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General Consumer Communication Tools for Improved Image Management and Communication in Medicine

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We elected to explore new technologies emerging on the general consumer market that can improve and facilitate image and data communication in medical and clinical environment. These new technologies developed for communication and storage of data can improve the user convenience and facilitate the communication and transport of images and related data beyond the usual limits and restrictions of a traditional picture archiving and communication systems (PACS) network. We specifically tested and implemented three new technologies provided on Apple computer platforms. (1) We adopted the iPod, a MP3 portable player with a hard disk storage, to easily and quickly move large number of DICOM images. (2) We adopted iChat, a videoconference and instant-messaging software, to transmit DICOM images in real time to a distant computer for conferencing teleradiology. (3) Finally, we developed a direct secure interface to use the iDisk service, a file-sharing service based on the WebDAV technology, to send and share DICOM files between distant computers. These three technologies were integrated in a new open-source image navigation and display software called OsiriX allowing for manipulation and communication of multimodality and multidimensional DICOM image data sets. This software is freely available as an open-source project at http://homepage.mac.com/rossetantoine/OsiriX. Our experience showed that the implementation of these technologies allowed us to significantly enhance the existing PACS with valuable new features without any additional investment or the need for complex extensions of our infrastructure. The added features such as teleradiology, secure and convenient image and data communication, and the use of external data storage services open the gate to a much broader extension of our imaging infrastructure to the outside world.

KEY WORDS: PACS, teleradiology, iPod, webcam, ASP

INTRODUCTION

Over the past two decades, most radiology departments have slowly evolved from film-based environment to digital environment by deploying picture archiving and communication systems (PACS).[1] It is estimated that by the end of this decade, well over half of all medical centers' radiology departments will be fully digital.[1] The introduction of PACS has, in many cases, introduced major changes in workflow and was often disruptive of existing clinical workflow. This resulted in a fair amount of resistance from the users that did not perceive sufficient benefits from the migration to a digital environment that is often too rigid and lacks the flexibility to easily adapt to user preferences and needs. On the other hand, in the general consumer market, the penetration of personal computers and electronic communication technology was only possible when these technologies became widely accessible and easy to use. Similarly, it is expected that a technology widely adopted and easy to use will rapidly penetrate vertical markets such as medical informatics and medical imaging.

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In recent years, major efforts were deployed to promote and implement standards such as DICOM[2] and to adopt standard technology in an effort to achieve better integration and wider interoperability. Latest generations of PACS are becoming part of enterprise-wide electronic medical records.

The difficult transition from film-based environment to digital environment has often focused on the basic functions of PACS: storage and communication. In early implementations, reliability of storage and speed of communication have been the limitations of PACS deployment. These limitations are less prominent today with the wider availability of faster and more reliable storage and communication products.[3]

The early radiology workstations were designed as substitute to traditional light boxes for simple visualization of static images. They have progressively been adopted to support more modalities and to load and display rapidly and conveniently very large volume of images, produced by the new multidetector CT scanners for example. More recently, some systems began to offer 3D reconstructions and visualization capabilities as part of PACS workstations.[4]

But even with these recent improvements and changes in PACS and radiology workstations, many problems are still limiting the wider use of imaging technology by broader number of users:

(1) Clinicians and referring physicians from other departments have often only limited access to digital images. In best situations, they have access to PACS images through a web-based system[5] with slow access and relatively limited image manipulation capabilities. With the recent evolution of imaging modalities toward high-resolution multidimensional imaging techniques generating extremely large image sets, users have started to rely on advanced image display and navigation features such as 3D volume rendering and multiplanar reformatting. These features are becoming essential for physicians and surgeons that depend on adequate visualization of the image data to perform complex interventions or assess the effect of a given therapeutic procedure. The ability to adequately navigate through these large data sets is often lacking in existing web-based image distribution systems.

(2) Another limitation of existing PACS and image management systems is the lack of adequate means for easy communication and consultation among distant users. The ability of radiologists interpreting physicians to consult their piers in a convenient and nondisruptive way would certainly allow for more frequent multidisciplinary dialog among specialists, leading to better quality of interpretation of complex cases. Interpreting radiologist would more often consult a colleague when in doubt if the mechanism for sharing and reviewing an image remotely would be available and convenient to use without complex setup. In current interactive teleradiology systems, remote consultations require dedicated software and hardware systems that require complex and expensive setup. These systems also often require images to be sent remotely ahead of time before an interactive consultation can take place limiting its usability for quick and occasional consultations between colleagues who just want to get a second opinion or a quick confirmation on a given finding. The same observation applies to referring physicians and caregivers that would like to get a quick consultation with a radiologist over a given image or finding. In current settings, such a scenario requires relatively rigid and time-consuming process to initiate a remote collaborative discussion where two remote users could simultaneously share the access to an image. If such functionality was more accessible and easier to initiate, it would certainly be much more widely adopted improving thereby the communication between referring physicians and radiologists, which ultimately should improve efficiency and quality of patient care.

(3) With the changes in radiology practice, increased diversity of imaging modalities, and a shift toward interventional radiology and image-based procedures, the radiologist's workflow is changing drastically requiring more mobility and more distributed and efficient access to images. Particularly in academic settings, the radiologists need to be able to transfer and communicate images constantly from one location to another. Image processing and quantitative analysis, clinical conferences, teaching sessions, and

research studies will require to constantly move image data from one location to another often beyond the capability of traditional PACS network. Users have started to rely on off-line media such as CD and DVD media to rapidly transfer images. With the increasing size of image studies such as multidetector CT, functional MRI, and multimodality PET-CT, the size of the data tends to exceed the capacity of traditional media, and therefore, alternative solutions for convenient transportation of very large image data from one location to another are desperately needed.

(4) Medicine, particularly emergency medicine, relies heavily on imaging procedures for patient management and clinical decision making resulting in a progressive shift of radiology to become an emergency specialty with extremely fast turnaround time and round-the-clock availability. This trend required the radiologist to adopt and provide broader and more efficient coverage through night and off-hours coverage using teleradiology and electronic image communication techniques for remote access and rapid image interpretation. Most teleradiology systems, however, require substantial capital investments that are often difficult to justify because they do not lead to any incremental revenue. Radiologists are therefore compelled to adopt more affordable general consumer communication tools such as E-mail, instant messaging, and off-line data storage services to conveniently communicate image data.

This is why we elected to explore, evaluate, and integrate new emerging technologies to expand capabilities of current PACS beyond its current limitations. We intentionally selected general consumer products for their wide availability, low cost, convenience, and ease of use. We specifically selected a set of new products and services recently released by Apple Computer[6] and adopted them for medical imaging applications. (1) The iPod[7], a popular portable music player, was integrated to serve as a high-capacity portable DICOM storage with a high-speed transfer rate. (2) iChat AV[8] instant messaging and videoconferencing software was adopted to allow real-time radiology videoconferencing tool for remote image viewing and screen sharing. (3) iDisk[9], an Internet service provided by Apple for secure data storage on a virtual hard disk, based on the Web Distributed Authoring and Versioning (WebDAV)[9] standard was adopted as a DICOM data storage solution tool to quickly and easily store and transfer DICOM images between different locations.

MATERIALS AND METHODS

For implementation and testing of these new technologies, we used our own Open-Source Imaging platform called OsiriX that was developed for multimodality and multidimensional image display and visualization.[10] This versatile platform offers the ideal flexibility for development and testing of innovative image manipulation tools. OsiriX is a free and open-source software available at this web site: http://homepage.mac.com/rossetantoine/OsiriX. This software was developed using open-source libraries such as Papyrus Toolkit[11] for DICOM files, PixelMed[12] and DICOM Offis[13] for DICOM network, the Visualization Toolkit[14] for 3D rendering, and the Insight Toolkit[15] for registration and segmentation. This software supports all classic functions of a standard PACS workstation. It is developed in Objective-C/C++ language on the MacOS X platform, a Unix-based operating system. The software and its source code are made available to other developers under the Open-Source General Public License.[16]

Listed below are the more detailed specifications of the different tools that were adopted and integrated to the OsiriX software platform:

(1) The iPod.[7] The iPod is a portable music player (Image 1). It integrates a fast and high-capacity hard disk to store up to 40 GB of data. It can be connected to any computers that have a FireWire 400 (IEEE 1394 interface)[17] or a USB-2[18] interface. Transmission speed of these two interfaces is up to 400 and 480 Mbits/s, respectively. The iPod does not require a power cable to work. The size is $4.1 \times 2.4 \times 0.69$ in. ($10.4 \times 6 \times 1.75$ cm), and the weight is 6.2 oz (175 g). We used a 40-GB model for our tests. It is compatible with MacOS or Windows operating systems. OsiriX software was adopted to automatically detect when an iPod is connected to the computer and automatically updates its local DICOM database to display the studies available on the iPod disk. These studies are not copied to the hard disk of the computer but directly loaded from the iPod hard disk to the computer RAM for display. The user can then select and open a study located on the iPod from the OsiriX study list. The user can also copy image data from and to the iPod by clicking on a specific icon in the toolbar (Image 1). With the recent generation of iPod photo device, it is also now possible to display color images on the iPod screen (resolution of 220×176 pixels). To take advantage of this added feature, we also modified OsiriX to allow the user to export selected images or image sets to the iPod through the iPhoto software provided by Apple allowing these images to be uploaded to the iPod and displayed on the screen. To be displayable on the iPod, these images have to be exported

Image 1. Dr. Osman Ratib, on the front right, and Dr. Antoine Rosset, on the left back, using their iPod to quickly load and display DICOM images on the OsiriX software. DICOM images are directly loaded from the iPod without the need to copy them on the computer hard disk. The iPod is connected through the FireWire interface and is automatically recognized by the OsiriX software (displayed on the screen) as a DICOM storage.

as JPEG snapshot and exported in a specific photo album of the iPod.

(2) iChat AV.[8] iChat is Apple's instant messaging software that also supports videoconferencing. It allows to transmit real-time video stream and audio data through a standard Internet connection. It is compatible with the instant messaging technology from American Online (AIM)[19] and from Apple (".Mac").[8] It is compatible with most USB or FireWire video cameras. Quality and frame rate of the live video depends on Internet connection speed, and also depends on the computer processor performance because it requires adequate speed for MPEG-4[20] image compression in real time. The use of this software requires an instant messaging account on AIM or ".Mac". iChat AV is compatible with MacOS 10.3 or higher operating systems only, but the video stream can be received and viewed also on Windows operating systems. iChat AV uses the http on ports 5060, 16384, and 16403. This allows users to use this teleconferencing tool without problems through firewalls if these ports are opened. There is no need for complex VPN encryption for communication across enterprise firewalls with people outside the institution. Because iChat AV is restricted to use only the external video camera, a special software modification was necessary to allow the transmission of the content of the OsiriX window through the video stream allowing remote users to see the images displayed and manipulated on the screen in real time. We added a small "broadcasting" icon in the toolbar of our OsiriX software. By clicking on this icon, the user is able to activate or deactivate immediately the transmission of the current displayed images. OsiriX sends the content of the OsiriX window to the active iChat AV correspondent. It means that the remote user can see the exact window content in real time including interactive adjustments and image manipulations such as the window level and width adjustment, the rotation, the zoom, the mouse position, the displayed regions of interest, etc. (see Image 2). Both users are able to communicate through the real-time audio communication function built-in iChat AV.

(3) iDisk.[9] The iDisk secure data storage service provided by Apple offers an Internet virtual disk accessible from any computers connected to Internet. This service is based on the WebDAV standard, compatible with all operating systems. The transmission rate depends on the WebDAV service provider and on the Internet connection bandwidth. The transmission is encrypted by using the Secure-http (HTTPS). This encryption assures that the transmitted data are securely copied and cannot be intercepted by someone else during the transfer on Internet. The user has to identify itself with a username and password to read or write data to the virtual disk. The annual costs of a 250-MB disk is less than $100 per year, and a 1-GB storage space costs approximately $150 per year. We modified the OsiriX software and added two icons in the OsiriX database

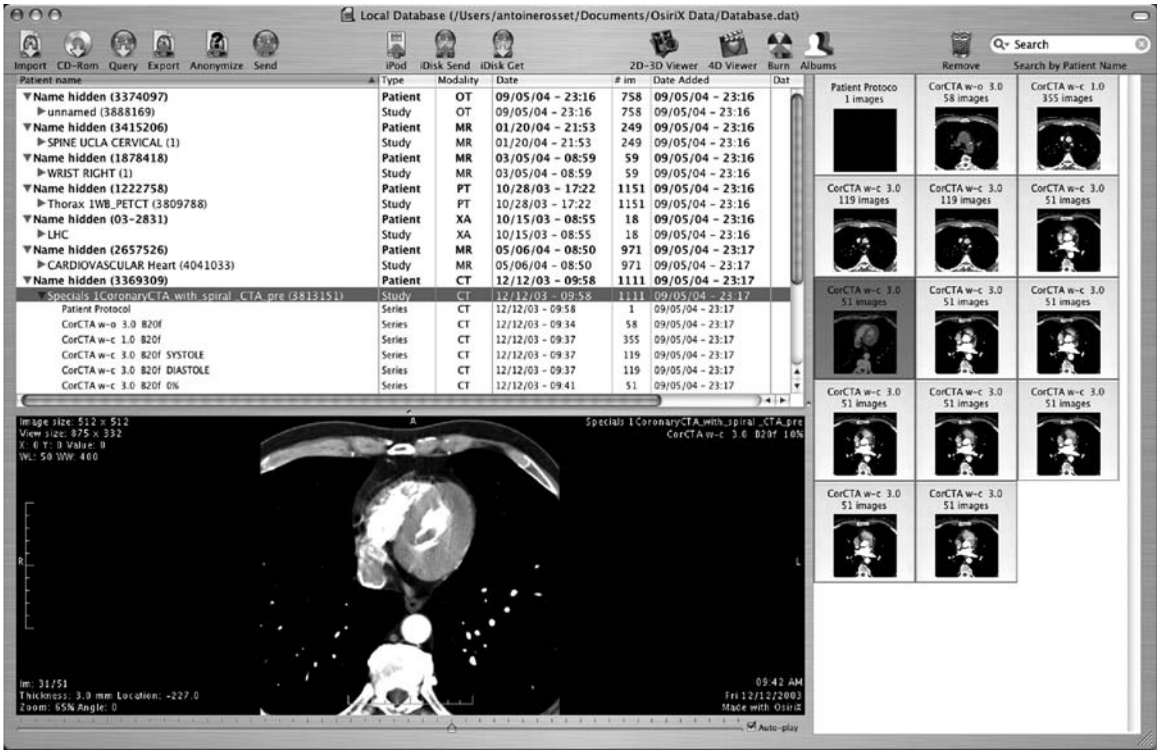

Image 2. This window represents the local DICOM database with the customizable toolbar allowing users to easily transfer or retrieve DICOM images from an iPod or from an iDisk account.

toolbar to easily send and retrieve selected DICOM series from and to a remote iDisk, WebDAV-based Internet virtual disk. Using this embedded feature, users can easily archive and retrieve image data on their own personal iDisk storage space or transfer and retrieve images from a shared departmental or institutional disk account.

We successfully integrated these three technologies into our DICOM viewer, OsiriX. We used the standard FireWire/USB-2 IO library to read and write DICOM files from and to iPod. We used the standard OpenGL screen capture functions to generate real-time images from the DICOM images displayed in OsiriX and to transmit them to iChat AV software. iChat AV software generates then the MPEG-4 compressed video stream. For iDisk, we used the IO WebDAV toolkit from Apple[21] to read and write DICOM images to the on-line virtual disk.

RESULTS

We successfully adopted our open-source DICOM viewer, OsiriX,[10] to support these three new technologies in less than 4 months of development efforts. These technologies use standard well-documented protocols and interfaces supported by all programming frameworks and operating systems. We installed our updated version of OsiriX on dual-G5 1.8-GHz processors Apple PowerMac with 1.2 GB of RAM. We obtained the following performance results for each of the three technologies that we tested:

(1) The iPod device used for off-line image storage. We first tested the performance of opening two different sets of images directly from the iPod hard disk, and, subsequently, we evaluated the performance in copying two large data sets from the computer local hard disk to the iPod hard disk. Results are displayed in Table 1.

We also evaluated the potential maximum storage capacity of the 40-GB iPod. Using the standard DICOM file format, we were able to successfully store up to 70,200 noncompressed CT images of 512 $\times$ 512 pixels by 16 bits or up to 250,000 noncompressed MRI images of 256 $\times$ 256 pixels by 16 bits.

Table 1. Performance measures for reading and writing noncompressed DICOM files from and to the iPod hard disk

	119 CT images (512×512 pixels), 60 MB	220 PET images (128×128 pixels), 7.9 MB
Copying an entire exam from the computer local hard disk to the iPod hard disk		
USB 2.0	2 s, 30 MB/s	1 s, 7.9 MB/s
FireWire 400 (IEEE 1394)	2 s, 30 MB/s	1 s, 7.9 MB/s
Reading and displaying of the entire exam		
USB 2.0	3.2 s, 18.8 MB/s	1.3 s, 6.1 MB/s
FireWire 400 (IEEE 1394)	3.4 s, 17.6 MB/s	1.4 s, 5.6 MB/s

(2) iChat AV videoconferencing capability for teleradiology applications. We successfully tested a real-time teleconference between our dual-G5 PowerMac and a G4 667-MHz PowerBook both located on the UCLA campus connected to our 100 MPB/s Ethernet local area network (LAN). The image used for our test was limited to 640×480 and is compressed in the MPEG-4 standard[20] with a frame rate of about 20 images/s. We also tested the system between a dual-G5 computer located in Los Angeles and another dual-G5 computer located in Geneva, Switzerland, with a distance of more than 12,000 km. Both computers were connected to the Internet with a T1 connection. We obtained the same image quality and a frame rate of about 18 images/s. The MPEG-4 compression and the limited resolution degrade somewhat the quality of static images (Image 3). While this image quality is certainly not sufficient for diagnostic purposes, it is still quite adequate for remote consultations because the user is able to move and zoom in real time on the displayed image, and the user can adjust the

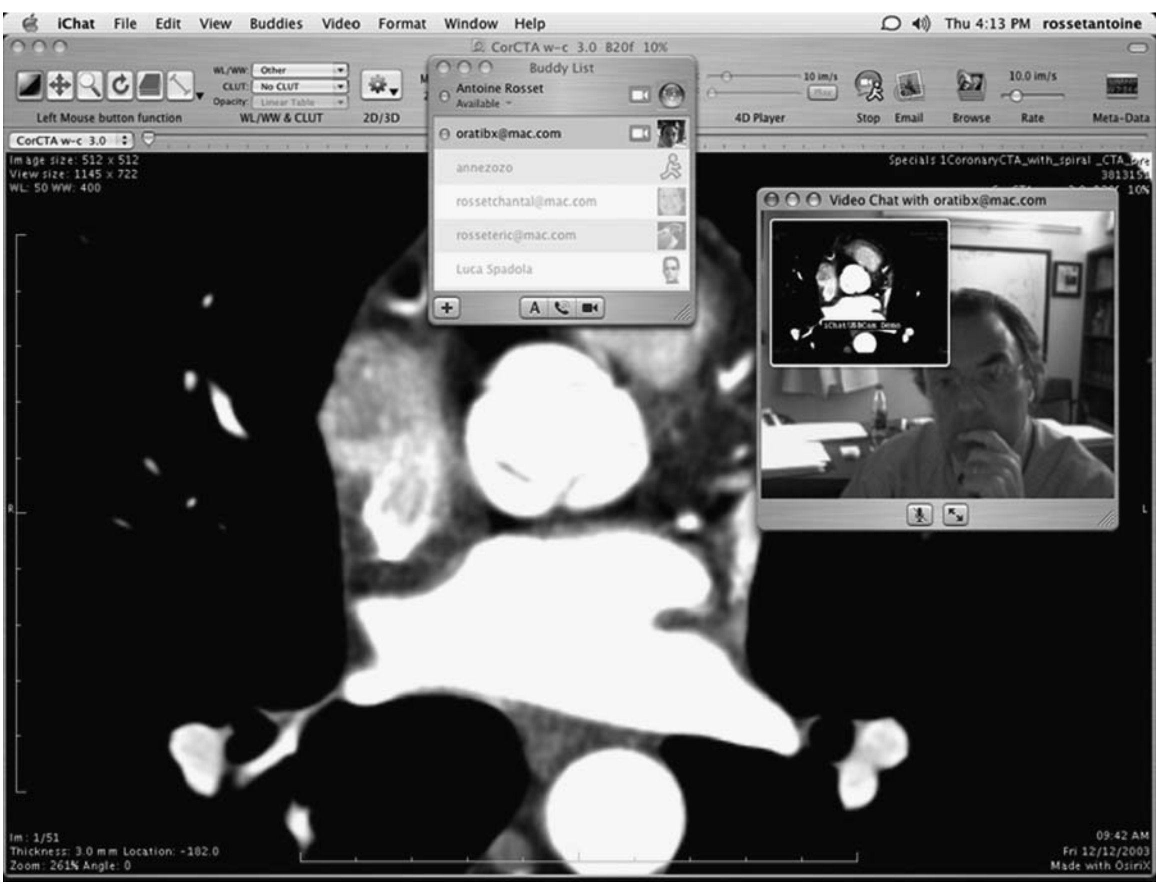

Image 3. This screen capture demonstrates a teleconference by using iChat AV to transmit the current content of the DICOM viewer. The images are transmitted in real-time by using the MPEG-4 compression.

view to clearly demonstrate even small area of a large image as demonstrated in Image 3. Furthermore, the system allows at anytime during a videoconference to send a full-resolution snapshot of the image displayed on the screen to the remote viewer. This full-fidelity image can take several seconds to be transmitted depending on the size of the image, but it allows the remote user to get a full-resolution image at anytime during the consultation (Image 4).

(3) iDisk on-line storage service. For our tests, we purchased an account for an iDisk storage space of 1 GB. We tested successfully the "send" and "retrieve" functions for 119 uncompressed DICOM CT images (total of 60 MB) from a dual-G5 Apple computer located in Los Angeles and from another identical computer located in Geneva, Switzerland. Both computers were connected to Internet through a T1 connection. Results are displayed in Table 2.

Table 2. Transmission time and rate for sending and receiving a set of 119 noncompressed DICOM CT images (Total of 60 MB)

	Los Angeles, CA	Geneva, Switzerland
Send	162 s = 2 min 42 s, 0.38 MB/s	182 s = 3 min 2 s, 0.34 MB/s
Retrieve	164 s = 2 min 44 s, 0.38 MB/s	182 s = 3 min 2 s, 0.34 MB/s

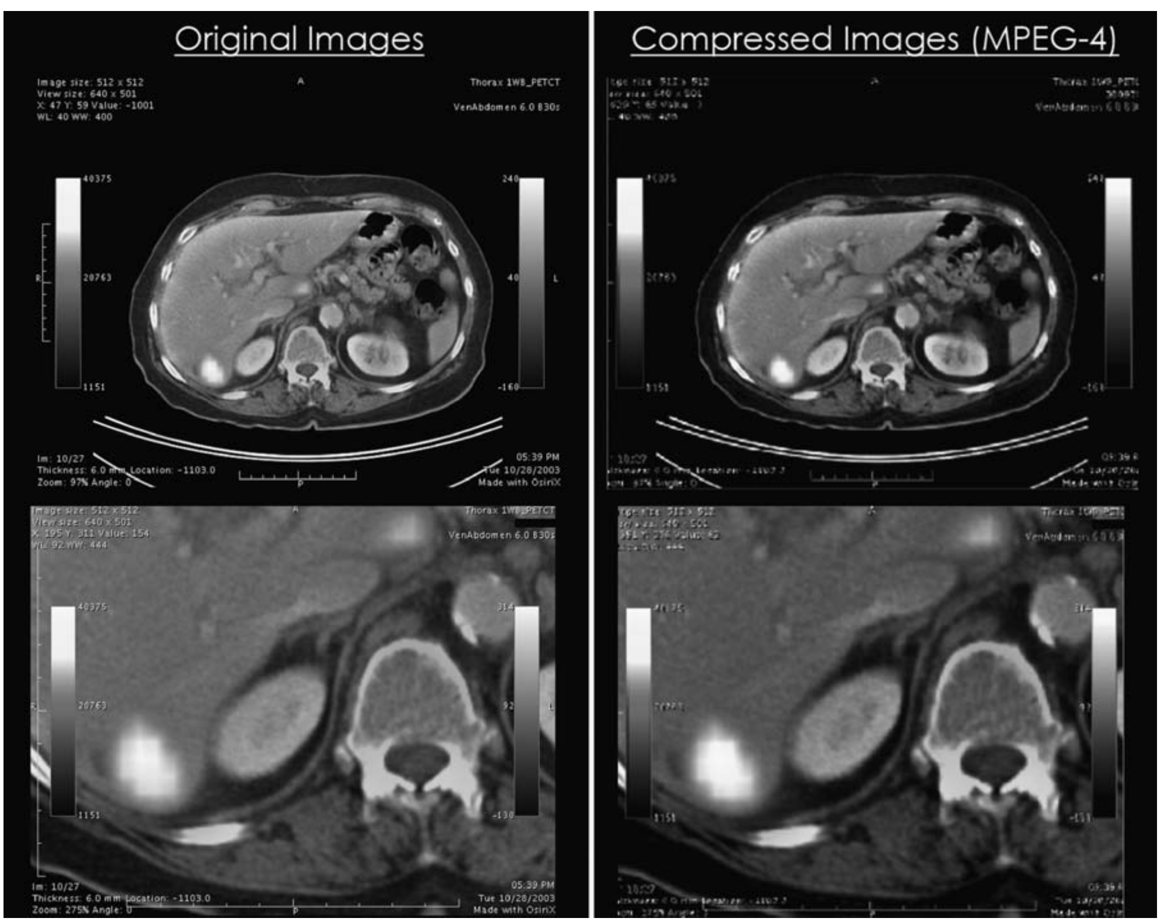

Image 4. Comparison between the original displayed DICOM image of a PET-CT study with and without zoom in area of interest and the MPEG-4 compressed image transmitted through iChat AV software.

SECURITY

All these technologies have been developed to offer greater mobility and communication to the users. They go beyond the traditional limits of PACS of a radiology department. But the enhanced mobility and communication raise some concerns regarding data security and confidentiality of patient's data related to the Health Insurance Portability and Accountability Act (HIPAA). We review hereby the techniques and tools that can ensure adequate protection of data security and confidentiality:

(1) The iPod. From a security and confidentiality point of view, storing images on the iPod hard disk is no different from storing them on a DICOM compliant CD-ROM. On these media, data are saved and stored without any encryption or security controls. It is, however, possible to limit the use of iPod devices to selected OsiriX workstations requiring controlled identification and authentication of users. The user has also the option to deidentify the image data before transferring them to the iPod device by removing the patient demographic data from the DICOM header leaving only anonymous data on the off-line disk of the iPod. Another option is to use a file encryption mechanism: MacOS X operating system offers a built-in encryption/decryption system, called FileVault. This FileVault option automatically and transparently encrypts and decrypts the files when used by an identified user. FileVault uses the latest government-approved encryption standard, the Advanced Encryption Standard with 128-bit keys. Local regulations and policies will dictate the adequate usage of this movable storage while respecting patient confidentiality and patient protection laws.

(2) iChat AV. This teleradiology and teleconferencing tool transmits video and audio data over the Internet without any encryption. These data are only compressed using MPEG-4 video compression standard. Hence, it is theoretically possible to intercept the MPEG-4 video stream during the transmission on Internet; it would require a direct and complex access to Internet nodes and routers used during the teleconference to properly intercept and display the video stream. This is why no patient name or patient's metadata are transmitted on the images. The MPEG-4 video stream does not contain any textual information about demographic data.

(3) The iDisk. As described in Materials and Methods, the iDisk technology relies on the WebDAV standard and is encrypted with the well-known and widely accepted HTTPS. Multiple web-based PACS or RIS systems already use this protocol for transmission of image data over the web. Hence, data are securely transmitted from the OsiriX workstation to the iDisk server. A personal iDisk account is required by each user and is only accessible after identification through a username and a password. An iDisk account is based on the Application Service Provider (ASP) concept.[22] Several PACS or RIS systems are today based on this kind of ASP concept: this technology is already well accepted and known in radiology departments. Apple Computer who offers this iDisk technology is responsible for the quality and the support of the virtual storage space. The iDisk technology is only suitable for temporary storage of data and should not be considered as an ASP-based long-term storage solution.

Adoption of these new technologies for facilitating image access and communication requires adequate procedures and policies to be reinforced to warrant data security and confidentiality and legal concerns related to the HIPAA.

DISCUSSION AND CONCLUSION

The adoption of new disruptive technologies that are emerging in the large consumer market such as instant messaging, on-line, and ultraportable storage can dramatically change the basic concepts of image storage and communication in medicine. These new technologies that are widely adopted in the general consumer market are considerably easier and more convenient to use than traditional PACS and teleradiology applications. They will certainly influence the way the next generation of image archiving and communication systems will be designed and implemented. These new technologies will facilitate the mobility of radiologists and ease the communication of diagnosis and images. As always with new technologies, some changes will have to be carried out concerning security policies and workflow.

Thanks to the important community of users that are already working with our open-source viewer, OsiriX[10], these new technologies have already been tested in several other settings. The new version of OsiriX, integrating these new technologies, is available for free download since June 2004 on our web site: http://homepage.mac.com/rossetantoine/OsiriX. Between June and August 2004, this new version was downloaded more than 4000 times. We already received many positive feedbacks from radiologists using the iPod when moving from a hospital to another, allowing them to review and interpret radiological studies anywhere and at anytime, even on a personal laptop computer. Other users are using the iDisk technologies during on-call weekends: technologists send the exam of their iDisk account and the radiologists are then able to download the images anywhere and securely without the need of using complex encrypted communication tools (like VPN) or limited and slow web-based PACS. To increase the acceptability of this Internet virtual hard disk, we are currently working on the development of a DICOM JPEG-2000 automatic lossless compression tool: it will allow to increase the speed of image transmission by decreasing the size of the DICOM images. Our tests showed a speed of transmission of about 1 CT image (512×512 pixels) per second in DICOM format. This relatively low speed can be a limitation with the increasing number of images produced by new imaging modalities such as multislice CT.

While the ability to use the iPod as a convenient off-line storage device seems to have attracted most of the attention in the initial phase of the adoption of the OsiriX software, we believe that other features borrowed from the consumer market such as videoconferencing with iChat will rapidly become another popular feature of the software. In its current version, the remote teleradiology feature of the software using iChat is limited in its performance and quality. It is also limited to a point-to-point communication between two remote users. In the next release of Macintosh operating system, OS X version 10.4 (also referred to as Tiger) will support videoconferencing of up to four interactive users as well as broadcasting to up to 10 participants that can watch the on-going conference. This opens new perspective for remote clinical conferences, clinical rounds, as well as teaching and training sessions. In addition, in its new implementation, Apple will support higher performance H.264 compression scheme that allows higher resolution and better frame rate that will significantly improve the quality of the image being transmitted even on lower bandwidth networks. OsiriX will certainly benefit from these significant improvements and become a very simple and cost-effective platform for remote teleradiology.

The implementation of these innovative technologies on OsiriX Open-Source platform benefits from the flexibility of a software platform that can easily be adopted and modified. Its wide distribution among the medical and academic community offers the unique opportunity to gather input and feedback from different users in different settings. The only limitation is that the current version of OsiriX is only available for Macintosh computers, a platform that was completely abandoned by major PACS manufacturers. The integration of these new technologies in the OsiriX platform can only serve as a proof of concept and in an experimental setting. The full integration in a PACS environment could only be achieved through a user-driven initiative that would request from PACS vendors to integrate and adopt these new tools in their future products.

A classic limitation of new technologies in the medical digital imaging domain is often related to costs and complex and expensive support. By using general consumer products, one can benefit from low costs and widely available technical support: these products are already widely available and have been extensively tested on multiple platforms and environments.

The adoption of these innovative technologies is likely to change the architecture of traditional picture archiving and communication systems often limited and centralized around a unique radiology department. They clearly provide more flexible and efficient means of communication.

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