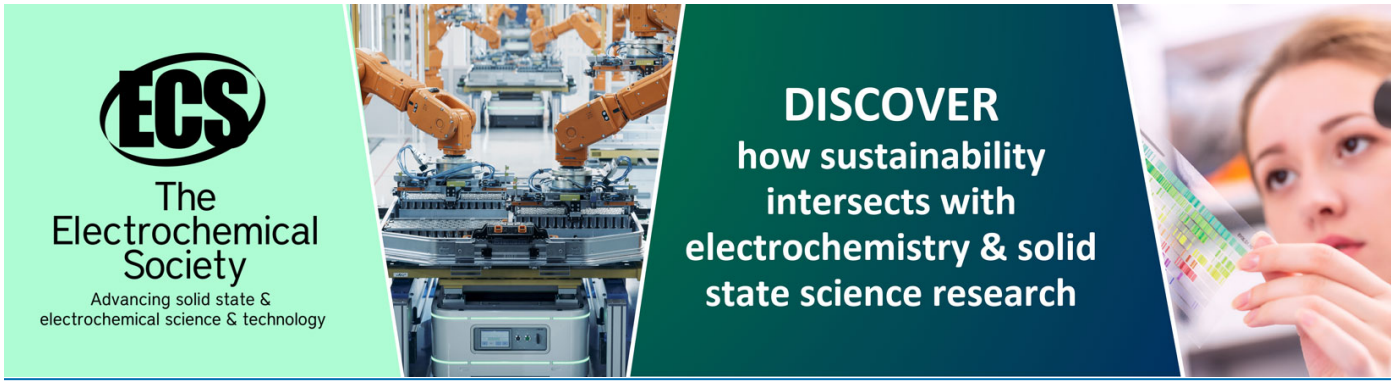
A DICOM based radiotherapy plan database for research collaboration and reporting



A DICOM based radiotherapy plan database for research collaboration and reporting

J Westberg[1], S Krogh[1], C Brink[1,2] and I R Vogelius[3]

[1]Laboratory of Radiation Physics, Odense University Hospital, Sdr. Boulevard 29, 5000 Odense, Denmark
[2]Institute of Clinical Research, University of Southern Denmark, Winsløwparken 19, 5000 Odense, Denmark
[3]Department of Radiation Oncology, Rigshospitalet, University of Copenhagen, Copenhagen, Blegdamsvej 9, 2100 København Ø, Denmark

jonas.westberg@rsyd.dk

Abstract. Purpose: To create a central radiotherapy (RT) plan database for dose analysis and reporting, capable of calculating and presenting statistics on user defined patient groups. The goal is to facilitate multi-center research studies with easy and secure access to RT plans and statistics on protocol compliance. Methods: RT institutions are able to send data to the central database using DICOM communications on a secure computer network. The central system is composed of a number of DICOM servers, an SQL database and in-house developed software services to process the incoming data. A web site within the secure network allows the user to manage their submitted data. Results: The RT plan database has been developed in Microsoft .NET and users are able to send DICOM data between RT centers in Denmark. Dose-volume histogram (DVH) calculations performed by the system are comparable to those of conventional RT software. A permission system was implemented to ensure access control and easy, yet secure, data sharing across centers. The reports contain DVH statistics for structures in user defined patient groups. The system currently contains over 2200 patients in 14 collaborations. Conclusions: A central RT plan repository for use in multi-center trials and quality assurance was created. The system provides an attractive alternative to dummy runs by enabling continuous monitoring of protocol conformity and plan metrics in a trial.

1. Introduction

The DICOM protocol and file format was designed in the 1980's to facilitate a standardized way of communicating and interchanging data between medical imaging devices [1]. This made it possible for manufacturers to exchange information in medical images, structured documents, and workflow over a network. The DICOM data model is hierarchical with its patient, study, series and object (modality), and defines a large dictionary of tags to compose the objects and allows vendors to incorporate proprietary information [2, 3]. The DICOM RT supplement includes the RtPlan, RtStruct, RtImage, RtDose and RtRecord modalities [4].

The DICOM standard does not require user credentials to access patient information on a server [5]. A typical PACS only implements a list of clients it is allowed to communicate with, but have no or minimal restrictions on access control after the connection is established.

There exists an increasing demand for tools to interpret and analyze RT plans. With the variety of treatment techniques and treatment planning systems (TPS) it requires technical skills to extract the

information from all variations of DICOM datasets. This paper describes a system designed to meet some of the challenges related to dose analysis using DICOM RT data from multiple centers. Similar systems exist [6, 7, 8, 9, 10, 11] with different support of data formats, transmission protocols, data anonymization, distribution model of the computations, review tools, statistics and data aggregation. The goal of this study is to design and implement a system with new features for easy and secure sharing of non-anonymized DICOM RT data.

2. Methods

2.1. Design

The system is designed as a three-tier system as shown in figure 1. Each center has a dedicated DICOM gateway configured on a secure network, which serves as a security entry to protect the central DICOM server. The gateway forwards data to the central DICOM server in the first tier.

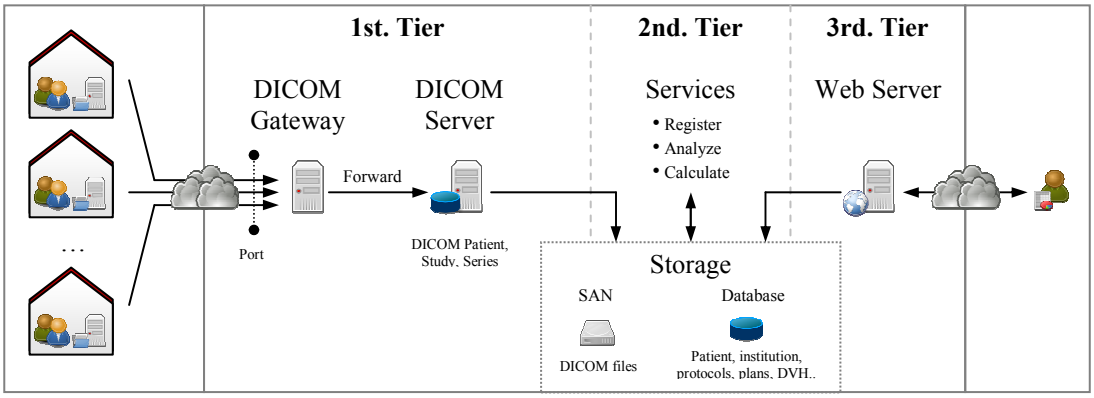


Figure 1. Architecture and design of the system. The centers submit DICOM RT data to the DICOM server (gateway), then data is handled by a three-tier system, and finally the users can access the DICOM RT data and dose reports from a web interface.

The second tier is the core of the system. It contains a series of independent services deployed on computers dedicated for computation. The first service (Register) reads the DICOM file and registers the patient, DICOM series, study and modality in the database. The second service (Analyze) analyzes the content of the file and extracts details depending on the modality (e.g. beams for RT plan). The third service (Calculate) recalculates and stores the DVHs in the database. The third tier implements an ASP.NET website for users to administer and group patient data, configure and retrieve dose reports.

Structure names are not unique and centers can have local naming conventions. To compare DVHs structures names are mapped to a unique identifier. Users can define a structure dictionary to map local structure names to a common name used in the study.

Sharing and grouping data is an important aspect of the system. The database contains a list of data groups and each group can be related to a clinical protocol, a scientific study or created ad-hoc. All new data submitted to the server is by default not included in any data group. A user must log in via the web interface and add the patients data to one or more data groups. The data groups define the basis for collaboration, sharing data and setting up dose reports. Data not included in any group is presumed to be unused and deleted after a certain time.

2.2. Security

A key feature is secure network communication with modern encryption techniques. In our system, the safety of the data transport is provided by The Danish Healthcare Data Network (SDN).

Each data group has a permission matrix with the participating centers as columns and the users as rows as shown in table 1. Three permission rights are available; "group summary" (sum) will allow data from the center to be include in the summary of the dose report, "patient information" (info) allows the user to see patient information too, and "send" gives an option to export the DICOM data from the system to predefined DICOM servers at any center.

Center / User	A			B			C		
	Sum	Info	Send	Sum	Info	Send	Sum	Info	Send
1				x					
2				x	x				
3							x	x	x

Table 1. Permission matrix example. Each data group has a permission matrix where the collaborating users can be granted access to data from other centers in the group. In this example user 1 only have permission to view summarized data from center B. User 2 is able to do the same and view the plan and patient information too. User 3 has access to all data from center C and able to send the DICOM data to a center. None of the users have access to data in the group from center A.

Special data groups are also provided for transmitting DICOM data ad-hoc between centers.

2.3. DVH Calculation

The DVH calculation depends on the resolution of the dose grid and interpolation method, as the dose grid resolution is often configured to use coarser resolution than the reference CT. This dependency becomes more pronounced for small structures in regions with high dose gradients [12, 13]. To ensure consistency all DVHs are recalculated and stored in the database for comparison and generation of dose statistics. DICOM datasets containing pre-calculated DVHs from TPSs are still imported into the database for visualization purposes but not included in the statistics. DVHs are stored in 1 cGy resolution as binary large objects (BLOB) in the database, and have database fields for the minimum, maximum, and mean doses as well as volumes radiated above specific doses (V_{1Gy}-V_{100Gy} in step of 1 Gy) and dose levels for specific volumes ($D_{2\%}$, $D_{50\%}$ and $D_{98\%}$).

2.4. Data Validation And Verification

Data validation and verification is performed at three levels to comply with the ontology, business logic and ensure quality of data. First the contents of the DICOM files are validated to ensure that it contains a supported modality and verify whether or not the patient, study and series exist in the database. Secondly, the actual RT plan is interpreted to validate the existence of prescription, CT, structures, beams, and dose and verify that all referenced data has been received. Thirdly, it is verified that the submitted patient data in a data group properly describes a treatment course. The third step is the most complicated, and might involve user input for ambiguous cases to determine what action to perform. Examples could be duplicated plans or plan modifications before or during the treatment course. The user is notified in case the automatic process fails.

2.5. Dose Reports

Users can compose dose reports in a data group by selecting the dose or volume to report in the DVH for the structure of interest. The report is generated on-demand from the selected fields in the database when the user views the report in the web interface.

3. Results

All RT centers in Denmark are connected and working in 14 collaboration groups on the server. Currently, the database contains over 2200 patients and almost 300.000 DICOM files. The database is hosted in a SQL hotel, files on a storage area network (SAN), and the DICOM servers, web site, and the DVH calculations run on virtual computers. The NARLAL (National phase II lung trial which is scheduled to include 116 patient [14]) group uses the system to extract the dosimetric information (e.g. dose coverage of tumor and dose to OAR such as lung, spinal cord, heart, and esophagus). This has reduced the costs and workload in reporting dosimetric data and in cases where a patient is referred for re-treatment in another center the previous RT plan is easily exchanged between centers.

4. Discussion

With the transparent setup it is simple to export data from the TPSs and into the system. In the initial setup all the software was running on one computer. As the data traffic increased the core services (from the 2nd tier in figure 1) were moved to another virtual computer to reduce workload. The database was moved to a hosted location and into a more scalable environment.

MedCom handles the SDN in Denmark and provides solutions for foreign countries to connect, with several countries in the EU connected already. Legal issues may arise as countries may have regulations on how data should be handled when transmitting data across borders to an external host.

Computing resources on the internet are moving to cloud based architectures to deliver Software as a Service (SaS). Though cloud computing is an attractive technology to dynamically allocate hosted resources as needed, it has not gained acceptance for storing and handling person related information yet.

Submitting anonymized data could be accommodated. This would require 1) an agreement on how to anonymize DICOM data correctly, 2) ensure that the new patient identifications does not collide, and 3) patients scanned or treated at multiple centers still map to the same identification in all DICOM files. Modifying a DICOM file would require new unique IDs to be generated, which could result in broken references between files. Surprisingly, anonymization software can produce different results and personal information can still be hidden in images as pixels, private DICOM tags, and use of initials or other personal information in text fields.

Missing data or unreported changes is of major concern. E.g. data submitted before end of treatment would describe the intended plan, while the actual treated plan(s) are recorded in the Record and Verify System (RVS). Exporting the treatment records from the RVSs would increase the quality of data. Unfortunately, the export of treatment records in DICOM format is not yet supported by all major RVSs.

5. Conclusion

We have implemented a multi-center collaboration platform for research in radiotherapy based on DICOM RT. Data can be transmitted to the server using DICOM export from a TPS or PACS, and it is not mandatory to anonymize data. Users can set up dose reports from a web interface to ensure protocol compliance.

Acknowledgment

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