PUT /drl/:name controllers.DRLs.editDRL(name:String)
24
25 #Simulated Studies
26 GET /simulatedStudies controllers.Application.getSimulatedStudies()
27 PUT /simulation/:user/:study/:modality/:ctdiVol/:dip/:coefficient controllers.Application.addStudy(user:String,study:String,modality:String,ctdiVol:String,dip:String,coefficient:String)
28
29 GET /currentUsername controllers.Application.getCurrentUsername()
30
31 GET /organizations controllers.Organizations.getAll()
32 GET /organization/:id controllers.Organizations.get(id:Long)
33 GET /organization/:id/sessionID controllers.Organizations.getOrganizationSessionID()
34 GET /organization/:id/facilities controllers.Organizations.getFacilities(id:Long)
35 DELETE /organization/:id controllers.Organizations.remove(id:Long)
36 #GET /organization/:id/drls controllers.DRLs.getAll(id:Long)
37
38 #Users
39 GET /users controllers.Application.getUsers()
40
41 #Facilities
42 GET /facilities controllers.Facilities.getAll()
43 GET /facility/:id controllers.Facilities.get(id:Long)
44 DELETE /facility/:id controllers.Facilities.remove(id:Long)
45
46 #Patients
47 GET /patients controllers.Patients.getAll()
48 GET /patient/:id controllers.Patients.get(id:Long)
49 DELETE /patient/:id controllers.Patients.remove(id:Long)
50
51 #Studies
52 GET /patient/:id/studies controllers.Studies.getAll(id:Long)
53 GET /study/:id controllers.Studies.get(id:Long)
54 DELETE /study/:id controllers.Studies.remove(id:Long)
55
56 # Map static resources from the /public folder to the /assets URL path
57 GET /assets/:file controllers.Assets.versioned(path="/public", file:Asset)

```

Figure 30. Dose Center routes file (*conf/routes*)

The URI pattern defines the request path to the routes, for example: */login*, and this will trigger the *login()* method that resides in Application Controller class.

Simply just add */login* to URL defined by the application in a web browser (assuming the server is running) and the login method is executed.

5.2.4 Web Technologies

This section provides some useful information about web technologies used in the Dose Center Frontend, i.e. the interface between web servers and clients.

There are numerous web technologies that were used in the development of this project, including: *JavaScript*, *jQuery*, *Handlebars.js*, *RequireJS*, *Promises*, *Google Charts*, *Bootstrap*.

JavaScript [109] is one of the world's popular programming languages and represents a great dynamic object-oriented general-purpose programming language. *JavaScript* has a syntactic similarity to Java language but it is possible to start working with it without knowing much about the language, and this is considered one of the most advantages of this language.

JavaScript drives the web from frontend user interface design to backend server-side programming.

In *JavaScript*, every object is linked to a prototype object from which it can inherit properties and methods and all objects that are created from object literals are linked to *Object.prototype* [110]. The statement of all functions implemented in *JavaScript* files (*.js* extension) at the Dose Center was initialized through the object Prototype.

jQuery [111] is a fast, small and a feature-rich *JavaScript* library and through this, it is possible to make HTML documents manipulation, animation and event handling. It is easy to use for developers and works across a multitude of web browsers.

This library has changed the way that millions of people write *JavaScript* code with a combination of extensibility and functionality.

Some of advantages of *jQuery* are: lightweight footprint with only 32kBytes minified and “gzipped”, supports CSS3 (Cascading Style Sheets) selectors to find elements as well as in style property manipulation and cross-browser (Internet Explorer, Google Chrome, Safari, Firefox, Opera, among others).

Nowadays, web applications are using *JavaScript* to create dynamic user interfaces and there are only a few *JavaScript* templating libraries available. The most common *JavaScript* templating language is *Handlebars.js*.

Handlebars [112] templates provide the necessary tools to build semantic templates effectively. It is compatible with other templates that are also supported by most web browsers.

These templates look like regular HTML documents, but with embedded handlebars expressions providing the possibility to precompile the templates created resulting in a smaller required runtime.

RequireJS [113] was also considered a module loader optimized for in-browser usage but with the possibility of being used in other *JavaScript* environments (such as *NodeJS*, for instance). It improves the speed and quality of developers programming code.

A *Promise* [113 - 114] is used to support asynchronous operation and has three distinct states:

- **Pending** – the initial state of a promise;
- **Fulfilled** – the state of a promise representing a successful operation;
- **Rejected** – the state of a promise representing a failed operation.

Once a promise is fulfilled or rejected, i.e. successful or failed operation occurs, it can never change again.

The *Promise* interface represents a proxy for a value when the promise is created and allows us to associate handlers to an asynchronous action (success or failure operation). Through this, it makes possible to let asynchronous methods return values like synchronous.

A pending promise may become fulfilled with a value or, perhaps, rejected with a reason and, when this happens, the associated handlers queued up by a promise's "then" method are called (Figure 31).

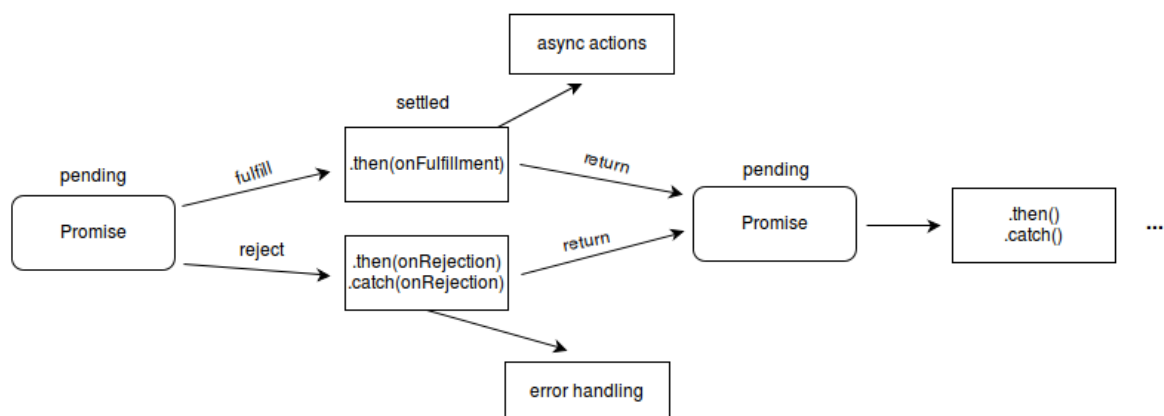


Figure 31. Promise state operations [112]

Many times, developers had to face with callbacks, nested inside of callbacks, nested inside of callbacks again, and so on. This reflects asynchronous access and most of the code needs more than a single input / output call. This could be a complicated problem because it consists in a lot of nesting. However, *Promises* also allows us to return a promise instead of asynchronous call accepting a callback.

Google Charts [116] is a powerful and simplest tool (with simple *JavaScript*) for drawing interactive charts and data tools. It is free, and supports a great variety of charts: area, bar, column, line, pie, timelines or even table, among others.

In Dose Center, only table, pie, column and bar charts were used to visualize the statistical data in terms of average cumulative dose and productivity (Chapter 6).

This tool allows developers to configure an extensive set of options to match the look of web applications. It is also cross-browser and uses a variety of data connection tools and protocols.

Finally, another web technology used is *Bootstrap* [117]. It is the most popular HTML, CSS and JS framework designed for developing projects on the web. It makes front-end web development faster and easier. It supports one framework to every each device, phones, tablets and desktops.

Bootstrap is open source with extensible documentation for HTML elements and CSS components. Through this framework, it was possible to make the Dose Center much more user-friendly.

To manage the client-side web dependencies, *WebJars* libraries (packaged into JAR files) were used and so that it was just use the Play dependencies from *WebJars* and put them in Play configuration file named *build.sbt*. For instance, if we want to add *jQuery* library to our Play application, then just need to select the WebJar associated (e.g. "org.webjars" % "jquery" % "2.1.4") and add it to *build.sbt* file, that the import of libraries is done dynamically to the project.

It was also created three different files/packages in *assets/javascripts* path associated to the instantaneous import of *RequireJS*:

- ***configsRequire.js*** – where the paths are defined to access libraries and where dependencies are indicated;
- ***commonRequire*** – file that do the connection between *configsRequire.js* and *specificRequire*;
- ***specificRequire*** - where the libs to import are indicated and where the *js* code is inserted.

All these technologies are essential to the successful development of Dose Center because each of them supports different functionalities and together they contribute to a better application. Each web technology supports also a lot of documentation that explains in an easy way how to install and how to use it.

5.2.5 Security

Implementing security is one of the most important concerns that need to be considered in this solution.

Certain aspects of web application security may be configured when the application is installed, or deployed, to the web container.

This section provides a detailed explanation of security concept in Play framework as well as methods of authentication that were considered in Dose Center development.

The use of RBAC (Role-Based Access Control) module is also considered here in order to briefly explain what it roles were considered in Dose Center and the features which are allowed for each.

5.2.5.1 Security in Play Framework

Play Framework supports several tools that developers may use for authentication processes in web applications.

There are three different ways to add authentication in Play using Java programming language: *@Security.Authenticated* on each action, *@With* using a custom action and *@With* on a Controller using a custom action. For the Dose Center developing, the first annotation was used [118].

@Security.Authenticated [118] annotation adds a check to any action that supports this annotation and by default, the method *getUsername(Http.Context ctx)* from *Security.Authenticator* class is called, and it will attempt to retrieve the current username from the session cookie.

If the username exists, then the action will continue normally but, if doesn't exists, then an error response will be returned (typically a HTTP 401 error).

It was created a package named "security" in Dose Center project with two Java classes: *Secured.java* and *Secured2.java*. The first one is used to see if the current user is authorized or not. Figure 32 show the authenticator implementation:

```

1  package security;
2
3  import controllers.Application;
4  import play.mvc.Http;
5  import play.mvc.Result;
6  import play.mvc.Security;
7
8  /**
9   * Created by Tiago on 04/03/2015.
10 */
11 public class Secured extends Security.Authenticator {
12
13     @Override
14     //if authorized, then get current username
15     public String getUsername(Http.Context ctx) { return ctx.session().get("username"); }
16
17
18     @Override
19     //if not authorized, then return to login page
20     public Result onUnauthorized(Http.Context ctx) { return Application.login(); }
21
22 }
23
24
25

```

Figure 32. Authentication in Play Framework using *Security.Authenticator* class

This class extends *Security.Authenticator* class and contains two different methods: *getUsername(Http.Context ctx)* that gets the current username. If, however, the method returns *null* value, then the authenticator will block the request and instead invoke the *onUnauthorized(Http.Context ctx)* that calls again *login()* method.

The *Secured2.java* class contains the same methods and does the same thing, but this one gets the current context request, gets authorization header from URL connection (provided by Provider Dose Info from Dose Extractor plugin) and the facility ID from URL POST path. Then, checks if authorization exists or not and, if exists, gets the respective credentials (username and password). Finally, it will verify if account with that credentials and facility ID exists or not in Dose Center database and returns the ID of the organization, only if does not exists. If already exists, then *onUnauthorized(Http.Context ctx)* is invoked.

Then, *@Security.Authenticated(Secured.class)* [118] annotation will be added to each method present in each Controller class. This way could be used to add other kinds of checks or to add a layer of authorization to client requests.

Play may also be configured to serve HTTPS (Hyper Text Transfer Protocol Secure) for secure communication over a computer network. To enable HTTPS, just need to tell which port will be used to listen using the *https.port* property (Dose Center is configured to listen at the port 9443) [119].

Play uses Java key stores to configure SSL (Secure Socket Layer) certificates and keys. To generate a new keystore, Oracle provides documentation on how to create these ones using the JDK keytool [120].

After generate the new keystore (keystore.jks), just need to add it to *conf* package and some properties need to be configured to permit its correct use by Play (Figure 33):

```
-Dhttp.port=disabled -Dhttps.port=9443 -Dhttps.keyStore=conf/keystore.jks  
-Dhttps.keyStorePassword=password -Dhttps.trustStore=noCA
```

Figure 33. Configuring Play to support HTTPS

The properties used were: *https.keySore*, *https.keyStorePassword* and *https.trustStore*.

- *https.keySore* – the path to the keystore generated containing the private key and certificate;
- *https.keyStorePassword* – corresponds to the password, defaults to a blank password;
- *https.trustStore* – while keyStore provides credential, this one verify credential and stores certificates from third party, signed by CA (Certification Authority) certificate, which may be used to identify third party.

5.2.5.2 Role-Based Access Control

Role-based access control (RBAC) [121] corresponds to the security mechanism that may lower the cost and complexity of security administration in large networked applications and web-based systems. RBAC may be configured to support a lot of variety of access control policies, including organization-specific policies.

Under this mechanism, the security administration is simplified by using roles, hierarchies or even constraints to organize the privileges or permissions.

It provides safety and an effective way of access management to the information of organizations, while reduce the costs of administration and minimize existing errors.

This concept usage has been increasing over the time, and most of Information Technology (IT) vendors already offer a product that includes some form of role-based access. Dose Center is an example of information system that incorporates a RBAC module and it's very useful to control what are the privileges / permissions for a specific user in this system.

There are other access control models like, for instance, the superuser model [122]. It is a conventional model that the user has the ability to read and write any file or run all programs, so anyone who can be superuser, may modify a site's firewall or read confidential data records, for instance. However, RBAC provides a more

secure solution that uses the security principle of *least privilege* (here, the user has the amount of privilege or permission to perform whatever task).

Access concept corresponds to the ability of an individual user perform a specific task such as: VIEW, CREATE, MODIFY or EDIT a file. These tasks correspond to the Operation name in database model presenting in Figure 18.

Roles are defined according to the task competency, authority and responsibility within the medical institution. Figure 34 show the generalized RBAC model.

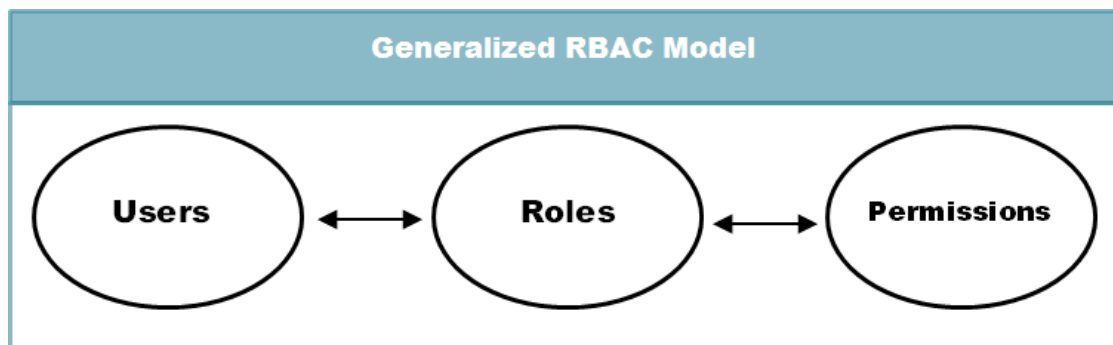


Figure 34. Generalized RBAC Model [121]

The package RBAC in Figure 18 was based in this generalized model.

Each of the roles has only one category associated with the name USER and the role Provider Dose Info ranks as CREATE, the Viewer role ranks as VIEW and only the Administrator has access to all categories: VIEW, CREATE , EDIT, REMOVE. These kind of permissions associated to each role are defined in the “*permissions.props*” (Figure 35) that these permissions are triggered when Dose Center runs for the first time.

```
p! permissions.props x
1 secret=4EA8C44C86C30BC0A4CEBBC9CC3E050BF76626AD
2 # Note: Any text following '#' is a comment
3 #
4 # Format:
5 # > Role : { Operation : [Category] }
6 # > requires valid json format
7 #
8 # Secret:
9 # > Erase for reload
10 {
11     "ProviderDoseInfo" : {
12         "User" : ["CREATE"]
13     },
14     "Viewer" : {
15         "User" : ["VIEW"]
16     },
17     "Admin" : {
18         "User" : ["VIEW", "CREATE", "EDIT", "REMOVE"]
19     }
20 }
21 }
22 }
```

Figure 35. Permissions Configuration File (Java Properties File)

It is important to note that the administrator of this system can change, create or remove whatever are the users, roles or permissions, making the necessary changes in this file.

6. Results and Validation

This section will present the results obtained with developed application. The exposition of results will be supported by pictures of the graphical user interface with all associated features and examples of tests.

6.1 Global Initialization

To launch the Play console, which allows to manage the Play application's complete development cycle, just need to enter any existing Play application directory (directory to Dose Center in this case) and run the play script: "\$ play".

Play supports also a command that get basic help about the available commands, through "\$ help play" command. To run Dose Center in development mode, we could use the run command by command line: "\$ run" or simply edit configurations in IntelliJ IDEA and select "Run" command.

If the server is launched with the auto-reload feature enabled, Play will check the project and recompile required sources for each request and, if needed, the application will restart automatically. When "Server started" statement appears in console, the server is running and Dose Center is also ready to be manipulated by user.

It was also developed an important Java class named by "*Global.java*" that is responsible for the global initialization of Dose Center application. It consists in add some default entity values, at the beginning, in Dose Center database, such values are: Organizations, Facilities, DRL Ranges, among others. This class has the functionality of getting those entity values from a properties file and persist them into the database, but only if there are no users or DRLs there.

The name of property file related above is "*global.props*" and it contains those entity values defined by the administrator of the system. This file follows a simple structure in order to *Global.java* understand the properties of each entity (Figure 36).

```

1 #organization = {name}
2 organization = {Org1,Org2}
3
4 #drl = {drl name, drl selected}
5 drl = {[NDRL,true] ;[LDRL,false]}
6
7 #drlRange = {[drl name, age, study, minValDLP, maxValDLP, minValCTDIvol, maxValCTDIvol]}
8 drlRange = {[NDRL,0,brain,270,340,20,27] ;[NDRL,1,brain,270,470,25,33] ;[NDRL,5,brain,470,600,35,40] ;[NDRL,10,brain,620,900,40,50] ;[NDRL,adult,brain,850,920,40,50] ...}
9
10 #facility = {[organization name, facility name, address]}
11 facility = {[Org1,Institution1,Gaia] ;[Org1,Institution2,Maia]}
12
13 #user = {[organization name, firstname, lastname, username, password]}
14 user = {[Org1,Dicoogle,Dicoogle,dicoogle1,123] ;[Org1,Viewer,Viewer,viewer1,1234] ;[Org1,Admin,Admin,admin,admin]}
15
16 #role = {[user firstname, role name]}
17 role = {[Dicoogle,ProviderDoseInfo] ;[Viewer,Viewer] ;[Admin,Admin]}
18
19 #simulated studies = {[user firstname, simulated study name, simulated modality name, coefficient, simulated dlp, simulated ctdivol]}
20 simulatedStudies = {[Admin,MyStudy1,CT,0.17,4000,400] ;[Admin,MyStudy2,Modality2,0.17,3000,300]}
21

```

Figure 36. "global.props" - Global initialization property file

Figure 36 show some values associated to each of represented entities: Organization, DRL, DRL Range, Facility, User, Role and Simulated Studies.

As we can see, there are two different organizations ("Org1" and "Org2"), two DRL lists ("NDRL" and "LDRL" where the first one is the active DRL by default), a set of DRL Ranges and each one has the associated patient age, study and minimum and maximum values of DLP and $CTDI_{vol}$ (according to section 2.4.2), two facilities ("Insitution1" and "Institution2" with Gaia and Maia addresses, respectively), three users (Provider Dose Info, Viewer and Administrator) with three different roles associated (Provider Dose Info, Viewer and Administrator - section 4.3) and two simulated studies by default which are: "MyStudy1" with DLP of 4000 mGy·cm and $CTDI_{vol}$ of 400 mGy and "MyStudy2" with DLP of 3000 mGy·cm and $CTDI_{vol}$ of 300 mGy. These studies correspond to the list of favorite's simulated studies defined by administrator.

After "global.props" creation, the *Global.java* will check if there are no users or DRLs in Dose Center database, and if so, them it will read this property file, load the properties from file reader, get those entity values and save them directly into database.

It is important to note that these values could be updated anytime by the administrator of that Organization (when properly authenticated), and what he need to do is simply change the properties in "global.props" file which is in project folder, respecting the structure of it. This file will be dynamically uploaded and those values are automatically merged in Dose Center database.

6.2 Testing the Dose Extractor

To send new medical studies for Dose Center, along with their dose values, it must run the Dicoogle PACS software and, for that, it was created a batch file: "\$ Dicoogle.bat" (Windows file batch). After that, the

Figure 38 shows an example of DICOM image received by Dicoogle and processed by Dose Center. It is possible to see OCR (red rectangle) was used to extract relevant dose values. The yellow rectangle shows the properties that were inserted by administrator in *configs.properties* file. In this case, the DICOM image was sent to the organization “Org1” because facility ID is 2 that correspond to the “Institution2” (Figure 36). In Dose Center, this image will be present at the search view associated to facility “Institution2” from organization “Org1” (Figure 40). The dose values and other relevant information are saved automatically in Dose Center database.

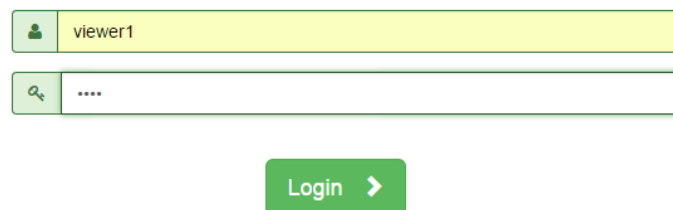
If the facility does not exist or the credentials for the Provider Dose Info are not correct, then a message would appear in this output, which does not occur in Figure 38.

6.3 Dose Center – Web Application

This section presents the web application that supports Dose Center solution (Figure 39). The description will be focused on the radiation dose analysis features available.

First, the user needs to login to the Dose Center system. By default, there are two different users that may interact with this application: Viewer and Administrator.

Welcome to Dose Center



The image shows a login form with two input fields and a button. The first field is labeled 'viewer1' and the second field contains four dots. Below the fields is a green button with the text 'Login >'.

Figure 39. Login - Dose Center homepage

The user needs to insert the correct credentials, with username (“viewer1”) and password (“1234”) associated, respectively (Figure 39).

After select “Login” option, it is possible to search at patient centric and see a list of patients and associated studies. The results are presented in a table (Figure 40) according to the performed query.

#	Patient Name	Patient DoB	Patient ID	Patient Sex	Institution	
1	VIDAL*ANTONIO MANUEL DIAS	1962/11/05	748661	M	Institution1	[Dose]
						DLP: 212.46 mGy.cm (Green)
						CTDIvol: 2.81 mGy (Yellow)
						Study: Cardiac Coronary
						Study Date: 2014/10/22
						Modality: CT
2	Patient Demo 1	1942/03/01	33333	F	Institution1	[Dose]
						DLP: 196.17 mGy.cm (Green)
						CTDIvol: 2.52 mGy (Green)
						Study: Cardiac Coronary
						Study Date: 2010/12/15
						Modality: CT
						DLP: 221.45 mGy.cm (Green)
						CTDIvol: 2.56 mGy (Green)
						Study: Cardiac Coronary
						Study Date: 2014/12/09
						Modality: CT
						DLP: 344.44 mGy.cm (Green)
						CTDIvol: 3.59 mGy (Red)
						Study: Cardiac Coronary
						Study Date: 2012/12/12
						Modality: CT
3	MR/BRAIN/GRASE/1024	1901/01/01	7	M	Institution2	
4	Patient Demo 1	1962/10/10	33333	M	Institution2	[Dose]
5	PATIENT6	1970/01/01	0000006	M	Institution2	
6	VIDAL*ANTONIO MANUEL DIAS	1962/11/05	748661	M	Institution2	[Dose]
						DLP: 212.46 mGy.cm (Green)
						CTDIvol: 2.81 mGy (Yellow)
						Study: Cardiac Coronary
						Study Date: 2014/10/22
						Modality: CT

metric value Undefined metric value Low Exposure metric value Normal Exposure metric value High Exposure

Figure 40. Dose Center Search View

If the user selects one table row, patient studies will come up. The information of studies such as Study Description, Study Date and Modality will be displayed but also the dose measures such as the DLP and $CTDI_{vol}$, in CT examinations.

To each dose measure, it will be applied one color that depends on dose reference levels (section 2.4.5). They are colored as green, yellow or red depending on the risk of radiation dose (low exposure, medium exposure and high exposure, respectively), which helps radiologists to improve patient’s safety.

Some studies don’t support dose values because despite being official, manufacturers do not put this information in DICOM tags and, in these cases, a grey color appears to define those dose measures as “undefined”.

For example, if user selects the patient name “Patient Demo 1” from Institution1, then he will see that there are three different studies associated to that patient (Figure 40), three CT exams with the same Study Description: “Cardiac Coronary”. Dose measures are colored as green which means that they define low exposure, except the $CTDI_{vol}$ measure with 3.59 mGy that represents high exposure.

As expressed, these dose reference levels are defined in the *global.props* file (Figure 36) and, by default, NDRL is the active one, which means that all dose measures depend on the risk of radiation defined in NDRL list. And if the maximum value of $CTDI_{vol}$ for adult patient (by Patient date of birth information) and CT Cardiac Coronary is 3 mGy defined in NDRL list, 3.59 mGy value is higher and then represents high exposure.

The active DRL could be changed but this user doesn't have permissions to do that, only Administrator could edit the DRL lists (Figure 19).

Dose Center could be configured to provide automatic alerts when radiation levels exceed the established thresholds. It is possible to analyse which are the ranges of acceptable and unacceptable values for each of dose indicators.

Other important information like Patient Name, Patient Date of Birth, Patient ID, Patient Sex and Institution/Facility are presented here in this search table.

Dose Center allows us to visualize the effective and cumulative radiation dose that was applied to a particular patient. If we select "Dose" option for patient name "Patient Demo 1" from Institution1, the system will redirect us to the web page presented in Figure 41.

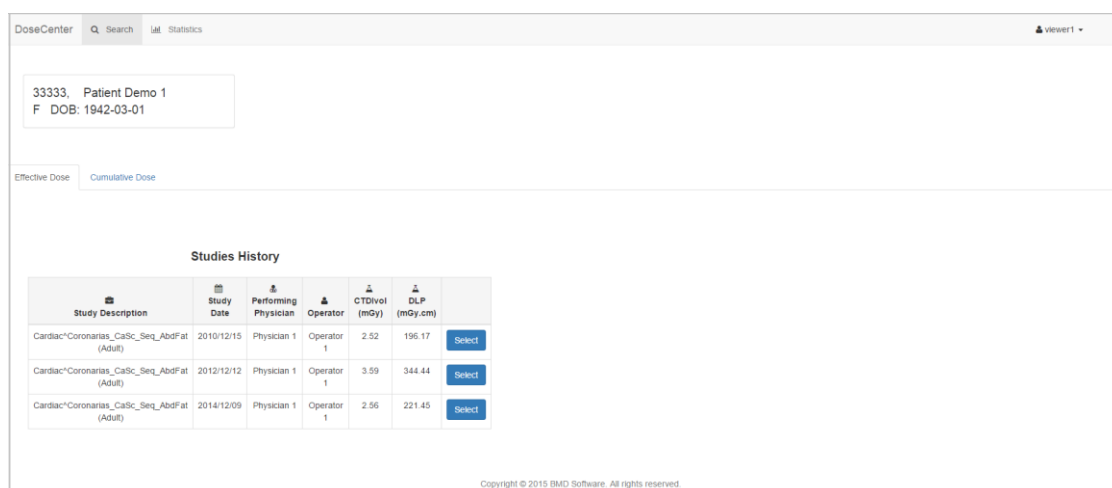


Figure 41. Studies History for a specific patient

In Figure 41, it is possible to view not only the selected patient data (Patient ID = 33333, Patient Name = Patient Demo 1, Gender = Female, and DOB = 1942-03-01), but also the studies history for that particular patient, exactly the same three CT studies that were presented in the search table (Figure 40). However, we have now available a set of analysis tools.

If the user chooses the "Select" option from a study, then it will appear a graphic (bar chart type) that represents the effective dose obtained in the study carried out (Figure 42).

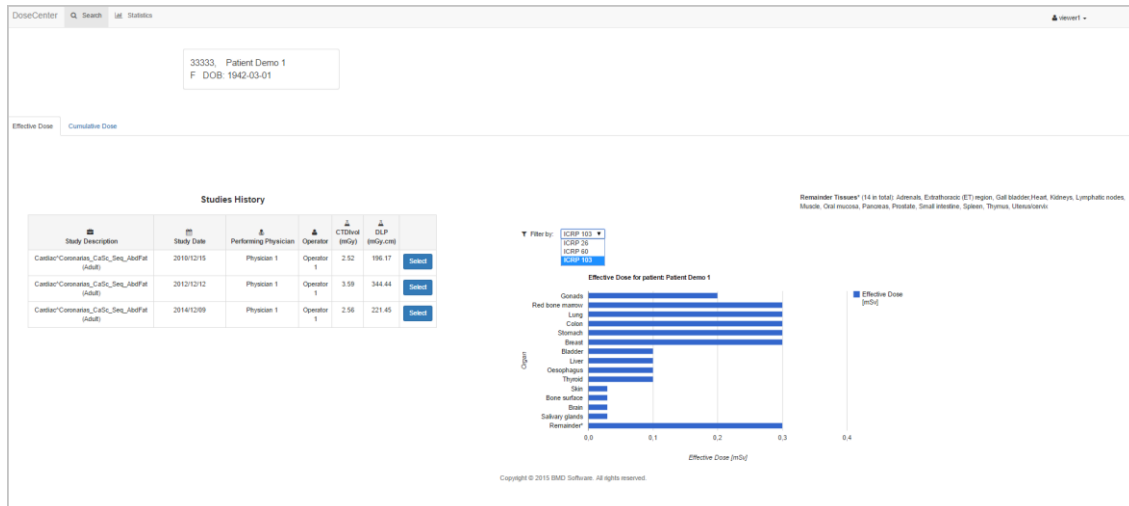


Figure 42. Effective Dose for a specific patient

A dropdown list allows filtering the effective dose for three different ICRP publications: ICRP 26, ICRP 60 and ICRP 103. Figure 42 presents an "organ-by-organ" case, where the health professional may track the effective dose for different organs of the human body.

The values of tissue weighting factors for each organ are presented in Table 3 of section 2.4.3.1. For ICRP 103 publication, the remainder tissues [123] are: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus and Uterus/cervix.

The Effective Dose section is the active one by default, when user selects "Dose" option from search table.

Additionally, it is also possible to visualize a chart of cumulative dose applied to the patient over the last 7, 5 and 3 years (Figure 43).

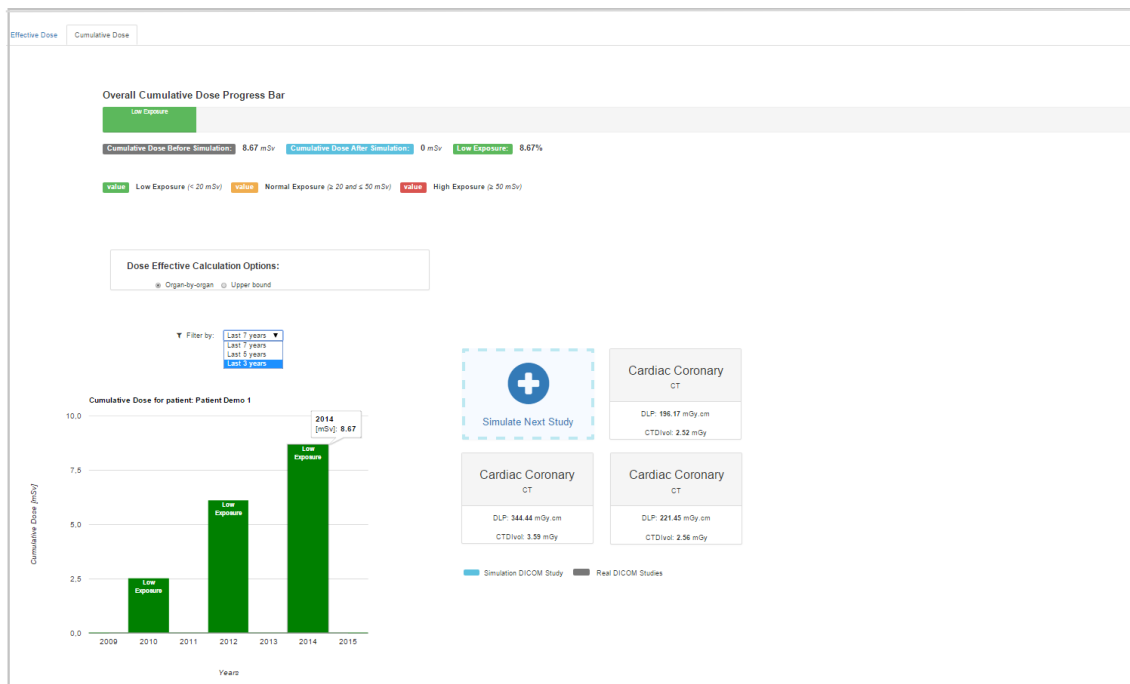


Figure 43. Cumulative Dose ("organ-by-organ" method) applied to a specific patient

Figure 43 shows the three studies performed by Patient Demo 1, one in 2010 with 2,52 mSv of effective dose (based on organ-by-organ dose estimates method that is the select method by default), another in 2012 with 3,59 mSv and the last one in 2014 with 2,56 mSv. The cumulative dose chart support dose values from each of one study performed in the respective year. In 2010, the value of cumulative dose is 2,52 mSv, in 2012 the cumulative dose value is approximately 6, 11 mSv (2,52 + 3,59) and in 2014 the value of cumulative dose is 8,67 mSv (6, 11 + 2,56).

The cumulative effective dose levels for individuals [22] have been specified according to the values shown in Table 12:

Cumulative effective dose Level	Low Exposure	Moderate Exposure	High Exposure
Effective dose range (mSv)	> 0 - 19	> 20- 49	> 50 - 100

Table 12. Cumulative effective dose level categories [123]

At the top of this page (Figure 43), there is an overall cumulative dose progress bar with the updated cumulative dose and thus, healthcare professionals may view a summary of warning progress bar based on the cumulative dose limits exceeded in a given medical examination. This is a very helpful feature for optimizing the dose monitoring process applied to each patient and helps health professionals to have a better awareness of the dose that is applied to the patients and thus ensure the welfare and safety of them.

This progress bar varies according to the method chosen for dose effective calculation and according to the simulation done by the user. It supports some labels, one that indicates the cumulative dose applied before simulation (to both effective dose calculation methods), another for cumulative dose after simulation and the last one for exposure type [125] according to the Table 12.

In Figure 43 case, the last label corresponds to the low exposure because the cumulative dose is 8,67 mSv and it is smaller than 20 mSv. It is considered normal exposure when cumulative dose is between 20 and 50 mSv and higher exposure when cumulative dose exceeds 50 mSv (Table 12).

But if the user prefers to see the cumulative effective dose using the k conversion factors and DLP, then must select the option “Upper bound” from checkbox lying on the cumulative dose chart (Figure 44).

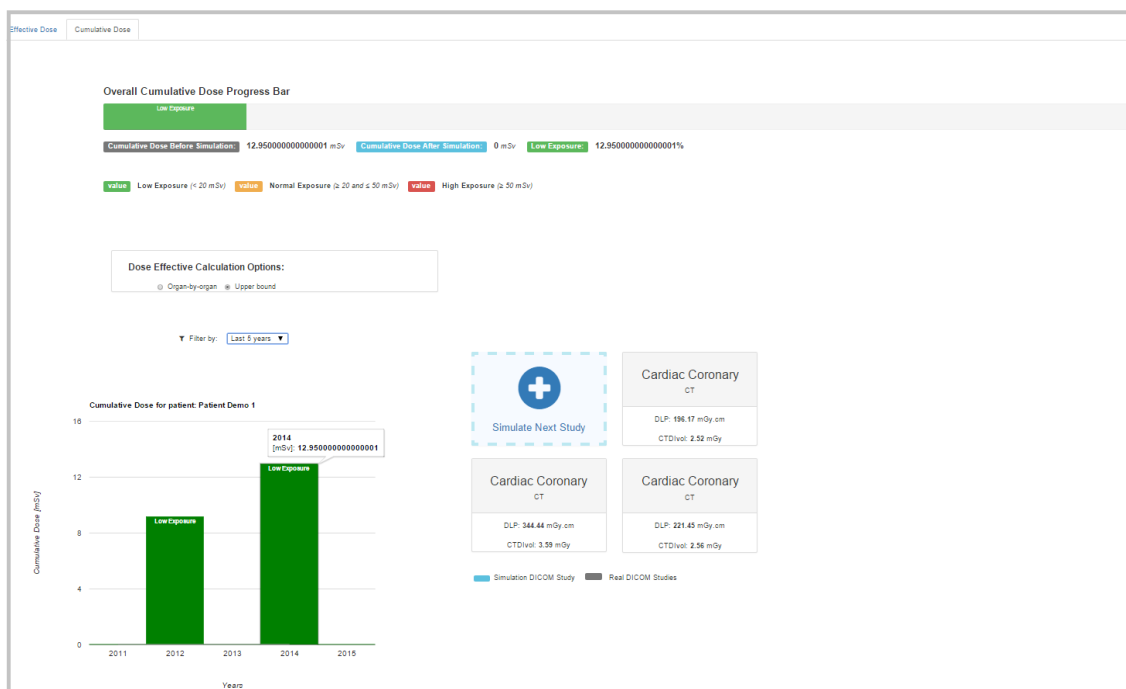


Figure 44. Cumulative Dose ("Upper bound") applied to a specific patient

In this case, the total cumulative dose is approximately 12,95 mSv (there is more cumulative dose comparing to the previous method) and the overall progress bar is already updated to this value. It contains green colour again because 12, 95 is smaller yet than 20 mSv, so it continues to correspond to low exposure.

The cumulative dose chart is also updated, in 2010, the value of cumulative dose is 3,33 mSv, in 2012 the cumulative dose value is approximately 9,19 mSv (3,33 + 5,86) and in 2014 the value of cumulative dose is 12,95 mSv (9,19 + 3,76). Filter by “last 5 years” was applied, so year 2010 does not appear.

The results of these calculations were established according to patient age and study description (section 2.4.3).

In the right side of cumulative dose chart there are the three studies (CT Cardiac Coronary) performed by patient Patient Demo 1 and also the possibility to simulate the next CT study (this feature was only applied to CT modality), so that user may see what are the implications in cumulative dose after simulation.

If user selects the “Simulate next study” option, then a modal will appear (Figure 45):

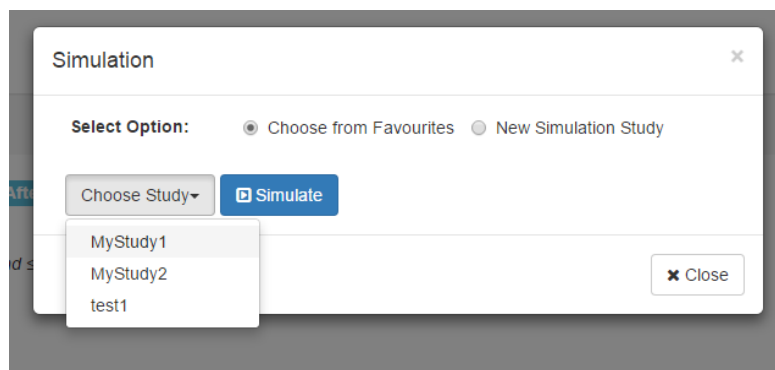


Figure 45. "Choose from Favourites" simulation option

There are two different simulation options: simulate from a list of favourites simulated studies or add a new simulation study. Figure 45 shows the first option, selected by default, and the user may choose simulated studies from the favourites list. These lists of simulated studies are created in “*global.props*” file (Figure 36).

However, if the user wants to create a new simulation study, then it must choose the second option and another modal view appears (Figure 46).

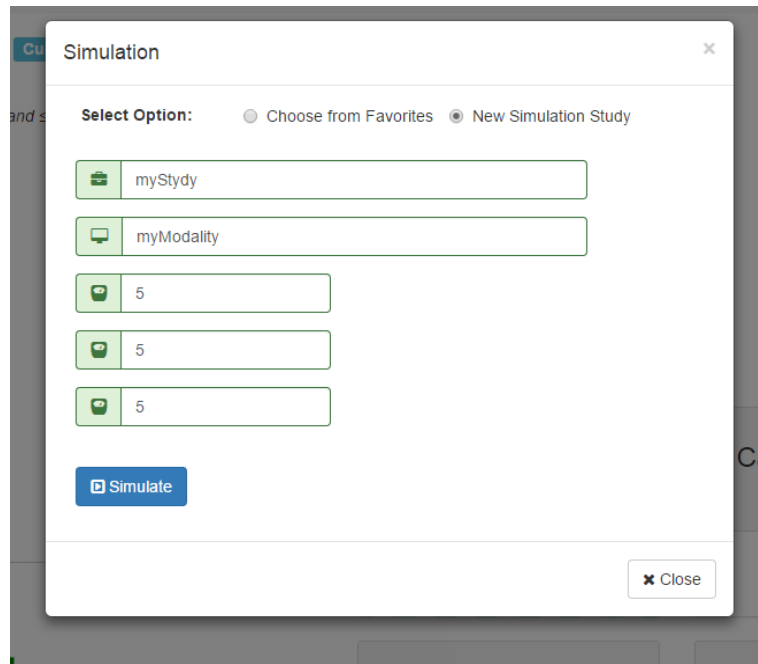


Figure 46. "New Simulation Study" simulation option

To simulate a new study, user needs to fill some fields like study name, modality, DLP value, $CTDI_{vol}$ value and conversion factor (k-factor) value. The result, according to the simulation option, will be similar to the following (Figure 47):

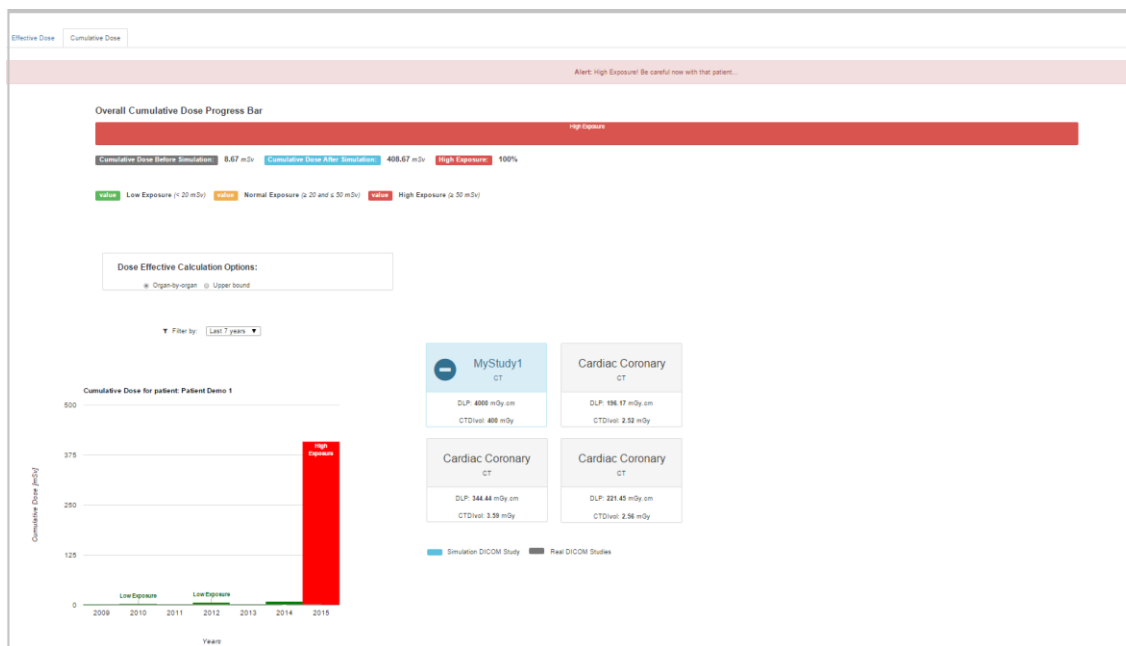


Figure 47. Cumulative Dose after simulation

To the simulation, it was used the study “MyStudy1” from favourites with DLP 4000 mGy.cm and $CTDI_{vol}$ with 400 mGy. If the method “Organ-by-organ” was selected, then the cumulative dose value in current year, 2015, is 408,67 (400 + 8,67 until 2014) mSv (Figure 47).

The color of progress bar and the bar for 2015 year changed to red which means that this patient will be submitted to high exposure because total cumulative after simulation is higher than the maximum cumulative dose threshold (Table 12). When this threshold is exceeded, an alert message appears to warn radiologists that need to careful with that patient (Figure 47).

When user decides to do another simulation, then selects the minus button from simulated study (blue rectangle) to remove the last one and then is able to do another one, and so on.

Dose Center provides also a statistics tool (Figure 48). The “Statistics” tab allows to view statistics in terms of dose and productivity / equipment performance and make comparisons between different populations. It provides a dose reporting dashboard with graphics or tables where it is possible to choose the category (by Modality, Facility or Equipment) to analyse the data for specific patient populations.

Dose Center makes possible to have a more interactive analysis and a better perception of the percentage amount of risk in the population, or even to check the percentage of average cumulative dose level according with different characteristics of patient’s. The healthcare professionals may now have a better understanding in terms of percentages when we approached the radiation dose, and thus monitor risks and ensure patient safety. Figure 48 shows different charts for comparison percentage among populations and monitoring of radiation dose.

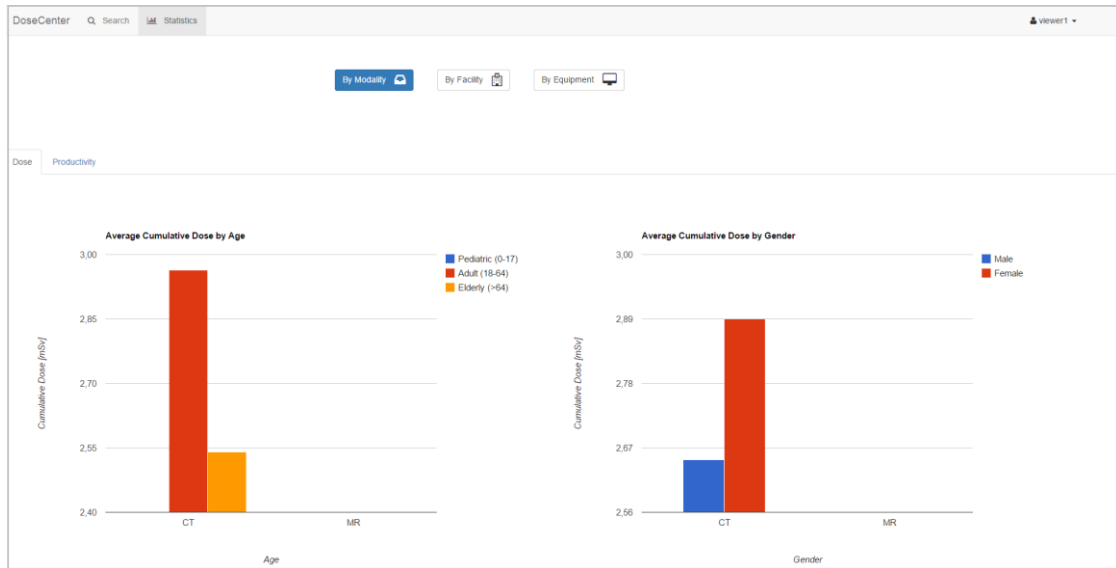


Figure 48. Average Cumulative Dose - Statistics by Dose (by Modality)

In Figure 48, user could see the average cumulative dose by age group or gender from a specific organization by modality.

Figure 49 shows different charts for comparison percentage among populations according to productivity. This is an extra functionality that was developed in order to providing more information improving the health professionals work process.

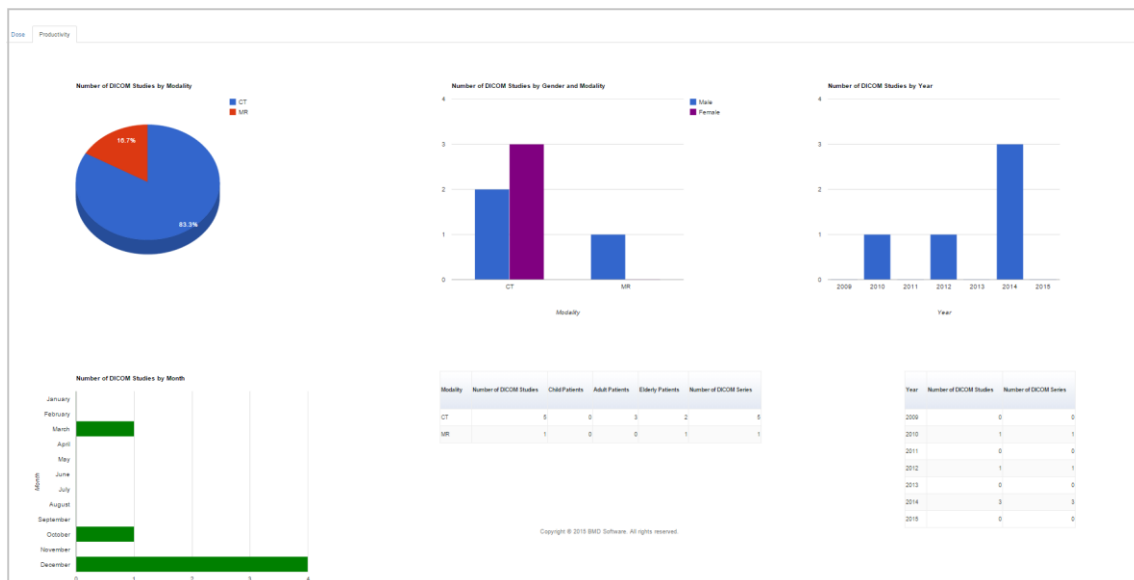


Figure 49. Statistics by Productivity (by Modality)

Figure 49 shows the total number of DICOM Studies by modality, gender, year and month and two tables that the first one indicates for each modality, what is the number of DICOM studies, the patients *per* age group; number of DICOM series and the second one illustrates the number of DICOM studies and series *per* year.

The option “By Modality” is the selected by default, but the same thing is applied to the others.

Another extra functionality developed is that the Administrator has access to more two features that a regular user (i.e. Viewer). Administrator could also change the active DRLs (Figure 50) and , in “Statistics” tab, the option “By Physician/Operator” is also available.

To change the DRLs, Administrator needs to select the option “Change DRLs” which is in the upper right corner of the admin user page. It will appear a simple modal as shown in Figure 50:

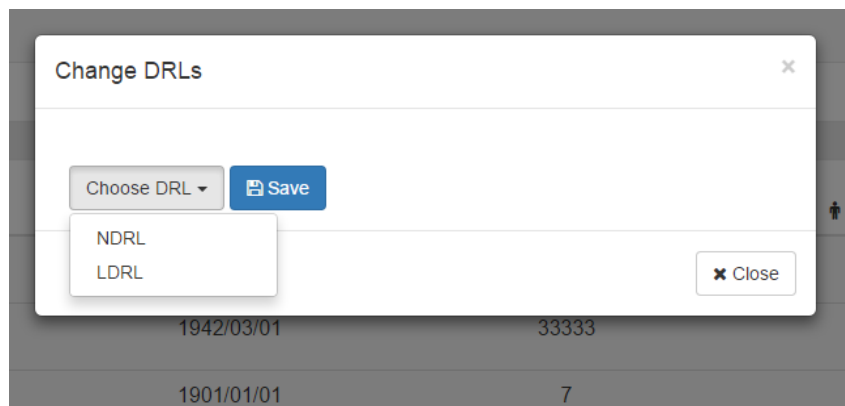


Figure 50. "Change DRLs" option

Administrator can choose a DRL from the available list that were configured in “*global.props*”. Next the active DRL will be automatically updated to all dose measures that are included in search table. When some user logout from the application and login again, the active DRL will be updated.

Another useful feature that is available to the system Administrator is the possibility of seeing some relevant productivity metrics related to physicians / operators from a specific institution and organization. For instance, the number of DICOM studies by age and by physician/operator, the working days of each physician/operator, the number of DICOM series and also the number of patients by age group or gender.

The Physician and Operator names were extracted from “Performing Physician Name” and “Operator Name” tags, respectively. However, these attributes have *null* values because we are dealing with optional tags. However those elements could be retrieved from RIS (via HL7, for instance) and integrated in database of Dose Center (section 7.1).

7. Conclusion

Nowadays, medical image departments have to face with some challenges such as good practice in radiation dose management, reduce costs (at medium/long term), optimize resources and ensure patient safety, with particular interest in achieve a better balance between radiation dose and image quality.

Systematic monitoring of dose radiation is required allowing performance control, protocol optimization and rapid rectification of wrong practices.

Radio diagnostic episodes should keep the radiation exposure as low as reasonably achievable (ALARA principle) preserving the diagnostic quality required. Dose monitoring should be performed individually ensuring an adequate dose usage.

However, many of actual healthcare information systems do not allow dose analysis and its continuous monitoring is rare.

Monitoring dose tools are used to capture, locate and report examinations dose report and there are many examples of this tools like, for instance, Radimetrics (Bayer), Dose Track (Sectra), Dose Watch, among others. However, there is a lack of full integration with other data sources and most of them were not focused on patient and they don't support cross institution between different medical institutions.

Dose Center represents a web solution, inherently multi-platform, robust and reliable to ensure the quick, simple and effective access by healthcare professionals, to answer their needs. This solution will be accessible via web, allowing its usage whatever the operating system is with web access.

This monitoring tool allows extracting and storing automatically dose data applied to each examination with ionizing radiation and supports multiple levels of access, depending on user profile. It provides an aggregated view of several information sources as well as dose analysis at different scopes (patient and population centric) and allows dashboards for comparative analysis according to cumulative dose and patient history. Cases exceeding radiation dose limits (dose reference levels) are automatically flagged, ensuring patient safety.

Dose Center is focused on CT studies because CT is a modality with higher dose radiation and it must be considered. It is a system with the ability to integrate with source information such PACS and follows the DICOM standard for treatment, storage and transmission of medical images in a structured way.

It provides a set of graphical functionalities giving the possibility to filter the statistical dose data by Modality, Equipment, Operator/Physician or even by Facility not only in terms of cumulative dose but also in terms of productivity, depending on gender of the patient, age, among others.

It is a user-friendly monitoring tool that allows better protocol optimization and security, containing a progress bar with cumulative dose values for a particular patient according to the reference levels of exposure. It works like a traffic light, when the green, yellow/orange and red colours represent the low, normal and high exposures, respectively.

This tool allows also the possibility to simulate the next CT study for a specific patient, through this the radiologists may use the simulated studies from favourites or simply simulate a new one and Dose Center automatically save this study in its database, only if does not exists already.

Throughout the development of this project, there were some meetings with physicists and radiologists, including professor Milton Rodrigues dos Santos and professor Joana Vale from “Escola Superior de Saúde da Universidade de Aveiro” (ESSUA) with potential interest in this tool. They were important meetings where some theoretical concepts were discussed as well as some features in terms of user interface.

Finally, the work resulted in a scientific contribution to this research area with an article and oral presentation in an international congress:

- Tiago Soares, Luís S. Ribeiro, Luís A. Bastião Silva, Carlos Costa, "DoseCenter - A New Radiation Dose Monitoring Paradigm", 29th Computer Assisted Radiology and Surgery (CARS 2015), Barcelona, 2015.

7.1 Future Work

This work could evolve in different directions with the aim of contributing to a better dose monitoring in several medical institutions. At the end of this work, have been identified some possibilities of evolution that could be contemplated in future work:

- Allow the simulation of studies of different modalities, not just CT. Dose Center was essentially focused on CT, but it would be interesting to simulate also radiography and mammography studies;
- The support to other modalities in addition to CT like, for instance, Radiography, Fluoroscopy, Mammography, among others. It was already included a theoretical study on how calculating the effective dose in such arrangements;
- The possibility of having simulation with organs view that are affected. This feature would be more elaborate, eventually using one of the most common techniques, e.g. Monte Carlo simulation;

- The possibility of linking Dose Center to the RIS to extract the attributes “Performing Physician” and “Operator Name”, when they are not available in DICOM objects meta-data.

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Annex 1

Patient Tags:

Tag ID	Tag Name
(0010, 0020)	Patient ID
(0010, 0010)	Patient Name
(0010, 0030)	Patient Birth Date
(0010, 0032)	Patient Birth Time
(0010, 1005)	Patient Birth Name
(0010, 0040)	Patient Sex
(0010, 1000)	Other Patient IDs
(0010, 1001)	Other Patient Names
(0010, 2160)	Ethnic Group
(0010, 4000)	Patient Comments
(0010, 1040)	Patient Address
(0038, 0400)	Patient Institution Residence
(0038, 0500)	Patient State

Study Tags:

Tag ID	Tag Name
(0020, 000D)	Study Instance UID
(0008, 0020)	Study Date
(0008, 0030)	Study Time
(0008, 0050)	Accession Number
(0020, 0010)	Study ID
(0008, 0090)	Referring Physician Name
(0008, 1050)	Performing Physician Name
(0008, 1070)	Operators Name
(0040, 0006)	Scheduled Performing Physicians Name
(0008, 1030)	Study Description
(0008, 1032)	Procedure Code Sequence
(0010, 0021)	Issuer of Patient ID
(0010, 1010)	Patient Age
(0010, 1020)	Patient Size
(0010, 1030)	Patient Weight
(0010, 2180)	Occupation
(0010, 21B0)	Additional Patient History
(0020, 1070)	Other Study Numbers
(0008, 0061)	Modalities in Study
(0008, 0062)	SOP Classes in Study

Series Tags:

Tag ID	Tag Name
(0020, 000E)	Series Instance UID
(0008, 0060)	Modality
(0020, 0011)	Series Number
(0008, 0021)	Series Date

Dose Objects (Image Level) Tags:

Tag ID	Tag Name
(0008, 0018)	SOP Instance UID
(0008, 0022)	Acquisition Date
(0008, 0023)	Content Date
(0008, 0070)	Manufacturer
(0008, 0016)	SOP Class UID
(0002, 0010)	Transfer Syntax UID
(0008, 0080)	Institution Name
(0008, 0081)	Institution Address
(0008, 0082)	Institution Code Sequence
(0008, 1010)	Station Name
(0008, 2229)	Anatomic Structure or Region Sequence
(0040, 0300)	Total Time of Fluoroscopy
(0040, 0301)	Total Number of Exposures
(0018, 1110)	Distance Source to Detector
(0040, 0306)	Distance Source to Entrance

(0040, 0302)	Entrance Dose
(0040, 8302)	Entrance Dose in mGy
(0040, 0303)	Exposed Area
(0018, 7060)	Exposure Control Mode
(0018, 7062)	Exposure Control Mode Description
(0018, 9324)	Estimated Dose Saving
(0018, 9434)	Exposure Control Sensing Region Seq.
(0018, 9435)	Exposure Control Sensing Region Shape
(0018, 9436)	Exposure Control Sens. Region Left Edge
(0018, 9437)	Exposure Control Sens. Region Right Edge
(0040, 030E)	Exposure Dose Sequence
(0018, 9332)	Exposure in mAs
(0018, 9323)	Exposure Modulation Type
(3002, 0030)	Exposure Sequence
(0018, 1404)	Exposures on Plate
(0018, 7064)	Exposure Status
(0018, 1150)	Exposure Time
(0018, 8150)	Exposure Time in μ s
(0018, 9328)	Exposure Time in ms
(0018, 6000)	Sensitivity
(0018, 9767)	Sensitivity Calibrated
(0018, 115E)	Image and Fluoroscopy Area Dose Product
(0040, 0310)	Comments on Radiation Dose
(300A, 0304)	Radiation Atomic Number
(300A, 0306)	Radiation Charge State

(3002, 0020)	Radiation Machine Name
(3002, 0022)	Radiation Machine SAD
(3002, 0024)	Radiation Machine SSD
(300A, 0302)	Radiation Mass Number
(0018, 115A)	Radiation Mode
(0018, 1155)	Radiation Setting
(300A, 00C6)	Radiation Type
(0018, 0060)	KVP
(0018, 1151)	X-Ray Tube Current
(0018, 8151)	X-Ray Tube Current in μ A
(0018, 9330)	X-Ray Tube Current in mA
(0018, 7050)	Filter Material
(0018, 1044)	Contrast Bolus Total Dose
(0018, 1074)	Radionuclide Total Dose
(0018, 9473)	Acquired Image Area Dose Product
(0040, 0316)	Organ Dose
(0040, 0318)	Organ Exposed
(0054, 1322)	Dose Calibration Factor
(3004, 0006)	Dose Comment
(3004, 000E)	Dose Grid Scaling
(3008, 0048)	Dose Rate Delivered
(300A, 0115)	Dose Rate Set
(300A, 0016)	Dose Reference Description
(300A, 0012)	Dose Reference Number
(300A, 0018)	Dose Reference Point Coordinates

(300A, 0010)	Dose Reference Sequence
(300A, 0014)	Dose Reference Structure Type
(300A, 0020)	Dose Reference Type
(300A, 0013)	Dose Reference UID
(3004, 000A)	Dose Summation Type
(3004, 0004)	Dose Type
(3004, 0002)	Dose Units
(3004, 0012)	Dose Value
(3004, 0010)	RT Dose ROI Sequence
(3004, 0042)	DVH Normalization Dose Value
(3004, 0052)	DVH Dose Scaling
(3004, 0072)	DVH Maximum Dose
(3004, 0074)	DVH Mean Dose
(3004, 0070)	DVH Minimum Dose
(3008, 0012)	Measured Dose Description
(3008, 0064)	Measured Dose Reference Number
(3008, 0010)	Measured Dose Reference Sequence
(3008, 0014)	Measured Dose Type
(3008, 0016)	Measured Dose Value
(3008, 0050)	Treatment Summary Calc. Dose Ref. Seq.
(3008, 00E0)	Treatment Summary Meas. Dose Ref. Seq.
(300A, 010C)	Cumulative Dose Reference Coefficient
(0018, 9321)	CT Exposure Sequence
(0018, 9345)	CTDIvol
(3008, 0052)	Cumulative Dose to Dose Reference

(3008, 0074)	Calculated Dose Reference Description
(3008, 0076)	Calculated Dose Reference Value
(3008, 0072)	Calculated Dose Reference Number
(3008, 0070)	Calculated Dose Reference Sequence
(3008, 0092)	Reference Calculated Dose Ref. Number
(3008, 0090)	Reference Calculated Dose Ref. Seq.
(300C, 0051)	Referenced Dose Reference Number
(300C, 0050)	Referenced Dose Reference Sequence
(300C, 0080)	Referenced Dose Sequence
(3008, 0080)	Referenced Measured Dose Ref. Sequence
(3008, 0082)	Referenced Measured Dose Ref. Number
(300A, 001A)	Nominal Prior Dose
(300A, 0023)	Delivery Maximum Dose
(300A, 0022)	Delivery Warning Dose
(300A, 0027)	Target Maximum Dose
(300A, 0025)	Target Minimum Dose
(300A, 0026)	Target Prescription Dose
(300A, 0028)	Target Under Dose Volume Fraction
(300A, 002A)	Organ at Risk Full Volume Dose
(300A, 002B)	Organ at Risk Limit Dose
(300A, 002C)	Organ at Risk Maximum Dose
(300A, 002D)	Organ at Risk Overdose Volume Fraction
(300A, 0084)	Beam Dose
(300A, 0088)	Beam Dose Point Depth
(300A, 0089)	Beam Dose Point Equivalent Depth

(300A, 008A)	Beam Dose Point SSD
(300A, 0082)	Beam Dose Specification Point
(300A, 00A4)	Brachy Application Setup Dose
(300A, 00C7)	High Dose Technique Type
(300C, 0055)	Brachy Referenced Dose Ref. Seq.
(0018, 9477)	Irradiation Event ID Sequene
(0008, 3010)	Irradiation Event UID
(0018, 1152)	Expoure
(0018, 1405)	Relative X-Ray Exposure
(0018, 7012)	Detector Time Since Last Exposure
(0018, 9441)	Radius of Circ. Expos. Control Sens. Region
(0074, 103A)	Double Exposure Field Delta
(0074, 1034)	Double Exposure Flag
(0074, 1038)	Double Exposure Meterset
(0074, 1036)	Double Exposure Ordering
(3002, 0032)	Meterset Exposure
(0020, 0013)	Instance Number
(0008, 3001)	Alternate Representation Sequence
(0008, 001A)	Related General SOP Class UID
(0040, A043)	Concept Name Code Sequence
(0040, A504)	Content Template Sequence