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System Integration and DICOM Image Creation for PET-MR Fusion

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This article demonstrates a gateway system for converting image fusion results to digital imaging and communication in medicine (DICOM) objects. For the purpose of standardization and integration, we have followed the guidelines of the Integrated Healthcare Enterprise technical framework and developed a DICOM gateway. The gateway system combines data from hospital information system, image fusion results, and the information generated itself to constitute new DICOM objects. All the mandatory tags defined in standard DICOM object were generated in the gateway system. The gateway system will generate two series of SOP instances of each PET-MR fusion result; SOP (Service Object Pair) one for the reconstructed magnetic resonance (MR) images and the other for position emission tomography (PET) images. The size, resolution, spatial coordinates, and number of frames are the same in both series of SOP instances. Every new generated MR image exactly fits with one of the reconstructed PET images. Those DICOM images are stored to the picture archiving and communication system (PACS) server by means of standard DICOM protocols. When those images are retrieved and viewed by standard DICOM viewing systems, both images can be viewed at the same anatomy location. This system is useful for precise diagnosis and therapy.

KEY WORDS: DICOM gateway, image fusion, IHE

DIGITAL IMAGING SYSTEMS are gradually replacing conventional film equipment in hospital radiology departments. During the replacement process, integration of imaging and information systems shows a lot of benefits by reducing processing efforts, patient throughput time, and data errors. System integration is the foundation for many precise diagnoses and treatments. However, in many hospitals, there are still a lot of modalities and information systems that do not support the standard integration protocols (HL7, DICOM) and cannot interchange information freely with other systems. One solution to this problem is applying gateway systems to combine the nonstandard systems and convert nonstandard data to standard format.[1-3]

According to the digital imaging and communication in medicine (DICOM) standard and the IHE (Integrated Healthcare Enterprise) technical framework,[4] patient information and orders in the HIS (Hospital Information System) are transferred into DICOM image objects by a DICOM MWL (Modality Working List) protocol. Modalities combine the information in the MWL protocol and information generated in modalities to constitute the DICOM image objects. However, many HIS systems and modalities in hospitals do not support the standard MWL protocol. For the purposes of system integration, a gateway system can be used to obtain patient information from HIS, combine the image data generated by a

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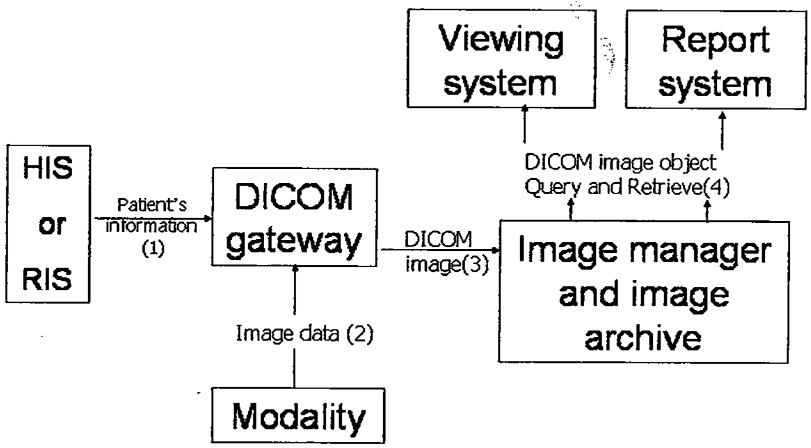

Fig 1. DICOM gateway system for nonstandard HIS and modalities. The operating procedures are as follows: (1) Patient's data and orders are transferred to the DICOM gateway by means of direct database link or standard Modality Working List (MWL) protocol. (2) Modalities transport image data to the gateway through the DICOM image storage service or a proprietary data connection. (3) The DICOM gateway combines all the information into DICOM image objects and sends these objects to the image manager via the DICOM storage service. (4) Viewing or report system queries and retrieves those image objects. Both patient information and image can be obtained in those objects.

modality, and store the generated DICOM object to an image archiving system.[5,6] Figure 1 illustrates the general framework of a DICOM gateway system connected with HIS and PACS systems.

Not only modalities generate medical images; many post-processing systems produce new image objects for clinical needs. It would be more convenient and useful if those post-processing systems could be integrated into the standard healthcare environment. This article examines a case involving the integration of image post-processing system for image registration and fusion.[7-9] Post-processing systems play a role as image creators, as defined in the IHE technical framework. For integration into the standard healthcare enterprise, such an image creator must implement the network transactions claimed in the technical framework. Because many post-processing systems now in use do not support those transaction protocols, a DICOM gateway is designed to meet this need. The post-processing system in our study handles non-standard positron emission tomography (PET) image data and DICOM MR or CT images, adjusts their 3-D locations, and fuses PET with MR images to form a new series of images. This study aimed to demonstrate the procedures for converting those fusion results into standard DICOM format. The process of image fusion, the DICOM gateway development procedures, and the DICOM object generation steps are introduced here. Using the gateway system, we can generate standard DICOM objects for image fusion and can exchange data with a standard picture archiving and communication system (PACS). The DICOM gateway was ultimately set in the Nuclear Medicine Department and was integrated with our PACS. The generated DICOM objects were examined and evaluated in our DICOM viewer and treatment planning system for radiotherapy.

METHODS

Fusion of PET and MR Images

In the Nuclear Medicine Department of the Veterans General Hospital, Taipei, Taiwan (VGHTPE), PET images are generated by a GE PC4096-15WB scanner. The generated results constitute image interfiles with 4096 bytes of header. The header contains information about the patient, scanning parameters, image reconstruction method, and tracer of corresponding images. These PET image files and standard CT or MR image files from the DICOM server were input into the fusion system. Three-dimensional structures of both PET and MR were

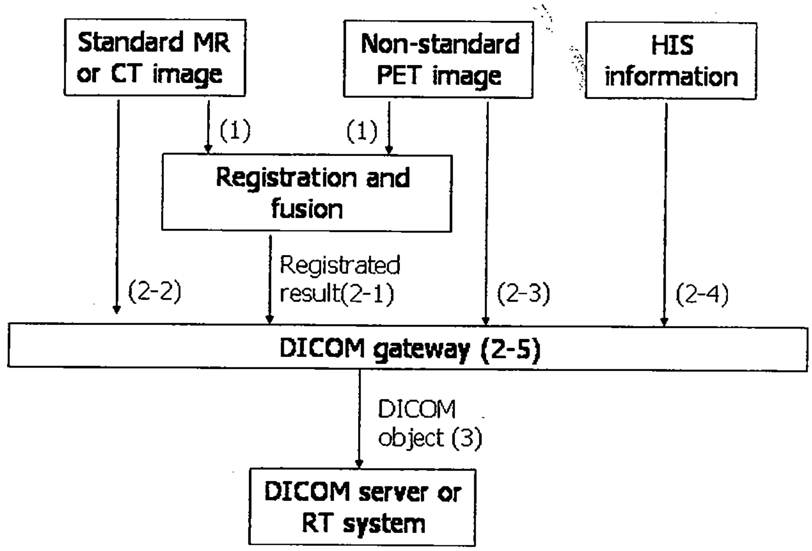

Fig 2. (1) DICOM gateway system for a nonstandard image creator. MR and PET original images are input into the fusion system. (2) The gateway system combines all the information required to constitute DICOM image objects. The series instance UID (Unique Identifier), series date, series time, and SOP (Service Object Pair) instance UID of each created image object are generated automatically in the gateway. (3) DICOM objects are sent to other systems through standard DICOM object interchange protocols.

reconstructed using interpolation techniques in the fusion system. After interpolation, two 3-D images of the same format (255 ×— 255 ×— 255 of 1 mm^3 cube) were generated. Using the user interface of the fusion system, experienced technicians adjusted and rotated the two 3-D images, registering them according to anatomic characteristics on both the PET and the MR images. These registration results constituted two new groups of images; both the MR and PET images were located at the same anatomic position. Including both functional and structural images, these fusion results are useful and helpful for diagnosis, radiotherapy (RT), and other clinical needs.[10-13]

Information Sources of the DICOM Gateway System

The registration results were non-DICOM format and could not be directly read by standard viewing systems. For the purpose of generating standard output results, we designed a gateway system to integrate the essential information for a DICOM object. Five essential information sources (original MR images, original PET images, fusion result, HIS information, and information generated from the DICOM gateway itself) provide required information for composing a DICOM fusion image. A DICOM gateway system for a non-standard image creator is shown in Figure 2.

The DICOM gateway has three kinds of input images: 3-D fusion images, original MR images, and original PET images. The original MR images were stored in the standard DICOM format. It was therefore easy to obtain tag information of the MR objects. The gateway system set the tag information about orientation, position, and scale based on the spatial information in the original MR image objects. Because these fusion objects should be assigned to the same study as that of the original DICOM MR images, the study instance. UID of new fusion objects was set to be the same as those of the original MR object.

The PET images were not stored in DICOM format. The data defined in the instrument's technical menu of PET images were checked with the tags defined in the DICOM PET information object definition (IOD). Matched data were extracted from PET images and were put into the newly generated DICOM objects. However, there were many deviations of data defined in the PET images and DICOM PET IOD. Some original and useful data from the original PET image would be lost in the transfer

Table 1. DICOM Part 4 K.6.2.2.2 General Purpose Worklist Attributes

Module	Attribute Name	Tag	Enabled	Length
Imaging Service Request	Accession Number	00080050	TRUE	10
Scheduled Procedure Step	Modality	00080060	TRUE	3
Imaging Service Request	Referring Physician's Name	00080090	FALSE	32
Patient Identification	Patient's Name	00100010	TRUE	32
Patient Identification	Patient ID	00100020	TRUE	12
Patient Identification	Issuer of Patient ID	00100021	TRUE	12
Patient Demographic	Patient's Birth Date	00100030	TRUE	8
Patient Demographic	Patient's Birth Time	00100032	FALSE	4
Patient Demographic	Patient's Sex	00100040	TRUE	1
	*			
	*			
	*			

Note: Each record becomes a field of the worklist table when the field Enabled is set to true.

to standard PET DICOM objects. Therefore, we added a private tag (0021, 1011) and assigned its value representation type as LT (Long Text) to preserve all the original header data (4096 bytes) of PET images. A standard DICOM image object must contain patient and order information that were stored in HIS. Because the HIS in VGHTPE did not follow HL7 and DICOM standards, the gateway could not receive the information of a patient and the patient's scheduled orders by the standard MWL protocol defined in DICOM. There are two different ways to solve this problem. The information may be transferred into the gateway by linking to the HIS database directly (Steps 2–4 in Figure 2), or information on patient and orders can be extracted from those source input images. However, the source input images also lack many required data points defined in the DICOM standard. To obtain those required data, we designed a worklist table to acquire patient and study information from HIS. These fields of the worklist table were set according to DICOM Part 4 K.6.2.2.2 general-purpose worklist attributes[14] (Table 1).

Figure 3 shows the user interface in the gateway system that links to the HIS database for querying HIS data to the worklist table. In the interface, we can identify which patient's data were ordered to perform the fusion process. The query conditions in the user interface were translated to the selecting conditions of the SQL (Structure Query Language) statement in the gateway system. After SQL statement execution, the query results constituted a record set. These results were shown as the worklist table in the user interface. Then the information in the worklist table was added into the created SOP instances. This user interface in the gateway is functionally the same as a DICOM worklist service in the modality or image creator. Consequently, the DICOM images generated in the gateway system will contain the same required information as those SOP instances generated by following the IHE technical framework with standard HL7/DICOM protocols.

In addition to the information form HIS and the input images, a DICOM object contains series and image information generated by the image creator itself. The series instance UID, series date, series time, and SOP instance UID of each created image object were generated in the gateway system automatically and then stored in the DICOM fusion object (Steps 2–4 in Figure 2).

Implementation of the DICOM Gateway System

A DICOM gateway system for the image creator must have the ability to generate DICOM data objects and to support DICOM verification and storage services to communicate with the PACS server. To accomplish those functions in the gateway system, we chose a free and open source library (UCD DICOM Network Protocol, University of California, Davis, CA, USA) to implement those DICOM objects and network services. Some modifications were made for the usage in Borland C++ Builder

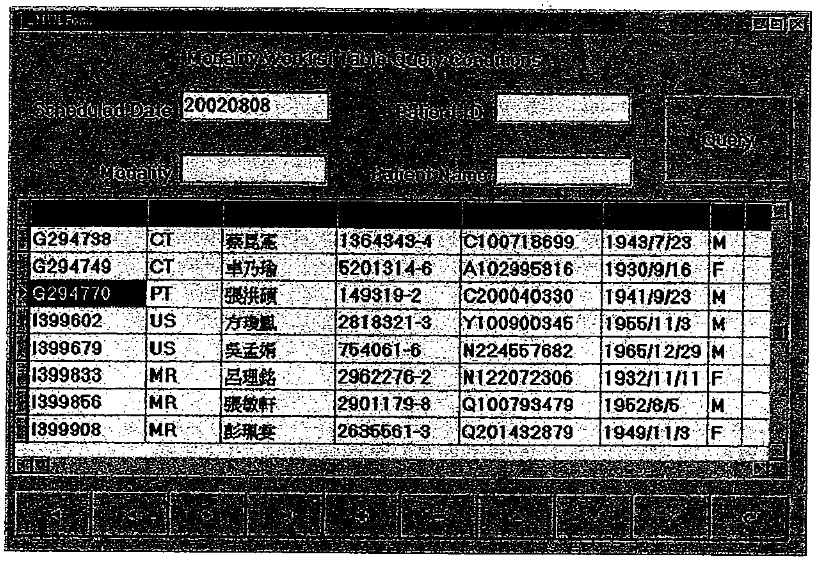

Fig 3. User interface to acquire information from HIS database to a worklist table. In the interface, we can use Scheduled Date, Modality, Patient ID, or Patient Name as selected conditions to query the HIS database.

(Borland Inc., Scotts Valley, CA, USA). We used the Borland Database Engine (BDE) to link the HIS database and database control components to select and control source tables from the HIS database. All the source code and user interface of the gateway system were designed in the C+ + builder integrated development environment. Base on the UCD DICOM library, we also implemented a DICOM tag viewer, which we used to view and edit DICOM objects. In addition, some fixed parameters of DICOM tags were initially set through the viewer (Fig. 4). The tag viewer is also useful to manage the complicated DICOM objects.

RESULTS

The gateway system was set up in the Nuclear Medicine Department. AT present it operates separately from the MR-PET fusion system. After the image registration process, the fusion system generated two 3-D image files. These results were stored in a file system using patient ID as the filename. In the gateway system, both MR and PET registration results were stored in a 3-D voxel array. Each voxel of the 3-D image array contains both PET and MR data value information. According to the definition in the DICOM image pixel module, one image pixel may contain multiple sample values. In this study, it might be reasonable to assign two sample values (MR and PET data) to each pixel of the created image object. However, DICOM does not define such created image objects, and none of the DICOM image viewers in our hospital can display DICOM objects that contain two sample values in a pixel. Consequently, our gateway system does not generate a single series of DICOM image objects with the format described above. Rather, the gateway system generates two new series of SOP instances to represent the fusion results. One is from the reconstructed MR images and the other from the reconstructed PET images. Because there was no created image object IOD defined in DICOM Part 3, we assigned MR or PET class UID to each created image in these two series. These two series of SOP instances have the same patient and study information. Also, the study instance UID and accession number in the two series are the same as those in the original MR SOP instances input to the fusion and gateway system. However, the gateway system can acquire HIS information through the worklist table designed in the system; in fact, the gateway system–generated SOP instances contain much more HIS information than the original MR images. The size, spatial resolution, spatial coordinates, and number of frames were the same in both series of created SOP instances.

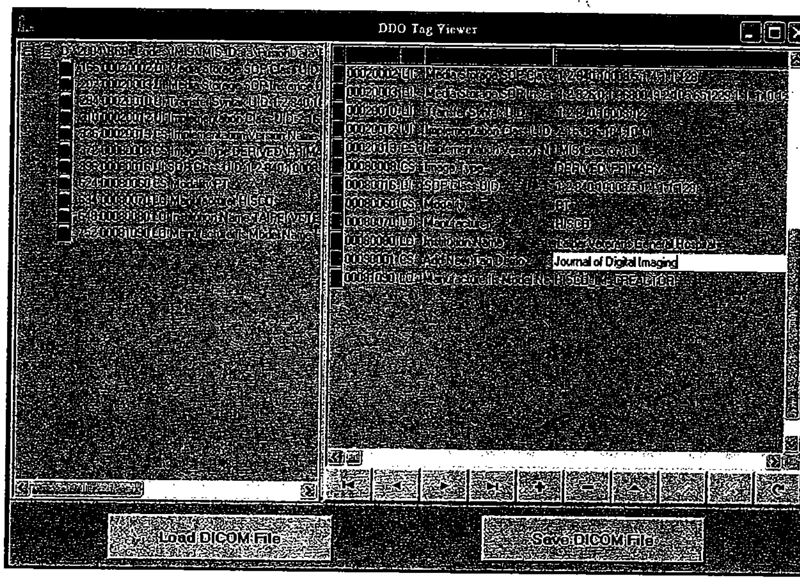

Fig 4. DICOM tag viewer for viewing and editing DICOM objects. The tree view on the left of the user interface can be used to view the tree type structure of a DICOM object. The table on the right side of the user interface was designed to edit tags of DICOM objects. As demonstrated in this figure, we can add a DICOM tag to the table. We can also delete or edit tags on the table. The editing results wilt be added to the DICOM object before we store the DICOM object.

The gateway system supports the DICOM storage service as an SCU (Service Class User) and can store the generated DICOM images to the DICOM storage server. The created DICOM images can be queried, retrieved, and viewed by standard viewers in the hospital (Fig. 5). The gateway system also can output the created image object as DICOM Part 10 files. Other systems can also view our fusion results by importing the DICOM files through the network system in the hospital. In our Radiotherapy Department, the treatment planning system does not support DICOM network services. However, the planning system has the ability to import DICOM Part 10 files. Consequently, the gateway system–created MR and PET DICOM images can be viewed in the treatment planning system (Fig. 6). This result is useful for accurate diagnosis and treatment in the radiotherapy department.

DISCUSSION

According to IHE technical framework, HIS and PACS communicate with each other by the standard DICOM MWL and modality performed procedure step (MPPS) protocols. But the HIS in VGHTPE does not support these standard protocols. When we tried to obtain HIS information for the created DICOM objects, the gateway system acquired data by linking to the HIS database directly. As explained in the Methods, we used the user interface in the gateway system to query and choose the patient and order data for the created DICOM object. However, fitting our HIS data to required attributes defined in the DICOM standard is not an easy task. The database schema of the HIS makes it difficult to match the information model and worklist attributes defined in DICOM Part 3. Many attributes defined in the worklist protocol cannot find a corresponding field in our HIS database.

Neither the proprietary HIS nor the PET instrument in our Nuclear Medicine Department outputs standard DICOM objects. The PET instrument generates interfiles with proprietary format. The interfile header contains information about patient, equipment, reconstruction parameter, isotope, and image format. The definition and format of the header differ significantly from the tags defined in DICOM PET IOD. This would cause problems in applying DICOM PET object and protocol in the Nuclear Medicine Department, and so the interfile is useful in that setting. Many systems

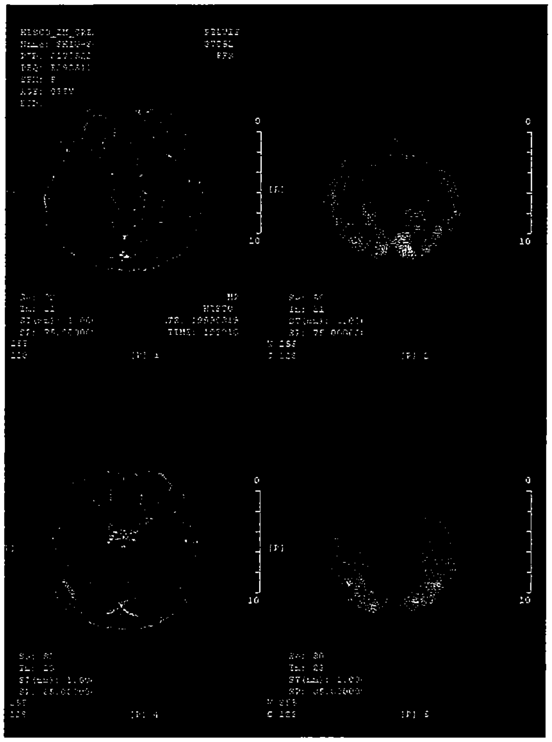

Fig 5. DICOM fusion images being viewed in our PACS viewer (TEDPC SmartView). Through the registration and fusion process, the spatial orientation and resolution are the same for the two series of created DICOM PET and MR images.

in the department can deal with the interfile and cannot process standard DICOM PET objects. The interfiles are stored and archived in a proprietary server. And those files are interchanged in the Nuclear Medicine Department by a network file-sharing protocol. In the normal workflow of PET examinations, the PET acquisition results do not output directly to other departments. The interfiles are processed and diagnosed in the department, and eventually, we generate reports that contain graphic PET images and text diagnosis results. The reports are in HTML or Microsoft Word format, which can easily be viewed and handled in other departments. It would have tremendous impact to apply the DICOM standard in our Nuclear Medicine Department for message communication and data exchange, but it will require a lot of effort to modify the systems in the department to support the DICOM standard. Additionally, our Radiotherapy Department is only partially supporting the DICOM standard. As demonstrated by our results, the planning system in the department has the ability to import DICOM Part 10 files. The treatment planning system can accept and process standard MR, CT, and PET DICOM images. In the planning system, we identify tumor and vital organs, prescribe the dose distributions of target areas, design the radiation intensities and beam orientations, and simulate the dose-delivery results. The planning system works with verification and dose-delivery systems in the department. However, the planning system communicates with other systems in the RT department by specific data format and proprietary network protocols. Radiotherapy information systems must fulfill existing quality standards and a lot of domain-specific requirements. The RT objects defined in the DICOM standard show significant differences from diagnostic image objects. Most of the systems in our RT department do not support DICOM communication protocols and those standard RT objects. At this time, a lot of effort needs to be made for system integration in the RT department. As in the Nuclear Medicine Department, applying DICOM standard in the RT department is not an easy job.

CONCLUSIONS

The original purpose of this study was to design a gateway system for post-processing systems to integrate with standard PACS. As demonstrated in this article, a lot of programming effort has been spent to design the gateway and achieve the integration. We have tried to create DICOM objects that contain the same information as those DICOM objects generated in the normal workflow of the IHE technical framework. With the steps described in the *Methods*, the gateway system can link and acquire data from proprietary systems and can create standard DICOM objects. We have shown that the created DICOM objects are useful in the Radiotherapy Department, and the standard objects can also be viewed and handled by PACS in the hospital. System integration shows considerable benefit in the clinical healthcare process, and using standard data format and network protocols seems to be a proper approach to system integration. At

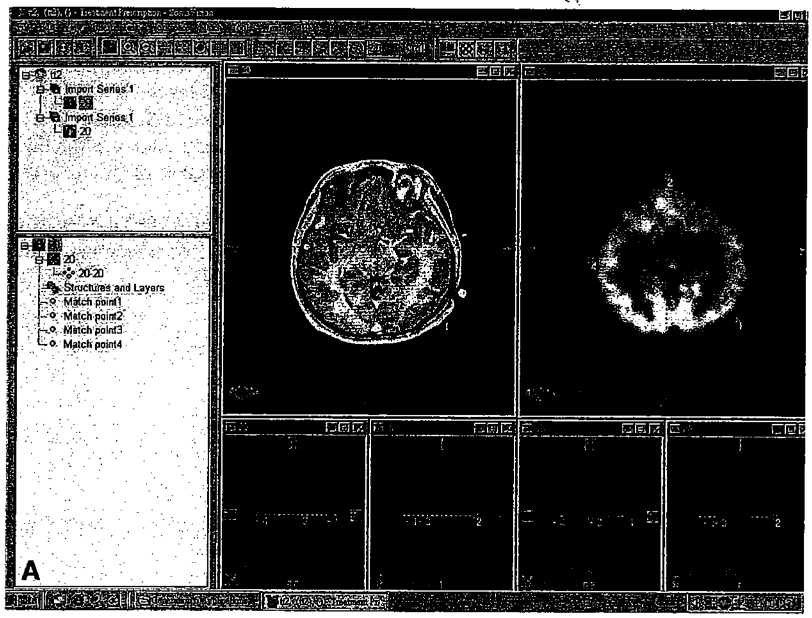

Fig 6. DICOM fusion images being viewed in the treatment planning system in our Radiotherapy Department. The treatment planning system allows viewing two series of DICOM images at the same special position simultaneously. (a) MR and PET result images of the same image position can be displayed on two viewing panels, or (b) the two images can be overlaid and viewed on the same display panel.

present PACS is successfully used in the Radiography Department. Most of the vendors in this domain claim that their systems support the DICOM standard. However, as proposed in IHE technical framework, the healthcare information systems are required to support quite a few DICOM and HL7 protocols to ensure that all required information for medical decisions is both correct and easily available to professionals in modern healthcare institutions. In our hospital, most modalities and information systems do not fully support those required protocols. Also, the DICOM standard is not so successfully and widely used in nuclear medicine and radiotherapy departments as in radiography departments. Nonstandard equipment in those departments usually works with gateways to support DICOM standard. It seems that many gateway systems must be established to achieve information integration in the hospital. We have demonstrated how to construct a DICOM gateway system for an image post-processing fusion system in a nuclear medicine department. But, more effort is needed to revise the gateway to fit with other proprietary HIS or non-standard modalities. System integration is not a plug-in-and-play job in a real hospital.

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