



4ª ed

MIM

# **DICOM-RT standard in Radiotherapy Information Systems** *A National Study*

**Celeste Oliveira**

MESTRADO EM  
**INFORMÁTICA MÉDICA**  
2º CICLO DE ESTUDOS

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ORIENTADORES:  
Pedro Pereira Rodrigues

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*To Marcos for being an unconditional source  
of patience and tenderness.*





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# Context

Being graduated in radiotherapy at the University of Aveiro and working in radiotherapy (RT) department of the Portuguese Oncology Institute [Instituto Português de Oncologia] – Porto, the author started in 2009 a master's degree in Medical Informatics at the Faculty of Medicine and Faculty of Sciences, University of Porto. This academic degree increased the author's interest in information systems (IS) and interoperability.

At the discipline of “Medicine and Health Systems” from the master's degree, the author had to work in partnership with a professional of informatics, who presented the health issues with guidelines and the author presented the informatics domain specifying the IS involved. In this work, entitled "Therapeutic approach for breast cancer," the author realized that the standard used by IS in RT is the RT extension of the standard DICOM, namely DICOM-RT, extension not well known by the author. Knowing different workflows of various RT departments, the author found it interesting to analyze the RT departments at the level of their IS and interoperability, particularly in the DICOM-RT utilization.

This thesis challenged the author's knowledge in the informatics domain obtained in this degree together with the knowledge obtained in the radiotherapy domain obtained in the “licentiate” degree, in the curricular traineeship performed in four institutions, and in the exercise of his profession in two institutions.

# Abstract

Currently, in radiotherapy (RT) departments, there are different proprietary and stand-alone Information Systems (IS) for single-purpose applications, having most of the data distributed through multiple systems with limited interface between them. The IS are focused on the system instead of being patient-centered, limiting the data availability due to incompatible formats between the equipment workstations and the IS. The need to integrate all the scattered information from different IS of RT department is steadily recognizable because of its imaging intensive nature and ever increasing demands for better treatment equipment and complete information. Besides transfer of RT data between IS there is the problem of clinical data exchange, between departments and hospitals impeding the research collaboration between institutions. This lack of interoperability in IS, causes discontinuity in health care leading to redundant clinical evaluations and clinical decisions based on incomplete information limiting clinical trials and scientific investigations.

The digital imaging and communications in medicine - radiation therapy (DICOM-RT) extensions consists of various DICOM-RT objects that provide a standardized mean of transferring much of the information circulating in the RT workflow. DICOM-RT plays an important task in enabling application interoperability (“plug and play”), however its implementation has some problems, the “communication” part works but the “interoperation” part is difficult at the RT workflow.

This thesis aims to investigate the relevance of DICOM-RT in the RT workflow, integration profiles of integrating the healthcare enterprise – radiation oncology (IHE-RO) task force, and in the data model of DICOM-RT based electronic patient record (ePR). To accomplish this aim, the work was divided in different phases: a comprehensive review of the state of the art focusing this issues, a bivalent study with: a survey of Portuguese RT departments characterizing facilities in terms of treatment equipments, imaging modalities and IS, and its compliance standards; and a study about DICOM-RT expert’s opinion about interoperability in RT context and the relevance of DICOM-RT.

This study is cross-sectional representing the reality found in RT departments and the opinion given by the DICOM-RT experts from the participating departments, and results presented in this master thesis are relative to the period May-September 2011. It was created a questionnaire online that was sent by email for one expert of each department.

The response rate of the target population (all RT departments from Portugal) was 70% (n=14) and results show that RT departments have IS and equipments from different manufacturers, but there are few departments with multiple-treatment units from different vendors. This fact reveals that departments have the tendency of purchasing treatment machines from the same manufacturer to not have to resolve integration problems between them and other equipments and IS. Regarding expert’s opinion about interoperability and DICOM-RT, results shows that they trust in the benefits of integration between the IS and equipments provided by DICOM-RT but with lack of specific information about this pertinent issue.

According to the results, a list of recommendations was established to advise RT professionals regarding interoperability issues. Recommendations for a good policy in RT department are listed for definition of IS specifications, new equipments/IS purchasing, problems occurrence, etc. Compliance with DICOM-RT is recommended, when buying new RT equipments preferably with all DICOM-RT

objects available, and compliance with DICOM v3.0 is suggested, when acquiring new imaging equipments. It is important to adapt the existing RT workflows to IHE-RO integration profiles for optimization of the RT interoperability in Portuguese departments.

**Keywords:** DICOM-RT, radiotherapy, information systems, interoperability.

# Resumo

Atualmente, nos serviços de radioterapia existem diferentes Sistemas de Informação (SI) “proprietários” que funcionam de forma isolada com aplicações muito específicas, sendo que grande parte da informação disseminada em vários sistemas com fraca interface entre eles. Estes SI são muito orientados para o próprio sistema em vez de serem centrados no paciente, o que condiciona a disponibilidade da informação devido a incompatibilidades de formatos entre as estações de trabalho dos equipamentos e dos SI. A necessidade de integrar toda a informação dispersa dos múltiplos SI do serviço de radioterapia é amplamente reconhecida devido à sua natureza imagiológica e a demanda pela completude da informação clínica e melhoria tecnológica a nível de equipamentos. Para além do problema existente na transmissão de informação específica de radioterapia entre os SI do serviço, existe a limitação de partilha desta informação com outros serviços de radioterapia e instituições condicionando a investigação nesta área. Esta visível falta de interoperabilidade nestes SI causa descontinuidade nos cuidados de saúde ao doente oncológico, condicionando os ensaios clínicos, sujeitando-o a avaliações clínicas repetidas e decisões clínicas baseadas em informação incompleta.

A norma “imagem digital e comunicações em medicina” [digital imaging and communications in medicine – DICOM] possui uma extensão dedicada à radioterapia (DICOM-RT), que consiste numa série de objetos DICOM-RT que providenciam uma normalização da transmissão de grande parte da informação que circula no fluxo de trabalho da radioterapia. A norma DICOM-RT para além de permitir a conectividade entre os sistemas potencia a interoperabilidade entre as aplicações contudo, a sua implementação tem alguns problemas associados.

A presente tese visa investigar a relevância das extensões da norma DICOM-RT no fluxo de trabalho da radioterapia, nos perfis de integração da “iniciativa de integração da saúde para a radioterapia” [integrating the healthcare enterprise: radiation oncology- IHE-RO] e no modelo de informação do registo clínico eletrónico baseado em DICOM-RT. Para se atingir este objetivo, o trabalho foi dividido em diferentes fases. A primeira fase aborda uma revisão bibliográfica compreensiva do estado da arte da norma DICOM-RT. A segunda fase estuda a realidade dos serviços de radioterapia através de um levantamento nacional relativamente aos equipamentos de tratamento implementados, modalidades de imagem utilizadas, SI existentes e respetiva conformidade à norma DICOM. A terceira fase analisa a opinião dos peritos dos departamentos participantes acerca da interoperabilidade no contexto da radioterapia e importância da norma DICOM-RT.

O desenho do estudo é transversal e visa a representação da realidade encontrada nos serviços de radioterapia e da opinião dada pelos peritos das instituições participantes. Reporta resultados relativos ao período de maio a setembro de 2011. Um questionário foi criado e disponibilizado *online* para ser enviado via correio eletrónico para um perito de cada instituição.

A taxa de respostas da população alvo (todos os departamento portugueses) foi de 70% e os resultados evidenciam que os serviços de radioterapia possuem SI e equipamentos de diferentes fornecedores, mas que existem poucos serviços com aceleradores lineares de diferentes fornecedores. Este facto revela que os serviços de radioterapia tendem a adquirir equipamentos do mesmo fornecedor para não terem que resolver os problemas de integração. Em relação às opiniões dos peritos acerca da interoperabilidade e da norma DICOM-RT, os resultados demonstram que eles acreditam nos benefícios decorrentes da

integração entre os SI e equipamentos com a norma DICOM-RT, contudo revelam pouco conhecimento acerca da interoperabilidade.

De acordo com os resultados, uma lista de recomendações foi criada para aconselhar os profissionais envolvidos nestas questões de interoperabilidade na área da radioterapia. Recomendações para uma boa política na gestão de um serviço de radioterapia são enumeradas para diversas situações, tais como: na definição das especificações dos SI, na compra de novos equipamentos ou SI, na ocorrência de problemas de integração, etc. A conformidade com a extensão DICOM-RT e disponibilidade de todos os objectos DICOM-RT para a radioterapia externa é uma característica altamente recomendável para a aquisição de novos equipamentos de radioterapia, ao passo que a conformidade com a norma DICOM v.3.0 é essencial para os equipamentos imagiológicos. Um aspecto que também se considera importante na radioterapia é a adaptação dos fluxos de trabalho e de informação existentes aos perfis de integração do IHE-RO para a optimização da interoperabilidade nos departamentos de radioterapia.

**Palavras-chave:** DICOM-RT, radioterapia, sistemas de informação, interoperabilidade.

*After all, science is essentially international,  
and it is only through lack of the historical sense that national qualities have been attributed to it.*

*Marie Curie*





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# List of Abbreviations and Acronyms

<b>1-D</b>	one-dimensional
<b>2-D</b>	two-dimensional
<b>3-D</b>	three-dimensional
<b>AAPM</b>	American Association of Physicists in Medicine
<b>ACR</b>	American College of Radiology
<b>AE</b>	application entity
<b>ANSI</b>	American National Standards Institute
<b>ASTRO</b>	American Society for Radiation Oncology
<b>BEV</b>	beam's eye view
<b>CEN/TC</b>	European Committee of Standardization/Technical Committee [Comité Européen de Normalisation]
<b>CT</b>	computerized tomography
<b>DICOM</b>	digital imaging and communications in medicine
<b>DICOM-RT</b>	DICOM radiation therapy extensions
<b>DRR</b>	digitally reconstructed radiograph
<b>DVH</b>	dose-volume histogram
<b>EPID</b>	electronic portal imaging device
<b>ePR</b>	electronic patient record
<b>ESTRO</b>	European Society for Therapeutic Radiology and Oncology
<b>GUI</b>	graphic user interface
<b>HIMSS</b>	Healthcare Information and Management Systems Society
<b>HIS</b>	hospital information system
<b>HL7</b>	health level 7
<b>HTTP</b>	hypertext transfer protocol
<b>ICRU</b>	International Commission on Radiation Units and Measurements
<b>IEC</b>	international electrotechnical commission
<b>IEEE</b>	institute of electrical and electronics engineers
<b>IGRT</b>	image guided radiotherapy
<b>IHE</b>	integrating the healthcare enterprise
<b>IHE-RO</b>	integrating the healthcare enterprise in radiation oncology
<b>IMRT</b>	intensity modulated radiotherapy
<b>IP</b>	internet protocol
<b>IPEM</b>	Institute of Physics and Engineering in Medicine
<b>IS</b>	information system
<b>ISO</b>	International Standards Organization
<b>IT</b>	information technology
<b>JPEG</b>	joint photographic experts group
<b>linac</b>	linear accelerator

<b>MLC</b>	multi-leaf collimator
<b>MRI</b>	magnetic resonance imaging
<b>MU</b>	monitor unit
<b>NEMA</b>	National Electrical Manufacturers Association
<b>OSI</b>	open system interconnection
<b>PACS</b>	picture archiving and communication system
<b>PC</b>	planning committee
<b>PET</b>	positron emission tomography
<b>R&amp;V</b>	record and verify
<b>REV</b>	room's eye view
<b>RIS</b>	radiology information systems
<b>RO</b>	radiation oncology
<b>RSNA</b>	Radiological Society of North America
<b>RTOG</b>	Radiation Therapy Oncology Group
<b>RT-PACS</b>	radiotherapy-dedicated PACS
<b>SCP</b>	service class provider
<b>SCU</b>	service class user
<b>SOP</b>	service-object pair
<b>SPECT</b>	single-photon emission computed tomography
<b>SRO</b>	spatial registration object
<b>TC</b>	technical committee
<b>TCP</b>	transmission control protocol
<b>TDS</b>	treatment delivery system
<b>TMS</b>	treatment management system
<b>TPS</b>	treatment planning system
<b>URL</b>	uniform resource locator
<b>VS</b>	virtual simulation
<b>WG</b>	working group
<b>WS</b>	workstation
<b>XML</b>	extensible markup language
<b>x,y,z</b>	point coordinates
<b>cm</b>	centimeters
<b>kV</b>	kilovolt
<b>mm</b>	millimeters
<b>MeV</b>	mega electron volt
<b>MV</b>	megavolt
$\alpha$	significance level
$\gamma$ -rays	gamma-radiation

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# Thesis Outline

- Chapter 1* Introduces a brief history of computers in radiotherapy, shows the problem setting and explains the aim of the thesis.
- Chapter 2* Contains the state of the art on radiotherapy focusing the information systems used in the workflow, on DICOM-RT describing the contents for understanding the standard, on IHE-RO initiative presenting the integration profiles, and on DICOM-RT based ePR showing a potential model.
- Chapter 3* Covers the bivalent study on radiotherapy information systems survey and DICOM-RT relevance in interoperability, presenting an introduction of the two issues and a global methodology, containing the participant's characterization, definition of study design, questionnaire description, data collection details and statistical analysis.
- Chapter 4* Presents the results from the RT national survey, showing the Portuguese radiotherapy departments in terms of facilities characterization, including treatment equipments, imaging modalities and information systems. Also presents DICOM-RT expert's opinions about interoperability and DICOM-RT relevance.
- Chapter 5* Discusses the results from the bivalent study according to the state of the art, describes the main contributions and the research limitations of the work, proposes a list of recommendations for radiotherapy professionals, and gives some directions for future work.

# Scientific Results and Financing

The present work was submitted for publication in the “*HealthInf 2012* - International Conference on Health Informatics”, with preliminary results of the study titled “The relevance of DICOM-RT in radiotherapy information systems - preliminary results from a national survey” (see Appendix E).

Preliminary results of the thesis were presented in “4<sup>th</sup> Medical Informatics Symposium”, Faculty of Sciences, University of Porto, October 8, 2011.

The work of this thesis did not receive funding from any organization, but the author as a student of the master’s degree in Medical Informatics received financial support from the master programme, for the following poster presentations in “*Healtinf 2011*” and subsequent publications:

- Celeste Oliveira and Pedro Pereira Rodrigues. “Automatic organ delineation of computed tomography images for radiotherapy planning in prostate cancer: an overview”. In *Proceedings of the International Conference on Health Informatics - HEALTHINF 2011*, 482-485, ISBN 978-989-8425-34-8, INSTICC Press. Rome, Italy. January 2011.
- Cátia Pereira, Celeste Oliveira, Cláudia Vilaça and Ana Ferreira. “Protection of clinical data: comparison of European with American legislation and respective technological applicability”. In *Proceedings of the International Conference on Health Informatics - HEALTHINF 2011*, 567-570, ISBN 978-989-8425-34-8, INSTICC Press. Rome, Italy. January 2011.

The article “Automatic organ delineation of computed tomography images for radiotherapy planning in prostate cancer: an overview” was presented in “3<sup>rd</sup> Medical Informatics Symposium”, Faculty of Sciences, University of Porto, October 29, 2010 and in “Journeys of Oncology”, IPO Porto, Solverde Espinho hotel, July 8,



*I shall particularly insist on the following fact,  
which appears to me very important and quite outside the range of phenomena one might expect to observe.*

*Henry Becquerel*



# 1. Introduction

This introductory chapter describes a brief history of computers in radiotherapy, explains the problem setting and the aim of the present thesis.

## 1.1 Computers in Radiotherapy

Radiotherapy (RT), also referred as radiation therapy, radiation oncology (RO) or therapeutic radiology, is one of the three principal modalities used in the treatment of cancer, the other two being surgery and chemotherapy (Podgoršak, 2005). The word radiotherapy comes from the Greek *radius*, a ray and *therapeia*, cure (Expert Working Group on Radiation Oncology Services, 2003). For more than a century, ionizing radiation has been used against diseases that usually are malignant. RT is, after surgery, the most successfully treatment modality used for cancer (Schlegel et al., 2006). The power of radiotherapy is that the radiation can be precisely adjusted in space and time, unlike chemotherapy, where drugs are administrated hoping that will be selectively absorbed by the malignant cells (Kalet, 2008). The goal of RT has always been to maximize the probability of controlling the tumor and minimizing normal tissue complications. The achievement of this goal is the key component driving the technological developments (Dyk, 2005). In contrast to other medical specialties that are based mainly on clinical knowledge and experience, RT relies greatly on modern technology and multidisciplinary team approach (Podgoršak, 2005).

In the 1960s RT was considered an empirical discipline with low probability of success, but from its early commercial introduction, linear accelerators (linacs) providing megavoltage X-rays and electron beams has undergone notable expansion. In the 1970's the introduction of the computerized tomography (CT) and the help of computers for the radiation calculations it produced universal atlases of isodose distributions. The practice of RT defined itself and developed into a distinct discipline was in the 1980's. In the middle 1980's, the first treatment management systems (TMS) with low-functionality were custom systems developed by academic departments or equipment manufacturers (Dyk, 1999, Schlegel et al., 2006, Wu, 2008) .

RT is an early example of computer programming application to help the clinical treatment decision. The computer modeling focused on the physics of radiation absorption in human tissue relative to the geometry of radiation beams and on the design of interactive systems that could be used for manual computer aided design (Kalet, 2008). Advances in RT have always resulted from successful combinations of technological progress combined with improved biological understanding. The computer revolution characterized by the development of powerful computers had a major impact on planning and delivery of the radiation treatment (Bentzen et al., 2008). In to sum up, RT is based on physics, radiation biology, mathematics, computer science, electrical and mechanical engineering, making it an interdisciplinary field (Schlegel et al., 2006).

Currently, RT can be applied so accurately that the tumor control and the probability of cure, has significantly increased for many cancers due to physics and technology innovations. The development and implementation of modern informatics have intensely changed the management and practice of RT (Schlegel et al., 2006).

## 1.2 Problem Setting

Nowadays, in RT departments, the treatments are based on technological advancements in diagnostic imaging, image processing and high computerization technology, such as the treatment planning system (TPS), leading to an increase of the complexity of storage and availability of RT data (Law et al., 2009).

Often there are different proprietary and stand-alone information systems (IS) for single-purpose applications. Each system has its own “storage area” and oftentimes has limited interface with other systems. These IS, focused on the system instead of being patient-centered, acquire the necessary information during the RT treatment course, being most of the data distributed through each IS. This data isn’t immediately available due to incompatibles formats between the equipment workstations (WS) and the IS, leading to utilization of multiple IS in the search of clinical information of a particular patient. For example, radiation oncologists need to go to dedicated WS to delineate volumes, to approve treatment plans or portal images, because there is no “home base” for all images of the patient. The need to integrate all the scattered information from different IS of RT department is steadily recognizable because of its imaging intensive nature and ever increasing demands for better treatment equipments and complete information. RT involves radiobiologic factors which demand the record of all treatment parameters for patient future reference. One problem in RT concerns about the exchange of specific information between IS, departments and hospitals. This has impeded the research collaboration between institutions. This lack of interoperability between the IS causes discontinuity in health care, leading to redundant clinical evaluations and clinical decisions based on incomplete information limiting clinical trials and scientific investigations (Law, 2005, Liu et al., 2007, Law et al., 2009, Shakeshaft, 2010).

“Quality standards” of the RT is the set of recognized criteria against which the quality of the RT workflow can be evaluated, being part of the quality assurance program that supports the IS maintenance too. Various organizations, such as the American Association of Physicists in Medicine (AAPM) and the European Society for Therapeutic Radiology and Oncology (ESTRO) have issued recommendations for standards in RT, whereas other organizations, such as the International Electrotechnical Commission (IEC) and the Institute of Physics and Engineering in Medicine (IPEM), have addressed recommendations for certain parts of the RT workflow. RT departments where industry standards are not available, local standards need to be developed, based on a local assessment of requirements (Podgoršak, 2005).

The adoption of the digital imaging and communications in medicine – radiation therapy (DICOM-RT) extensions, integration profiles from Integrating the Healthcare Enterprise – Radiation Oncology (IHE-RO), and of Radiotherapy Picture Archiving and Communication Systems (RT-PACS) allows a system integration infrastructure. All RT information and images from various sources can be converted to the DICOM-RT standard and integrated into a DICOM-based database. Benefits of this integration are the reduction of time and effort in searching for information related to the treatment (Liu et al., 2007, Law and Liu, 2009).

## 1.3 Aim

The aim of this thesis is to study the relevance of the standard DICOM-RT in the interoperability between the IS used in RT, through the revision of existing reality in the Portuguese RT departments and the analysis of expert’s opinion about the issue. We intend to clarify the state of art, finding the main problems and recommend some ways to optimize the DICOM-RT utilization in order to achieve interoperability.

To accomplish this aim, the present work was divided in different phases: a comprehensive review of the state of the art focusing radiotherapy, DICOM-RT, IHE-RO and DICOM-based electronic patient record (ePR) in RT, present in chapter 2; a bivalent study with national survey characterizing RT facilities

in terms of equipments and IS, and an expert's opinion about the DICOM-RT relevance and interoperability in RT context, present in chapter 3 and 4; and the discussion with the main contributions and suggestion of some recommendations for RT professionals, present in chapter 5.



*To the electron:  
may it never be of any use!*

*Joseph Thomson*





## 2. State of the Art

This chapter presents the radiotherapy, its workflow, equipment and types of IS dedicated. Also reviews the state of the art of DICOM-RT with a description of DICOM-RT objects, their use in integration profiles from IHE-RO, and in the model creation of a DICOM-RT based ePR.

### 2.1 Radiotherapy

In modern medicine, one of the most technologically advanced fields is RT, that is a comprehensive and dynamic discipline which plays a major role in cancer care (Schlegel et al., 2006). About 60% of patients with cancer will require RT during the course of their illness and those who are cured, 80-90% of patients underwent RT (Perez and Brady, 1998).

The aim of RT is to deliver the prescribed radiation dose to the tumor, while sparing as much as possible the surrounding normal tissues. This therapy includes two treatment modalities: external beam radiotherapy, also called teletherapy that uses radiation produced by a machine, mainly photons or electrons, where the tumors are treated at a long distance from the radiation source; and internal radiation, designated brachytherapy that administers radiation with small radioactive sources placed on or in the tissue to be irradiated. The brachytherapy can be intracavitary (sources that are loaded within body cavities), interstitial (sources that are implanted into tissues), intraluminal (trains of sources within the lumen of organs) and superficial brachytherapy (sources supported in a mould over a tumor). Whereas teletherapy is designed to produce a homogenous dose distribution in most cases, brachytherapy uses the inhomogeneous dose distributions found around sources to create a high dose in tumors and producing a low dose in normal tissue. External beam RT represents over 90% of the workload in RT departments and it is an image and computer graphic intensive process (Mayles et al., 2007, Cleto et al., 2008, Law and Liu, 2009, Law et al., 2009).

#### 2.1.1 History

The discovery of X-rays in 1895 by Wilhelm Roentgen, in Germany, revolutionized the field of medicine. That same year Henri Becquerel announced his discovery of a new type of invisible radiation emitted from uranium salts. He called this radiation as “Becquerel rays”, later termed “radioactivity” by Marie Curie who studied this type of radiation and set the stage for the development of new tools for diagnosis and therapy. A year later Joseph Thomson, in Cambridge, announced the discovery of the electron (Senior, 1998, Dyk, 1999).

In 1899 was reported the first patient cured by RT and in 1910 was used for the first time the brachytherapy with the insertion of radium needles and tubes (Perez and Brady, 1998). During the 1930's and 1940's brachytherapy systems of calculation evolved with the *Manchester* system being one of the predominant systems. In 1951 the first patient was treated with cobalt-60  $\gamma$ -rays, in London. Between 1910 and 1950, kilovoltage X-ray units played an important role in the early development of RT and later in the treatment of superficial lesions. Teletherapy cobalt-60, machines with penetrating  $\gamma$ -ray beams emitted from a radioactive source was first used for patient treatment in 1951, in Canada. Cobalt units

became the mainstay of external beam therapy for the next 30 years. The linacs, machines with megavoltage X-ray beams and electron beams, which achieved routine clinic status in the 1960's, were used with a manual treatment planning through the manipulation of isodose charts into patient body contours that were generated by direct tracing and relied on the careful choice of beam weight and wedging. In the late 1960's, the simulator was introduced as an additional device to assist the simulation of external RT treatment. In 1972 Godfrey Hounsfield introduced the CT in the medical community. In the end of the 1970's the development of CT along with the advent of accessible computing power led to the development of CT based computerized treatment planning providing the ability to view dose distributions directly superimposed upon a patient's axial anatomy. In this decade, diagnostic radiology and RT began to separate into distinct medical specialties. The CT-based treatment planning was later supplemented with magnetic resonance imaging (MRI) in order to understand the tumor morphology more precisely, and thus achieve improved definition of target volumes through image registration. In the early 1980's, the introduction of stereotactic into RT allowed the high accuracy execution of the computer plans to the patient. Stereotactic treatment techniques were first developed for single-dose irradiations, called radiosurgery; then for fractionated treatments in the brain and the "head and neck region", designated stereotactic RT; later for extra-cranial tumor locations, named extra-cranial stereotactic RT. In the middle 1980's, appeared the first TMS with dynamic treatments, thanks to commercial availability of computerized multi-leaf collimators (MLC). In the middle 1990's, 3-D conformal RT was supplemented by a new treatment technique, the intensity modulated radiation therapy (IMRT) in combination with inverse planning software. At the beginning of the new millennium, the field of adaptive RT brought the temporal alterations of the target volume that can be assessed and taken into account. Image-guided radiotherapy (IGRT) detects deformations and motion between fractions (inter-fractional) and during irradiation (intra-fractional), correcting these changes with gating or tracking of the irradiation beam. In the last decade of the past century the superiority of linac became evident and the number of cobalt-60 machines started to decrease all over the world except in developing countries where they are still considered as the best option, mainly because of their reliability (Dyk, 1999, Podgoršak, 2005, Schlegel et al., 2006, Mayles et al., 2007).

Modern RT continues to progress and this development is strongly linked to the evolution of computer technology and corresponding advances in diagnostic imaging equipment, sophistication in computer-assisted treatment planning and delivery (Levitt et al., 2008). With the introduction of 3-D imaging, 3-D virtual therapy simulation and 3-D dose calculation the requisite for an individualized and effective treatment is satisfied. Conformal treatments became less expensive and considerably faster because the modern linacs are more reliable by having a high mechanical accuracy with high dose rates providing the basis of modern precision RT (Schlegel et al., 2006). More new RT techniques and tools appeared, such as intraoperative, tomotherapy, breathing control, image segmentation, proton therapy, total body irradiation, total skin electron irradiation, volumetric modulated arc therapy, intensity modulated arc therapy, etc (Dyk, 2005).

### 2.1.2 Workflow

The basis of the RT covers different aspects of all links in the "chain of radiotherapy" procedure, as shown in figure 1. The link of treatment planning includes the following steps: delineation of the target volumes and organs at risk, definition of the treatment technique, dose calculation and evaluation of the 3-D dose distribution (Schlegel et al., 2006).

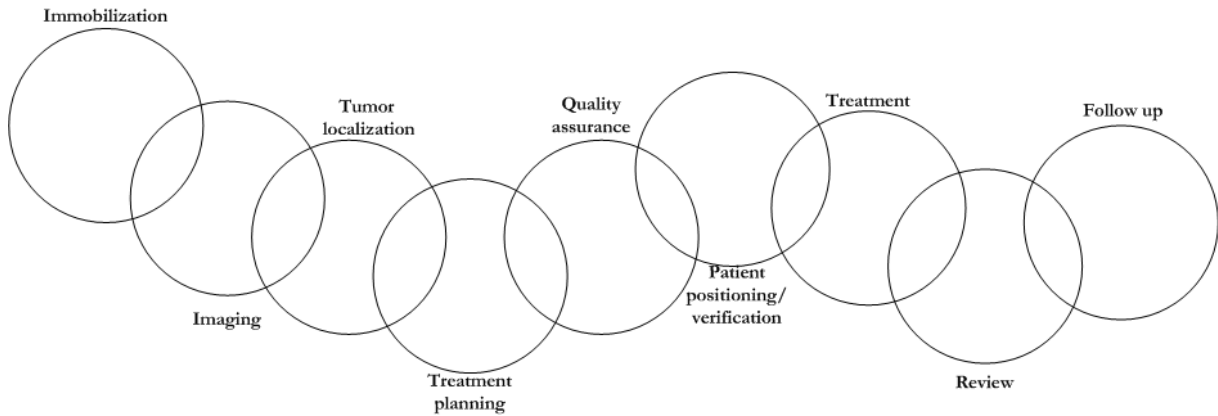


Figure 1. Chain of RT adapted from (Schlegel et al., 2006)

The authors describe some types of workflows in the external RT representing the flows depending the perspective, such as: clinical workflow (Law, 2005, Liu et al., 2007, Law and Liu, 2009), DICOM images flow (Law and Liu, 2009), DICOM-RT objects flow (Law, 2005, Law and Liu, 2009), RT dataflow (Law, 2005), etc. The RT workflow has two distinct phases: treatment planning and treatment delivery, and is described ahead with the identification of IS used and associated DICOM-RT objects. (see figure 2).

In the treatment planning the process starts with a CT image study of the anatomic region to localize the tumor volume, performed with either CT-simulator or CT scanner or simulator-CT. The radiation therapist sets the patient up in his treatment position for scanning in CT room. The DICOM images are associated to the patient's information and stored in the WS or in the picture archiving communication system (PACS) (step1). If the CT study is acquired at CT-simulator, a virtual simulation (VS) application retrieves the images and performs the simulation producing RT structure set and RT plan. The TPS reads the CT images (step2) and other previous available diagnostic images (diagnostic CT, MRI and positron emission tomography (PET) can be fused with the CT to aid in the delineation of tumor volume), the RT structure set, and the RT plan. At TPS, target volumes and organs at risk are delineated interactively by medical physicist, radiation oncologist or dosimetrist according to International Commission on Radiation Units and Measurements (ICRU) reports n° 50 (I.C.R.U., 1993) and 62 (I.C.R.U., 1999). After this procedure, the machine's parameters are determined (beam modifiers and beam geometries) and the radiation dose distribution within the body is calculated (dosimetry data). This planning requires a balance between accurate target volume coverage and sparing of neighboring normal tissue evaluated by dose-volume histogram (DVH) and isodoses distribution superimposed on CT images. From CT study projection X-ray image can be reconstructed named digitally reconstructed radiograph (DRR) creating RT image (step3). These images or the simulator images will serve as the reference images for treatment verification. At TPS new RT Plan object is created, and RT image is produced. After the evaluation and approval by radiation oncologist the treatment is prescribed (step4) and the treatment sessions are scheduled in the TMS (step5) and transferred to the treatment unit (linac) through the completed RT plan by network for the treatment delivery system (TDS) (Law and Liu, 2009, Huang, 2010).

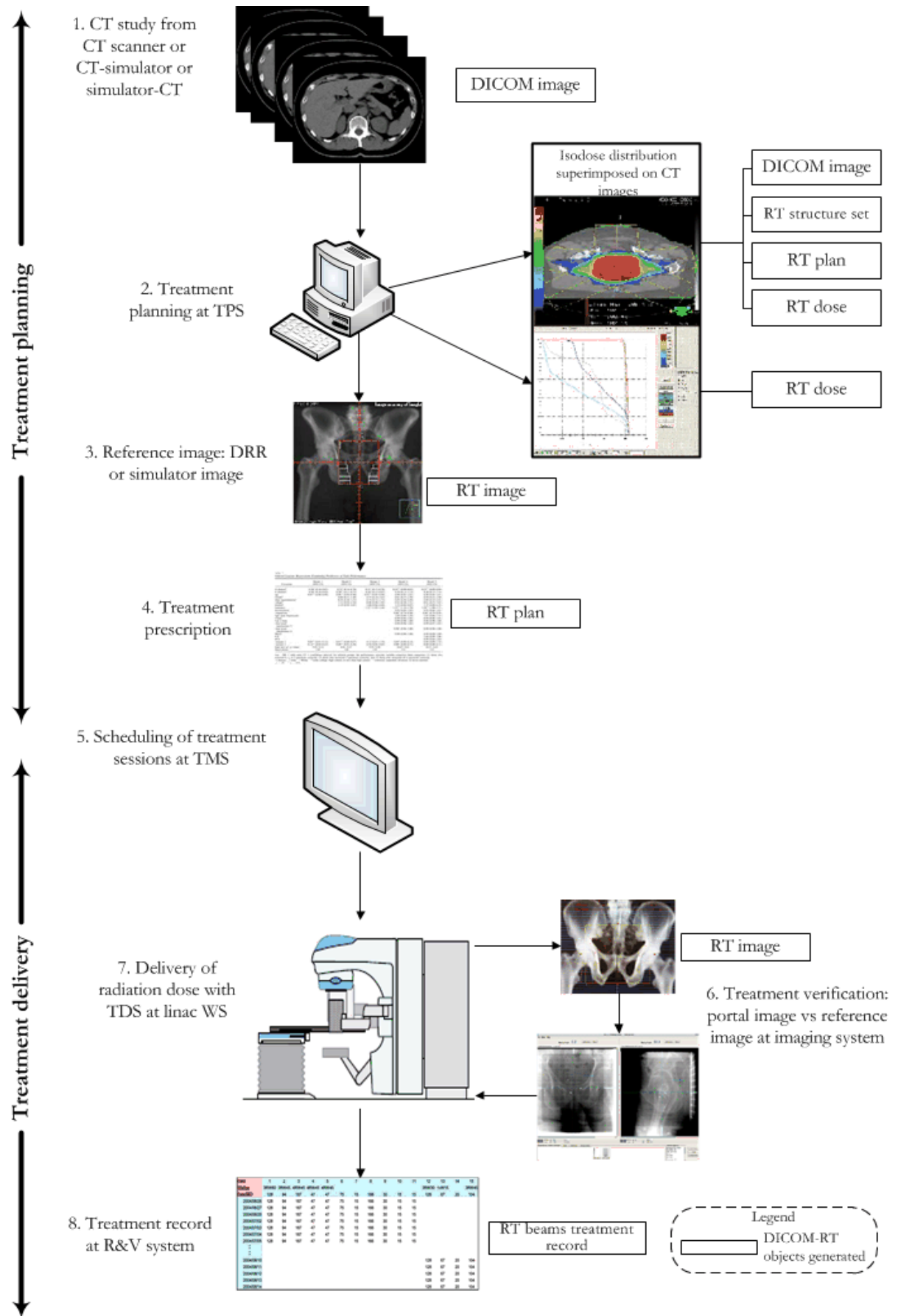


Figure 2. Chart illustrating RT workflow with DICOM-RT objects adapted from (Law and Liu, 2009)

In the treatment delivery the process starts with the verification of the treatment; a portal image is obtained at the linac to be compared with the reference image using imaging system, creating RT image (step6). After this procedure, the treatment is delivery (step7) if the portal images were found to match the reference images in aligning with the treatment field. At each session, every parameters of the treatment will be recorded at linac WS or (record and verify) R&V system, creating RT beams treatment record (step8). Usually, a treatment session is daily, five days a week, during 5 to 7 weeks, depending on the type of cancer. The radiation oncologist will review the patient's progress and a follow-up appointment will be made at the TMS (Law and Liu, 2009, Huang, 2010).

RT is prepared for the individual patient, so it is important use informatics to optimize workflow and patient treatment outcomes. Problems with the integration of the IS and equipments of the RT department compromise the efficiency of RT workflow (Huang, 2010).

### 2.1.3 Equipments

The kilovoltage X-rays has been used in RT from the earliest attempts at external beam treatments. The kilovoltage range covers X-ray beams generated between 10 kV and 400 kV and is usually subdivided into four categories according to beam penetration: grenz rays (10 kV to 20 kV), rarely used in modern RT; contact therapy (10 kV to 60 kV), provides a useful treatment depth up to several mm; superficial therapy (50 kV to 150 kV), affords treatment for many superficial lesions and an adequate alternative to electrons; orthovoltage therapy (150 kV to 400 kV), has the 90% dose in 1 cm to 2 cm beneath the incident skin surface at the usual treatment distance of 50 cm source to surface distance. Multi-energy units covering both the superficial and orthovoltage ranges are used in many RT departments (Podgoršak, 2005, Mayles et al., 2007).

The cobalt-60 introduced the early megavoltage RT generating  $\gamma$ -rays at two well-defined energies (1.173 MeV and 1.332 MeV). Additional *Compton* emission generated in the source results in the beam incident on the patient having a continuum of energies below this with a mean energy less than 1 MeV (Mayles et al., 2007).

The linacs produce more penetrating beams with the versatility of the choice of beam energy delivering in a higher dose rate. A 6 MV beam will have a mean X-ray energy of around 2 MeV, and the range of the secondary electrons produced by interaction in tissue will be about 16 mm. This machine can have MLC, dynamic wedges, and electron beam generation (Mayles et al., 2007).

The simulator was introduced as an additional device to help the preparation of external RT, by checking before the treatment if the plan can be delivered in practice and if the relationship of the beam setup to the patient's anatomical features is accurate. This equipment has similar mechanical and geometrical characteristics of the therapy machine and the treatment table, and fitted with a radiodiagnostic X-ray tube. Simulator provides the ability to mimic the treatment geometries and to visualize the resulting treatment fields on radiographs or under fluoroscopic examination of the patient. Modern simulators are universal and match the characteristics of most existing therapy machines. Some simulators have a special attachment that allows them to collect patient cross-sectional information similarly to a CT scanner being designated a simulator-CT (Boyer et al., 2001, Mayles et al., 2007).

Dedicated CT scanners used in treatment planning and simulation are known as CT-simulators. The components of a CT-simulator include: a large bore CT scanner (with a large opening for patient positions with treatment accessories), room lasers (for patient setup and marking), a flat table top (to closely reproduce RT treatment tables) and a powerful graphics WS (Podgoršak, 2005).

The portal imaging devices were introduced in RT to provide quality assurance of patient setup. In order to provide online verification electronic portal imaging device (EPID) has been developed to acquire and display portal images. This suitable radiation detector is attached to the gantry of the linac and is capable of transferring the detector information to a computer that will process and convert it to an image that can be analyzed instantly (Podgoršak, 2005, Mayles et al., 2007).

## 2.1.4 Information Systems

IS will never replace the RT professionals, but it helps in making repetitive and time-consuming tasks with perfection and in presenting the patient information clearly freeing the professionals to work in the clinical care efficiently (Ambider, 2000). In RT departments the following IS are used: TPS, TMS, TDS, and imaging systems (e.g. RT-PACS). The abbreviation “R&V” has been used to describe systems that receive data from the TPS and interact with the TDS having the function of RT process control through the network. Data integrity in the RT workflow must be preserved and available in real time at the treatment WS (Siochi et al., 2009).

Most IS in RT fit a client-server architectural data processing model, consisting of multiple computers that share the application processing. The components are often heterogeneous, provided by different hardware and software vendors, and they transfer data via messages across a network. The network, given the complexity and amount of data and images, usually is internal network to allow the total interconnection among all equipment. This network of RT can be connected to a pre-existing external network (e.g hospital information system - HIS), in order to share common data, including clinical, administrative and financial database of the patient (Brooks et al., 1997, Dyk, 1999, Huh et al., 2000).

Generally, treatment plans are stored at TPS, simulated fields are stored at simulator WS, and treatment records are stored at R&V systems. The treatment information for a patient whose treatment involves various IS will be stored in different places, normally being linked by paper record. If the paper record is lost, the patient’s treatment information disintegrates (Law and Liu, 2009).

### Treatment Planning System - TPS

The TPS is used in the treatment planning process, having the following steps: data acquisition and entry (characteristics of the linac and treatment field configurations); patient data acquisition through CT scan with possibility of additional radiological information (coregistered CT, MRI, ultrasound, PET, single-photon emission computed tomography (SPECT), etc) to help in geometric planning in order to obtain a theoretical distribution of doses within the body’s patient; treatment plan generation with operator-specific information (tissue delineation, application of margins and treatment extent); and transfer of data to the TDS (via DICOM-RT format). The electron density information extracted from CT data set is vital for calculation of dose heterogeneities due to the differing composition of human tissues and the theoretical dose distributions depend on the dosimetry, calibration of the linac, checks of the treatment and *in vivo* dosimetry (Ebert et al., 2004, Podgoršak, 2005, Mayles et al., 2007).

Regarding software components, TPS contain dose calculation algorithms, beam modifiers, heterogeneity corrections, image display with DVH, and biological modeling. Dose calculation algorithms are the most critical software component being responsible for the correct representation of dose in the patient, from simple 2-D calculations to full 3-D dose models. There are numerous dose calculation algorithms and ICRU report n° 42 (I.C.R.U., 1987) lists the chronological development of these for photon and electron beams as: *Monte Carlo* techniques, pencil beam algorithms, etc. The TPS must be capable of handling the many diverse beam modifying devices found on linac models, the photon beam modifiers consisting of jaws (monitorized collimating devices), blocks (field shielding), MLC (beam shaping device), wedges (static or motorized or dynamic), custom compensator (compensating filter), bolus (tissue equivalent material placed in contact with the skin) and the electron beam modifiers consisting of cones (applicators for external collimation), etc. Most TPS algorithms apply either a correction factor approach or a model based approach to heterogeneity corrections. Concerning image display, TPS calculates DVH, Beam’s Eye View (BEV) often used in conjunction with DRR to aid in assessing tumor coverage and for beam shaping, and Room’s Eye View (REV) to give the user a perception of the gantry and table relation helping the virtual plan to be practicable in actual patient setup. Optimization routines including inverse planning are provided by modern TPS with varying degrees of complexity. Algorithms can modify beam weights and geometry or calculate beams with a modulated

beam intensity to satisfy the user criteria. Beam time and monitor unit (MU) calculation by TPS is optional, and total prescription dose and fractionation information can be incorporated. Automatic contouring for regions, image segmentation for the DVH evaluation and algorithms for the distributions modeled on biological effects can also be incorporated in the TPS (Podgoršak, 2005).

TPS can be dedicated for special techniques as stand-alone systems and there are clinical procedures that require careful consideration, owing to their inherent complexity. A list of techniques that require special consideration and that may result in dedicated TPS is shown in table 1.

Table 1. RT techniques which require dedicated TPS (Podgoršak, 2005)

RT Techniques	
RT with dynamic MLC	Intraoperative radiotherapy
RT with micro MLC	Stereotactic radiosurgery
Orthovoltage	Electron beam arc therapy
IMRT	Brachytherapy
Total body irradiation	Tomotherapy
Total skin electron irradiation	

The development of new techniques of RT involves the unconditional utilization of the TPS with successive improvements in treatment planning hardware and software that have been most notable in the graphics, calculation and optimization aspects. The acquisition of images with more detail of the anatomy and tumor location, and the systems encompassing the virtual patient and image registration routines leads to an increasing complexity in the data handling. Traditional forward treatment planning, based on a trial and error approach is giving way to inverse planning, that makes use of dose optimization techniques to satisfy the user specified criteria for dose in the target and critical structures (Podgoršak, 2005, Mayles et al., 2007, Song and Li, 2008).

The TPS are connected via networks to the other equipments to enable the sharing of data and images. If the TPS and the simulator are linked to the network, the patients are simulated with the same planned data without the need for typing in filed parameters. The TPS can also be connected to exterior systems, including imaging systems, for importation of images acquired by CT or by other imaging modalities to image registration routines. One existing problem is that treatment plans from an old TPS cannot be retrieved for review after a system upgrade. The exchange of RT data between various TPS and different institutions has become an important issue (Wang and Huang, 2006, Mayles et al., 2007).

### Treatment Management Systems - TMS

The TMS, also called radiation oncology information management systems or RT specific ePR, facilitates the management of clinical tasks and technical information. It centralizes information, controls, records and checks all aspects of each individual treatment, facilitates access, provides data handling, and integrates imaging, planning, and therapy modalities linking them to the administrative services. The TMS is increasingly important because of the complexity of new treatment modalities that require different data sources and complex software tools (Huh et al., 2000, Boyer et al., 2001, Wu, 2008).

The system is designed in response to clinical operations requirements such as patient registration (demographics information and referring physician), patient consultation (physician, nursing and other clinical staff), departmental scheduling (patient, equipments and staff), patient tracking, departmental patient charting (shared electronic chart, chart checks), patient treatment simulation (resources scheduling, geometric field setup information), patient treatment with backup data (R&V system containing radiation field information for each patient controlling the use of assisted setup and automated treatments), and administrative services (billing, tumor registry, documentation)(Dyk, 1999).

A TMS should be nominated to manage the R&V systems, that checks the adequate dosing of patients at the linac by comparing the daily treatment setup parameters with the prescribed values and respective

tolerances, and at the end of the treatment session, it records a daily sheet of all treatments carried out including the accumulated dose, the treated fraction, and overrides along with the identification of the operator that performed them. In order to customize the system to the users' requirements, and help to provide maximum use of all the features of the system, different levels of authorization are password protected and different tolerance tables are customizable by the user to specify the range over which parameters can differ from the prescribed value before treatment is inhibited. Regarding backup and archiving, the large amount of data requires considerable storage capacity. It is useful if the backup system allows individual patient records to be retrieved as well as a full restore of the database. A daily backup of patients on treatment is usually performed. Old data are permanently removed from the system and transferred to long-term storage during the archival process. It is important that backups of archived data are also maintained. Data storage should comply with national regulations relating to patient privacy. Another important issue is the system resilience and the fault reporting. In summary, TMS supplies critical information for the control of treatment units and other extras functions such as user rights, networking, backup, archiving and security services (Podgoršak, 2005, Mayles et al., 2007, Siochi et al., 2009, Colonias et al., 2011).

The TMS may be provided by the TPS manufacturer, the linac manufacturer or third party software. It should drive the RT workflow of any linked equipment from any vendor using standards such as DICOM-RT. It is vital that the data in R&V systems be quality controlled using independent checking to verify the input, and that the network infrastructure can handle the transfer of the large amounts of data, for not compromise the patient treatment. The performance of the TMS should be included in an appropriate quality assurance program with specific tests according to specific system (Podgoršak, 2005, Siochi et al., 2009).

### **Treatment Delivery Systems - TDS**

In order to deliver RT treatments, parameters are electronically parsed out from a TMS database to the TDS in the linac WS for cooperation with localization and treatment couch. Depending on the capabilities and vendor selection for a given treatment unit, it is usual for a single console area to have at least five computers (Siochi et al., 2009).

TDS systems beyond enabling a computer-controlled user interface with electronic monitoring circuits also provides beam shaping systems, image-guided setup systems, respiratory gating systems, among others. These systems improve the accuracy of the treatment delivery by eliminating as many errors as possible, ensuring that the machine settings will be repeated throughout the treatment course and that the programmed total dose will not be exceeded. These systems can be linked together by networking, and the high-speed connectivity between image acquisition, treatment planning and final treatment delivery improves the efficiency of the process (Mayles et al., 2007).

The normative requirements for the TDS system are: linac system, fully integrated MLC, shapes integrated in patient chart, auto-setup of MLC, integrated display of MLC shape, integrated system of MLC shape, in-room MLC display, pendant control of MLC, capability for pre-planning treatment field changes, advanced planning of treatment courses, easy implementation of hyperfractionation, field setup capabilities, user defined setup fields, setup photos, auto-sequencing of fields, in-room call-up of next field, port films integrated into treatment course, override of individual treatment parameters, demographic functions, schedule functions, treatments parameters, treatment parameters tolerances, dose information and emergency treatment provisions (Dyk, 1999).

If the TDS are networked, it is possible to switch patients from one treatment machine unit to another from a different vendor with the utilization of DICOM-RT without having to re-enter the treatment data reducing the errors in data entry (Mayles et al., 2007).



## Imaging Systems

The RT process requires diagnostic images for identification, characterization, and localization of tumor, and image-based treatment workflow for planning, simulation, execution, and verification of treatment. The imaging systems handles with BEVs, REVs, DRR, simulation images, portal images, reconstructed images, images resultant of co-registration, and with segmentation, automatic contouring, VS, etc.

The normative requirements for the imaging systems are: WS functions, demographic data, setup parameters, data entry and edit capability, field capture, volumes delineation, image comparison, image approval, image enhancement tools, image review, image tasks tracking, etc (Dyk, 1999).

Systems used for the acquisition, archiving, communication, display, control, image database manager, and processing of RT images and related data are referred to as a radiotherapy picture archival and communication system (RT-PACS), also known as oncology-specific PACS. The practice of RT has specific functions that a conventional PACS cannot guarantee. For one patient, the images required include several simulation images, a set of initial portal images, and a set of on-treatment portal images. In addition to the images themselves, various other types of data also must be incorporated, like scalar data (geometric parameters), vector data (outlines of treatment portals on simulator images and target volumes on CT images), and character strings (annotations and messages). Different types of users are involved in the acquisition of images (simulator technologist, CT technologist, and treatment machine technologist) and in other tasks related to these images (dosimetrist, physician, and radiation oncologist). The PACS must differentiate among the various types of users providing a common platform for supporting the various user-specific tasks. It should integrate modalities and WS with scalable archive to meet departmental needs, having RT information online and accessible any time and from any location through its web-based application (Mayles et al., 2007).

The portal imaging application can be separated into offline and online analysis: offline analysis can be used to quantify uncertainties for individual patients and online imaging allows a quick decision about continuation of treatment by comparing the portal image with the reference image and looking for unacceptable discrepancies. The application includes features for image edition, image approval, image comparison, and measuring tools for field placement errors by using overlays of patient anatomy and of field shape. The values of the field placement errors need to be stored along with the images (Hendee and Ritenour, 2002, Podgoršak, 2005, Mayles et al., 2007).

As the amount of non-textual data generated in RT has radically increased image integration into the patient database is also a major condition in RT practice. The diagnosis and treatment decision are made from CT study becoming the burden of the RT department to archive this information for legal purposes (Starkschall, 1997, Huh et al., 2000, Podgoršak, 2005).

## Standards

A result of the commercial development of IS for the RT is proprietary data formats (e.g. *TMS export format- Helax®*, *iCOM- Elekta®*, *RTP link- Impac®*, *Varis link- Varian®*) that lead to problems in interface between the IS. Unless all the equipment being used in a department is from a single software supplier, it is a requirement that image and other data should be transferable between different IS in such a way that it can be interpreted by different software. The need to improve the RT workflow, as well as efforts to analyze and collect the treatment information for clinical trials has motivated the development of standards on RT information sharing. Some attempts by collaborative groups for the standardization of RT data formats, resulted in two relevant formats: the Radiation Therapy Oncology Group (RTOG) format and DICOM-RT extension. Another standards used are: for images, standards like the DICOM and the American College of Radiology-National Electrical Manufacturers Association (ACR-NEMA) 2.0, and file formats like joint photographic experts group (JPEG) and tagged image file format (TIFF); for administrative data, standards such as health level 7 (HL7) and languages such as extensible markup language (XML) (Ebert et al., 2004, Bosch et al., 2010).

Since 1994 the North American Radiation Therapy Oncology Group – use the format RTOG based on report nr.10 of the AAPM (1982), designed for the purpose of transferring RT data to the Radiotherapy and Oncology Group data centre (now called the Image-Guided Therapy Centre) so that quality assurance of clinical trials could be performed. It is widely used in systems originating in the U.S.A providing a common format for CT data, structures, treatment data and dose distributions used in RT. A typical RTOG data set consists of a collection of data files with a common name. The files are numbered sequentially, ‘Patient0000, Patient0001, ...’ with file ‘0000’ containing patient demographic information and a description of data contained in all other files and the subsequent files containing planning information. This format is limited, because there are no modules for brachytherapy treatments and for IMRT. It also does not present any record of actual treatment (i.e. data from R&V system) or images used for alignment (i.e. simulator images, DRR, portal images) (Ebert et al., 2004).

The RT extension of DICOM standard was created under the auspices of NEMA to support the RT data transferring between IS from within and outside RT department. It consists of a collection of DICOM-RT objects that can store information describing various components of a treatment plan (Dicom Standards Committee, 1999, Ebert et al., 2004). In next section, this standard will be present with more details.

## 2.2 DICOM-RT

The *de facto* standard for connectivity in the RT community has become with specifically designed objects of the DICOM standard. These have for been known as DICOM-RT, however, they form an integral part of the full DICOM standard being RT specific DICOM objects (Shakeshaft, 2010).

### 2.2.1 History

With the great development of medical images and the different ways to acquire, transfer and visualize images it became apparent the need for standardization in order to ensure connectivity and interoperability of all systems. In 1983, a committee formed by members of the medical community and of the medical equipment industry represented by the ACR and the NEMA respectively, introduced an industry standard to which all vendors of medical equipment could conform. Even though, the first versions of the standard, ACR-NEMA 1.0 (1985) and ACR-NEMA 2.0 (1988) never became popular among vendors, the later version DICOM 3.0 (1992) is by present-day standards ubiquitous. The main goals of the standard are to solve compatibility problems of digital image, concerning information exchange, interconnectivity and communications among IS to facilitate the expansion of PACS, and allow the creation of diagnostic information databases (Schlegel et al., 2006, Huang, 2010).

The first version specified standards in point-to-point message transmission, data formatting, and presentation and included a preliminary set of communication commands and a data format dictionary. The second version included hardware definitions and software protocols, as well as a standard data dictionary. Networking issues were not addressed sufficiently in either version. For this reason a new version aiming to include network protocols was released in 1992. Because of the magnitude of changes and additions it was given a new name: digital imaging and communications in medicine version 3.0 (DICOM 3.0). The two most distinguished new features in DICOM are adaptation of the object-oriented data model for message exchange and utilization of existing standard network communication protocols (Huang, 2010).

The DICOM was adopted by other standardization organizations including the European Committee for Standardization-Technical Committee (CEN/TC) 251, the Institute of Electrical and Electronics Engineers (IEEE), the HL7 and the American National Standards Institute (ANSI) and demonstrated at the Radiological Society of North America (RSNA) Annual Meetings. In 1994, during the RSNA meeting, the need for standardization of the way that RT data are transferred from one piece of equipment to

another was expressed and resulting an *ad-hoc* Working Group (WG), later to become WG 7. Members of this group include manufacturers of RT equipment, academics and members involved with the IEC (Schlegel et al., 2006). The current international WGs are listed in table 2.

In 1997 and 1999 DICOM committee decided to extend the standard from radiology to RT with the ratification of seven DICOM-RT objects (Dicom Standards Committee, 1997, Dicom Standards Committee, 1999). These objects helped set the standard for data integration and interoperability between RT equipment and IS from different manufacturers. In 2006, two additional objects were defined for ion therapy (Dicom Standards Committee, 2006).

Table 2. Working groups of DICOM 3.0 (Dicom Standards Committee, 2009)

Working Group	Focus Area
01	Cardiac and vascular information
02	Projection radiography and angiography
03	Nuclear medicine
04	Compression
05	Exchange media
06	Base standard
<b>07</b>	<b>Radiotherapy</b>
08	Structured reporting
09	Ophthalmology
10	Strategic advisory
11	Display function standard
12	Ultrasound
13	Visible light
14	Security
15	Digital mammography and computer-aided diagnosis
16	MRI
17	3-D
18	Clinical trials and education
19	Dermatologic standards
20	Integration of imaging and information systems
21	Computed tomography
22	Dentistry

### 2.2.2 The DICOM Standard

The DICOM standard being a product according to the NEMA procedures, defines international standards for communication of biomedical diagnostic and therapeutic information in fields that use digital images and associated data. The goals of DICOM are to achieve compatibility and to improve workflow efficiency between imaging systems and other IS within the healthcare scope (Lim and Zein, 2006).

#### Scope

The DICOM standard facilitates interoperability of biomedical informatics by specifying (Dicom Standards Committee, 2009):

- a set of protocols to be followed by DICOM compliant devices for network communication;
- the syntax and semantics of commands and associated information for data exchange;

- a set of storage services to be followed by DICOM compliant devices, a file format and a medical directory structure for media communication;
- information that must be included in DICOM conformance statement.

This standard consists in many different services providing the following capabilities applied to diagnostic image data (Schlegel et al., 2006, Mayles et al., 2007):

- Storage includes definition of how images and other data (structured reports, etc) are stored to be easily sent to a PACS or WS.
- Storage commitment confirms that an image has been permanently stored by a device.
- Network image transfer provides communication between two devices by sending objects.
- Query/retrieve enables a WS to find lists of images or other such objects and then retrieve them from a PACS.
- Modality worklist enables an imaging modality to obtain information of patients and scheduled examinations electronically.
- Modality performed procedure step enables the modality to send a report about a performed examination including data about the images acquired, beginning time, end time, and duration of a study, dose delivered, etc.
- Print management sends high quality images to a DICOM printer by network.
- Online imaging study management allows integration by network of medical devices with radiology information System (RIS), PACS, archives, etc.
- Open media interchange provides manually exchange objects and related information.

### **Normative References**

The DICOM standards have the following normative references (Dicom Standards Committee, 2009):

- International Standards Organization (ISO)/International Electrotechnical Commission (IEC) Directives, 1989 Part 3 - Drafting and presentation of international standards (I.S.O., 2011);
- ACR-NEMA 300, 1988 - Digital imaging and communications (N.E.M.A., 2011a);
- ISO 8822 - Information processing systems - Open systems interconnection (OSI) - Connection oriented presentation service definition (I.S.O., 2011);
- ISO 8649, Information processing systems - OSI - Service definition for the association control service element (I.S.O., 2011).

One important reason for the development of the DICOM is the utilization of network communication standards based on the ISO - OSI, which constitutes a reference model to be used as an architectural framework for network communication. The ISO-OSI model describes how data in one application is transported through a network to another application. The model concept consists of seven different layers from the lowest physical layer to the highest application layer, each layer specifying a particular network function (see table 3). When imaging information objects are sent between layers in the same device, the process is called a service. When objects are sent between two devices, it is called a protocol. When a protocol is involved, several steps are invoked in two devices; it is considered that the devices are in “association” using DICOM. It deals with the application layer and some of its terminology, such as Application Entities (AE) title that is derived from this (Schlegel et al., 2006, Mayles et al., 2007, Huang, 2010).

Table 3. An OSI model realization with Ethernet adapted from (Schlegel et al., 2006)

Layer	OSI model	Ethernet
7	Application	Telnet
6	Presentation	Data formats (e.g. JPEG)
5	Session	Session control protocol
4	Transport	Transmission control protocol (TCP)
3	Network	Internet protocol (IP)
2	Data link	Ethernet network interface card
1	Physical	Fiberchannel

## Contents

The DICOM standard is divided into related but independent parts following the ISO guidelines as shown in table 4. Additions to the standard (supplements and change proposals) that enhance the existing base standard are available on the DICOM website (N.E.M.A., 2011b).

Table 4. Structure of the DICOM 3.0 (Dicom Standards Committee, 2009)

Parts	Title
1	Introduction and overview
2	Conformance
3	Information object definitions
4	Service class specifications
5	Data structures and encoding
6	Data dictionary
7	Message exchange
8	Network communication support for message exchange
9	Point-to-point communication support for message exchange (retired)
10	Media storage and file format for media interchange
11	Media storage application profiles
12	Media formats and physical media-for-media interchange
13	Print management point-to-point communication support (retired)
14	Gray scale standard display function
15	Security and system management profiles
16	Content mapping resource
17	Explanatory information
18	Web access to dicom persistent objects

The DICOM conformance statement document is an instruction to manufacturers for the conformance of their devices to the DICOM standard. It describes the DICOM capabilities of the device and how the device or its associate software conforms to the standard. Potential connectivity between two pieces of equipment can be evaluated by reading this document which provides a foundation to determine connectivity and assess the potential inter-operability of two products (Mayles et al., 2007, Huang, 2010).

In general, the contents of the conformance statement include (Schlegel et al., 2006, Dicom Standards Committee, 2009, Huang, 2010):

1. *The implementation model of the AE and how these relate to both local and remote real-world activities.*
2. *The proposed and acceptable presentation contexts used by each AE.*
3. *The Service-Object Pair (SOP) classes and their options supported by each AE, and the policies with which an AE initiates or accepts associations.*
4. *The communication protocols to be used in the implementation.*
5. *A description of any extensions, specializations, and publicly disclosed privatizations to be used in the implementation.*

6. *A description of any implementation details which may be related to DICOM conformance or interoperability.*

A conformance statement only means that the device follows a certain subset of DICOM. If a manufacturer claims that its imaging device is DICOM compliant, it means that any system integrator who follows this manufacturer's conformance document will be able to interface the device. The statement "This product is DICOM" has low significance in the RT domain, in which interoperability is a complex issue, not being possible to determine interoperability *a priori*, only being confirmed with extensive data transfer testing (Schlegel et al., 2006, Huang, 2010).

The DICOM data format that groups information into data sets includes the DICOM model of the real world and the DICOM file format. The DICOM model of the real world provides an abstract definition of real-world objects in the clinical image arena and their interrelationships within the scope of DICOM standard. The DICOM model has four object levels: patient, study, series and equipment, and image, waveform and structured report (see table 5.). The DICOM file format defines how to encapsulate the DICOM data set of a SOP instance in a DICOM file. Each file usually contains one SOP instance. The DICOM file starts with the DICOM file meta information (optional) followed by the bit stream of data set and ends with the image pixel data (Huang, 2010).

Table 5. The four object levels of the DICOM model (Huang, 2010)

Level	Object Description
Patient	Person receiving, or registering to receive healthcare services.
Clinical Study	Historical study, a currently performed study, or a study to be performed in the future.
Series and Equipment	Series are created by equipment, which is an imaging modality. A series can include several images, documents, etc.
Image, Waveform and Structured Report	Any image from all sorts of modalities.

The DICOM object class consists of normalized objects (attributes inherent in the real-world entity represented) and composite objects (attributes from the study information and the patient information). DICOM uses a unique identifier, to identify a specific part of an object, but it does not carry information. This system identifies objects in such a way that each IS that generates data can create an identifier for the data that is guaranteed to be unique. The unique identifier can be used as a pointer that allows objects to be linked together (Mayles et al., 2007, Huang, 2010).

The DICOM services are used for communication of imaging information objects within a device and for the device to perform a service for the object. A service is built on top of a set of "DICOM message service elements" that are computer software programs written to perform specific tasks that involve a sequence of transactions (Huang, 2010). Examples of some services are: "modality worklist management" that enables scheduling information to be transmitted at the modalities and supplies the DICOM objects with HIS data such as patient demographics; "modality performed procedure step" that updates a the schedules and notifies the PACS when a scheduled procedure has been completed; and "storage commitment" (SC) facilitates automated deletion of the images on the modalities as the PACS confirms their safe storage (Schlegel et al., 2006).

### 2.2.3 RT Objects

The dedicated DICOM-RT standard provides information objects to transfer most of the standardized information that circulates in the RT. Figure 3 shows the dataflow in RT department with the relevant RT objects that are transferred. Data transfer between devices implies that a connection has been specifically established between them, or that interfaces have been setup between each device and the archive (Mayles et al., 2007).

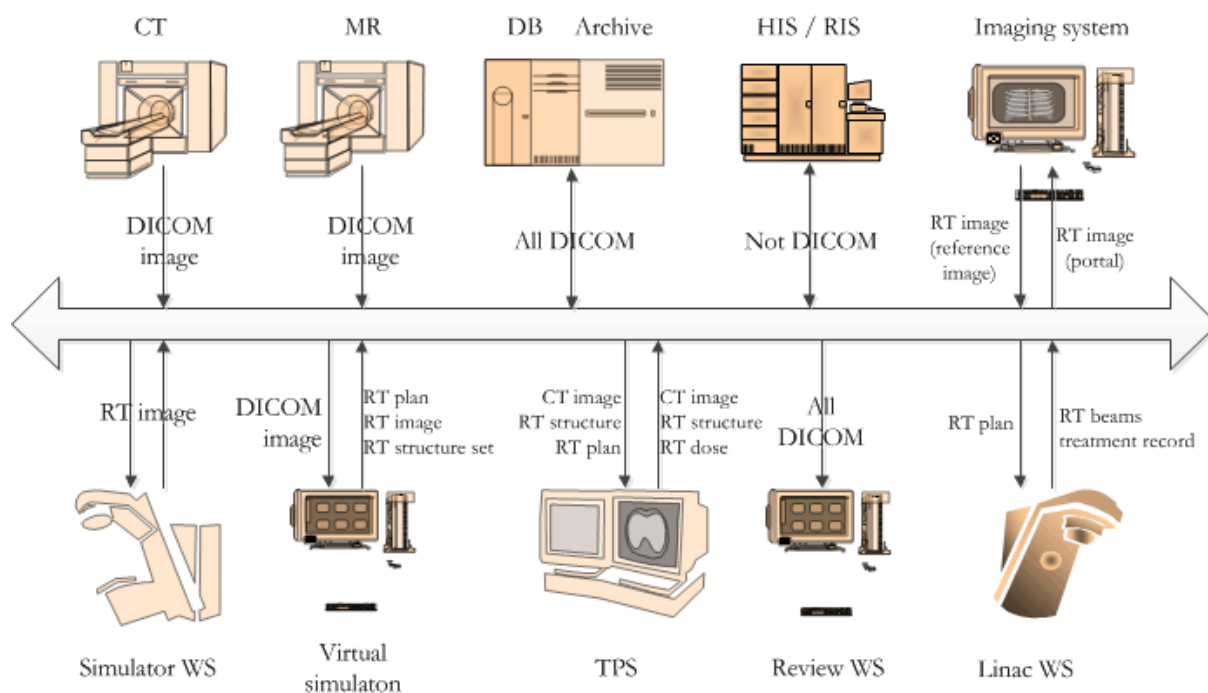


Figure 3. Diagram of DICOM data at RT workflow adapted from (Mayles et al., 2007)

The DICOM-RT objects are the following (Dicom Standards Committee, 1997, Dicom Standards Committee, 1999, Dicom Standards Committee, 2006):

#### **RT structure set**

It defines a set of structures of significance in RT related to patient anatomy, markers and isocenters. The process of segmentation of the CT images leads to a set of structures, such as: body (external) contour; target volumes: gross target volume, clinical target volume, and planning target volume, organs at risk defined as avoidance structures, regions and volumes of interest, points of interest (e.g. dose references). These structures have special meanings that must be maintained across the different IS having the object a link to an image. The structures can be complemented with observations and are identified on devices such as CT scanners, physical or virtual simulation WS or TPS.

#### **RT plan**

It contains geometric and dosimetric data specifying a course of external beam treatment, whether generated by a VS system or by a TPS before being transferred to R&V system. Such information includes treatment delivery details including an indication of the position of the treatment isocentre, field sizes and beam orientations (gantry and collimator angles), beam modifiers, tolerance table, fractionation scheme, number of MU, accessories used, patient setup, plan relationship, and control point concept. Transmission of a RT plan may require a number of data translations, including the name of the treatment unit, the name of the wedge, etc. Therefore, it is very important to verify such data transfers when the link is set up.

#### **RT dose**

It includes the dose data generated by TPS in one or more formats: 1-D, 2-D, and 3-D dose distributions, isodose curves, cumulative and integral DVH, dose statistics, etc.

#### **RT image**

It specifies the attributes of RT images that are acquired or calculated on a “conical imaging geometry” giving additional information about the exact geometry of the image, such as the distance to the source, and also to combine the image with the field definition modules. Such images are simulator images, portal images acquired at linac, or DRR generated from CT scans at TPS.

#### **RT beams treatment record**

It holds external beam treatment session records during a RT treatment course, containing data obtained from actual RT treatments in order to be the historical record of treatment. Mainly have textual data that specify treatment sessions report generated by the R&V system during a course of RT or treatment information during treatment delivery. Such information includes machine, radiation type and energy, date and time of treatment, external beam details, treatment fraction details, the MU, dose calculations, dose measurements, cumulative dose, and treatment summary.

#### **RT brachy treatment record**

Is similar to RT beams treatment record but includes information acquired during the course of brachytherapy.

#### **RT treatment summary record**

It contains treatment summaries indicating the cumulative state of a treatment course. The treatment summary it is provided such that the process may be re-created at any given point in time providing completeness. It is more usual for this type of information to be interfaced directly with the TMS.

#### **RT ion plan**

Is specifies the requirements for transfer of treatment plans generated by manual entry, VS, or TPS before or during a course of ion therapy treatment.

#### **RT ion beams**

It addresses the requirements for transfer of treatment session reports generated by R&V system during a course of ion therapy, with optional cumulative summary information.

In the RT process, various DICOM-RT objects are created and each object contains references to the DICOM objects which preceded it having a system of dependencies. The DICOM-RT data model (figure 4) can be used as the data structure for the ePR, having DICOM-RT objects integrated within the series module, along with the diagnostic image object in the hierarchical structure of the DICOM four levels (Mayles et al., 2007).

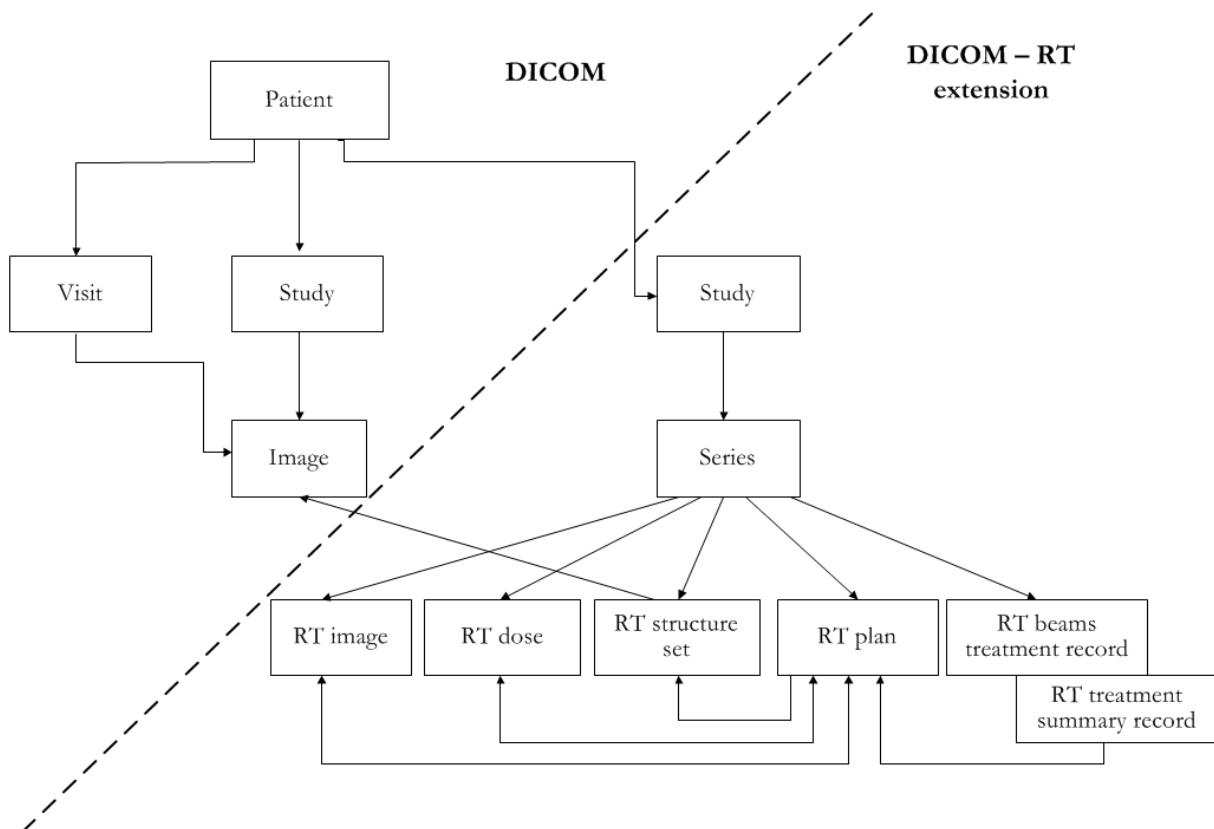


Figure 4. DICOM-RT data model of external beam RT adapted from (Dicom Standards Committee, 2009)



## 2.2.4 RT Modules

In the DICOM standard each information object contains modules of information related to the object, including both modules that are common to all modalities in radiology (e.g., Patient, Study) and modules that are specific to each imaging modality (e.g., CT Image module for CT). In these modality-specific modules, the attributes of the images are specified (Kalet, 2008).

In DICOM-RT objects each object contains several associated modules. Figure 5 shows the six DICOM-RT objects of external beam RT and their associated modules, where the RT data generated during the workflow are distributed over the various objects. The attributes of each module are described in detail by documents of DICOM organization (Dicom Standards Committee, 2001).

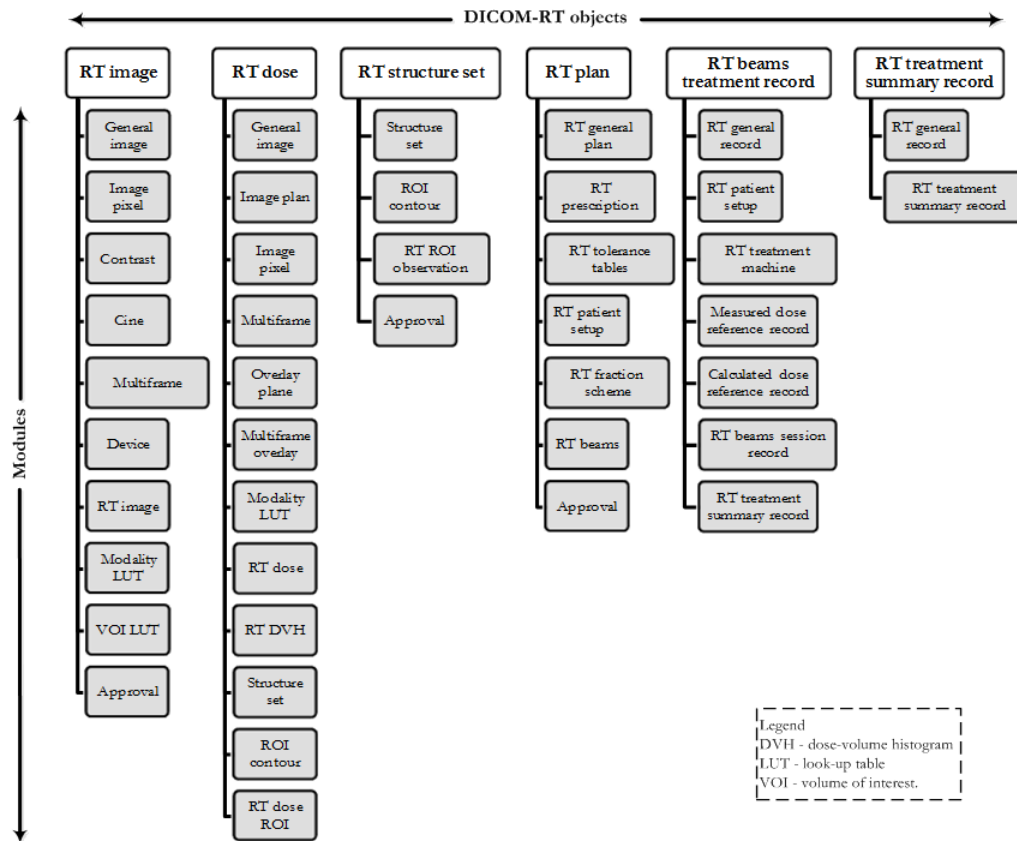


Figure 5. Chart illustrating the six DICOM-RT objects of external beam RT and their associated modules adapted from (Law and Liu, 2009)

The data cycle of RT instruments (figure 6) includes detection, measurement, analysis, transmission, storage, display and feedback data which entails the information object modules of DICOM-RT that are applicable in the above listed eight TDS. In conformity with IEC 61217 (I.E.C., 2008), the TDS used in DICOM standard are (Tee, 2010):

- Fixed reference system
- Gantry system
- Beam limiting device system
- Wedge filter system
- X-ray image receptor system
- Patient coordinate system
- Table top eccentric system
- Table top system

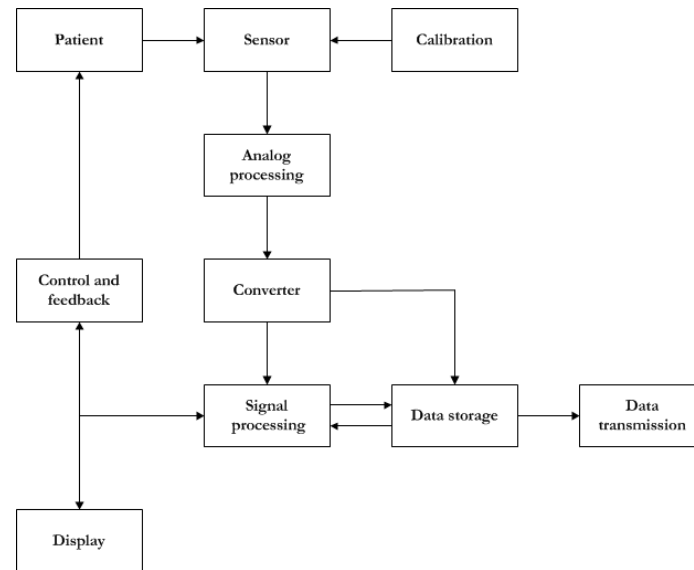


Figure 6. Data cycle of RT instruments (Tee, 2010)

### 2.2.5 Benefits

The DICOM standard provides a method to enhance interoperability between IS in RT. The standardization provided by DICOM-RT objects allows the opportunity for RT data visualization using generic DICOM compliant display tools. The possibilities are (Mayles et al., 2007):

- Display of target volumes with the possibility of editing them in other clinics through the use of RT structure set;
- Visualization of RT images acquired at simulation or DRR from CT with associated beam overlay and be able to editing parameters at radiation oncologist WS;
- Interchange of data between TPS and help in the independent verification of dose calculations through the availability of the DICOM-RT objects;
- 3-D view of the dose display and its relation to the volumes and 2-D view display superimposed on reformatted images at different moments, before the approval treatment and in the patient consultations for review;
- Action of approve objects by professionals with an electronic signature.

The general benefits of using DICOM-RT objects in RT departments can be (Law and Huang, 2003, Law and Liu, 2009):

- Transmission of the textual information and images between IS from different vendors with minimal effort from users providing communication between isolated IS;
- Full integration of IS with technologies from different vendors helping save time and effort spent in searching and minimizing the loss of records and images;
- Monitoring and analysis of the RT workflow facilitating the process of planning, delivering, and recording radiation treatments;
- Reduction of transcription errors in transferring information from TPS to TDS;
- Transmission of data for TDS to execute treatments such as IMRT;
- Integration of the treatment process into an ePR;
- Platform for information sharing with HIS and other IS allowing cross-center clinical research and expert consultation;
- Development of decision support tools and a knowledge base in the medical imaging informatics research through the patient outcomes.

## 2.2.6 Problems

The various attempts to integrate RT equipment and IS with the DICOM-RT objects have demonstrated a number of problems according to the following issues (Schlegel et al., 2006, Mayles et al., 2007, Bosch et al., 2010, Shakeshaft, 2010):

### **DICOM flexibility**

The RT objects are quite flexible and contain optional elements, type-2\* (mandatory, but may be null) or type-3\* (optional) due to:

- existence of alternative treatment techniques and beam modification devices;
- DICOM change proposals that are used to correct errors in the standard or to improve the functionality;
- attempt to preserve the conformance of existing applications.

### **DICOM redundancy**

Redundant representations of RT data with multiple elements with essentially same purpose led to various incompatible implementations of the standard.

### **DICOM architecture**

The architecture of the DICOM-RT objects, specially the RT plan and RT dose, involves the use of a single object for several use cases. And it contains multiple attributes that represent the same related information.

### **DICOM conformance**

The conformance does not guarantee compatibility, because may be difficult to determine whether two products are compatible and different systems may implement same features in different ways.

### **DICOM complexity**

The standard may be difficult in requirements interpretation and may involve complex local configuration depending the vendor's systems rules.

### **DICOM and IEC 61217 standard**

The DICOM standard requires that beam definitions follow the IEC 61217 standard apart from the definition of the fixed reference system. The following discrepancies can lead to confusion:

- In DICOM, the positive Z direction is along the couch towards the gantry, whereas in IEC, this is the Y direction;
- In DICOM, the positive Y direction is posterior, whereas in IEC, the positive Z direction is anterior (for a supine patient);

### **DICOM image sets**

Each vendor of imaging equipment organizes 3-D image sets into series and some RT IS rely on all images of a given type (e.g. axial images) to exist in the same series in order to create a 3-D reconstructed volumetric data representation. Older CT/MR scanners tend to split such data sets into several series.

### **RT development**

The changes that occur in RT technology leads to pieces of information that need to be stored that do not have a suitable DICOM element. This has led to the extensive use of manufacturer-specific elements. For example, the associated field placement errors, which are calculated, by comparison of portal image with the reference image, are not currently covered by a DICOM object.

### **RT plan revisions**

Unlike DICOM objects in diagnostic imaging, in RT a number of versions of the same object rapidly accumulate (plan revisions). In some cases these can be deleted as they are simply works in progress, but in other cases the different versions may be important.

### **RT identification**

If DICOM-RT objects are stored on PACS, the identification of the object that is required can be difficult, because the objects have a description in a DICOM element specific to the object modality. These descriptions are not returned in a query/retrieve.

Patient identifiers stored in different objects should be consistent. Recipient systems often require the ability to identify different DICOM-RT objects as belonging to the same patient data set. It is essential that the specifications applied to issues such as the spaces between names and at the end of fields are identical for all the objects.

#### **RT quality assurance**

Electronic transfer of data is more reliable than human data transfer by typing at a keyboard, but because of the many translations that occur during data transfer, accuracy cannot be guaranteed. Considered protocols with electronic methods of data verification independent of DICOM need to be developed, because of the potential for serious harm in RT treatment.

#### **RT data**

Some IS does not support visualization of particular objects, so it is essential that the storage system should accept the objects without modification and be able to transmit them to other IS. And some IS are unable to accept particular objects, so it is important that the objects transmitted by the storage system must be selectable.

## **2.3 IHE-RO**

Specification of a standard and ensuring that it works in practice are two different tasks. Even with the DICOM and HL7 standards available, there is still a need of common consensus how to use these standards for integrating heterogeneous healthcare IS. A variety of parameters can be specified, for example, in an HL7 message, it is not guaranteed, just because two systems use HL7, that their messages can be exchanged and understood (Huang, 2010).

A joint initiative termed “integrating the healthcare enterprise” (IHE) (I.H.E., 2011a) started in 1998 with the RSNA and HIMSS (Healthcare Information and Management Systems Society), consists of annual elaborate suites of communication capabilities that are demonstrated by vendors at the meetings of the two organizations. In 1999, the first large-scale demonstration was held at the RSNA annual meeting and in these demonstration the manufacturers showed how their products could be integrated together according to IHE protocols (Shortliffe and Cimino, 2006, Huang, 2010).

IHE-radiation oncology (IHE-RO), an American Society for Radiation Oncology (ASTRO) initiative, began with a multinational task force with meeting at the 2004 annual meeting of RSNA. The committees of IHE-RO began work in January, 2005 (Abdel-Wahab et al., 2010, Bosch et al., 2010).

### **2.3.1 Mission**

The mission of IHE is define and stimulate manufacturers to use standards-compliant equipment and IS to facilitate daily clinical operation at promoting connectivity and integration of equipment from different modalities and IS, through documented clinical workflows and communication pathways. The challenge is to satisfy the requirements of clinical and management scenarios by operating environments in which applications or components from various vendors worked together (Huang, 2010).

IHE is not a standard neither a certifying authority, instead it is a high-level information model for driving adoption of standards, in other words, it supports and encourages adoption of standards already developed to inform the standards development organizations where deficiencies were found in the specifications (Shortliffe and Cimino, 2006, Huang, 2010).

The mission of the IHE-RO task force is to promote connectivity and integration of RT equipment and IS. Sponsered by ASTRO it includes members from 12 other associations (e.g. RSNA, AAPM, ACR, NEMA, ESTRO), more than 20 academic institutions and cancer centers, and more than 20 vendors (e.g. *Varian Medical Systems®*, *Impac®*, *Elekta®*, *Nucletron®*, *Philips®*, *BrainLAB®*, *Siemens Medical Systems®*, *Accuray®TomoTherapy®*, *Calypso Medical Technologies®*, *Fuji Medical Systems®*, *Kodak Health Group®*, *Global*

*Technical Services Group®*, *Sun Nuclear Corporation®*, *Dynamic Imaging Systems®*, *Navotek Medical®*, *IBA Particle Therapy®*, *Vision RT®*).

### 2.3.2 Structure

The IHE-RO task force consists of a planning committee (PC) and a technical committee (TC). The schedules of activities, meetings and working documents can be found at the IHE website (I.H.E., 2011a) and at the collaborative environment of the IHE wiki (I.H.E., 2011b) where is described IHE in progress and details.

PC consists of users with clinical and operational experience and product management representatives from equipment manufacturers of relevant IS. The task is to identify clinically interoperability problems within the RT domain and to abstract these as proposed use cases, developing examples of hypothetical scenarios where software compatibility issues that may be related to access to information, clinical workflow, administration, and infrastructure of clinical care. The PC reviews and prioritizes integration and information interoperability problems, approves proposals selected by the TC and develops educational materials (Abdel-Wahab et al., 2010, Bosch et al., 2010, Field et al., 2010).

TC consists of users with technical experience (medical physicists, DICOM engineers and analysts from manufacturers and academia). The task is to evaluate the use cases proposed by determining technical requirements, feasibility and estimated effort to develop integration profiles specifying how existing standards are to be used to solve interoperability problems. The TC discusses on the appropriate standards-based solutions, develops a document describing in detail the technical aspects of the solution, known as the “integration profile”, and maintains the technical framework for the domain (Abdel-Wahab et al., 2010, Bosch et al., 2010, Field et al., 2010).

### 2.3.3 Integration Profiles

IHE technical framework documents all integration profiles to describe the solution of the interoperability problem by defining a common information model and vocabulary for using standards to complete clinical transactions for a certain task (Huang, 2010). There are important key concepts in the IHE technical framework such as: the data model that shows the relationships between the key frames of reference; the actor (system or part of a system) that exchanges messages with other actors to achieve specific tasks, creating, managing or acting upon data; and the transaction that identifies the behavior that is required to assure interoperability (Huang, 2010).

IHE integration profile provides a platform for healthcare providers and manufacturers to discuss integration needs and the integration capabilities of products. It describes the data and workflows and documents how to use established standards to accomplish it providing an implementation guide for equipment vendors and a support to specify integration requirements when purchasing systems for healthcare providers (Huang, 2010).

The both IHE-RO committees work together to complete the phases of the IHE process, having five basic steps (Abdel-Wahab et al., 2010):

1. Identifying common interoperability issues in RT workflow - the use cases are defined by PC and submitted to the TC for technical requirements determination and setup the priority use cases.
2. Development of integration profiles - the TC selects standards that address each use case identified and then creates a document describing the propose integration profile. The document progress through a series of phases: development, public comment, trial implementation and final text.
3. Testing at *connectathons* - annual testing for verification of connection of the various IS. Successful completion of the testing requires the vendor’s system to receive information from

at least three other vendors who support the previous steps in the information flow and to transmit information to three vendors whose applications represent the next steps.

4. Public demonstrations - vendors who pass the *connectathon* testing for one or more of the profiles are eligible to participate in the IHE-RO public demonstration at the ASTRO annual meeting.
5. Publishing of integration profiles for use in requests for proposals - incorporation of completed integration profiles to guide users to reference integration profiles in requests for proposals, simplifying the systems acquisition process, when purchasing new equipment.

Presently, there are four completed integration profiles, described below, four in development and one under consideration for development into integration profile (I.H.E., 2011b).

The completed integration profiles are the following (Bosch et al., 2010, Field et al., 2010):

- Basic RT treatment planning: illustrates the flow of 3-D treatment planning data from CT to dose review. It provides the structural mechanisms defining a common process for vendors to develop TPS based on current DICOM standard. It addresses the clinical dataflow from CT scanner through treatment plan review for 3-D conformal external RT. The result is a patient specific, image based treatment plan that can be clinically implemented: contourer (segmentation WS), geometric planner (virtual-simulation), dosimetric planner (TPS), dose displayer (plan review WS) and archive (RT-PACS). The integration profile for this process is illustrated in figure 7.

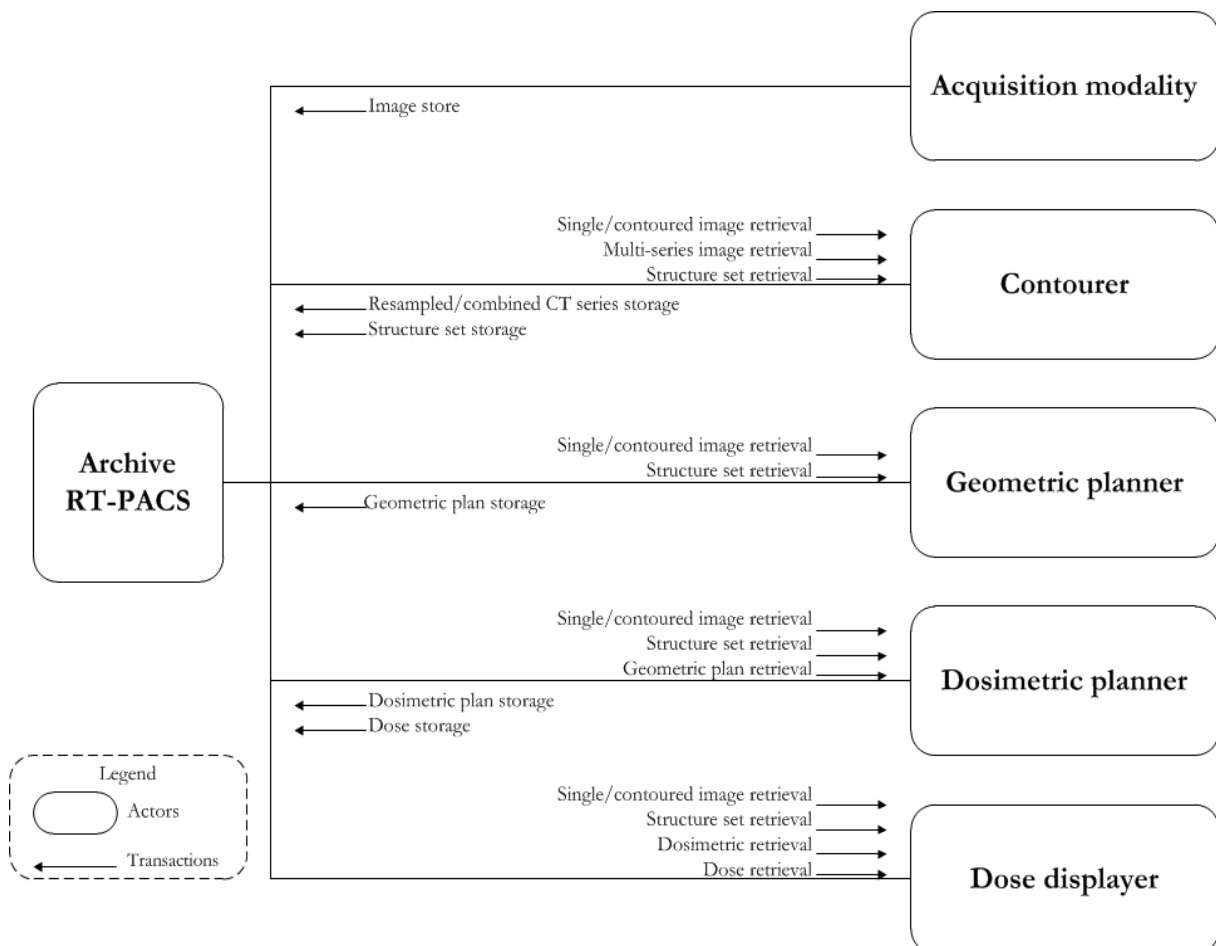


Figure 7. Diagram of the IHE-RO integration profile "basic RT treatment planning" adapted from (I.H.E., 2011b)

- Multimodality registration for RT: clarifies how the images, contours (RT structure set), doses and their associated DICOM spatial registration object (SRO) can be exchanged between IS, "stored & retrieved", processed and displayed. Results from image registration of CT, MRI, PET and

SPECT are not always readily transferable between IS, but with a collection of DICOM SRO this problem is solved. Five actors are defined: registrator (spacial registration), registered display (display registered images), registered contourer (segmentation), registered dose display (spatial registrations with contours, doses) and archive (RT-PACS).

- Treatment delivery workflow: describes the patient setup and delivery executed by a single device, which can acquire treatment images, perform a registration with the reference images, and reposition the patient (if necessary) to deliver the intended treatment. Extensions include the use case of treatment delivery interruption.
- Advanced RT objects: specifies an extension of the basic RT treatment planning integration profile to includes a variety of RT techniques, defining the structure for the exchange of RT plan data between TPS (re-planning patient on a different TPS) and between TPS and TMS.

The integration profiles in development are: “enterprise schedule integration”, “dose compositing”, “prescription automation”, “structure templates: creation, import, and export”; and the use case being considered for development into integration profile is “user authentication and authorization” (I.H.E., 2011b).

### 2.3.4 Benefits

These IHE-RO solutions are now available in many commercial TPS, R&V and TMS being implemented in RT departments around the world. For RT professionals, IHE-RO brings gains to productivity, cost efficiency, improving the oncologic patient care through the integration of hardware and software products. For vendors, IHE-RO provides cost-effective testing of interfaces, reducing the cost of solving connectivity and workflow problems (Bosch et al., 2010).

The IHE-RO integration profiles provide the respective benefits (Field et al., 2010, Able et al., 2011):

- Basic RT treatment planning: the RT-PACS utilization as archive ensures interoperability between vendors for each component which will allow users to move data between IS in the treatment planning process.
- Multimodality registration for RT: the multimodality images used in TPS, the image guided RT used in treatment verification and the image studies used for follow-up can be exchanged between IS within and outside RT department.
- Treatment delivery workflow: the management of this data in a systematic way across IS avoids errors in data transcription between them.
- Advanced RT objects: implementation by a TPS ensures the ability to re-plan a patient treatment based on the output of another TPS for a variety of RT techniques; implementation by a TMS allows the transfer of data to R&V systems from different vendors.

## 2.4 DICOM-based ePR in Radiotherapy

RT patient’s record can never be complete if the RT data isn’t integrated into the ePR system, where a central database contains all patient data being linked to all the treatment units, simulator and TPS and handling images from these WS. In RT the ePR should address the clinical aspects of patient care, but also technical components of radiation treatment, making all RT-related information (multimedia, graphs, images, records and clinician’s remarks from different RT sources) available in one system (Law, 2005, Mayles et al., 2007, Huang, 2010).

“ePR” is an promising concept to substitute or supplement the HIS, being a patient-based digital folder of clinical information obtained from various IS with imaging data and tools of decision support. There are currently no international standards for a specific ePR such as that required in the practice of RT. The exclusive demands for a R&V system, a TDS, a TMS, access to the TPS, real-time data

acquisition, ease of database accession and integration within the HIS make a comprehensive RT ePR system difficult to achieve (Liu, 2008, Colonias et al., 2011).

The implementation of the DICOM-RT based ePR has been delayed by RT manufacturers, each of whom is competing to be the major provider. Although the attempt to develop a comprehensive RT ePR, the systems have been planned for implementation with a single source vendor's equipment and their interoperability with other vendors' equipment is limited because records are still in vendor-specific formats (Law et al., 2009, Huang, 2010).

## 2.4.1 Infrastructure and System Components

To develop an ePR in RT, a conceptual data model of the RT workflow with user's requirements is necessary to determine how patient data is represented in the database. The ePR system development involves system design, implementation, testing and evaluation (Law et al., 2009, Huang, 2010).

The open architecture of the DICOM-RT based ePR system can be similar to PACS being the data model and the dataflow of PACS a guide for the design (Law et al., 2009, Huang, 2010). The ePR system consists of three major components (figure 8): the DICOM-RT objects input, the DICOM-RT gateway, and the ePR platform. This platform includes three components: the DICOM-RT archive server, the RT web application server and the web client WS (Law et al., 2009, Huang, 2010).

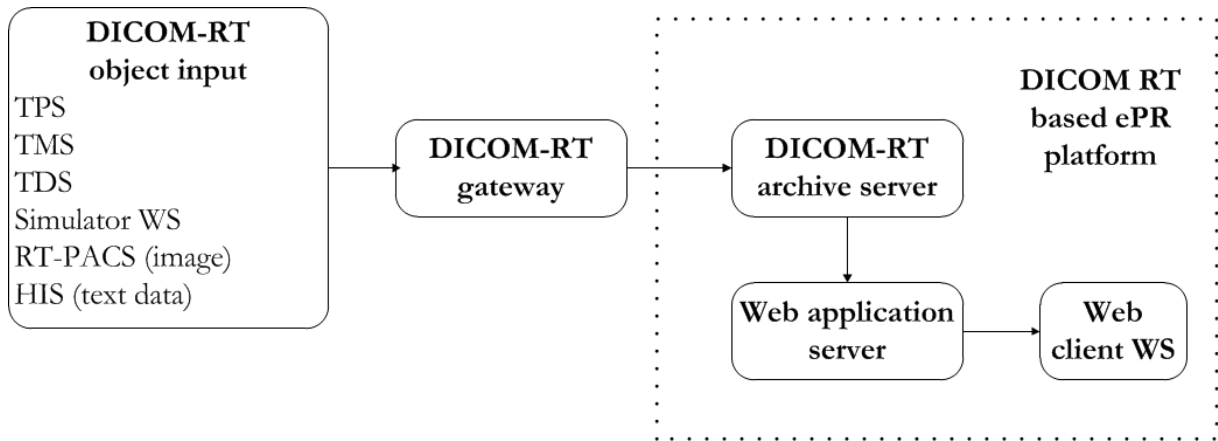


Figure 8. DICOM-RT based ePR system components adapted from (Law et al., 2009)

The DICOM-RT objects input receive RT objects from various IS, all connected by internet or departmental Intranet communication networks. DICOM images and DICOM-RT objects are identified by each system and then either pushed to, or pulled by the DICOM-RT gateway.

The DICOM-RT gateway receives all RT objects, acknowledges receipt of the objects and extracts information from them and puts them into the RT data model. It also converts any nonstandard data object to the standard. Outputs of the gateway are packaged DICOM and DICOM-RT objects, which are automatically pushed by the gateway to the RT archive server.

In the ePR platform, the RT archive server can construct a database schema following the DICOM hierarchic structure, consisting of 4 levels. The archive server is responsible for storage, management, and transmission of DICOM-RT objects and DICOM images being a database server. It extracts only the essential aspects of the objects entities and auto routes all the data to the RT web application server. This server accepts the objects, decodes them to the corresponding position in the web database, and organizes the data into the web viewing mode for display at the client WS all actions processed here thought six key components. In figure 9 are shown the components from the RT web server in the workflow process between the DICOM-RT archive server and the RT web server. *The images are received by the object receiver (1) using DICOM-service class provider (SCP). RT objects are translated by a decoder (2), and the data are arranged in the RT tables on RT database (3). The data from the tables are superimposed on the corresponding positions of the DICOM*



images by the RT converter (4) and be sent by the web server (5) to the client WS using hypertext transfer protocol (HTTP). When the RT web server has generated the new data needed to update the DICOM-RT archive server the object sender (6) in the RT web server will be called upon to perform the task. In this case it uses the DICOM-service class user (SCU) service to send the updated objects to the RT archive server via the DICOM-RT gateway for storage. For the web client WS, the graphical user interface (GUI) represented in figure 10, is designed to access information within the database according to the functional requirements of the users (Huang, 2010).

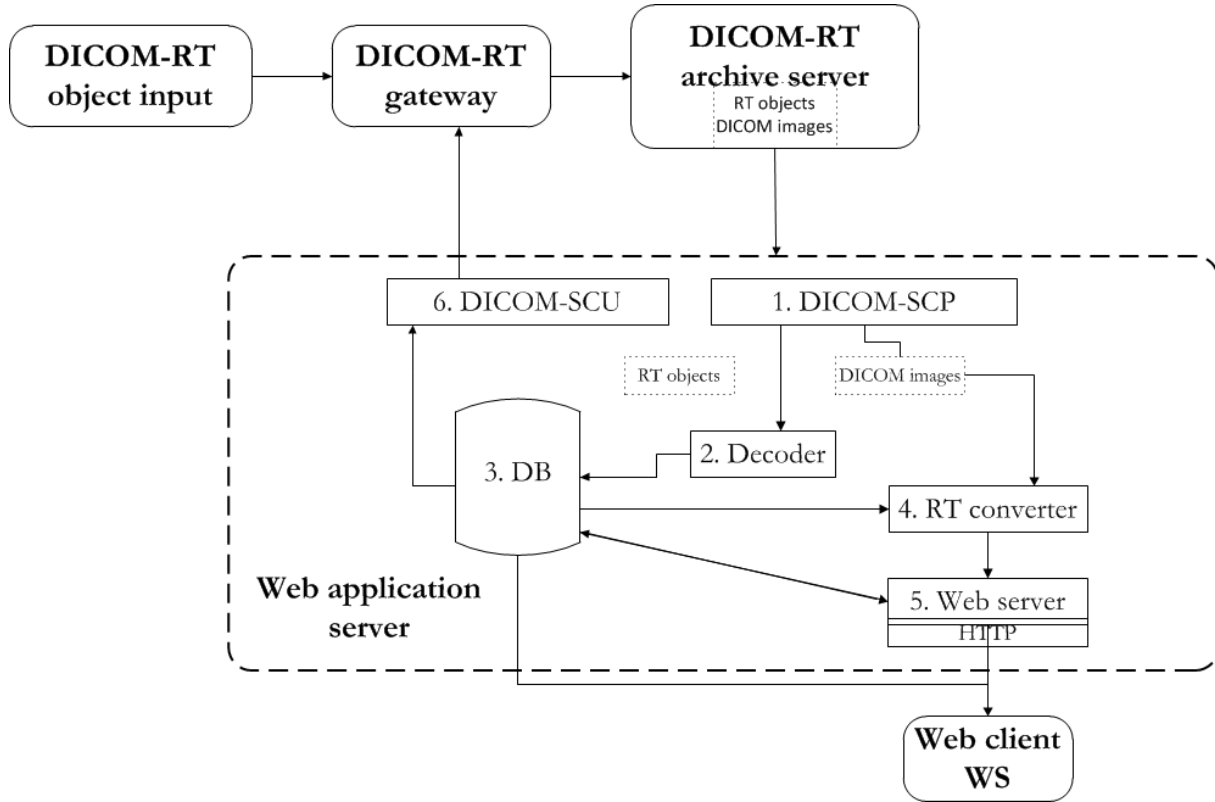


Figure 9. Architecture of the web application server of the DICOM-RT-based ePR system adapted from (Law et al., 2009)

## 2.4.2 Database Schema

The data schema in the RT database refers to how data is physically represented with data structures, file organizations, and mechanism for the operation of the system and data storage. As shown in figure 7, the ePR system has two databases, one for the RT archive server for management and storage of DICOM objects and the other for the RT web application server for partition of the collected DICOM-RT objects data and then the server parses them to be viewed by users at the web client WS. It is important to design the database schema to be as flexible as possible to allow the addition of a knowledge base and outcomes data, not belonging to the DICOM standard. (Law, 2005, Huang, 2010)

To the DICOM-RT archive server, the database only needs to identify what an object is and what it does, whereas in the application server of the web-based RT server, the internal details or the data structure of an object can be implemented or processed later (Huang, 2010).

In the RT web application server, for implementing the details of the DICOM-RT objects a complex data model is required with design and implementation according to the DICOM standard documents that defines the basic data structures (Huang, 2010).

### 2.4.3 Benefits

Current TPS, TMS, TDS, and imaging systems contain some of the DICOM-RT objects however an ePR system is more comprehensive, because it presents the entire scope of DICOM-RT objects in a timeline format for navigation of patient data (Law et al., 2009).

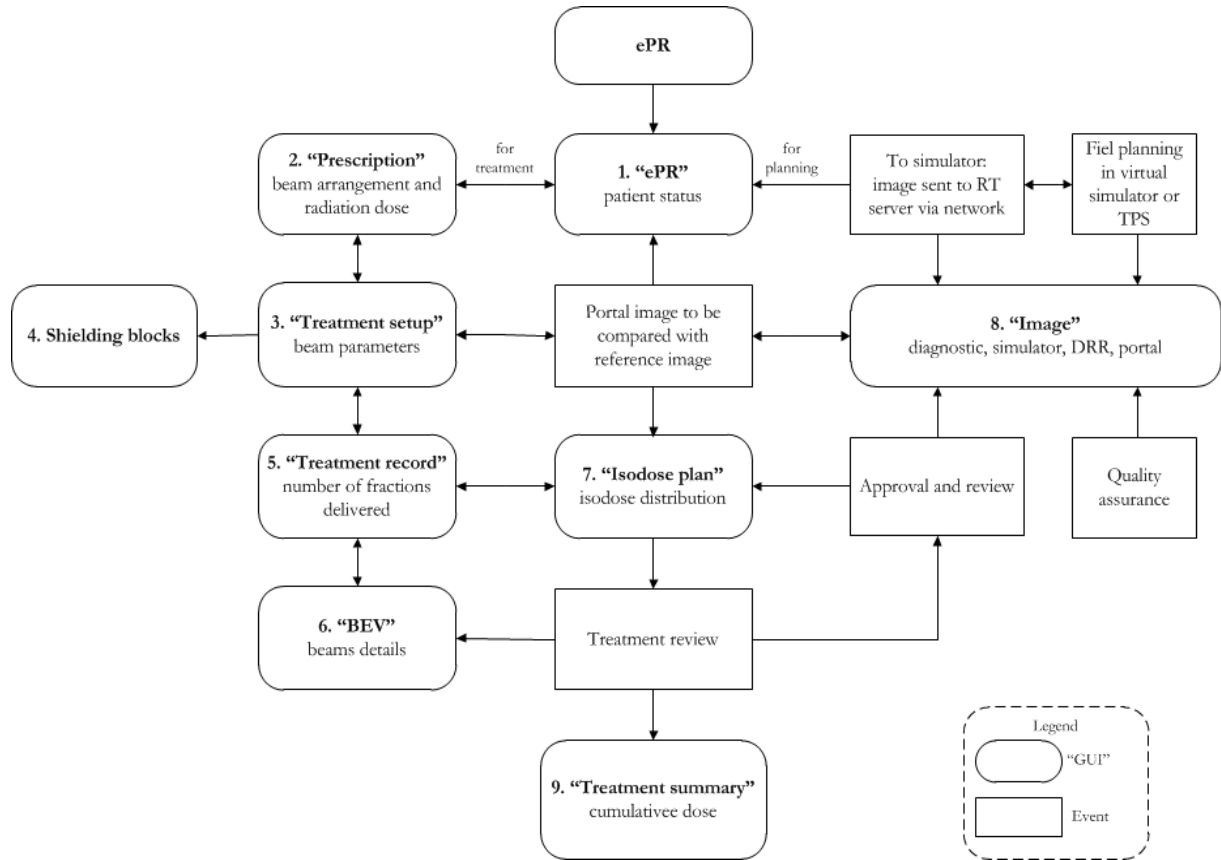


Figure 10. RT workflow based on GUI adapted from (Law, 2005)

The advantages of the DICOM-RT based ePR system for RT practice can be various according to the RT departments' reality (Law et al., 2009, Huang, 2010, Colonias et al., 2011):

#### Communication between isolated IS

- Often there are many isolated IS with small scope and single-purpose applications. Usually come with the purchase of individual applications, standing alone without other IS interface.
- This system enhances application interoperability among multi-vendor modalities that provides open environment for data exchange so that RT department will not be restricted to a single vendor's systems allowing the use of the best tool for the task with flexibility.

#### Archival of information

- The patient information capture will be at different moments (consult, radiation treatment planning, treatment delivery and follow) and treatment involves various IS that will archive information in different places, which is linked by a paper record of the patient, with the risk of loss and patient information disintegration. In other words, many independent IS are used with independent databases that contain the same data.

- Using DICOM-RT archive integrated into ePR system the IS management is easier because exits less data to back up, information control is improved, and efforts and time in searching for records are saved.

### **Radiobiology**

- The RT data needs to be recorded for future reference in the management of cancer patients and evaluation of treatment outcomes.
- The efficient collection of standardized RT data allows the capture of patient information related to efficacy, toxicity and quality of life, helping in large-scale analysis across patients and providers.

### **Information sharing**

- The inexistence of common databases between institutions and the lack of an integrated database limits the ability to conduct cross-center clinical research and causes discontinuities in care by clinical decisions based on incomplete data.
- Open architecture can improve patient care by distributing information across different platforms and IS. For example: acceptance of the treatment planning information from other clinical centers for real-time expert consultation and peer review.

### **Information availability**

- Patient data collected in RT are not widely available for immediate integration due to the differences in formats between WS and IS.
- With ePR system all pertinent imaging and informatics data can be reviewed at any client WS, the clinical decision is improved by providing one source for data visualization.

### **Data handling**

- When IS do not communicate the patient information has to be re-entered, which is prone to errors affecting the patient treatment.
- Acceptance of direct digital input of patient data facilitating documentation by transcription process control, improving accuracy and reliability of point of service billing.

### **Patient-oriented system**

- The most of HIS are organization-oriented or system-oriented not facilitating the query of patient's information using several systems.
- A patient-oriented system as the ePR improves patient care by timely and accurate review of patient treatment information.

### **Standards utilization**

- Using the DICOM images and the entire scope of DICOM-RT objects the patient information from different IS is integrated, and a summary of the patient's treatment record can be displayed in a timeline format for navigation of historical and new treatment data.
- This ePR promotes not only technical standards, but also other standards by incorporating standardized quality guidelines in clinical, education and management areas.

### **Model of comprehensive ePR**

- Many IS are used in the RT workflow without interconnection between them.
- With the DICOM-RT, RT-PACS, and IHE-RO integration profiles, researchers are working toward incorporating all clinical data from patient in one integrated concept and prototype system to comprehensive ePR improving the RT workflow.

### **Image-assisted knowledge**

- The actual use of imaging informatics tools is limited, DICOM is mostly used for transmitting PACS images to an RT system and TPS are limited to dose computations and graphical data displays.
- Effective way for tracking the treatment progress of patients by integrating data from the various sources, providing a foundation of standardized data objects to build a knowledge base.

**Decision support**

- Pertinent RT data results do not have a standardized protocol.
- Imaging informatics methodology (tools of quantification, visualization or data mining) based on the ePR is a current trend of research in RT to assist in the decision support suggesting courses of treatment.

This review of DICOM-RT shows that DICOM-RT objects are important for the electronic workflow in RT departments, especially in the context of IS from different manufacturers, but there exist some problems in the extension, which needs to be improved to follow the RT development and its complexity.

*Life is not easy for any of us. But what of that?  
We must have perseverance and above all confidence in ourselves.  
We must believe that we are gifted for something and that this thing must be attained.*

*Marie Curie*



## 3. Bivalent Study on Radiotherapy Information Systems and DICOM-RT

This thesis focuses on two studies, the first study is about a survey of the Portuguese RT departments in terms of facilities, including treatment equipments, imaging modalities and IS, and the second study is about the DICOM-RT expert's opinion about interoperability and DICOM-RT relevance.

As both studies used the same measuring instrument (questionnaire) having similar methods, this issue will be presented with an introduction for the theoretical background, and a global methodology.

### 3.1 Introduction

Many countries have conducted structure surveys of RT facilities and some results are compared between different countries to illustrate similarities and differences to each country improve their own structure using the resultant international information (Teshima et al., 1996). The surveys are focused in equipments, workforce, workloads, geographic distribution, treatment's patterns, etc (Owen et al., 1997, Van Daal and Bos, 1997, Wigg and Morgan, 2001, Expert Working Group on Radiation Oncology Services, 2003, Budiharto et al., 2008, Teshima et al., 2008, Jefferies et al., 2009).

The document created by High Commissioner for Health [Alto Comissariado da Saúde], "Strategy of radiotherapy in Portugal for the next decade" (Pereira et al., 2008), published in 2008, presents a national survey reporting the RT structure for the entire country, providing census data of departments, workforce and equipment. Regarding IS of RT departments, the survey only addressed the TPS of the public institutions. This document was prepared by group of RT experts (including radiation oncologists, medical physicists, and radiation therapists) under the auspices of the National Coordination for Oncological Diseases [Coordenação Nacional para as Doenças Oncológicas]. The aim was to evaluate the RT situation in Portugal to prepare a strategy for the future development of RT (Pereira et al., 2008).

In order to confirm if there were more relevant documents about this issue, on March 10, 2011, was sent an email to the National Coordinator for Oncological Diseases (*acportugal@cndo.min-saude.pt*) to ask if they had other relevant documents on this subject or access of such data or study about IS installed in RT departments, under the "National plan for prevention and control of oncological diseases". On March 22, the adviser of the Coordination answered that this document is the only one that reports the Portuguese RT facilities and equipments and about IS installed there is no study to date (see Appendix B).

The survey presents the identification of RT departments divided into public and private institutions, lists the staff in radiation oncologists, trainee radiation oncologists, radiation therapists, and medical physicists with the age profiles. Regarding the equipment in operation was included: number and type of megavoltage treatment units (linac or cobalt-60); kilovoltage X-ray machines; brachytherapy units, simulators and regarding IS in utilization was included only TPS. This data included the commercial designation, the manufacturer, and year of installation of the equipment. To analyze the equipments the experts grouped in three classes: I – linac or brachytherapy unit under 10 years; II - linac or brachytherapy unit with 10 years or more; III – cobalt units or kilovoltage machines over 10 years (Pereira et al., 2008).

In the year of 2008, our country had 20 RT departments, being 8 of them public institutions, and it is estimated that in total, the number of external RT equipment was around 40 units, being 25 of them respective to class I. Concerning public departments about half of the equipment belonged to class II and III. In respect of the personnel, there were 68 radiation oncologists, 232 radiation therapists, and 50 medical physicists (Pereira et al., 2008). This data was actualized with the information provided by the following Portuguese websites “Radiotherapy and Oncology” [Radioterapia e Oncologia] (Rodrigues, 2011) and “Radiation Therapists Association” [Associação dos Técnicos de Radioterapia] (A.R.T., 2011). The total number on institutions of RT departments is the same (20) but with some changes because some institutions were purchased by others groups maintaining the two physical facilities for working in partnership.

The size and capacity of a RT department is measured by the number of RT equipment, the technologies of support to its operation and the multidisciplinary team, since these are the factors that determine the number of patients that can be treated by a RT facility. According to the recommendations of the European project “Quantification of radiation therapy infrastructure and staffing needs” of the ESTRO, each linac has the capacity to treat 400 to 500 patients per year, estimating the need of these machines as 6 devices per million of habitants (Belletti et al., 1996).

From this national survey there are two relevant conclusions from the experts (Pereira et al., 2008):

- Imperative need for replacement of 15 treatment units belonging to II and III classes;
- Allocation by the end of the next decade of 64 units of external RT according to the distribution proposed in the document.

It is well-known that interoperability in healthcare is an issue of vital importance, but also of vast complexity. The challenge is to find a way to allow interoperability between different IS in order to share information and resources (Walker et al., 2005, Ribeiro et al., 2010). A simple definition of interoperability is the ability for IS to exchange data and operate in a coordinated, seamless manner. Establishing ePR standards that would promote interoperability is the most recognized need in health IT. Within institutions that have implemented specific departmental applications, extensive time is spent developing and maintaining interfaces among the various IS (Shortliffe and Cimino, 2006).

In RT the interoperability between IS from different manufacturers is a problem if there is noncompliance with the DICOM-RT. In order to understand what DICOM-RT can and cannot provide it is important to distinguish between DICOM connectivity and application interoperability. DICOM connectivity refers to the DICOM message exchange standard responsible for establishing connections and exchanging correctly structured messages so that an information object sent from one node will be completely received by the receiving node. In other words, the “plug and exchange” between two pieces of equipment. DICOM application interoperability is the ability to process and manipulate information objects. In other words, the “plug and play” between IS of RT. DICOM-RT plays an important task in enabling such interoperability, requiring more than the standardized definition and coding of information provided by DICOM. It is not sufficient for a vendor to declare DICOM conformance to enable “plug and play” integration, because DICOM does not standardize applications. The DICOM standard has many optional attributes and only with specification and testing of the capabilities of the IS it guarantees effective integration of the various DICOM applications (Debruyne, 2009, N.E.M.A., 2011b).

The DICOM standard transfers RT data between IS and defines standard objects, services and protocols, being a widely accepted interface standard. It improves compatibility between applications and equipment supplied by different vendors constituting a reliable format with persistency of data and objects uniquely identifiable. In brief, it creates a basis for a data model, by defining a hierarchical data structure, information objects and services, and an archive DICOM-based. On the other hand, it does not handle all data needed in oncology, excluding administrative data, scheduling data, annotations, clinical data from other specialties, “quality assurance” related data (dosimetric data), etc. It does not specify: implementation details of any features of the standard on device with compliance, the set of functions to be expected from IS implemented by DICOM integration, the validation procedure to assess an



implementation's conformance to standard because that depends upon mutual conformance and proprietary processing of data once received. The DICOM conformance is voluntary; there are no conformance organizations in charge of legalizing compliance of IS or standard authorities for the approval or conformance enforcement. The responsibility to determine compatibility issues it is from the vendors and users.

Many forces were made for the product interoperability development and testing in the RT context, resulting in large number of manufacturers with products that support DICOM-RT objects. Vendors such as: *Elekta®*, *Impac®*, *Nucletron®*, *CMS® alphatec*, *Varian Medical Systems®*, *Siemens Medical Systems®*, *General Electric Medical Systems®*, *Merge Healthcare®*, *Multidata®*, *Best® nomos®*, *Philips®*, *Picker Network Solutions®*, *Open eye® rRocs®*, *Accuray® TomoTherapy®*, *CMS alphatech®* have products in conformance with DICOM-RT extension, but there are few vendors that fully support the DICOM-RT standard (Schlegel et al., 2006).

DICOM-RT implementation has some problems, because the “communication” part works but the “interoperation” part is difficult at the RT workflow being required custom made solutions. These problems lie on interpretation issues, optional elements and unsupported DICOM elements. Most commonly encountered DICOM-RT objects are RT structure set, RT plan and RT image and objects under development are RT worklist and RT dose calculation service.

According Nathan, *could be argued that it amounts to management negligence if a hospital acquires imaging modalities or PACS that do not conform to DICOM standard or adopt IHE-RO integration profiles* (Nathan, 2005).

The present bivalent study, in one hand, aims to characterize the Portuguese RT facilities, collecting data about treatment equipment, imaging modalities and IS, and on the other hand, aims to know the RT expert's opinion about the DICOM compliance, the DICOM-RT objects utilization and the interoperability existing in the IS of Portuguese RT departments.

## 3.2 Global Methodology

This section presents the characterization of study participants, the study design, details of the measuring instrument, description of the data collection and the statistical analysis.

### 3.2.1 Participants

The target population of this study are all RT departments from Portugal (n=20), which are represented geographically in figure 11, and listed in table 6 with identification of hospital type. For information, at present there are three RT departments that are under construction in the following cities: Braga, Ponta Delgada and Santa Maria da Feira that are not part of the target population.

Some departments belong to university hospitals or cancer centers representing about 30% of the total RT departments. In the scope of this study we have just considered facilities of external beam RT (most common type of RT). All RT departments which have agreed to participate have been included in the present study.

Each RT department is represented by one professional who provides the data required for both studies. Considered as DICOM-RT expert, were the following professionals: information technology (IT) director, head of medical physics, manager of radiation therapist and medical physicist.

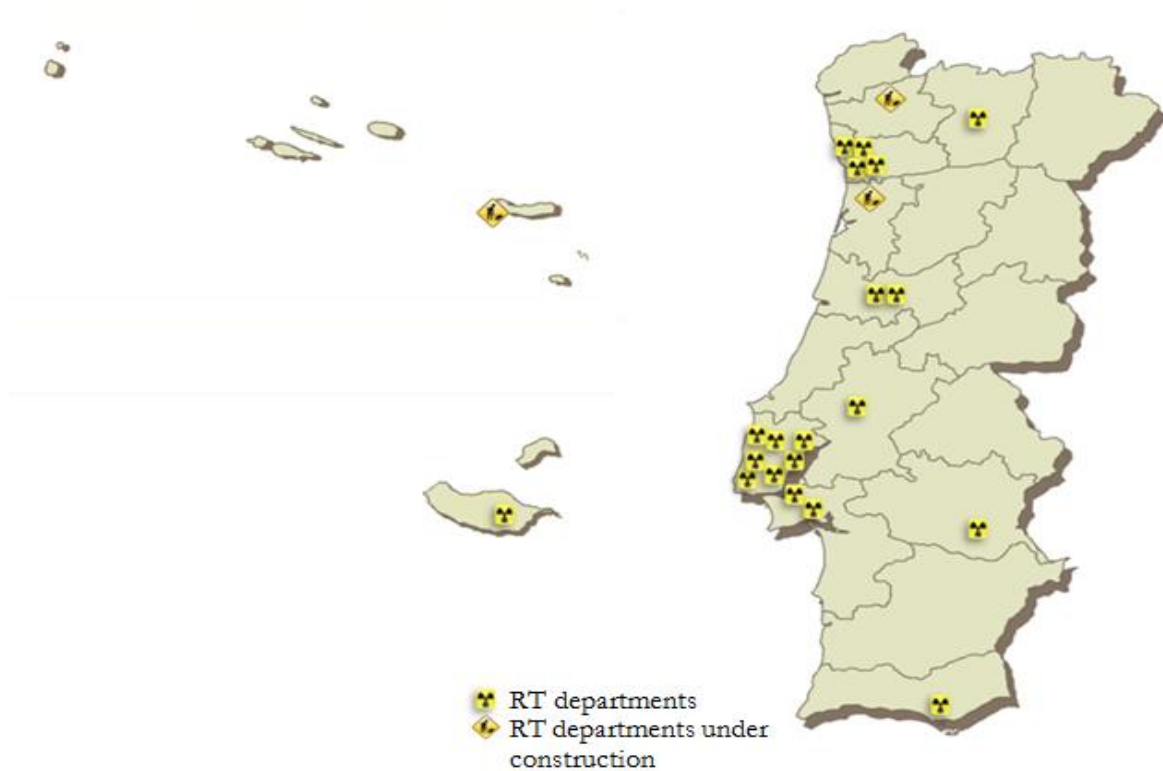


Figure 11. Geographical distribution of Portuguese RT departments

Table 6. Portuguese institutions with RT departments listed by geographic distribution

Portuguese institution	Health system
<b>North</b>	
Instituto Português de Oncologia do Porto	Public
Hospital São João	Public
Clínica de Radioterapia do Porto/Instituto de Diagnóstico e Tratamento *	Private
Quadrantes Porto	Private
Centro Hospitalar de Trás-os-Montes e Alto Douro (Hospital Vila Real)	Public
<b>Center</b>	
Instituto Português de Oncologia de Coimbra	Public
Hospitais da Universidade de Coimbra	Public
Quadrantes Santarém	Private
<b>South - Lisbon</b>	
Instituto Português de Oncologia de Lisboa	Public
Hospital Santa Marinha**	Public
Hospital Nossa Sra. do Rosário (Barreiro)	Public
Hospitalcuf Descobertas	Private
Hospital da Luz/Instituto de Radiologia Dr. Idílio de Oliveira *	Private
Quadrantes Lisboa (Centro Oncológico Dr.ª Natália Chaves)	Private
Clínica de Santo António	Private
Hospital SAMS (Serviços de Assistência Médico-Social) **	Mixed
<b>South</b>	
Hospital de Évora	Mixed
Hospital de Santiago (Setúbal)	Mixed
Quadrantes Faro (Clínica de Radioterapia e Medicina Nuclear de Faro)	Private
<b>Islands</b>	
Quadrantes Funchal	Mixed
* institutions that have two physical facilities for the RT department	
** institutions that work in partnership	

### 3.2.2 Study Design

This is a cross-sectional survey representing the reality found in RT departments and the opinion given by the DICOM-RT experts from the participating departments, and results presented in this master thesis are relative to the period May-September 2011.

### 3.2.3 Questionnaire

A structured questionnaire (see Appendix A) with five groups identified in table 7 was created by the researcher using professional experience (the researcher is radiation therapist) and theoretical background. For the RT national survey, the study focuses on questions of groups II and III, whereas for the DICOM-RT expert's opinion, the study addresses issues of groups I, IV and V.

Table 7. Structure of the questionnaire “DICOM-RT in the radiotherapy information systems”

Group	Title
I	Profile of the respondents
II	Characterization of the RT department <ul style="list-style-type: none"> <li>- Survey of technological resources</li> <li>- Survey of imaging modalities</li> <li>- Survey of IS</li> </ul>
III	Characterization of PACS
IV	Characterization of IS and the DICOM utilization
V	Opinion about interoperability

Group I collects personal data to characterize the participants in the study in terms of age group, sex, academic qualifications, professional position and experience, familiarity with DICOM and DICOM-RT and respective level of knowledge.

The group II for the survey of technological resources and imaging modalities was constructed based on the government document “Development strategy for the development of radiotherapy in Portugal for the next decade”(Pereira et al., 2008), and in some articles of national surveys from the U.K. (Jefferies et al., 2009), Japan (Teshima et al., 2008), Australia (Wigg and Morgan, 2001), and U.S.A. (Owen et al., 1997).

The other groups were based on the books “PACS and imaging informatics: basic principles and applications” (Huang, 2010), “Handbook of radiotherapy physics: theory and practice” (Mayles et al., 2007) and “Radiation oncology physics: a handbook for teachers and students” (Podgoršak, 2005), and on DICOM documents (N.E.M.A., 2011b). It is important to note that DICOM-RT objects addressed in the questionnaire for this study are the objects belonging to external beam RT, excluding two RT objects of ion therapy and one RT object of brachytherapy.

The questions types were closed response with single or multiple categories, and open response. The positive sentences using a *Likert* scale were used to obtain the opinion about interoperability (Mcdowell, 2006, Streiner and Norman, 2008).

The questionnaire was constructed during the period from January to April 2011, aiming to be adapted to the Portuguese reality and was reviewed by three experts (one medical physicist, one radiation therapist, and one professor of RT) that suggested some changes that were made. The web technology *MedQuest* was used to create the questionnaire (Gomes, 2009).

### 3.2.4 Data Collection

All chiefs of RT departments were informed about the survey and cooperation was asked by telephone and personally (to some chiefs of north institutions) during the period from April to June 2011. After confirming the collaboration in the study, an indication of the professional to be the future respondent was asked and advised to be one of the following: the IT director, the head of medical physics, or the manager of radiation therapist.

For some institutions, a formal requirement for authorization to conduct the survey was requested and other specific documents were demanded to sent to the administrative councils or ethics committee or research office (see Appendix C). The documents requested were filling specific questionnaires of the institution, letters to the chairman of the board of directors or of the ethics commission for the health, documents with the agreement of chiefs of RT departments, study protocol, statement's advisor of the thesis, researcher's *curriculum vitae*, etc.

After their support and multiple telephone calls with the participants, an e-mail (see Appendix D) was sent to each department who agreed to collaborate in the study during the period from May to July 2011 and the Uniform Resource Locator (URL) of the questionnaire was addressed to the experts (each institution received one specific URL). During the period from August to September 2011, follow-up telephone calls and emails sought to remember the participants to fill the questionnaire. Returned questionnaires were reviewed for logical consistency, and doubts were answered by email and telephone.

### 3.2.5 Statistical Analysis

The data obtained with the questionnaire was exported from *MedQuest* to the *IBM® SPSS®* version 19 for statistical analysis. Several tests and analysis were carried out for this study, however only some are presented in the results. The nonparametric test *Mann-Whitney U test* ( $\alpha=0.05$ ) was used to discover if there are differences statistically relevant about opinions regarding some characteristics of the sample. And the *Spearman's rank correlation coefficient* ( $\alpha =0.05/\alpha=0.01$ ) was used to assess the relationship between all statements of each question of opinion.

*I didn't think;  
I experimented.*

*Wilhelm Roentgen*



## 4. Results

In this chapter the results of each study are presented after the description of variables, in descriptive and associative form. The opinion study also has results about the questions' correlation.

The global response rate of the bivalent study was 70% (n = 14), while 10% (n = 2) of the institutions did not authorize the RT department to cooperate in the survey and the remaining 20% (n=4) did not get to answer the questionnaire on time.

### 4.1 RT National Survey

The variables considered about reality inside RT departments are the following:

- Which existing techniques of external RT;
- Quantification of the personnel:
  - Radiation oncologists;
  - Radiation therapists;
  - Medical physicists.
- Which existing equipments of RT (commercial designation, manufacturer, installation year):
  - Treatment machines;
  - Simulation equipments;
  - Imaging equipments.
- Which existing imaging modalities;
- Which existing IS (commercial designation, manufacturer, version):
  - TPS;
  - R&V;
  - VS;
  - Imaging systems;
  - PACS;
  - Quality control;
  - Institution IS.
- If exist a PACS:
  - Typology;
  - Implementation model;
  - Architecture model;
  - Functions;
  - Interfaces;
  - Compliance with DICOM v3.0.

### 4.1.1 Descriptive Results

The response rate of the national survey was 65% ( $n = 13$ ), because one department that participate in the study only collaborated in the expert's opinion. The institutions that answered the questionnaire are widely separated geographically and of varying departmental size (facilities with only 1 to 8 treatment units). The number of RT professionals per institution varies between 7 and 68, with a median of 13. Per RT department, radiation oncologists are in a median of 3, medical physicists in a median of 3, and radiation therapists in a median of 9. The nursing staff, assistants and clerks were not considered in this study.

Most of all RT departments have 3-D conformal RT (92.3%), and 50% of them have conventional RT too. The IMRT is present in 30.8% of departments and IGRT is present in the same proportion. Other existing techniques in departments are: total body irradiation (23.1%), gating (15.4%), radiosurgery (15.4%), intraoperative RT (7.7%), and stereotactic body RT (7.7%). One of the RT departments gathers seven different techniques.

In terms of treatment machines, all of the facilities have linac and one department has one cobalt-60 machine. The linac median installation year is 2007. Multiple treatment units are 61.5% of the departments, and 37.5% of them have treatment equipment from different manufacturers (see table 8 with the generic identification of the manufacturers). This means that only three departments (23.1%) have multiple-treatment units with machines from different vendors. From the total of 27 linacs, 20 of them are from the vendor A that also is the major vendor in simulators. Relatively to simulation, 38.5% have this equipment and 38.5% have virtual simulation. The simulators come from two vendors with a median utilization of 7 years, and the virtual simulation comes from other three different vendors (table 8). Concerning imaging, the vast majority of centers (76.9%) have CT at the department, two departments have a dedicated MRI and one department has SPECT/CT for RT planning purposes. The imaging equipment median installation year is 2009. All this imaging equipment is from three vendors (table 8) being 6 equipments from the manufacturer C, and other 6 from the manufacturer D.

All departments no longer work with analog image, using digital image, working mostly with CT and image registration carried out between planning CT with MRI, PET or diagnostic CT. Other images types used by RT departments, in order of frequency are: portal image of megavoltage, MRI, DRR from TPS, PET/CT, DRR from VS, portal image of kilovoltage, digital fluoroscopy, PET, and SPECT/CT.

Regarding IS, all departments have at least one TPS and one institution has three systems from different vendors. The major vendor of the TPS is the manufacturer A, implemented in 69.2% of departments followed by the vendor B implemented in 38.5% of departments. Imaging systems are from three different vendors being the same for the R&V systems. In RT departments with single-treatment unit, the R&V system is from the same vendor of linac, in departments with multiple treatment units, the R&V system is from the same vendor of one of the treatment machines. Therefore, the major manufacturer of the R&V systems is the same as linacs (manufacturer A). Quality control systems were not included in the table 8, because they are varied and with applications that have single-purpose tasks. Other IS are referred as used by RT department such as: HIS, RIS, electronic medical record, electronic nursing record, etc.

In terms of global number of manufacturers, just one department (7.7%) has one vendor for all equipment and IS. The most common scenario (46.2% of departments) is the department with two vendors, being one manufacturer for linacs, TPS and R&V system, and other manufacturer for imaging equipment. Departments with three vendors are 30.8%, with four vendors are 7.7% and with five vendors are 7.7%.



Table 8. Generic identification of the equipment/IS manufacturers of RT departments

		A	B	C	D	E	F	G	H	I
RT units	Linac	X	X	X	X					
	Cobal-60			X						
	Simulator	X			X					
Imaging equipment	CT			X	X	X				
	MRI			X						
	SPECT/CT				X					
RT information systems	VS		X	X					X	
	TPS	X	X				X	X		
	Imaging	X	X			X				
	R&V	X	X		X					
	PACS	X			X	X				X

Only four departments (30.8%) referred that use PACS in the RT workflow, being three of them dedicated for the RT department and the other one for the institution. These systems were implemented through the following models: turnkey, two-team effort and partnership, and the architecture of them is stand-alone, web-based and client server model respectively. The PACS implemented have DICOM compliance according to three institutions. The other institution doesn't have knowledge about these issues (implementation, architecture models and DICOM compliance). It was referred that PACS have interface mostly with R&V systems, CT WS, TPS, and fewer with simulator WS, imaging system, and application home-grown. The mainly functions appointed for the PACS were: archive, image reception, and database update.

In terms of manufacturers, by country of origin, Germany is the most common country (33.3%) followed by United States of America (22.2%), Netherlands (22.2%), Sweden (11.1%), and United Kingdom (11.1%). In RT departments, the country of manufacturers with the highest expression is United States of America. Equipments and IS from American vendors are implemented in 84.6% of RT departments. The vendor A has products in 76.9% of departments while the vendor C has products in 53.8% of departments.

#### 4.1.2 Associative Results

It is important to distinguish the results of some variables by health system (public, mixed or private) for the characterization of RT departments. These results are presented in tables 9, 10 and 11.

In terms of staffing patterns (see table 9), institutions with the lowest median belong to the private health system, having a median of 9 RT professionals by department. In contrast, public departments have the highest median, including a median of 22 RT professionals by department. A total of 193 RT professionals work at the RT departments, which are public hospitals, 35 professionals work at mixed institutions, and 42 professionals work at the departments belonging to clinics (private health system). The professional with less expression in RT departments is the medical physicist.

Table 9. Quantification of personnel and technologies by health system

Results	Public n=6	Mixed n=3	Private n=4	Total n=13
<b>Quantification of personnel, n:</b>				
Radiation oncologists	43	9	9	61
Radiation therapists	129	19	25	173
Medical physicists	21	7	8	36
Staff	193	35	42	270
<b>Personnel by department, median [min; max]:</b>				
Radiation oncologists	5 [3;15]	3 [2;4]	2 [2;3]	3 [2;15]
Radiation therapists	13 [5;48]	7 [3;9]	5 [4;9]	9 [3;48]
Medical physicists	3 [1;5]	2 [2;3]	2 [1;3]	3 [1;5]
staff	22 [9;68]	12 [7;16]	9 [9;13]	13 [7;68]
<b>Quantification of technologies, n:</b>				
Treatment machines	18	4	6	28
TPS	9	4	5	18
<b>Technologies by department, median [min; max]:</b>				
Treatment machines	2 [1;8]	1 [1;2]	1 [1;2]	2 [1;8]
TPS	1 [1;3]	1 [1;2]	1 [1;2]	1 [1;3]

Table 10. Techniques, equipments and imaging modalities by health system

Results, n (%)	Public n=6	Mixed n=3	Private n=4	Total n=13
<b>Techniques of external beam RT:</b>				
Conventional RT	3 (50)	1 (33.3)	2 (50)	6 (46.2)
3-D conformal RT	6 (100)	2 (66.7)	4 (100)	12 (92.3)
IMRT	4 (66.7)	0	0	4 (30.8)
IGRT	3 (50)	0	1 (25)	4 (30.8)
Intraoperative	1 (16.7)	0	0	1 (7.7)
Breathing control	2 (33.3)	0	0	2 (15.4)
Radiosurgery	1 (16.7)	1 (33.3)	0	2 (15.4)
Total body irradiation	3 (50)	0	0	3 (23.1)
Stereotactic Body RT	1 (16.7)	0	0	1 (7.7)
<b>Treatment machines:</b>				
Linac	6 (100)	3 (100)	4 (100)	13 (100)
Cobalt-60	0	0	1 (25)	1 (7.7)
Orthovoltage	0	0	0	0
<b>Simulation equipments:</b>				
Simulator	3 (50)	0	2 (50)	5 (38.5)
Virtual simulation	3 (50)	1 (33.3)	1 (25)	5 (38.5)
<b>Imaging equipments:</b>				
CT	6 (100)	2 (66.7)	2 (50)	10 (76.9)
MRI	1 (16.7)	1 (33.3)	0	2 (15.4)
SPECT/CT	0	1 (33.3)	0	1 (7.7)
<b>Imaging modalities:</b>				
Planning CT	6 (100)	3 (100)	4 (100)	13 (100)
PET/CT	2 (33.3)	1 (33.3)	2 (50)	5 (38.5)
SPECT/CT	1 (16.7)	1 (33.3)	0	2 (15.4)
PET	1 (16.7)	0	1 (25)	2 (15.4)
MRI	3 (50)	3 (100)	3 (75)	9 (69.2)
Planning CT-diagnostic CT	6 (100)	3 (100)	3 (75)	12 (92.3)
CT-MRI	6 (100)	3 (100)	4 (100)	13 (100)
CT-PET	6 (100)	2 (66.7)	4 (100)	12 (92.3)
DRR from TPS	4 (66.7)	2 (66.7)	3 (75)	9 (69.2)
DRR from VS	4 (66.7)	0	1 (25)	5 (38.5)
Portal image (megavoltage)	6 (100)	2 (66.7)	4 (100)	12 (92.3)
Portal image (kilovoltage)	3 (50)	0	1 (25)	4 (30.8)
Digital fluoroscopy imaging	3 (50)	0	1 (25)	4 (30.8)

Regarding treatment equipment (see table 9), there exists a total of 28 treatment units (27 linacs and 1 cobalt-60), operating 18 machines at public hospitals, 4 units implemented at mixed institutions and 6 units functioning at private institutions. The cobalt-60 machine is in use at one private institution (see table 10). The median of treatment machines are 2 for public departments, and 1 for mixed or private institutions. The most public departments are multiple treatment units(83.3%), and 50% of private institutions are single treatment unit and the other 50% are multiple treatment units (see table 11).

On the topic of TPS (see table 9), there exists a total of 18 systems implemented, being 6 different TPS belonging to 4 manufacturers: A, B, F, G (see table 8), having the manufacturer B 3 different systems. This vendor is present in 5 departments against vendor A, which is present in 9 departments. About 9 TPS are in use at public departments, 4 TPS are present at mixed institutions and 5 are in operation at RT clinics. Only 4 departments (30.8%) have multiple TPS for the RT workflow (see table 11).

According to the results presented in table 10, all public and private departments have 3-D conformal RT. Many techniques of external beam RT are only performed at public hospitals. These techniques are the following: IMRT, intraoperative, breathing control, total body irradiation and stereotactic body RT.

Regarding equipments, public hospitals performs virtual simulation in 50% of departments and the other 50% have simulator, while 50% of the private departments have simulator. All public hospitals have a CT at the department, and the SPECT/CT machine is present at a department belonging to mixed health system (see table 10).

On the subject of imaging modalities, all institutions independently of the health system type, use planning CT images and image registration between CT and MRI. Public and private departments use the image registration between CT and PET, and portal images with megavoltage. Public and mixed departments use the image registration between planning CT and diagnostic CT. All mixed departments use MRI for planning purpose (see table 10). About PACS utilization, a small % of departments use the system, implemented in 2 public hospitals and in 2 private institutions (table 11).

Table 11. PACS utilization, type of treatment units, and type of TPS workstations by health system

Results, n (%)	Public n=6	Mixed n=3	Private n=4	Total n=13
<b>PACS utilization:</b>				
PACS	2 (33.3)	0	2 (50)	4 (30.8)
<b>Type of treatment units:</b>				
Single treatment unit	1 (16.7)	2 (66.7)	2 (50)	5 (38.5)
Multiple treatment units	5 (83.3)	1 (33.3)	2 (50)	8 (61.5)
<b>Type of TPS workstation:</b>				
Single TPS	4 (66.7)	2 (66.7)	3 (75)	9 (69.2)
Multiple TPS	2 (33.3)	1 (33.3)	1 (25)	4 (30.8)

## 4.2 DICOM-RT Expert's Opinion

The variables considered about DICOM-RT expert's opinion are the following:

- Profile of the respondent:
  - Age group;
  - Sex;
  - Academic qualification;
  - Professional position;
  - Professional experience;
  - If know DICOM standard;
    - Level of knowledge;
  - If know DICOM-RT extension;
    - Level of knowledge;

- Characterization of IS:
  - Inventory of IS;
  - Compliance with DICOM v3.0;
  - Compliance with DICOM-RT;
  - Which DICOM-RT objects are in use;
  - Utilization of other communication standards.
- How to describe utilization of DICOM-RT in the RT workflow;
- How to describe the IS of RT department behavior (alone or interoperable);
- When purchasing a new IS for the department, the interoperability issue is addressed:
  - Which factors are more important;
  - Who defines the IS integration.
- For a good policy is it better one single vendor or multiple vendors;
- To achieve IS interoperability with DICOM-RT, which procedures are more important;
- Which factors are more important, for the immaturity of the DICOM-RT implementation;
- Which benefits of DICOM-RT are more important;
- If there are any interoperability problems between the IS in the RT department;
  - If yes, identify the problems specifying the IS participants.

#### 4.2.1 Descriptive Results

The response rate of the expert's opinion study was 70% ( $n = 14$ ). The respondents are mostly women (78.6%) with 71.4 % being at age group of 31 to 40 years old [21 to 30; 61 to 70], and as expected, all of them have higher education: 50% have a "licentiate" degree and the other 50% have a master's degree. Regarding professional position, they are mainly medical physicists (85.7%), being 58.3% of them head of medical physics with a median experience of 6.5 years [1; 28 years]. Almost all of the participants (92.9%) know the DICOM standard and RT extensions, and 50% of those consider their level of knowledge as reasonable and 28.6% as good.

According to 57.1% of experts, the RT department has an inventory of all IS in utilization, and 75% of these have a document that lists the functionalities of each IS. According to 64.3% of participants, the imaging equipments are in conformance with DICOM v3.0, and 85.7% of participants say that the IS of RT are DICOM-RT compliant. As to DICOM-RT objects implementation, RT plan and RT structure set are implemented in most departments (85.7%), followed by RT dose (78.6%), and RT image and RT beam treatment record (64.3%). With respect of other communication standards utilization, is referred by 35.7% of participants, but the only standard identified was HL7.

Respondents were asked about the utilization of DICOM-RT objects in the RT workflow, 71.4% of them classify the utilization as excellent or above average. The behavior of the IS, according to 57.1% of the participants, is interoperable because they integrate information from different IS vendors, and allow the data integration from HIS. The results respecting these variables are presented in table 12.

Table 12. Results from questions 4.2 and 7 (group IV) of the questionnaire

Results	Response levels										Total		Median
	n	%	n	%	n	%	n	%	n	%	n	%	
	extremely poor		below average		average		above average		excellent				
Evaluation of the DICOM-RT objects utilization at workflow of the RT department:	0	0	0	0	2	14.3	5	35.7	5	35.7	12	85.7	above average
	strongly disagree		disagree		undecided		agree		strongly agree				
The IS implemented in RT department behave like:													
1- Isolated systems	3	21.4	2	14.3	2	14.3	4	28.6	0	0	11	78.6	undecided
2- Systems that integrate clinical information between applications from different vendors	0	0	1	7.1	0	0	3	21.4	5	35.7	9	64.3	strongly agree
3- Systems that allow the integration of data from HIS	0	0	2	14.3	0	0	4	28.6	4	28.6	10	71.4	agree
4- Systems that allow integration of data from IS of other departments of the institution	1	7.1	2	14.3	0	0	3	21.4	3	21.4	9	64.3	agree

When purchasing a new IS for the department, 64.3% of respondents stated that the interoperability issue is addressed; the others answered “I have no knowledge” or not answered the question. The experts believe that the important factors in this issue are: (1<sup>st</sup>) integration problems in the existing IS, (2<sup>nds</sup>) IS need, interoperability problems in RT workflow, and (4<sup>th</sup>) context of the IS purchasing. The integration of the new IS in the workflow, is commonly defined by the vendor together with the IT staff and the medical physicist (see table 13).

Table 13. Results from questions 1.1 and 1.2 (group V) of the questionnaire

	Response levels										Total		Median
	n	%	n	%	n	%	n	%	n	%	n	%	
	unimportant		of little importance		moderately important		important		very important				
What is the preponderance of the following factors in interoperability approach:													
1- Context of the IS purchase	0	0	0	0	2	14.3	5	35.7	2	14.3	9	64.3	important
2- IS need	0	0	0	0	0	0	2	14.3	7	50	9	64.3	very important
3- Integration problems in the existing IS	0	0	0	0	0	0	2	14.3	8	57.1	10	71.4	very important
4- Interoperability problems in RT workflow	0	0	0	0	1	7.1	5	35.7	4	28.6	10	71.4	important
	never		rarely		sometimes		very often		always				
Who defines the IS integration:													
1- Only the vendor	5	35.7	0	0	1	7.1	2	14.3	1	7.1	9	64.3	never
2- Only the IT service	4	28.6	1	7.1	2	14.3	2	14.3	1	7.1	10	71.4	rarely
3- Only the medical physics	4	28.6	1	7.1	1	7.1	3	21.4	0	0	9	64.3	rarely
4- The vendor together with the IT service	2	14.3	2	14.3	2	14.3	1	7.1	2	14.3	9	64.3	sometimes
5- The vendor together with medical physics	1	7.1	2	14.3	2	14.3	3	21.4	0	0	8	57.1	sometimes
6- The vendor together with the IT service and medical physics	1	7.1	0	0	4	28.6	5	35.7	1	7.1	11	78.6	very often

For a good policy, 71.4% of experts assume that “most sophisticated equipments” and “flexibility of IS for integration in multi-vendor context” are important and very important for the RT department. To achieve IS interoperability with the DICOM-RT the procedures considered more important are: (1<sup>st</sup>)

replacement of analogue by digital image; (2<sup>nds</sup>) determination of workflows; creation of mechanisms for interface between IS and technologies; and version upgrade of RT IS. Results are shown in table 14.

Table 14. Results from questions 2 and 3 (group V) of the questionnaire

	Response levels										Total		Median
	n	%	n	%	n	%	n	%	n	%	n	%	
	unimportant		of little importance		moderately important		important		very important				
For a good policy in RT department, what the importance of:													
1- A single vendor for IS	0	0	4	28.6	2	14.3	3	21.4	2	14.3	11	78.6	moderately important
2- A single vendor for RT equipments	0	0	4	28.6	3	21.4	2	14.3	2	14.3	11	78.6	moderately important
3- The same vendor for RT equipments and IS	1	7.1	4	28.6	0	0	4	28.6	3	21.4	12	85.7	important
4- Multiple vendors	0	0	4	28.6	3	21.4	3	21.4	0	0	10	71.4	moderately important
5- Most sophisticated equipment for RT technique	0	0	0	0	0	0	6	42.9	4	28.6	10	71.4	important
6- Flexibility in IS for multi-vendor equipment integration	0	0	0	0	0	0	4	28.6	6	42.9	10	71.4	very important
To achieve IS interoperability with DICOM-RT, what the importance of:													
1- Version upgrade of RT IS	0	0	0	0	2	14.3	3	21.4	8	57.1	13	92,9	very important
2- Replacement of some technological resources	0	0	2	14.3	3	21.4	4	28.6	4	28.6	13	92,9	important
3- Determination of workflows	0	0	0	0	1	7.1	5	35.7	7	50	13	92,9	very important
4- Implementation of ePR in the institution	0	0	0	0	2	14.3	4	28.6	6	42.9	12	85.7	important
5- Replacement of analogue by digital image	0	0	0	0	0	0	3	21.4	10	71.4	13	92,9	very important
6- Creation of mechanisms for interface between IS and technologies	0	0	0	0	1	7.1	5	35.7	7	50	13	92,9	very important
7- PACS acquisition	0	0	2	14.3	3	21.4	5	35.7	3	21.4	13	92,9	important

The three most important reasons to justify the immaturity of the DICOM-RT implementation, classified by the experts are: (1<sup>st</sup>) inexistence of DICOM-based archive; (2<sup>nd</sup>) high complexity of RT workflows; and (3<sup>rd</sup>) lack of strategy management of the institution (see table 15).

Regarding DICOM-RT benefits (see table 15) experts rated the following order of importance (as shown in table 15): (1<sup>st</sup>) transfer of information between different IS vendors; (2<sup>nd</sup>) integration of RT technologies in IS multi-vendor context; (3<sup>rd</sup>) communication with other specialties; (4<sup>th</sup>) communication with other RT departments; (5<sup>th</sup>) integration into the ePR; (6<sup>th</sup>) workflow monitoring; (7<sup>th</sup>) support for computer-assisted decision; (8<sup>th</sup>) helpful in image-assisted knowledge discovery; and (9<sup>th</sup>) helpful in clinical research.

For the open question about the existence of interoperability problems between IS of the RT department, only two participants assumed that have problems. One expert specified that the problem resides in the interface between the R&V system with three different HIS, and the other expert identified that the problem is based on the fact of having many different vendors in the department.

Table 15. Results from questions 4 and 5 (group V) of the questionnaire

	Response levels										Total		Median
	n	%	n	%	n	%	n	%	n	%	n	%	
	unimportant		of little importance		moderately important		important		very important				
For the immaturity of the DICOM-RT implementation, what the importance of:													
1- Lack of strategy management of the institution	2	14.3	0	0	4	28.6	3	21.4	3	21.4	12	85.7	moderately important
2- Opposition to workflow's changing	1	7.1	2	14.3	3	21.4	4	28.6	2	14.3	12	85.7	moderately important
3- High complexity of RT workflows	0	0	1	7.1	5	35.7	4	28.6	2	14.3	12	85.7	moderately important
4- Inexistence of DICOM-based archive	2	14.3	0	0	0	0	6	42.9	4	28.6	12	85.7	important
5- Difficulties in DICOM-RT interpretation	2	14.3	3	21.4	0	0	5	35.7	2	14.3	12	85.7	important
6- Lack of DICOM-RT objects for some RT data	1	7.1	1	7.1	3	21.4	3	21.4	3	21.4	11	78.6	important
7- No regulation and certification of RT software	1	7.1	1	7.1	3	21.4	4	28.6	2	14.3	11	78.6	important
8- Low DICOM-RT compliance by manufacturers	2	14.3	1	7.1	1	7.1	6	42.9	1	7.1	11	78.6	important
9- Emergence of RT techniques with rapid technological change	0	0	2	14.3	3	21.4	4	28.6	2	14.3	11	78.6	important
From benefits of DICOM-RT, what the importance of:													
1- Transfer of information between different IS vendors	0	0	0	0	0	0	6	42.9	6	42.9	12	85.7	important
2- Integration of RT technologies in IS multi-vendor context	0	0	0	0	1	7.1	6	42.9	5	35.7	12	85.7	important
3- Workflow monitoring	0	0	0	0	2	14.3	7	50	3	21.4	12	85.7	important
4- Integration into the ePR	0	0	0	0	2	14.3	4	28.6	5	35.7	11	78.6	important
5- Communication with other specialties	0	0	0	0	3	21.4	4	28.6	5	35.7	12	85.7	important
6- Communication with other RT departments	0	0	1	7.1	2	14.3	5	35.7	4	28.6	12	85.7	important
7- Helpful in clinical research	0	0	1	7.1	2	14.3	5	35.7	3	21.4	11	78.6	important
8- Support for computer-assisted decision	0	0	0	0	2	14.3	6	42.9	3	21.4	11	78.6	important
9- Helpful in image-assisted knowledge discovery	0	0	0	0	3	21.4	5	35.7	3	21.4	11	78.6	important

## 4.2.2 Associative Results

For some questions it is pertinent to know if there exist differences in opinion dependent of some variables of the expert profile or RT department characterization. Important variables considered were: the academic qualification and the professional experience of the expert, and the type of RT department where the expert works (with linacs of single or multi-vendors). It was used the nonparametric test *Mann-Whitney U test* to discover if there are differences statistically relevant about opinions regarding the two defined groups by characteristics mentioned above. Results are shown in tables 16 to 21.

The evaluation of the DICOM-RT objects utilization and the behavior of IS implemented in RT department did not presented differences statistically significant between the groups of linac's context (see table 16). In other words, the opinion of the experts about the issues of DICOM-RT utilization and behavior of IS is not influenced by the type of treatment unit (single or multi-vendor) where they work.

Table 16. DICOM-RT utilization at RT workflow and IS behavior by linac's context of RT department

Results (n, median)	Linac's context		Test*	Total
	single-vendor	multi-vendor	p-value	n, median
<b>Evaluation of the DICOM-RT objects utilization at workflow of the RT department:</b>	9, excellent	3, above average	0.110	12, above average
<b>The IS implemented in RT department behave like:</b>				
1- Isolated systems	8, undecided	3, disagree	0.672	11, undecided
2- Systems that integrate clinical information between applications from different vendors	7, agree	2, strongly agree	0.190	9, strongly agree
3- Systems that allow the integration of data from HIS	8, agree	2, agree	0.576	10, agree
4- Systems that allow integration of data from IS of other departments of the institution	8, agree	1, strongly agree	0.227	9, agree

\*Mann-Whitney U test

Factors that affect the interoperability approach when purchasing new IS for the department did not presented differences statistically significant between the two groups of experts divided by the years of professional experience (see table 17). Regarding the identification of professionals that do the IS integration after the purchase, experts with less experience say that usually the professionals involved are the vendor together with the IT staff and the medical physicist. Experts with more years of experience think that professionals involved very often are only the vendor with the medical physicist. There is a difference statistically significant concerning the opinion about the frequency relative to the statement “the vendor together with the medical physics”; experts with less years of experience think that this rarely happens in the RT department and the other group of experts with more years of experience thinks that this happens very often.

Table 17. Preponderance of factors in interoperability approach and services involved in the IS integration by years of professional experience of experts

Results (n, median)	Professional experience		Test*	Total
	<6.5 years	≥6.5 years	P-value	n, median
<b>What is the preponderance of the following factors in interoperability approach:</b>				
1- Context of the IS purchase	4, important	5, important	1.000	9, important
2- IS need	4, very important	5, very important	0.866	9, very important
3- Integration problems in the existing IS	5, very important	5, very important	0.134	10, very important
4- Interoperability problems in RT workflow	5, important	5, important	0.729	10, important
<b>Who defines the IS integration:</b>				
1- Only the vendor	4, never	5, sometimes	0.345	9, never
2- Only the IT service	5, sometimes	5, rarely	0.828	10, rarely
3- Only the medical physics	5, never	4, rarely	0.696	9, rarely
4- The vendor together with the IT service	4, never	5, sometimes	0.455	9, sometimes
5- The vendor together with the medical physics	4, rarely	4, very often	<b>0.025</b>	8, sometimes
6- The vendor together with the IT service and medical physics	6, very often	5, sometimes	0.492	11, very often

\*Mann-Whitney U test

Experts of RT department with linacs from a single-vendor gave more importance to most scenarios of treatment units for a good policy in RT department, contrary to experts with multi-vendor context of linacs (see table 18). However, not was found difference statistically significant between these two groups (all *sig.* ≥ 0,05).



Table 18. Importance attributed to possible scenarios of treatment units for a good policy in RT departments by linac's context

For a good policy in RT department, what the importance of (n, median):	Linac's context		Test*	Total
	single-vendor	multi-vendor	p-value	n, median
1- A single vendor for IS	9, moderately important	2, of little importance	0.087	11, moderately important
2- A single vendor for RT equipments	9, important	2, of little importance	0.087	11, moderately important
3- The same vendor for RT equipments and IS	9, important	3, of little importance	0.440	12, important
4- Multiple vendors	8, moderately important	2, of little importance	0.890	10, moderately important
5- Most sophisticated equipment for RT technique	8, important	2, important	0.759	10, important
6- Flexibility in IS for multi-vendor equipment integration	8, very important	2, important	0.759	10, very important

\*Mann-Whitney U test

As shown in table 19, experts with “licenciate” degree gave more importance to most of the procedures to achieve interoperability, but only it was found statistically significant differences of opinion regarding the degree of importance on the “replacement of some technological resources” ( $sig. \leq 0,05$ ). Therefore, RT experts with more academic qualification attribute less importance to the “replacement of some technological resources” to achieve IS interoperability with DICOM-RT.

Table 19. Importance attributed to procedures to achieve interoperability with DICOM-RT by academic qualification of the experts

To achieve IS interoperability with DICOM-RT, what the importance of (n, median):	Academic qualification		Test*	Total
	“licenciate” degree	master's degree	p-value	n, median
1- Version upgrade of RT IS	6, very important	7, important	0.118	13, very important
2- Replacement of some technological resources	6, important	7, moderately important	<b>0.026</b>	13, important
3- Determination of workflows	6, very important	7, important	0.335	13, very important
4- Implementation of ePR in the institution	5, very important	7, important	0.375	12, important
5- Replacement of analogue by digital image	6, very important	7, very important	0.626	13, very important
6- Creation of mechanisms for interface between IS and technologies	6, very important	7, important	0.505	13, very important
7- PACS acquisition	6, important	7, important	0.602	13, important

\*Mann-Whitney U test

The factor classified as the most important for the immaturity of the DICOM-RT implementation was the “inexistence of DICOM-based archive”, and experts with less professional experience (table 20) attributed more importance than the others. This difference is statistically significant, and it can be concluded that experts with professional experience up to 6,5 years give more importance to the “inexistence of DICOM-based archive” than the experts with more professional experience.

Table 20. Importance attributed to factors for the immaturity of the DICOM-RT implementation by professional experience of the experts

For the immaturity of the DICOM-RT implementation, what the importance of (n, median):	Professional experience		Test*	Total
	<6.5 years	≥6.5 years	P-value	n, median
1- Lack of strategy management of the institution	5, moderately important	7, important	1.000	12, moderately important
2- Opposition to workflow's changing	5, moderately important	7, important	0.738	12, moderately important
3- High complexity of RT workflows	5, important	7, moderately important	0.229	12, moderately important
4- Inexistence of DICOM-based archive	5, very important	7, important	<b>0.008</b>	12, important
5- Difficulties in DICOM-RT interpretation	5, important	7, important	0.268	12, important
6- Lack of DICOM-RT objects for some RT data	5, very important	6, moderately important	0.133	11, important
7- No regulation and certification of RT software	5, important	6, moderately important	0.219	11, important
8- Low DICOM-RT compliance by manufacturers	5, important	6, important	0.549	11, important
9- Emergence of RT techniques with rapid technological change	5, moderately important	6, important	0.924	11, important

\*Mann-Whitney U test

In table 21 it is clear that experts with fewer years of professional experience gave more importance to all benefits of DICOM-RT comparatively with experts with more experience. Nevertheless, this difference is only statistically significant for the following two benefits: “integration into the ePR” and “helpful in clinical research”. So, we can conclude that experts of RT with less professional experience (<6.5 years) attribute more importance to some DICOM-RT benefits.

Table 21. Importance of DICOM-RT benefits by years of professional experience of the experts

From benefits of DICOM-RT, what the importance of (n, median):	Professional experience		Test*	Total
	<6.5 years	≥6.5 years	P-value	n, median
1- Transfer of information between different IS vendors	5, very important	7, important	0.093	12, important
2- Integration of RT technologies in IS multi-vendor context	5, very important	7, important	0.588	12, important
3- Workflow monitoring	5, very important	7, important	0.143	12, important
4- Integration into the ePR	5, very important	6, important	<b>0.039</b>	11, important
5- Communication with other specialties	5, very important	7, important	0.100	12, important
6- Communication with other RT departments	5, very important	7, important	0.197	12, important
7- Helpful in clinical research	5, very important	6, moderately important	<b>0.020</b>	11, important
8- Support for computer-assisted decision	5, very important	6, important	0.158	11, important
9- Helpful in image-assisted knowledge discovery	5, very important	6, important	0.118	11, important

\*Mann-Whitney U test

#### 4.2.3 Question Correlation Results

To assess the correlation between the variables of DICOM-RT expert's opinion a non-parametric measure of statistical dependence was used. The *Spearman's rank correlation coefficient* was used to show the relationship between the variables (opinions).

The *Spearman* correlation between the question about the IS behavior in RT department and factors preponderant in interoperability approach when purchasing new IS for RT department (table 22) detects four relationships between some opinions that are statistically significant. Questions that are most strongly

correlated are the question 7.1 with the question 1.1.4; they are negatively correlated, meaning that experts who disagreed with the behavior of “isolated systems” in his own department attributed importance to the “interoperability problems in RT workflow” as a preponderant factor when purchasing new IS for RT department. Question 7.1 is negatively correlated with the question 7.4, that is, experts who disagreed with the behavior of “isolated systems” agreed with the behavior of “systems that allow integration of data from IS of other departments of the institution”. Question 7.4 correlates positively with questions 7.3 and 1.1.4. In other words, experts who consider the behavior of IS of RT department which they represent, such as “systems that allow integration of data from IS of other departments of the institution”, also agree with “systems that allow the integration of data from HIS” and classify as an important factor “interoperability problems in RT workflow” when purchasing new IS for RT department.

Table 22. Correlation between questions about the IS behavior in RT department where the expert works and factors preponderant in interoperability approach when purchasing new IS for RT department

q7.1	1								
q7.2	-0.310	1							
q7.3	-0.406	0.662	1						
q7.4	<b>-0.723*</b>	0.392	<b>0.723*</b>	1					
q1.1.1	0.503	0.497	0.000	-0.400	1				
q1.1.2	0.054	-0.069	-0.267	-0.458	0.401	1			
q1.1.3	-0.404	0.612	0.498	0.269	-0.401	-0.286	1		
q1.1.4	<b>-0.861**</b>	0.429	0.528	<b>0.697*</b>	-0.289	0.231	0.289	1	
q7.1	q7.2	q7.3	q7.4	q1.1.1	q1.1.2	q1.1.3	q1.1.4		

\* Statistically significant at a level of 5%

\*\* Statistically significant at a level of 1%

Concerning the relationship between questions about professionals who define the IS integration when implementing new IS in RT department, there are four relations statistically significant between answers (see table 23). Questions that are most strongly correlated are question 1.2.4 and 1.2.2; they are positively correlated, meaning that experts who believe that sometimes the IS integration is defined by the vendor together with the IT staff, also believe that rarely the integration is defined only by the IT staff. Question 1.2.1 correlates positively with questions 1.2.3 and 1.2.4. In other words, experts who consider that rarely the IS integration is defined only by the vendor, also think that rarely is made only by the medical physicist and that is carried sometimes by the vendor together with the IT staff. Question 1.2.6 is negatively correlated with question 1.2.3, and this means those experts who assume that the integration is performed by the vendor together with the IT staff and the medical physics staff very often, think that this task is rarely performed only by the medical physics.

Table 23. Correlation between questions about the professionals that defines the IS integration when implementing new IS in RT department

q1.2.1	1					
q1.2.2	0.603	1				
q1.2.3	<b>0.819*</b>	0.430	1			
q1.2.4	<b>0.801**</b>	<b>0.886**</b>	0.701	1		
q1.2.5	0.269	-0.106	0.386	0.237	1	
q1.2.6	-0.313	-0.390	<b>-0.735*</b>	-0.594	-0.343	1
q1.2.1	q1.2.2	q1.2.3	q1.2.4	q1.2.5	q1.2.6	

\* Statistically significant at a level of 5%

\*\* Statistically significant at a level of 1%

With reference to the relationship between questions about possible scenarios of treatment unit's context that contribute for a good policy in RT department, there are three strong relations statistically significant between answers (see table 24). Question 2.1 correlates positively with questions 2.2 and 2.3, which also have a positive correlation between them. Therefore, experts who attribute moderately importance for “a single vendor for IS” as well for “a single vendor for RT equipments”, also attribute importance for “the same vendor for RT equipments and IS”.

Table 24. Correlation between various scenarios of treatment unit's context that contribute for a good policy in RT department

q2.1	1					
q2.2	<b>0.896**</b>	1				
q2.3	<b>0.894**</b>	<b>0.806**</b>	1			
q2.4	-0.120	-0.334	-0.095	1		
q2.5	0.204	0.508	0.161	-0.147	1	
q2.6	0.204	0.274	0.161	0.393	0.250	1
	q2.1	q2.2	q2.3	q2.4	q2.5	q2.6

\*\*Statistically significant at a level of 1%

About the correlation between procedures to achieve interoperability with DICOM-RT, there are six relations with correlation values of moderate and strong positive correlation (see table 25). Question 3.4 is correlated with questions 3.2, 3.3, 3.5 and 3.7. This means that experts, who classify the “implementation of ePR in the institution” as an important procedure to achieve interoperability with DICOM-RT, also classify as important “replacement of some technological resources” and “PACS acquisition”, and classify as very important “determination of workflows” too. Question 3.5 is correlated with questions 3.3 and 3.7, and which means that experts who consider “replacement of analogue by digital image” as a very important procedure (most experts, n=10), also consider “determination of workflows” a very important procedure and “PACS acquisition” a important procedure.

Table 25. Correlation between procedures to achieve interoperability with DICOM-RT

q3.1	1						
q3.2	0.431	1					
q3.3	0.038	0.507	1				
q3.4	-0.098	<b>0.718**</b>	<b>0.693*</b>	1			
q3.5	-0.151	0.402	<b>0.686**</b>	<b>0.775**</b>	1		
q3.6	-0.065	0.023	-0.326	-0.151	-0.317	1	
q3.7	-0.016	0.450	0.226	<b>0.689*</b>	<b>0.567*</b>	0.086	1
	q3.1	q3.2	q3.3	q3.4	q3.5	q3.6	q3.7

\* Statistically significant at a level of 5%

\*\*Statistically significant at a level of 1%

The correlation among the all factors for the immaturity of the DICOM-RT implementation (table 26) shows many relationships between the expert's opinions, having various strong positive correlations and one very strong correlation. Question 4.7 is very strongly correlated with question 4.6 positively, and this means that experts who classify “no regulation and certification of RT software” as an importance factor for the immaturity of the DICOM-RT implementation did the same for “lack of DICOM-RT objects for some RT data”.

Table 26. Correlation between factors for the immaturity of the DICOM-RT implementation

q4.1	1								
q4.2	<b>0.854**</b>	1							
q4.3	0.372	0.270	1						
q4.4	0.415	0.560	0.228	1					
q4.5	<b>0.727**</b>	<b>0.688*</b>	0.539	<b>0.721**</b>	1				
q4.6	0.422	0.439	0.557	<b>0.688*</b>	<b>0.892**</b>	1			
q4.7	0.344	0.330	0.465	<b>0.667*</b>	<b>0.846*</b>	<b>0.973**</b>	1		
q4.8	<b>0.670*</b>	<b>0.765**</b>	0.267	<b>0.784**</b>	<b>0.820*</b>	<b>0.709*</b>	<b>0.711*</b>	1	
q4.9	0.527	0.209	0.592	-0.125	0.476	0.428	0.340	0.026	1
	q4.1	q4.2	q4.3	q4.4	q4.5	q4.6	q4.7	q4.8	q4.9

\* Statistically significant at a level of 5%

\*\*Statistically significant at a level of 1%

The relation among all benefits of DICOM-RT classified by experts presents many correlations, being the strong correlations all positives (see table 27). Question 5.8 is very strongly correlated with question 5.9, and this means that experts who attribute importance to “support for computer-assisted decision” did the same to “helpful in image-assisted knowledge discovery”.

Table 27. Correlation between levels of importance attributed to benefits of DICOM-RT

q5.1	1								
q5.2	0.267	1							
q5.3	0.391	-0.070	1						
q5.4	0.576	0.171	0.314	1					
q5.5	0.626	0.390	0.461	<b>0.794**</b>	1				
q5.6	0.548	0.000	0.143	<b>0.890**</b>	<b>0.685*</b>	1			
q5.7	0.498	0.045	0.467	<b>0.737*</b>	<b>0.776**</b>	<b>0.663*</b>	1		
q5.8	<b>0.696*</b>	0.161	0.389	0.535	<b>0.843**</b>	<b>0.619*</b>	<b>0.770**</b>	1	
q5.9	<b>0.742**</b>	0,000	0.369	<b>0.690*</b>	<b>0.777**</b>	<b>0.821**</b>	<b>0.821**</b>	<b>0.921**</b>	1
q5.1	q5.2	q5.3	q5.4	q5.5	q5.6	q5.7	q5.8	q5.9	

\* Statistically significant at a level of 5%

\*\* Statistically significant at a level of 1%



*One never notices what has been done;  
one can only see what remains to be done.*

*Marie Curie*





## 5. Discussion

Currently in health care, the question of interoperability is considered as crucial for achieving gains, by improving the quality and continuity of care, allowing cost reduction by minimizing repeated procedures, improving clinical research and decision support, among many others.

In RT the interoperability between IS from different manufacturers is an issue if there is no compliance with the DICOM-RT. The purchase of all equipment from a single manufacturer would solve the problem, but the department would be dependent of one manufacturer. Hypothetical situations of this scenario can be the following: the vendor is purchased by another vendor; the department needs some product that the vendor simply doesn't offer, etc. From the user's perspective this scenario is not a good situation; apart from that the exchange of RT data for cross-center research it would not be possible. The ideal situation for a RT department is the implementation of equipment multi-vendor to have the "best-of-breed" equipment. The cost of developing custom interfaces is high and it can be technically difficult. More important that achieve connectivity "plug and exchange" between two IS is to accomplish application interoperability "plug and play". The DICOM-RT extension through objects designed for RT provides a data format and a communication protocol, providing compatibility between IS, safety, repeatability, interoperability, and commoditization in enabling choice of vendors for "best of breed". With DICOM-RT a full electronic workflow is possible, a total data transfer between applications and linking unlimited between them are achievable, and management of information without proprietary databases with an open systems environment is reachable.

According to the authors Law, Huang, Liu, Chan, Bosh, and Field, the standard DICOM-RT with RT-PACS model following the IHE profiles makes integration of RT information possible. All data and images from various sources can be converted to DICOM-RT objects and integrated into DICOM-based database, being displayed as a DICOM-RT based ePR system. A single copy of any image data is held on a RT-PACS and accessed by multiple IS that allow removal of the image data from the local database and archival of the locally created DICOM-RT objects when not needed. From the DICOM-based database, the connection to other RT IS and the exchange of RT patient information are achievable leading to further initiatives in informatics research in RT context.

Shakeshaft declares that few manufacturers are using a generic DICOM archive in their implementations not minimizing multiple copies of the same data and not sharing data between IS (Shakeshaft, 2010). This reflects that the DICOM-RT extension is not yet fully mature due to the set of DICOM-RT problems, RT workflow complexity and technological development context.

Essential for RT departments' cooperation has been the issue of confidentiality and anonymity of participants. The data collection in the majority of the cases was hard due to the unavailability of the chiefs of RT departments and the lack of response to requests for authorization to apply the questionnaire by the administrations of the institutions. One institution (private) only answered part of the questionnaire (Groups I, IV and V), giving mainly the DICOM-RT expert opinion because did not want to identify the technologies implemented in the department. Some experts did not answer all the questions. This may be over due to some factors such as: the lack of documentation regarding existing IS and their integrations in departments, lack of knowledge on the subject of interoperability and DICOM-RT, questionnaire too long, lack of availability of the expert to answer the questionnaire, etc.

According to the results of the survey and taking into account the conclusions from the document of the High Commissioner for Health (Pereira et al., 2008), in our participants it was allocated 14 new units of external RT units, being 6 of them to replace units belonging to II and III classes and 2 from a new RT department. But, it was found there is still a treatment unit belonging to III class that needs to be replaced.

Results show that RT departments have IS and equipments from different vendors. The most public departments (83.3%) are multiple treatment units, but only 23.1% of all departments have multiple treatment units with equipments from different manufacturers. It becomes evident that Portuguese departments have no tendency to buy linacs from different vendors, not investing in the best equipments offered by the market, because departments that were built in the last decade implemented only treatment units with linacs from the same vendor. The main example of this trend is the case of the department that has nine treatment units, all from the same vendor. This fact may be due to the unwillingness of RT professionals to resolve integration problems between the linacs and the other equipments and IS at the RT department. With respect to imaging, all departments use digital image and images from registration, and the associated equipments are relatively recent. About the PACS, there are few departments that implemented it, being mostly dedicated to the department (RT-PACS) and with DICOM compliance.

Regarding vendors, it was found interesting data that revealed some relations between them. RT departments with manufacturer A (major vendor) for linacs, TPS and R&V system works with imaging equipment and virtual simulation from vendors C or D. The manufacturer B that supplies linacs, TPS and R&V system is implemented to work with all imaging equipment vendors. The major vendor (A) has all the six DICOM-RT objects for external beam RT commercially available.

Concerning the profile of the respondents, one of the respondents don't have any knowledge about the DICOM-RT, not answering the entire group V (opinion about interoperability) and some questions of group IV (characterization of IS and the DICOM utilization).

The DICOM-RT objects are mostly implemented in most of the departments and its utilization according to the majority of experts is classified as excellent or above average. The objects more implemented are the RT plan and the RT structure set between the Portuguese departments.

Experts somehow attribute importance to interoperability, but have low knowledge about their own IS and respective integrations; in the questions about the conformance with the DICOM v3.0 and DICOM-RT, some respondents answered "I have no knowledge". The same happens about the familiarity with other communication standards, being only identified the utilization of one standard, the HL7.

Regarding the behavior of IS implemented in RT department, some experts strongly agree with systems that allow some type of integration. Some correlations between behaviors were the expected. Because "isolated systems" were negatively correlated with "systems that allow integration of data from IS of other departments of the institution", and systems with two types of integration were positively correlated.

When purchasing new IS and equipments for RT department, experts stated that the most important preponderant factor in interoperability approach is the "integration problems in the existing IS". When implementing new acquisition the IS integration is defined very often by the vendor together with the IT service and the medical physics. It can be concluded, that experts with more years of experience assume, that very often they define the IS integration together with the vendor, contrary to experts with less experience that rarely assume this situation. This may be due to the fact of experts with more experience have more skills in integration problems that they have acquired throughout their career, not requiring the intervention of the IT staff with frequency.

For a good policy, experts considered the most important scenario the "flexibility in IS for multi-vendor equipment integration". The correlations between possible scenarios were not the expected. Because some statements, should have been strongly correlated negatively, such as "a single vendor for..." with "multiple vendors".

The opinion question with higher compliance is about the interoperability, where it is asked the classification of the level of importance of procedures to take in account to achieve interoperability

through DICOM-RT. Most experts attributed very importance or importance for most procedures. The procedure that stood out, where the majority (71.4%) rated as very important is “replacement of analogue by digital image”. About expert’s academic qualification, it can be concluded that experts with master’s degree attribute less importance to the “replacement of some technological resources”, contrary to experts with “licenciante” degree.

For the immaturity of the DICOM-RT implementation, experts stated that the most important reason is “inexistence of DICOM-based archive”. This opinion is believed by experts with less experience, contrary to experts with more experience that give less importance to DICOM-based archive. Concerning the correlation among reasons, the most positively correlated are “no regulation and certification of RT software” and “lack of DICOM-RT objects for some data”. This correlation was not expected, because these two ideas are not directly involved.

With respect of DICOM-RT benefits, the most important benefit according to experts, is “transfer of information between different IS vendors”. Regarding other benefits, such as “integration into ePR” and “helpful in clinical research” experts with more than 6.5 years of experience give less importance when compared with the others. The correlations between the benefits are strong positively, as expected, and the most correlated benefits are “support for computer-assisted decision” and “helpful in image-assisted knowledge discovery”, which is logical because the two concepts are directly related.

In brief, experts of this study believe in the benefits of integration between the IT but with few knowledge about this pertinent issue. Information that can be drawn from these opinions is that the RT professionals don’t have sufficient training on issues such as: application interoperability, communication standards, RT-PACS, etc.

## 5.1 Main Contributions

Throughout this master thesis some contributions were made. The main ones are listed below:

- A comprehensive review of the state of the art of DICOM-RT, clarifying the main problems and benefits.
- A construction of a questionnaire built from scratch for national survey of IS at RT departments and for expert’s opinion about DICOM-RT and interoperability in RT.
- The actualization of data relative to year 2008 about the existing reality in the Portuguese RT departments, in terms of treatment machines and TPS.
- National survey of current status of the RT technologies and the IS with its DICOM-RT compliance.
- Study of expert’s opinion about the relevance of the DICOM-RT and the interoperability in RT context.
- A proposal of recommendations for RT professionals to achieve or optimize the interoperability at the RT departments.

## 5.2 Research Limitations

A limitation that was found in the bibliographic research was the existence of few authors who study and publish about the IS of RT, DICOM-RT utilization, adoption of IHE-RO integration profiles, and interoperability problems in RT departments.

A constraint of the study is the inexistence of other similar studies for results comparison. National surveys of RT were found, but only focusing in the workforce, workloads and equipments. None of them

focuses on IS, DICOM-RT and interoperability; excluding the Portuguese survey that presented the list of TPS implemented in all public RT departments.

Concerning the measurement instrument of this bivalent study, looking at all the work of this thesis and dimension of the constructed questionnaire, would have more sense to developed one questionnaire for each study, to be applied sequentially in two different moments. The construction of the questionnaire was difficult because there were no similar questionnaires about the relevant issues of this study. The questionnaire review carried out by the three experts should have included a computer engineer with RT experience. The validation of answers could have been carried out by telephone interview, but respondents reported a lack of availability for that.

Another limitation that affected the data collection were protocols that some institutions follow for study request authorization (specific requirements and additional documentation) causing a time delay. This led to the fact that not all institutions who agreed to participate in the study had completed the questionnaire until the deadline.

The few interoperability problems between IS of RT departments, appointed by the respondents limited the analysis of this work in the development of recommendations for RT departments.

## 5.3 Recommendations

The questionnaire aimed to explore issues that could help departments to optimize there IS utilization at the RT workflow. But as the participants think that have no interoperability problems and those who think that have, didn't detailed with enough information. Therefore, only general recommendations can be suggested. Results showed that, experts underestimate the existence of interoperability problems, not knowing integration solutions by the use of communication standards and the creation of interface mechanisms.

For a good policy in RT department a clear vision of the goals is necessary when planning for growth and keeping up with technological advancements. Plans to deal with the expansion of the RT department should be part of IS resource needs assessment. Medical physicists, in consultation with IT staff, should select appropriate IS technologies that accommodate growth with flexible and scalable solutions. These may come from third party sources being the IS integration considered with the vendor. The buying strategy must focus on IS standardization, reliable computer applications with a high degree of built-in connectivity and equipment with the current specifications capable of future upgrades. The RT department should encourage the vendors to participate in the IHE initiatives and other relevant committees for getting experience and expertise to the issues that affect RT practice, because the standards, technical frameworks and integration profiles are not complete. RT professionals can participate in the IHE-RO initiative by identifying RT integration problems, writing a one page summary of the problem and e-mail it to *ihe-ro@astro.org*. Due to the rapid technical advancement in RT and consequent implementation of new technologies, a training program for RT staff should serve the needs of the RT department through an ongoing educational program for all RT professional stay informed in what is new inside and outside RT dynamic field.

When an issue such as incompatibility between IS, configuration problems or unexpected results occurs at RT department, a set of recommendations should be followed in order to solve the problem. The following recommendations for the RT professionals are important to optimize the integration between IS and equipments from RT departments.

When defining IS specifications for RT department:

- Complete a process map of how information flows in the department.
- Each area (e.g. administrative service, scheduling, medical physics, treatment unit, etc) needs to document the processes that are used on a daily basis. Questions that helps:

*Who enters what data when?*

*How many times does the same data get entered?*

*Are different groups doing the same function?*

- Combine specifications from different groups of users, grouped into specific functions and prioritized.
- Understand the RT workflow and the points of contact between all IS. Verify that the interface across those points of contact is addressed by a standard, and that the IS on either side are in fact interoperable.
- Develop a set of requirements for RT dataflow improvement.
- Follow a clear methodology for the needs assessments. The following questions need to be addressed for each IS:

*What is needed for archive and backup?*

*Who manages it?*

*What skill set is required to perform the work?*

*Does this require real-time service?*

*How does this affect the current network topology?*

*How does this change the amount of work required to maintain other IS that interact with this one?*

- Prepare budgets with clear explanations of the purpose of each IS.

When purchasing a new IS/equipment for RT department or next upgrade:

- Only buy imaging equipment in conformance with DICOM v3.0.
- Only buy RT equipment with DICOM-RT compliance with all DICOM-RT objects available.
- Require adherence to the IHE-RO integration profiles by including the proper language in your request for proposal or purchase order.
- Insist upon a conformance statement for the device that claims to be DICOM conformant to provide the basis for achieving application interoperability.
- Check the contents of the DICOM conformance statement that should include the six contents described in section 2.2.2. Generally these statements are available on vendor's websites.
- Demand that vendors provide documentation of the other standards compliance.
- Make sure IS has the most advanced interoperability design into the official requests for proposals or as an attachment to a purchase order.
- Require logging facilities in DICOM applications for problems identification.

When implementing new devices:

- Careful review of DICOM conformance statements.
- Adapt the existing RT workflows to IHE-RO integration profiles.
- Specification of the data flow needs to ensure effective integration.
- Interface testing of the clinical application capabilities.
- Cautious consideration to the physical design of the network.

When problems arise in the IS:

- Make a local diagnosis with available tools.
- Verify logging services to identify where the source of the problem avoiding unnecessary review of the code.
- If there is a need to develop service, use available toolkits to design the solution that needs to be drawn between usability and robustness.

- Resolve the problems with DICOM utilities freely available or with a small fee. Example of some utilities:
  - DICOM viewers applications:
    - *ImageJ* with robust viewer for almost all DICOM images with Java programming interface which can be extended (Rasband, 2011);
    - *Conquest DICOM* with image viewer and other tools with *Microsoft Windows®* interface and database (Herk, 2011).
  - DICOM file editors:
    - *Soft82* with DICOM framework and toolkit to develop software (Soft82, 2011).
  - DICOM client/server applications:
    - *DICOM@OFFIS* toolkit with server applications for DICOM to bitmap conversion tools (Eichelberg et al., 2011);
    - *Mallinckrodt Institute of Radiology Tools* with DICOM demos, conversion programs, etc (Mallinckrodt Institute of Radiology, 2010).
- Consult useful websites with free medical imaging software, such as “*I do imaging*” (Crabb, 2002-2011).

When setting configuration of a modern RT facility, it is important have as one of the operation objectives, the management of IT for the creation of a robust IS infrastructure. This management should allow a complete electronic operation with a comprehensive network platform to facilitate:

- An all inclusive treatment management connectivity between CT scanner, TPS, TDS, and on-board imaging system for setup and verification;
- Integrated ePR including medical record management, patient database management, treatment parameters management, R&V system interface, image archiving management system, patient scheduling, etc;
- Departmental computer network with high-speed internet connection, computers servers, office, management software, billing system, etc.

TPS must have full-capacity for DICOM connections to receive images (in-house CT, portals from linac, images from outside imaging centers) and for DICOM-RT objects to directly transfer planning parameters for R&V systems. Other requisite is remote planning capability, allowing radiation oncologists, medical physicists and dosimetrists to review and participate in the planning process remotely. For the efficient IT configuration is indispensable IT services that should be contracted to work with the initiators to design the network layout. The proper management of IS infrastructure is necessary to ensure patient data integrity, plan quality assurance, and availability of real-time patient care, and to maximize the potential for improved treatment outcomes.

The ideal RT department adopts the DICOM v3.0 and the RT-PACS model for the imaging, the DICOM-RT extension for the RT data, and the IHE-RO integration profiles for RT workflow allowing a system integration infrastructure for a comprehensive DICOM-RT based ePR.

## 5.4 Future Work

As a possible future work, it could be interviewed the major RT vendors about the DICOM-RT implementations, work in progress and future releases to study the reality about the standard compliance.

An interesting study is to perform a focus group formed with RT professionals, IT staff, equipment service engineers, and vendors. Through this method of qualitative research more relevant information about the interface problems between the IS and equipment could be obtained.

Another possible way to proceed this study is to do a case study of RT department which gathers the largest number of technologies and IS from different vendors. The analysis through the workflow and

dataflow of the RT department can give important information about existing integrations and interoperability problems where the relevance of the DICOM-RT can be studied more profoundly.





*I was taught that the way of progress  
was neither swift nor easy.*

*Marie Curie*



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# **Appendix**

**A. Questionnaire “DICOM-RT in the radiotherapy information systems”**

**B. Email sent to the National Coordination for Oncological Diseases**

**C. Examples of documents requested to conduct the survey**

1. Example of an email to request authorization for the chairman of the board of directors
2. Example of a specific request authorization
3. Example of a request for authorization approved

**D. Example of an email sent for the experts**

**E. Article submitted at the “HealthInf 2012 - International Conference on Health Informatics”**

