PET/CT Fusion Viewing Software for Use with Picture Archiving and Communication Systems

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We developed positron emission tomography (PET)/computed tomography (CT) viewing software (PETviewer) that can display co-registered PET and CT images obtained by PET/CT and stored on picture archiving and communication systems (PACS). PETviewer has tools for presetting windows for CT display; control bars for PET window level; zoom, pan, and pseudo-color functions; and allows the user to draw a rectangular region of interest (ROI) for standardized uptake value (SUV) measurement. SUV was calculated using PET DICOM header information and the pixel intensity in PETviewer. Reconstructed datasets of PET/CT and maximum intensity projection (MIP) of the PET images were transferred and archived in PACS. Phantom experiments were performed to evaluate the validity of image fusion. PET/CT images were displayed on an independent window in PACS. Transaxial PET images were reformatted as sagittal and coronal PET images, which were displayed with the corresponding CT and PET/CT fusion images with adjustable color and transparency. Transaxial, sagittal, and coronal PET images corresponding to the location of the cursor were shown using cine display of MIP images. All images were displayed in PETviewer within 20 s on a personal computer for PACS, which was equipped with a P4, 1.3-GHz CPU, and 512 Mb of RAM. We could measure maximum and mean SUV in a ROI using PETviewer. Transaxial fused images of patients and phantoms showed excellent registration and fusion of PET and CT images in the X and Y directions. PETviewer provided very useful clinical tools for assessing PET/CT images on PACS and should assist in maximizing the benefits derived from PET/CT imaging.

KEY WORDS: PET/CT, PACS, image fusion, multimodality imaging

INTRODUCTION

Combined positron emission tomography (PET)/computed tomography (CT) systems enable the acquisition of data for large areas of the body in a short time and provide spatially

registered images from the two modalities acquired in a single imaging session. The diagnostic advantages of integrated PET/CT include improved detection and characterization of lesions on both CT and PET images, better differentiation of physiologic foci from pathologic foci, and better localization of pathologic foci^{1, 2}. The combined approach of CT attenuation correction and image fusion with PET is a new diagnostic tool for nuclear medicine imaging, radiation therapy, and surgical planning. PET/CT fusion images affect clinical management by guiding decisions such as whether to perform additional procedures and whether to change therapies. The benefits of using a combination of PET and CT have presented health care providers, radiologists, and nuclear medicine physicians with the challenge of making this combined technology available for patient care.

The advent of multimodality imaging scanners such as PET/CT systems has led to a new paradigm in image display that raises new challenges in workstation interpretation software, image navigation, and communication³. Despite the introduction of this new paradigm in image

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display, combined PET/CT data still pose a challenge for picture archiving and communication systems (PACS) and image display programs.

PACS, and therefore soft-copy reading, have been widely implemented throughout the world and have been frequently applied in radiology. The ability to convey multimodality images to referring physicians is usually limited because of a lack of adequate viewing software through PACS⁴⁻⁷. Hence, PET/CT results are usually distributed as static "snapshots" of fused images generated by the nuclear medicine physician. However, this approach limits the degree to which the referring physician can navigate through the set of multimodality image data. Image displays must allow the user to manipulate the upper and lower display settings separately for both PET and CT rather than providing only the CT convention of window center and width.

This study is not an issue with the digital image communications in medicine (DICOM) standard, but rather a design issue concerning vendors' choices in implemented image displays^{8,9}. Systems optimized for efficient interpretation of CT and MRI images may be very awkward to use

when viewing nuclear medicine data. The development of the new DICOM viewer was motivated by the need for a tool that is more suitable for visualizing multidimensional and multimodality imaging data such as those produced in PET/CT studies^{10,11}.

The purpose of the present study was to develop new software (PETviewer) that enables users to efficiently and conveniently navigate through large sets of multidimensional data without the need for high-end expensive hardware or software on PACS.

MATERIALS AND METHODS

PETviewer

Boland C++ was used to develop PETviewer, a software system that allows image fusion as well as clinical application of fusion images. All images are assumed to be co-registered by PET/CT hardware. An image analysis platform on PACS must support the transfer and reading of images stored in the DICOM standard 3.0 format. Import-

Fig. 1. ASAN Medical Center Hospital PACS configuration.

tant design criteria were that the system should enable image analysis experts with varying degrees of computer expertise to review images via an easy-to-use radiology-oriented graphical user interface (GUI) and should support the standard image manipulation features available in PACS workstations. Similar to a standard PET/CT workstation, the PETviewer GUI should be designed to provide navigation capabilities for paging through image sequences. Axial PET and CT images are used to display fusion images in PETviewer. The reconstructed PET axial images can be displayed in a multi-planar rendering view where sagittal, axial, and coronal views of the same region are

displayed together. Axial PET images are reformatted as sagittal and coronal PET images, which are simultaneously displayed with CT and fusion images with adjustable color and transparency. Desirable tools include the facility to link sequences, enabling a user to page through several sequences in unison or a cine-mode feature, allowing the user to rapidly scan through all the slices of a sequence in one position. Maximum intensity projection (MIP) images are displayed as a cine-mode feature. Axial, sagittal, and coronal PET images corresponding to the location of the cursor are shown simultaneously. The provision of manual drawing and/or outline tools is also

Fig. 2. Result of phantom test displayed in series view. The first column is the PET image, the second column is the CT image, and third column is the fused image. PET images could be fused with CT images exactly.

fundamental. The minimum tools required include the drawing of simple rectangles shapes.

A semi-quantitative analysis of ^{18}F -fluoro-deoxy-glucose (^{18}F -FDG) activity was performed by calculating the maximum standardized uptake value (SUV_{max}), SUV_{mean} , and $\text{SUV}_{\text{max_mean}}$ for each focal ^{18}F -FDG uptake in the attenuation corrected PET data¹². The SUV is a glucose metabolism index derived from ^{18}F -FDG PET data. It represents the metabolism value of the uptake of a region of interest (ROI) relative to the whole body uptake. The SUV was calculated as follows:

$$\text{SUV} = K(\text{MBq/cc}) \times (\text{Wt}(\text{kg})/\text{Dose}(\text{MBq}) \times 1,000 \text{ cc/kg})$$

where K (MBq/cc) is a pixel value calibrated to megabecquerels per cubic centimeter and decay

corrected to the scan start time. Dose is the injected dose in megabecquerel at injection time, decay corrected to the scan start time. The injection time must be part of the dataset. Wt is the patient weight in kilograms. The factor 1,000 corresponds to the number of cubic centimeters per kilogram for water, with an approximate conversion of patient weight to distribution volume.

SUV_{max} is the maximum SUV value in a ROI and SUV_{mean} is the mean SUV value in a ROI. $\text{SUV}_{\text{max_mean}}$ is the mean SUV of nine neighbor SUVs included maximum SUV

Workflow

Image fusion was achieved in a PACS workstation (Petavision®, Asan Medical Center)¹³. Whole body PET and CT images were acquired

Fig. 3. PETviewer main display window. PETviewer has three viewing functions: exam list, orthogonal view, and series view. a Exam list displays the patient list for the PET exam and the diagnostic result. b Orthogonal view displays MIP data in movie style in the left upper image. Axial PET images are reformatted as sagittal and coronal PET images, which are simultaneously displayed with CT and fusion images with adjustable color and transparency. MIP, axial, sagittal, and coronal PET images corresponding to the location of the cursor are shown simultaneously; these images indicate lung metastasis. c Series view shows three axial images, with PET images in the first row, CT images in the second row, and fusion images in the third row.

b

Fig. 3. (continued)

with a PET/CT scanner. Reconstructed datasets of PET/CT were transferred and archived in PACS servers through a DICOM gateway.

The clinical application of fusion images was evaluated. Phantom experiments were performed to evaluate the validity of image fusion and registration. The SUV was calculated using activity, weight, and injected dose information in DICOM header files.

After performing the MIP of the PET image with scanner software, MIP, axial PET, and CT images were transmitted to the PACS developed by our hospital (Petavision®).

PET/CT Acquisition

Images were acquired using a Biograph Sensation 16 PET/CT scanner (Siemens, Knoxville, TN,

USA), a combined system that integrates a PET scanner based on the ECAT ACCEL (CPS Innovations) with a spiral CT scanner (Sensation 16; Siemens Medical Solutions using the syngo multimodality computer platform; Siemens, Knoxville, TN, USA). The Sensation 16 is a 16-slice CT scanner that can acquire images with slice thicknesses of 0.75 to 10 mm. The PET component of the Biograph is an ECAT ACCEL scanner (CPS Innovations), which acquires 47 transaxial images simultaneously¹⁴.

All patients fasted for at least 6 h before undergoing PET/CT. Scans were performed 60 min after intravenous injection of 555 MBq (15 mCi) of ¹⁸F-FDG. After the imaging field had been determined with an initial topogram scan, a 20- to 40-s whole body CT acquisition was performed using the following parameters:

Fig. 3. (continued)

120 kV(p), 110 mAs, 5-mm slice collimation, and a bed speed of 15 mm/s. On completion of the CT portion, the PET emission data were acquired for 2 min/bed position for all patients. Imaging included six to seven bed positions per patient. Patients were instructed to breathe shallowly during the PET and CT portions of the study to minimize misregistration and attenuation artifacts between PET and CT images.

The PET images were reconstructed using an attenuation-weighted ordered-subsets expectation maximization algorithm (two iterations, 16 subsets) followed by a postreconstruction smoothing Gaussian filter (full width at half-maximum, 6 mm). The images were reconstructed in a 128×128 matrix without zooming, resulting in a pixel size of 5.3 mm. These processing parameters are

representative of those typically used in routine clinical studies.

The ASAN Medical Center PACS

The PACS (Petavision®) used in this work was organized into three subsystems: the acquisition subsystem, database and storage subsystem, and display subsystem (Fig. 1). The display subsystem was a personal computer (PC)-based clinical workstation developed by ASAN Medical Center. The hardware components used in the display

Fig. 4. Orthogonal view functions. a MIP and PET images are displayed with pseudo color. b SUV was measured on the region of interest in the transaxial image. SUV results are shown in the window title bar as maximum SUV, mean SUV and max_mean SUV in 9 pixels on the center of maximum SUV.

subsystem were a Windows XP-based Pentium4 IBM PC, 8-Mb video memory card, 512-Mb RAM, 19-inch color LCD monitor, and 100-Mbps network adaptor¹³. PC-based diagnostic workstations are fully integrated with the Hospital Information System (HIS). Because the PACS is fully integrated with the HIS, it is possible to review the results of pathological reports or clinical laboratory reports. Clinical review workstations are connected via 100-Mbps fast Ethernet. All images are saved in DICOM 3.0 file format with 2:1 lossless compression. Measurable benefits of using an off-line PC DICOM viewer are cost savings associated with reducing the number of copy films and copy personnel¹⁵.

Phantom Experiment

Basic experiments using sphere phantoms were performed to evaluate the validity of image fusion on the PACS. Spheres with volumes of 0.5, 1.0, 2.0, 4.0, 8.0, and 16.0 ml were filled with a solution of uniform activity of ¹⁸F-FDG. The spheres were positioned in a circle of ~5-cm radius and placed in a 20-cm diameter phantom. Cylinder wall thickness was 6.4 mm. All images were reconstructed with 5-mm slice thickness both PET images and CT images.

RESULTS

MIP, PET, and CT images were successfully transferred to the PACS server and displayed as three series using the PACS main viewing tool.

The excellent registration of the PET and CT images in the X and Y directions is demonstrated in the transaxial fused image shown in Fig. 2.

A fusion image of a 59-year-old male patient with lung cancer was obtained. On an independent window in PACS, PETviewer supplied three functions: exam list, orthogonal view, and series view (Fig. 3). The exam list function provided the PET exam list and the diagnosis result for the clinician (Fig. 3a). Axial PET images were reformatted as sagittal and coronal PET images, which were simultaneously displayed with CT and fusion images with adjustable color and transparency on the orthogonal view (Fig. 3b). MIP images were first displayed as video streaming on the orthogonal view. Sagittal and coronal PET images were reformatted

using the axial PET image on the PET viewer. In three dimensions, axial, sagittal, and coronal PET images were made to move simultaneously so that the set of three images always corresponded to the same position. Using the system, the user can interactively blend the PET and CT images. The axial image supplied by the orthogonal view was seen in the "center of series" view. The series view was seen as three axial views—PET images, CT images, and fusion images—and zoom and pan functions were supplied (Fig. 3c).

PET images could be used to quantitatively measure SUVs on PETviewer (Fig. 4). We could define a rectangular ROI and measure the maximum, mean, and max_mean SUVs in an axial PET image. The SUV result was shown in the PETviewer title bar.

PETviewer had zoom, pan, and pseudo-color tools that could be applied to CT axial and fusion axial images (Fig. 5).

An MIP image could be generated and the PET/CT result transmitted to PACS in less than 1 min. Using PC-based PACS, a fusion image could be displayed within 20 s on a computer equipped with a Pentium 4, 1.3-GHz CPU, and 512 Mb of RAM.

DISCUSSION

Software for fusing PET/CT images was successfully developed to work on PACS. In the developed system, named PETviewer, PET images, CT images, and fusion images are supplied on the same monitor view. MIP, coronal, and sagittal PET images corresponding to the location of the cursor on axial PET, CT, and fusion images were shown simultaneously. PETviewer can thus display multiple settings of the same dataset simultaneously in the form of MIP, coronal PET, sagittal PET, and fusion PET images. Combined PET/CT adds a new dimension to the data that represent the metabolic activity of the tracer, and blending this functional parameter represents a fourth dimension that users can explore. The proposed system makes it possible to navigate interactively through orthogonal planes in coronal and sagittal orientations as well as in oblique planes. PETviewer was developed to enable faster navigation through very large image datasets with limited user interaction.

Fig. 5. Scaled CT and fused images. a The fusion image and CT image are displayed with pseudo-color and zoom. b The fusion image and CT image was zoomed. c Opacity was controlled to the PET image. d CT image was displayed with the lung window level.

Fig. 5. (continued)

Multimodality PET/CT fusion software programs that require significant interaction and manipulation by the user are not suitable for routine diagnostic interpretation of CT scans by radiologists on PACS. Currently, in most cases, only a subset of "snapshot" images is presented by the radiologist or the nuclear medicine physician, a situation that creates difficulties for clinical discussion of complex cases. When snapshot images are used, clinicians do not have access to the wealth of information contained in combined PET/CT images. Snapshot images provide only images of tumors without normal organs. In addition, the use of a snapshot from an original image fusion means that window/level and transparency settings are no longer adjustable.

The workstation stores the registration data for subsequent visualization and image processing. Such visualization may include side-by-side synchronized display or display of a fusion of images recorded using different modalities. The processes for such fusion are beyond the scope of the DICOM standard. The workstation may also create and store a ready-for-display fused image, which references both the source image instances and the registration instance that describes their alignment. With easier access to these multidimensional navigation and visualization tools in standard personal computers, these functions should soon become complementary tools for routine interpretation of complex diagnostic studies. The user can navigate along dimension by interactively adjusting the degree of blending or color-overlay transparency of the functional PET data with the anatomic CT data on PETviewer. PETviewer thus allows physicians to easily and efficiently navigate through multidimensional datasets.

A fusion image was displayed within 20 s in a computer for PACS on PETviewer. Advances in fusion software and computer speed have remarkably reduced the processing time, thereby increasing the feasibility of using multimodality imaging in clinical practice.

A PACS that provides efficient image transfer, storage, and processing capabilities is important in achieving a higher level of quality in imaging departments and throughout entire hospitals; productivity, efficiency, and cost-effectiveness increase, leading to better patient care. Clinicians working in a busy clinic under time pressure need to be able to read high-quality CT images in their

offices. To allow radiologists and clinicians to conveniently and efficiently interpret these large exam sets, traditional image viewers have to be redesigned and tailored to a new paradigm of multidimensional image navigation, visualization, and manipulation. PETviewer is displayed on an independent window without being redesigned as a viewing tool in PACS.

Another advantage of the proposed system is that it simplifies the operator's work procedures by automatically transferring patient images to PACS. Operators could easily send PET/CT images to PACS, and MIP, PET, and CT images were transmitted to the PACS server immediately after acquisition.

CONCLUSIONS

The combination of PACS and PETviewer provided a very useful clinical tool for assessing PET/CT images. Examination of combined PET/CT images yields valuable information for cancer diagnosis, for planning radiation therapy, and for assessing therapy outcomes. The PETviewer program on PACS increases the benefits that can be derived from PET/CT imaging.

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