Informatics in Radiology

DICOM-RT and Its Utilization in Radiation Therapy[1]

TEACHING POINTS
See last page

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The Digital Imaging and Communications in Medicine (DICOM) standard is now widely implemented in radiology as the standard for diagnostic imaging. It has also been extended for use in various subspecialties. One of the first extensions was applied to radiation therapy and is known as DICOM-RT. In addition to the protocol used in the DICOM standard, seven DICOM-RT objects—namely, RT Image, RT Structure Set, RT Plan, RT Dose, RT Beams Treatment Record, RT Brachy Treatment Record, and RT Treatment Summary Record—have been created, each with a well-defined data model. The data models set the standard for integration of radiation therapy information for an electronic patient record and would facilitate the interoperability of different radiation therapy systems, thus making possible the sharing of information from different systems.

Abbreviations: CTV = clinical target volume, DICOM = Digital Imaging and Communications in Medicine, DRR = digitally reconstructed radiograph, ePR = electronic patient record, IHE = Integrating the Healthcare Enterprise, OAR = organ at risk, PACS = picture archiving and communication system, PTV = planning target volume, ROI = region of interest, TPS = treatment planning system

RadioGraphics 2009; 29:655–667 • **Published online** 10.1148/rg.293075172 • **Content Codes:** IN RO

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Introduction

The Digital Imaging and Communications in Medicine (DICOM) standard is used for transmission of medical images. Its predecessor, the ACR-NEMA (American College of Radiology–National Electrical Manufacturers Association) standard, was published in 1982, followed by a second version, ACR-NEMA 2.0, in 1988 (1–3), neither of which addressed computer networking issues. A major revision named DICOM that incorporated the existing network standard was introduced in 1992, specifying standards for digital imaging systems in medicine for information handling and transmission. For details regarding the DICOM standard, readers are referred to the technical and nontechnical introduction to DICOM in two previous articles published in this journal (1,2).

DICOM is the cornerstone of the successful implementation of picture archiving and communication systems (PACS) in radiology, allowing communication between equipment from different vendors. In recent years, the DICOM standard has been extended to incorporate many medical specialties such as radiation therapy (4,5), cardiology (6,7), pathology (8,9), and ophthalmology (10,11) and allow the viewing of images together with specialty-specific information. Because radiation therapy is image intensive, it was the first specialty to be incorporated into the DICOM standard after radiology, with the creation of four DICOM-RT objects in 1997 (4) and three more in 1999 (5). In 2006, two additional objects were defined for ion therapy (12). Because this article is intended to serve as an introduction to the DICOM-RT standard, only the first seven objects for radiation therapy will be described.

For communication of radiation therapy data, the transfer protocol will largely follow the standard used in DICOM for communication of medical images, which will not be revisited in this article. It is the unique information in radiation therapy such as text, graphs, and isodose lines and their superimposition on medical images that gives rise to the creation of specific radiation therapy information object definitions and their attributes. In this article, we describe the work flow in radiation therapy compared with that in radiology and the DICOM-RT objects that are generated in the radiation therapy work flow. In addition, we discuss and illustrate the utilization of DICOM-RT in a sample case of prostate cancer and discuss the need to integrate radiation therapy information with use of DICOM-RT.

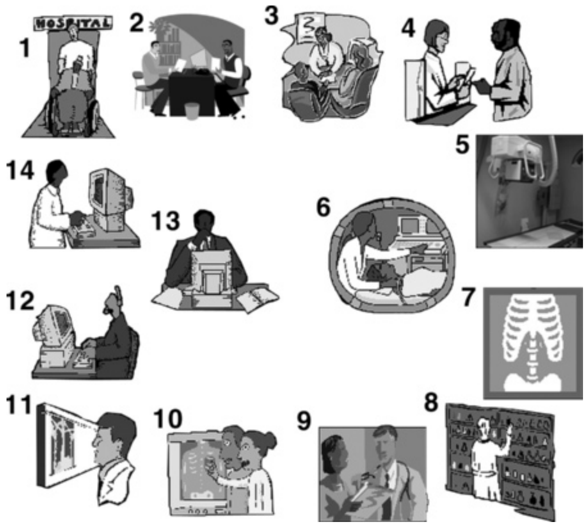


Figure 1. Chart illustrates the impact of a PACS on clinical work flow in a radiology department. Step 1, patient arrives at hospital; step 2, patient registers with hospital information system; step 3, examination is ordered at radiology information system; step 4, technologist receives information from clerk; step 5, patient is escorted into modality room; step 6, technologist performs examination; step 7, examination is completed; step 8, clerk pulls out old films; step 9, clerk prepares all necessary papers and films for radiologist; step 10, films are hung up for radiologist's review; step 11, radiologist reviews films, reads examinations, and dictates reports; step 12, transcriptionist types draft report from the dictation; step 13, radiologist reviews and signs off on report; step 14, final reports are input into radiology information system for clinical viewing. With the implementation of a PACS, steps 4, 8–10, 12, and 14 can be eliminated, making work flow more efficient. (Modified, with permission, from reference 3.)

Radiology Work Flow versus Radiation Therapy Work Flow

Radiology Work Flow

The DICOM-RT objects are extensions of the DICOM standard, which, as mentioned earlier, was first implemented for use in radiology.

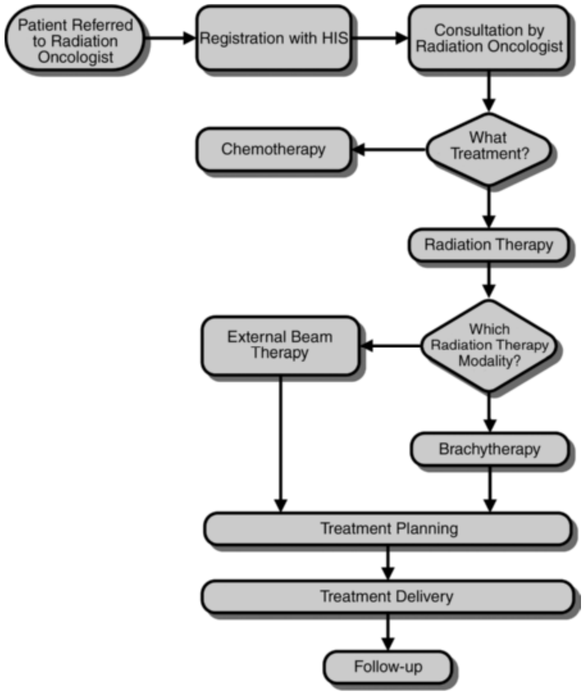


Figure 2. Chart illustrates cancer treatment work flow. Note that in some cases, the patient can receive both chemotherapy and radiation therapy as part of treatment. Whichever radiation therapy modality is chosen, the work flow involves treatment planning and delivery. *HIS* = hospital information system.

Reviewing the work flow in radiology before discussing the work flow in radiation therapy will help readers understand the similarities and differences between the information requirements of these two specialties in medicine.

Steps 1–14 in Figure 1 depict film-based radiology work flow without a PACS. With the implementation of digital radiography and a PACS, the work flow is greatly simplified. After the patient arrives at the hospital (step 1) and is registered with the hospital information system (step 2) and radiology information system (step 3), his or her personal information and the request for examination will be transmitted to the appropriate modality (step 5), saving the technologists from having to obtain the patient information from the reception counter (step 4). When the examination is performed (step 6), an image is generated (step 7). This image, together with any previous images, will be sent by the PACS to the workstation for reading by the radiologist (step 11), thereby saving steps 8–10. The prefetching of previous images by clerical staff is no longer required, and preparatory work for image reading is reduced. The radiologist can easily use some templates or a structured report at the reading workstation to type out the imaging findings (step 13), thereby saving steps 12 and 14.

In addition to saving both time and manpower in searching for old films and preparing reports, the implementation of digital radiography and a PACS allows integration of images from different modalities and vendors under the patient's unique identifier. These images can easily be retrieved without fear of losing data or film.

Radiation Therapy Work Flow

Radiation therapy consists of three modalities: external beam therapy, nuclear medicine, and brachytherapy. Upon being referred by a general physician for consultation, the patient is scheduled for an appointment. On the appointed day, the patient registers at the oncology department. The radiation oncologist sees the patient and determines the most appropriate modality for the patient on the basis of prior investigation results and treatment protocol. In general, radiation therapy entails treatment planning and delivery. Thus, when the oncologist decides that the patient should proceed with radiation therapy, the patient will be scheduled for treatment planning before undergoing treatment.

External beam therapy accounts for over 90% of the workload in a radiation therapy department. Brachytherapy often plays a supplementary role and is often used in the treatment of gynecologic cancers. Nuclear medicine has become independent of radiation therapy in many hospitals. Thus, for the sake of simplicity, only the work flow of external beam therapy will be considered. Figure 2 provides a brief overview of patient treatment in a radiation oncology department once the type of treatment has been determined. In some cases, the patient may receive both chemotherapy and radiation therapy. Figure 3 shows the general procedures involved in the planning and delivery of external beam therapy in a specific clinical case of prostate cancer.

Note how different radiation therapy data are generated within the work flow. The data are categorized and “contained” in the various DICOM-RT objects as defined by the DICOM standard (Fig 3).

Treatment Planning (Steps 1–5).—The goal of treatment planning is to deliver the highest and most uniform radiation dose possible to the tumor-bearing site but the smallest dose possible to the surrounding healthy tissue, especially critical and radiosensitive structures (the urinary bladder and rectum in cases of prostate cancer).

Information from medical images is crucial to the radiation therapy planning process. The process starts with the localization of the prostate tumor volume. For this purpose, the oncologist will order a CT study of the pelvis, performed on either the CT simulator or a CT scanner. The patient’s information is delivered to the CT simulator room, where the radiation therapist positions the patient for scanning. The pelvic CT scans are generated as DICOM images and stored either in a PACS or in the workstation there (step 1). The CT scans are then transferred to a computer treatment planning system (TPS) (step 2) for radiation field planning. Previous diagnostic images, CT scans, magnetic resonance (MR) images, or positron emission tomographic (PET) scans may also be retrieved to aid in the delineation of tumor volume.

At the TPS workstation, the tumor volume and the organs at risk (OARs) (urinary bladder and rectum) are delineated. Treatment fields of appropriate size and optimal gantry or collimator angles are determined. The TPS will compute the radiation dose distribution within the body region to be treated (step 2). Determining the best radiation therapy plan requires a clinical judgment based on the balance between adequate target

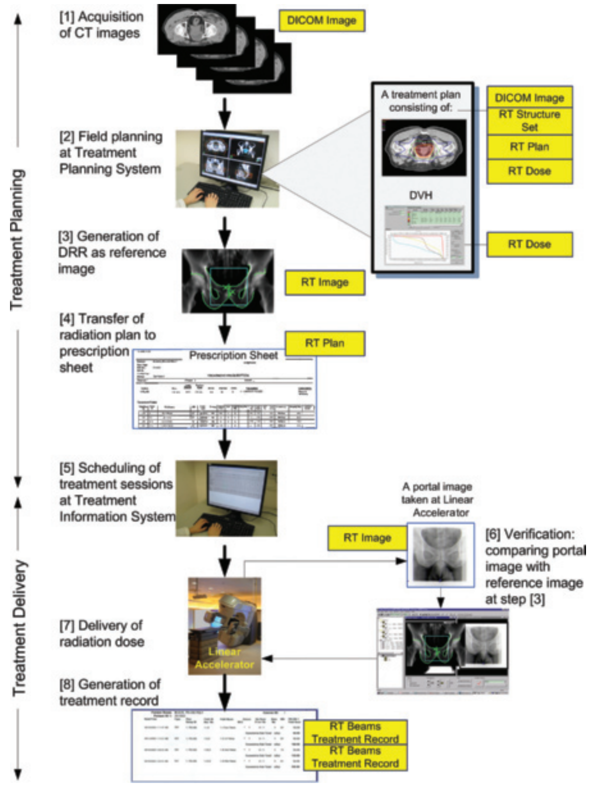


Figure 3. Chart illustrates radiation therapy work flow. Yellow boxes indicate the DICOM-RT objects that could be generated within the work flow. A radiation therapy treatment plan (step 2) with radiation dose distribution involves the superposition of the radiation therapy objects RT Plan, RT Structure Set, and RT Dose on the corresponding set of DICOM computed tomographic (CT) scans according to the coordinates in the DICOM-RT standard. Because the work flow is for external beam therapy, the RT Brachy Treatment Record information object is not shown. *DRR* = digitally reconstructed radiograph, *DVH* = dose-volume histogram.

volume coverage and sparing of OARs. Each plan should be evaluated carefully with use of dose-volume histograms and planar dose distributions. Although they do not provide spatial information, dose-volume histograms provide a global view as to whether the resultant plan meets the dose-volume criteria. A detailed slice-by-slice analysis of isodose distribution is crucial for examining target volume coverage and identifying the exact location of "hot" and "cold" spots with respect to radiation dose. When the OARs overlap with or are in proximity to the target volume, the dose is often limited by ranking the OARs in terms of relative importance.

Images similar to projectional images can be reconstructed from the CT scans to show the treatment field positions and are called digitally reconstructed radiographs (DRRs) (step 3). A DRR, or simulator image obtained for treatment planning, will serve as the reference image for treatment verification later. The finished plan is presented to the radiation oncologist for evaluation and approval. If the plan is found satisfactory, the oncologist prescribes the treatment (step 4) on the radiation therapy prescription sheet. A treatment record with all treatment details is prepared with the prescription. Treatment sessions are scheduled in the treatment information system (step 5) and transferred to the radiation treatment unit or linear accelerator, either through the department network or by manual paper delivery.

Treatment Delivery (Steps 6–12).—Before the actual radiation treatment commences, the accuracy of the treatment plan in terms of field sizes, setup, shielding positions, and so on needs to be verified at the linear accelerator. For such verification, a portal image is obtained at the linear accelerator (step 6), either as a film image or (with an electronic portal imaging device installed in the linear accelerator) as a digital portal image. The image is then compared with the reference DRR or simulator image. When the irradiated portal aligns correctly with the portal on the reference images, the oncologist will approve the verification. Radiation treatment can then proceed (step 7). Otherwise, a repeat portal image may be requested. Normally, the patient will be treated five times a week for 7–8 weeks. At each treatment session, each of the treatment beams will be recorded, as well as the radiation dose and the cumulative dose to date (step 8).

During the course of treatment, weekly verification images are acquired to ensure accuracy. The oncologist will also review the patient's progress and prescribe whatever medicine is required. Upon being completed, the patient's course of treatment will be summarized and filed. A follow-up appointment will usually be made with the patient for review purposes.

Comparison of Work Flow

Radiology mainly involves the generation of medical images and reporting of the diagnosis, whereas in radiation therapy, the images are used for treatment planning and specific kinds of images are generated for treatment verification. In radiology, the procedure is considered complete as soon as the imaging findings have been reported, but this is only the beginning for radiation therapy. Treatment planning and delivery, consultation, and follow-up are additional procedures in radiation therapy that generate information quite different from that in radiology. Table 1 compares radiology and radiation therapy in terms of the nature of the work involved and the requirements for information integration. In contrast to the radiology work flow, in which the data are mostly images and are generated together, the radiation therapy work flow entails additional imaging and informatics data that are generated over an extended period of time due to the many more steps involved. Although its framework looks similar in many areas, the DICOM information object is different. In radiology, the same DICOM image object information entity is deployed to accommodate the different modules of attributes. In radiation therapy, there are different objects to group the different types of information (Table 2).

Table 1
Requirements for Information Integration in Radiology versus Radiation Therapy

Radiology	Radiation Therapy
Imaging informatics based: image and informatics data for diagnosis, historical studies for diagnosis, computer-aided detection/diagnosis or decision support during diagnosis	Imaging informatics based: image and informatics data for treatment, historical plans for treatment planning, quantified knowledge or decision support during course of treatment
Modalities: radiography, computed radiography, CT, MR imaging, ultrasonography, PET, and so on	Modalities: external beam therapy, brachytherapy, ion therapy
Standards: DICOM, HL7, IHE Work Flow Profiles	Standards: DICOM-RT, DICOM, HL7, IHE Work Flow Profiles
Key imaging and informatics data objects: DICOM Image, DICOM-SR, other reports	Key imaging and informatics data objects: DICOM Image, DICOM-RT objects, DICOM-SR, other reports
Customers: patient, referring physician, radiologists	Customers: patient, referring physician, radiation oncologists
System integration necessary for improved work flow	System integration necessary for improved work flow
Solution: PACS	Solution: DICOM-RT electronic patient record (ePR) system

Note.—Data generated within the radiation therapy clinical work flow contain additional imaging and informatics data that are crucial for the work flow, which necessitates the DICOM-RT standard as well as an ePR system. HL7 = Health Level 7, IHE = Integrating the Healthcare Enterprise, SR = structured report.

Table 2
Image Object versus an RT Object IOD Module

Information Entity of DICOM Image Object	Module* (MR Imaging)	Information Entity of DICOM-RT Object	Module* (RT Structure Set)
Patient	Patient	Patient	Patient
Study	General Study	Study	General Study
Series	General Series	Series	RT Series
Frame of Reference	Frame of Reference	...	...
Equipment	General Equipment	Equipment	General Equipment
Image	General Image, Imaging Plane, Image Pixel, MR Image, SOP Common (13)	Structure Set	Structure Set, ROI Contour, RT ROI Observations, SOP Common (13)

*Only mandatory modules are listed. A module groups related information together. For example, the Patient module contains attributes related to the patient, such as Patient's Name, Patient ID, Patient's Birth Date, Patient's Sex, and so on. The modules for the image Information Entity depend on the modality concerned. In this table, the modality of interest is MR imaging; thus, in addition to the General Image module, Information Entity has a specific MR Image module and other related modules. Structure Set is one of the DICOM-RT objects and includes Structure Set, ROI Contour, and RT ROI Observations as its specific modules. IOD = information object definition, ROI = region of interest, SOP = service-object pair.

DICOM-RT Objects

Teaching Point

There are significant differences in the types of information required for radiology and radiation therapy as well as differences in the time at which and frequency with which the information is obtained. The different types of information require different categorization. On the basis of the standard DICOM query-retrieve model, the radiation therapy information is defined in seven information objects known as DICOM-RT objects for the transfer of data (10,11,13). These information objects include RT Structure Set, RT Plan, RT Dose, RT Image, and RT Treatment Record, which is further divided into RT Beams Treatment Record, RT Brachy Treatment Record, and RT Treatment Summary Record. Figure 4 shows these objects, how they are extensions of the DICOM model in radiology, and how they relate to each other and to the image object in radiology. The information in the DICOM-RT objects is described in the following paragraphs and illustrated in Figures 5–9.

Teaching Point

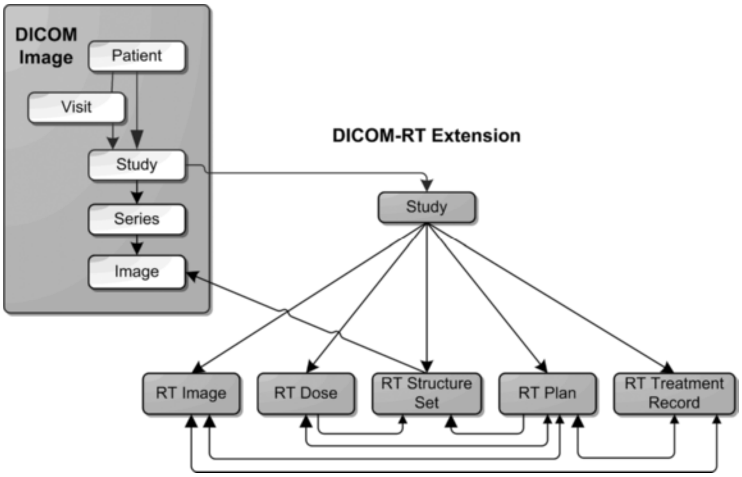


Figure 4. Chart illustrates DICOM-RT objects as an extension of the DICOM standard. Note that RT Plan, which contains all RT-related information, is an important object that is needed from the start of radiation therapy planning to the completion of treatment and is thus related to all other objects.

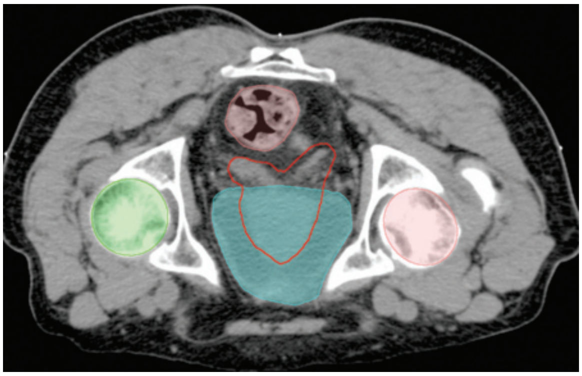
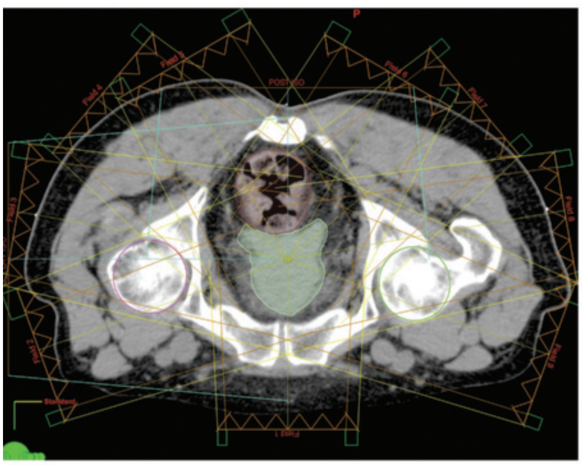


Figure 5. CT scan with superimposed color coding shows an RT Structure Set, which includes tumor volume (outlined in red), OARs (femoral heads [green and pink], rectum [purple], bladder [blue]), and body contour.

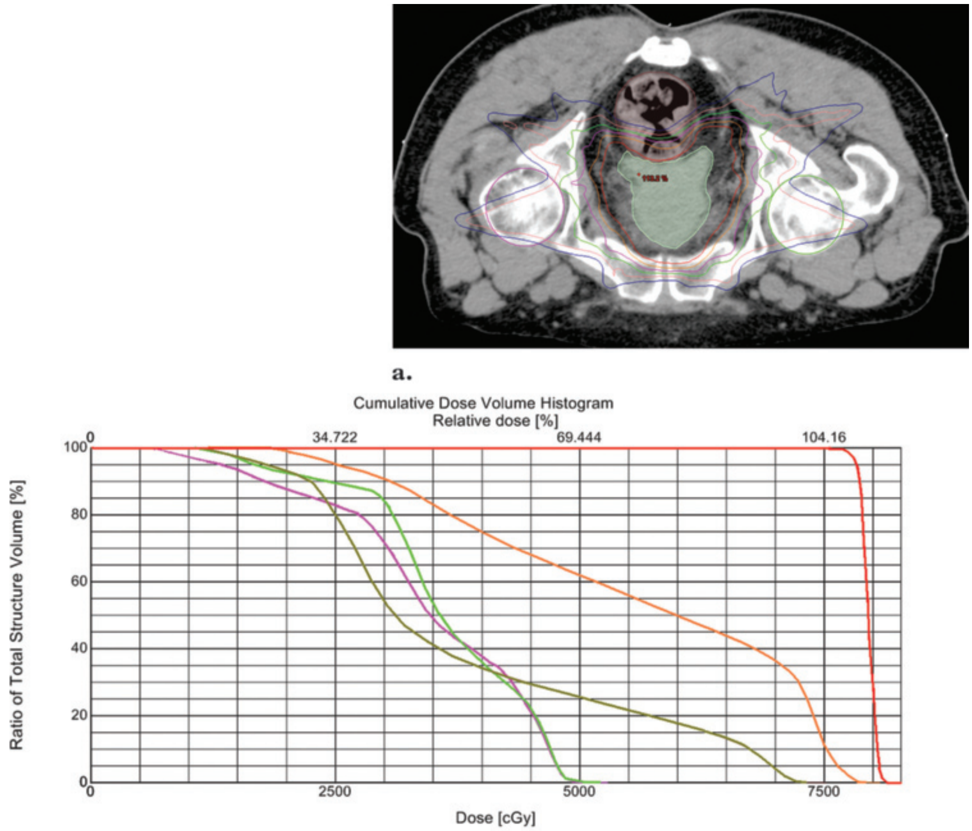
Dose Prescription												
RT to IMRT: Give 2 Gy/fr, 5 fr/wk at 100% I.L. to 76 Gy in 38 fr. and stop.												
Fields												
LA	Energy	ID	X1	X2	Y1	Y2	SSD	Gantry	Coll	Table	Weight	MU
LA2	6X	Field1	+5.8	+6.3	+4.5	+2.5	90.1	180 °	0°	0°	1.0	80
LA2	6X	Field2	+5.3	+5.5	+4.5	+2.5	85.2	110°	0°	0°	1.0	75
LA2	6X	Field3	+4.5	+5.3	+4.5	+2.5	82.8	85°	0°	0°	1.0	76
•												
•												
•												

a.



b.

Figure 6. RT Plan. **(a)** Chart illustrates an RT Plan. *Coll* = collimator rotation, *fr* = fraction, *ID* = identification, *I.L.* = isodose level, *IMRT* = intensity-modulated radiation therapy, *LA* = linear accelerator, *MU* = monitor unit, *RT* = radiation therapy, *SSD* = source-skin distance, *X* and *Y* = collimator leaves in the x and y directions. **(b)** Information from RT Plan superimposed on RT Structure Set and a CT scan. Nine radiation beams (attribute of RT Plan) are each indicated by a red label and three yellow lines.



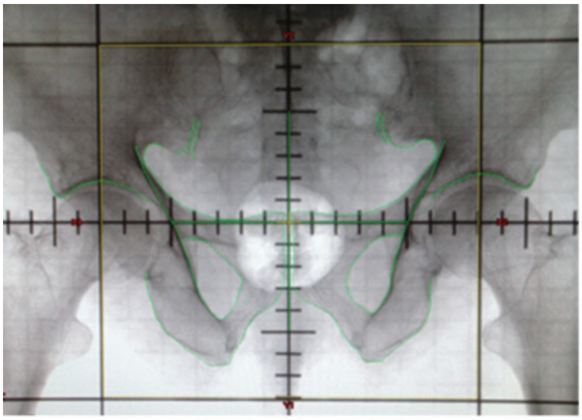
Structure	Plan	Plan Status	Course	Coverage [%/%]	Volume	Min Dose	Max Dose	Mean Dose	Modal Dose	Median Dose	Std Dev
RECTUM	TREATMENT (TREATMENT	Treatment Approved	IMRT	100.0 / 100.0	53.4 [cm³]	1031.8 cGy	7517.1 cGy	3812.1 cGy	2700.0 cGy	3103.1 cGy	1671.9 cGy
RT FEMORAL HEAD	TREATMENT (TREATMENT	Treatment Approved	IMRT	100.0 / 100.0	65.2 [cm³]	983.2 cGy	5157.9 cGy	3611.5 cGy	4708.8 cGy	3564.9 cGy	879.1 cGy
LT FEMORAL HEAD	TREATMENT (TREATMENT	Treatment Approved	IMRT	100.0 / 100.0	67.0 [cm³]	516.4 cGy	5287.5 cGy	3455.1 cGy	4680.0 cGy	3475.3 cGy	1060.7 cGy
BLADDER	TREATMENT (TREATMENT	Treatment Approved	IMRT	100.0 / 100.0	91.5 [cm³]	1639.6 cGy	8071.2 cGy	5614.4 cGy	7408.8 cGy	5999.8 cGy	1769.8 cGy
ptv-78	TREATMENT (TREATMENT	Treatment Approved	IMRT	100.0 / 100.0	118.7 [cm³]	7401.4 cGy	8287.2 cGy	7950.8 cGy	7956.0 cGy	7955.8 cGy	76.9 cGy

b.

Figure 7. RT Dose. **(a)** CT scan with superimposed color coding shows radiation dose data from a TPS. Isodose curves are shown in yellow, pink, green, magenta, and blue. Red shaded area indicates tumor volume (RT Structure Set). **(b)** A dose-volume histogram (which also belongs to the RT Dose object) is used for evaluation of a treatment plan. Such evaluation is key in determining whether a proper radiation dose is being applied to the target tumor while limiting the dose to surrounding critical healthy tissue and organs. Red line indicates that most of the tumor volume is receiving over 7500 cGy of radiation. Orange, green, magenta, and yellow lines show the dose received by the rectum, right femoral head, left femoral head, and bladder, respectively (OARs). *Max* = maximum, *Min* = minimum, *Std Dev* = standard deviation.

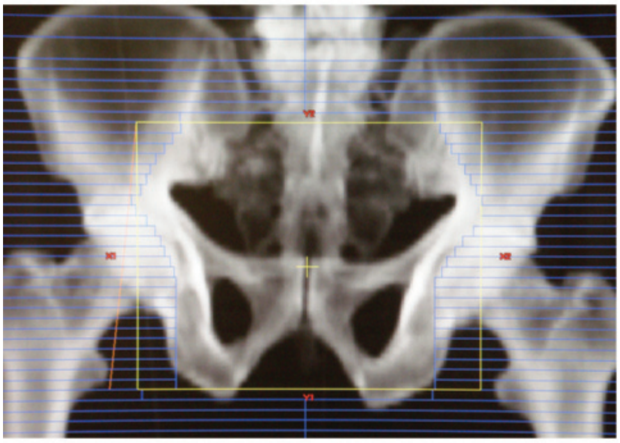
RT Structure Set

The RT Structure Set information object (Fig 5) defines a set of areas of significance in radiation therapy, such as body contours, tumor volumes (eg, gross target volume, clinical target volume [CTV], planning target volume [PTV]), OARs, and other ROIs. The target volumes are defined in accordance with the guidelines in International Commission on Radiation Units and Measurements Reports 50 and 62. The gross target volume is essentially the gross palpable, visible, or clinically demonstrable extent and location of a tumor. The CTV contains the demonstrable gross target volume plus a margin for subclinical disease spread, which cannot be fully imaged. The PTV is a geometric concept designed to ensure actual delivery of radiation therapy dose to the CTV and contains the CTV plus a margin to take into account uncertainties due to internal organ motion, patient motion, and setup error. In cases of prostate cancer, the target volume is the prostate gland and any periglandular cancerous areas. The OARs are the urinary bladder, the rectum, and the femoral heads. Each structure will be associated with a frame of reference, with or without reference to the diagnostic images.



a.

Figure 8. RT Image. Projectional simulator image **(a)**, DRR from a CT scan **(b)**, and portal image acquired at a linear accelerator **(c)** show the field to be irradiated and are examples of images "acquired or calculated using conical geometry" (13). Multileaf collimators are seen on the DRR (blue lines in **b**) and are an attribute of RT Image. Portal images verify the accuracy of the placement of the treatment portal; oftentimes only the irradiated portal will be exposed. Portal images should be compared with reference images from the simulator or with the DRRs.



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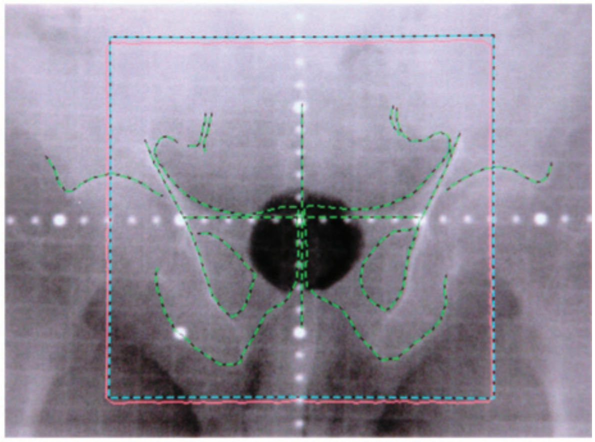

c.

Field	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Wedge	3RW60	3RW45	4RW45	4RW45	4RW45							3RW30	1vW15		3RW45
Date\MU	128	94	187	47	47	75	15	166	30	15	15	128	67	20	104
2004/06/26	128	94	187	47	47	75	15	166	30	15	15				
2004/06/27	128	94	187	47	47	75	15	166	30	15	15				
2004/06/29	128	94	187	47	47	75	15	166	30	15	15				
2004/07/02	128	94	187	47	47	75	15	166	30	15	15				
2004/07/03	128	94	187	47	47	75	15	166	30	15	15				
2004/07/04	128	94	187	47	47	75	15	166	30	15	15				
2004/07/05	128	94	187	47	47	75	15	166	30	15	15				
⋮															
2004/08/10												128	67	20	104
2004/08/11												128	67	20	104
2004/08/12												128	67	20	104
2004/08/13												128	67	20	104
2004/08/14												128	67	20	104

Figure 9. An RT Beams Treatment Record is used to record the dose (in monitor units *[MU]*) delivered to each of the radiation fields (top row) at each treatment session (dates shown in first column). The last four columns (radiation fields 12–15) show a second phase of treatment involving only four radiation fields.

RT Plan

As explained earlier, treatment planning is a process for determining the best placement of the radiation beam for optimal dose distribution. The procedure involves localization of the tumor and OARs, as well as the design (in terms of position and size) of radiation beams and their dose weighting with respect to the PTV and OARs. A clinical treatment plan may include all of the structures marked on the CT scan, the

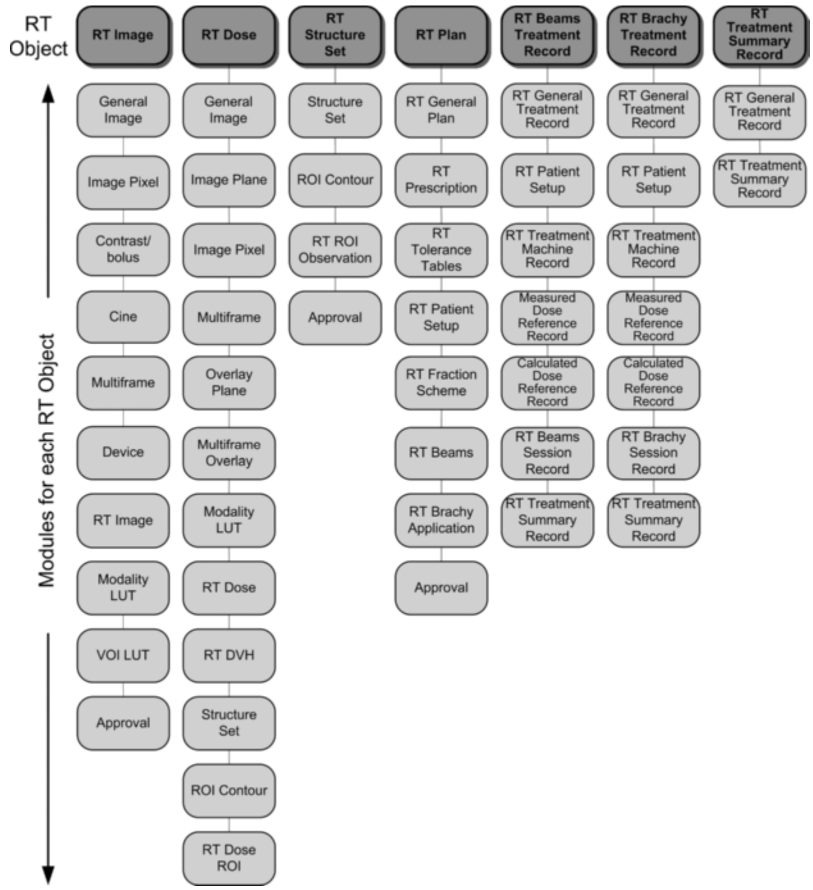

Figure 10. Chart illustrates the seven DICOM-RT objects and their associated modules. Note that the various radiation therapy data generated during the clinical work flow are distributed over the seven objects. *DVH* = dose-volume histogram, *LUT* = look-up table, *VOI* = volume of interest. Understanding how to extract key information from each of the DICOM-RT modules is crucial. The properties or attributes of each module are described in detail in reference 13.

beam positions and sizes, and the dose distribution displayed on the image. In the DICOM-RT standard, information about the structures of interest is contained in RT Structure Set and dose distribution in RT Dose, which requires the coordinates for placing their positions in relation to each other. Thus, the RT Plan object refers only to the textual information in treatment plans, whether generated manually or by a TPS. Such information includes treatment beams, fractionation scheme, prescription, accessories used, and patient setup in external beam therapy or brachytherapy (Fig 6a). In Figure 6b, information from RT Plan is superimposed on RT Structure Set and a CT scan to create a graphical presentation for better visualization.

RT Dose

The distribution of radiation dose for a treatment is represented by isodose lines expressed as a percentage or in dose units (grays). The isodose lines can be displayed in relation to the tumor volume and OARs and superimposed on images. RT Dose contains such radiation dose data from TPSs. It allows the transmission of "a 3D [three-dimensional] array of dose data as a set of 2D [two-dimensional] dose planes that may or may not be related to the CT or MR imaging planes" (Fig 7) (13).

RT Image

Teaching Point

Although RT Image has in common some of the framework used for radiology images in the DICOM standard (Table 2), it specifies the attributes of those images that are "acquired or calculated using conical geometry" (13) in radiation therapy. Such images include projectional simulator images (Fig 8a), DRRs generated from CT scans by a TPS (Fig 8b), and portal images acquired at linear accelerators (Fig 8c). Note that CT images generated with CT simulators are considered to be ordinary CT scans. In contrast to a DICOM image object, RT Image includes not only image information, but also the presentation of the image (ie, position, plane, and orientation of image; distance from radiation machine source to imaging plane). If necessary, RT Image will include the table position, isocenter position, and patient position, and the type of device used to limit the radiation therapy beam (eg, multileaf jaw pairs) (Fig 8b).

Table 3
RT Structure Set IOD Module

Entity	Module	Usage*
Patient	Patient	M
	Clinical Trial Subject	U
Study	General Study	M
	Patient Study	U
	Clinical Trial Study	U
Series	RT Series	M
	Clinical Trial Series	U
Frame of Reference	Frame of Reference	U
Equipment	General Equipment	M
RT Structure Set	Structure Set†	M
	ROI Contour†	M
	RT ROI Observations†	M
	Approval†	U
	SOP‡ Common	M

Source.—Reference 13. IOD = information object definition.
*C = conditional, M = mandatory, U = optional.
†Modules specific to the RT Structure Set DICOM-RT object. All other modules are common modules similar to those in other DICOM objects.
‡Service-object pair.

RT Treatment Record

The RT Treatment Record information object (Fig 9) includes RT Beams Treatment Record, RT Brachy Treatment Record, and RT Treatment Summary Record.

RT Beams Treatment Record.—RT Beams Treatment Record consists mainly of textual data that constitute a treatment session report. The information can be generated by a treatment verification system during the course of external beam therapy or gathered during treatment delivery. Such information includes machine used, radiation type and energy used, date and time of treatment, external beam details, treatment beam accessories, treatment fraction details, monitor units (dose), calculated dose, cumulative dose, verification image obtained, and treatment summary (optional). Each treatment is represented as an instance in an RT Beams Treatment Record object.

RT Brachy Treatment Record.—The RT Brachy Treatment Record information object is similar to RT Beams Treatment Record but consists mainly of information acquired during the course of brachytherapy, along with an optional treatment summary.

RT Treatment Summary Record.—The RT Treatment Summary Record information object summarizes cumulative information concerning the radiation treatment, including both external beam therapy and brachytherapy.

RT Object 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 (eg, Patient, General Study, General Equipment) and modules that are specific to each imaging modality (eg, CT Image module for CT, MR Image module for MR imaging). In these modality-specific modules, the properties (also known as attributes) of the images are specified. For example, the MR Image module contains both attributes that are found in other modalities (eg, Image Type, Samples per Pixel) and attributes of its own (eg, MR Acquisition Type, Magnetic Field Strength, Repetition Time, Echo Time). In radiation therapy objects, in addition to the common modules, each object contains several associated modules. Table 2 compares the modules in a DICOM image object (MR imaging) with those in a DICOM-RT object (RT Structure Set). Figure 10 shows the seven DICOM-RT objects and their associated modules.

For example, RT Structure Set includes Structure Set, ROI Contour, RT ROI Observations, and Approval modules as specific to the object (Table 3). The Structure Set module provides a framework for defining a set of areas of significance, each of which is associated with a frame of reference with or without reference to the images. If the set of structures have reference to the images, they can be displayed as an overlay on an image as in Figure 5, in which the tumor and the OARs are the ROIs, each with a unique identification number. In the ROI Contour module, the ROIs are a single contour or a sequence of two or more contours. These contours will be referenced to the ROI identification number in the Structure Set and to the CT images containing the contours (Fig 5). The RT ROI Observations module helps distinguish between individual instances or classes of ROIs specified in the previous two modules (Structure Set and ROI Contour)—for example, PTV1 and PTV2. The Approval module is a simple module that addresses the status of approval of the delineation of an important structure (eg, the PTV), a treatment plan, or a verification image and shows the reviewer's name and the date of approval. The Approval module is also included in the RT Image, RT Structure Set, and RT Plan objects (Fig 10).

Information Encoding

All DICOM objects are composed of DICOM elements (units of information). The DICOM standard defines the attributes of each module and assigns names and data element tags to the attributes. For example, the tag for Patient's Name is (0010,0010), and that for Patient ID (identification) is (0010,0020).

During treatment planning, contours (an RT Structure Set attribute) are drawn around the ROIs (eg, bladder, rectum), which are OARs of significance. A number with its respective name is assigned to each ROI. The DICOM encoder will insert the ROI (identification) number against the element tag (3006,0022), the ROI name against (3006,0026), the contour number against (3006,0048), the contour image sequence against (3006,0016), and so on. The contour image sequence introduces the sequence of images containing the contour. Other attributes are similarly encoded into their corresponding tags as defined by the DICOM standard. With the encoded information and reference to the corresponding CT scan, the structure sets can be reproduced on the CT scan as shown in Figure 5.

Utilization of DICOM-RT Objects in a Radiation Therapy–based ePR System

In a radiation therapy department, often there are different proprietary and stand-alone information systems for single-purpose applications (eg, a separate TPS for each of several treatment modalities, such as external beam therapy, brachytherapy, or stereotactic radiation therapy–radiosurgery). Each system has its own "storage area" for the plans performed at its workstation. Oftentimes these systems are stand-alone systems and have only limited interface with other systems. Typically, the treatment plans are stored in the conventional TPS, with treatment records stored in another information system. The treatment information for a patient whose treatment involves all three systems will be stored in three different places. Currently, such treatment information is normally "linked" by a paper record or folder on the patient. The foregoing description does not take into account the hard-copy film images that are stored separately in the film library, a practice that is common in many radiation therapy departments. Even so, if the paper record is lost, the patient's treatment information "disintegrates." What is more disturbing is that treatment plans from an old TPS cannot be retrieved for review after a system upgrade. Basically, this results in the treatment plans being "lost."

The radiation therapy department needs a "bridge" system to fill the gap, integrate all the disparate data, and provide a "one-stop shop" for historical treatment plans and key related data. Ideally, information and records scattered throughout the different systems could be integrated and a live summary of the patient's treatment record could be displayed when required. Such an endeavor would help save time and effort spent in searching and minimize the loss of records and films. However, interoperability between systems from different manufacturers is an issue if there is no standard or there is noncompliance with the dedicated DICOM-RT standard. It could be argued that purchasing all equipment from a single manufacturer would solve the problem. However, the matter is not that simple. First, the department would be "tied down" to one manufacturer and would have to accept whatever service the manufacturer provides. This is not a healthy situation from the user's perspective. Second, when there is a need for the exchange of radiation therapy patient records or for research collaboration between institutions, the problem still exists.

The current trend in information technology is toward ePRs, electronic medical records, or electronic health records (14), in which all medical and health information about a patient is organized under the patient's name or identification number. When a patient's name is queried, all reports and records are displayed without the need to go into different systems. With the maturity of the DICOM standard, PACS, and IHE (Integrating the Healthcare Enterprise) work flow profiles, researchers and even manufacturers are now working toward incorporating medical images (eg, radiologic, endoscopic, and microscopic images) into the ePRs.

Teaching Point

Using the DICOM-RT standard and following the model of the PACS makes integration of radiation therapy information possible (15,16). All radiation therapy information and images from various sources can be converted to the DICOM-RT standard and integrated into a DICOM-based database. This information can be displayed as a radiation therapy ePR. From the database, connection to other radiation therapy systems and exchange of radiation therapy patient information are also possible with DICOM-RT and a DICOM-based radiation therapy ePR system. The collection of radiation therapy information in the DICOM-RT objects will lead to further initiatives in informatics research in radiation therapy.

With the increasing popularity of proton beam therapy, two more RT objects—namely, RT Ion Plan and RT Ion Beams Treatment Record—have been defined. The implementation of these objects in a proton beam therapy system is being researched, and it is hoped that, with use of the DICOM standard, information from proton beam therapy can be integrated with that from conventional radiation therapy.

Conclusions

In addition to being image intensive, radiation therapy is highly technical, and its use of radiation also involves radiobiologic factors. All of these parameters have to be recorded for future reference regarding the treatment of cancer patients with radiation therapy. Hence, along with textual information, all related treatment planning information (including isodose lines, graphs, and so on) and images need to go into a single electronic folder on the patient.

Like the DICOM standard in radiology, the DICOM-RT standard is ratified for integration, archival, and sharing of information. Given the small number of vendors and the rapidly developing technology in radiation therapy, the industry tends to focus more on technologic development; thus, the adoption of the DICOM-RT standard is slow and incomplete in most cases. For objects that have been implemented, a user interface called "DICOM export/DICOM import" may exist in some TPSs for the conversion of information from a vendor-specific format to the DICOM format. With manufacturers' collaboration, radiation therapy information can, like diagnostic images, be linked to the ePR to produce a complete radiation therapy patient record. The DICOM-based radiation therapy database can provide a platform for data sharing and for future medical imaging informatics research and outcome analysis of standardized data.

Teaching Point

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DICOM-RT and Its Utilization in Radiation Therapy

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RadioGraphics 2009; 29:655–667 • **Published online** 10.1148/rg.293075172 • **Content Codes:** IN RO

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There are significant differences in the types of information required for radiology and radiation therapy as well as differences in the time at which and frequency with which the information is obtained.

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On the basis of the standard DICOM query-retrieve model, the radiation therapy information is defined in seven information objects known as DICOM-RT objects for the transfer of data (10,11,13). These information objects include RT Structure Set, RT Plan, RT Dose, RT Image, and RT Treatment Record, which is further divided into RT Beams Treatment Record, RT Brachy Treatment Record, and RT Treatment Summary Record.

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Although RT Image has in common some of the framework used for radiology images in the DICOM standard (Table 2), it specifies the attributes of those images that are "acquired or calculated using conical geometry" (13) in radiation therapy. Such images include projectional simulator images (Fig 8a), DRRs generated from CT scans by a TPS (Fig 8b), and portal images acquired at linear accelerators (Fig 8c).

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