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Synchronized, Interactive Teleconferencing with Digital Cardiac Images

C. Walsh,[1] J. Cosgrave,[1] P. Crean,[1] D. Murray,[2] R. Walsh,[2] J. Kennedy,[3] M. Buckley,[1] and N. O'Hare[1]

St James's Hospital is a tertiary referral center for percutaneous intervention and cardiothoracic surgery for a number of referring hospitals. This article reports on the development and implementation of a synchronized, interactive teleconferencing system for cardiac images that links St. James's Hospital with a remote site (Sligo General Hospital) and overcomes the problems of transmission of large image files. Teleconferencing was achieved by setting up lossless auto transmission of patient files overnight and conferencing the next morning with linked control signals and databases. As a suitable product was not available, a commercially new software was developed. The system links the imaging databases, monitors and synchronizes progress through imaging sequences, and links a range of image processing and control functions. All parties to the conference are ensured that they are looking at the same images as they are played or at specific aspects of an image that the other party is highlighting. The system allows patient management decisions to be made at a weekly joint teleconference with cardiothoracic surgeons and interventional cardiologists from both sites. Rapid decision making was facilitated with 70% of decisions obtained within 24 h, and 88% within 1 week of their procedure. In urgent cases, data can be transmitted within 20 min of the diagnostic procedure. The system allows increased access to angiography for patients living in rural areas, and provides a more focused referral for revascularization. Participation of the referring cardiologist has improved the quality of decision making.

KEY WORDS: Telemedicine, Digital Cardiac Imaging

INTRODUCTION

Telemedicine exploits developments in electronics, computing, and telecommunications to enhance the exchange of information, and to bring medical expertise and knowledge to remote locations. Telecardiology is the transmission of images of the heart by telemedicine. Cardiac conferences are interactive meetings where the decisions are not only based on the images shown, but also on the wishes and clinical situation of the patient. Telecardiology conferencing aims to provide a cardiac conferencing facility, which includes users at remote locations. Telemedicine and, in particular, teleradiology systems are well developed and available commercially. However, Digital Cardiology Image Sequences are often left out of teleradiology packages due to large file sizes and the high bandwidth required for transmission.[1]

St James's Hospital (SJH) in Dublin is an academic teaching hospital and a tertiary referral center, which carries out approximately 2500 angiograms, 950 angioplasties, and 500 cardiac operations per year. Patients are referred from all parts of Ireland, but the hospital has particularly strong links with Sligo General Hospital (SGH). In SGH, angiography is performed locally by using a mobile laboratory, which promotes more rapid access to angiography in the patient's own environment. In the past, if intervention was required the images had to be transported to Dublin by road (minimum 4 h) for discussion at the weekly conference. Another weakness in this system was that the referring cardiologist was

[1]*From the Department of Medical Physics, St. James Hospital, Dublin 8, Ireland.*

[2]*From the Sligo General Hospital, Sligo, Ireland.*

[3]*From the Captec Ltd, Dublin, Ireland.*

Correspondence to: C. Walsh, Department of Medical Physics, St. James Hospital, Dublin 8, Ireland, tel: 353-1-4162645; fax: 353-1-4103478; e-mail: clwalsh@stjames.ie

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unable to participate directly in the decision-making process. This article reports on a system designed to facilitate and improve the quality of medical decision making, and to be easily accessible to health care providers and patients. Image quality was taken as a main priority as any compromises in this area may diminish the quality of decision making. The project set up an interactive teleconferencing package enabling real-time discussion of diagnostic cases performed in Sligo Regional Hospital between the team of interventional cardiologists and cardiothoracic surgeons based in St James's Hospital and the referring cardiologist.

TRANSMISSION AND COMPRESSION OF DIGITAL IMAGES

Digital cardiac systems acquire dynamic image sequences. A coronary angiogram typically consists of a number of different views acquired at frame rates ranging from approximately 12.5 frames per second (fps) to 30 fps. Each frame, or digital image, is usually composed of a 512×512 matrix of pixels with each individual pixel coded to allow display a minimum of 256 gray levels (8-bit coding). To maintain full diagnostic image quality, this image information must be maintained throughout the telemedicine process. File sizes of up to 1 GB for an individual patient are possible.

Data compression is normally used in transmission of images. This can be lossy or lossless; lossless refers to the use of a compression method that is completely reversible, whereas lossy compression entails data loss and results in an image that is not totally identical with the original. Typically, a lossless compression scheme will yield a data reduction of approximately twofold.[2] In addition to the problem of irreversible data loss when lossy compression is permitted, there is the possibility that sequential compression might occur. In this circumstance, an image that had been compressed and decompressed once might be inadvertently subjected to a second or third cycle of compression.[3]

Published opinion varies in the degree of lossy compression acceptable. Robinson,[4] in a summary of a large number of studies, showed that in many image quality studies the variation attributable to raters (i.e., those performing evaluation, or the intersubjective error) was larger than the variation proceeding from image quality. Intersubjective errors also hinder image quality assessment using image quality test tools.[5–8] In a Study of Angiographic Data Compression, Brennecke et al.[9] conclude that a compression ratio (CR) of 6:1 provides equivalence with original cine runs, but if CR 16:1 were used, one would have to tolerate a significant increase in the diagnostic error rate over the baseline error rate. At CR 10:1, intermediate results were obtained.

Attempts to incorporate cardiac imaging into conferencing facilities usually involve compression, or the use of a "store and forward" method. Many conferencing solutions dealing with dynamic image sequences use video conferencing technology. Analog video signals are digitized and sent over a digital network. Compression or data reduction is usually achieved using digital computational techniques such as those defined in the Joint Photographic Experts Group (JPEG). Typical compression ratios might be 50:1.[10] This is above compression ratios deemed acceptable for diagnostic image quality, as noted above.

In store and forward solutions, images are sent in advance of a conference. When both sides to the conference have the data, a conference is held while each side individually reviews the imaging data. Sending images in advance of a conference has the advantage of allowing longer times to transmit images, thus removing the necessity to compress images. Stahl et al. developed a Telecardiology conferencing system combining store and forward technique with Microsoft Direct Show.[11,12] Images were sent in advance of conferences, without compression, and interactive teleconferencing was achieved by modifying the DirectShow software. During the conference, both sides were able to manipulate and play image sequences. Eight teleconferences were successfully held between geographically separate locations.

MATERIAL AND METHODS

Current telemedicine links implemented have focused substantially on "store and forward"-type applications, where the patients' data area acquired at some remote location and transmitted to the location providing the expert consultation. These systems do not allow for the close interaction of the referring physician in the decision-making process. To over-

come this problem, the system was designed around a number of specific objectives: (1) The implemented teleimaging system needed to be interactive between the referring clinician/team and the case conference where the expert consultation and decision was being determined. (2) The system needed to handle large data sets emanating from cardiac angiography imaging systems. (3) The system should integrate with the existing local area networks in both the referring and the case conferencing hospitals. Consequently, the system needed to be designed around open standards and standard network protocols. (4) The system should allow the emergency transmission and interactive consultation of patients, outside of the case conference setting. (5) The system should have the capability to expand to other sites as and when required, and to allow a multiconference of more than two sites.

Maintaining diagnostic image quality was a key project goal and it was decided that only lossless compression would be used. This ruled out video conferencing, which converts files to JPEG format through lossy compression algorithms. In addition, the solution should support all elements of the conferencing process including patient management, transmission of images, conferencing, and postconferencing data management, and, ideally, combine all these features in a single, user-friendly software package. No products were identified that could meet this requirement. The system was specified by SJH, designed in collaboration with CAPTEC, an Irish software development company, and the Teleconferencing System for Cardiology (TSC) software was developed by CAPTEC. The software solution includes proprietary lossless compression software called RICA. The software design built on software developed for a previous medical imaging multimedia conferencing project.[13,14]

There are several distinct parts of the TSC software. These can be grouped into three main parts:

1. The display module is able to decompress DICOM-XA and RICA encoded angio sequences for display and also perform image processing and display at frame rate. The loading and imaging functions are controlled by the control panel or during a teleconference by the conference coordinator program.
2. The control panel and archive/worklist manager allows the user to perform all the main operations of the software, such as importing data from DICOM CDs, adding and compressing images to the local database, processing worklists, controlling the display of angiograms, scheduling the transfer of patient data to remote systems, etc.
3. The communications programs are a group of independent modules that perform background tasks such as transferring worklists and the associated data to remote systems, receiving data from remote systems, and coordinating the synchronous display of data on multiple workstations

The image archive contains data stored in DICOM format but archived and compressed in RICA format to guarantee lossless reconstruction back into the original DICOM file. RICA can typically achieve a 3:1 or 4:1 compression ratio compared to the 2:1 ratio achieved by the lossless JPEG method used in DICOM. The software components of the imaging stations are shown in Figure 1.

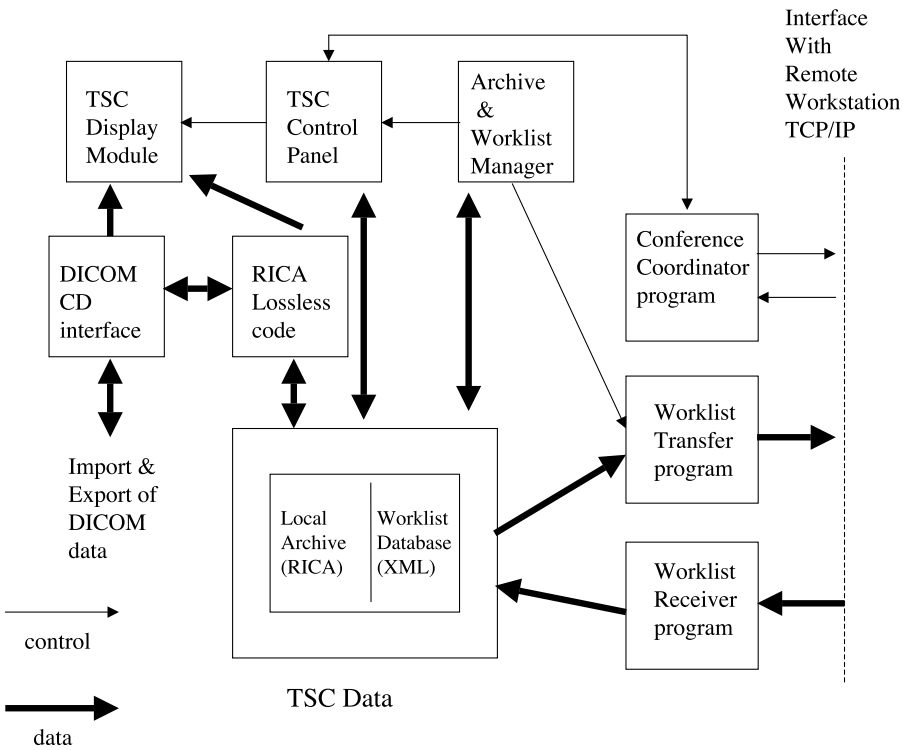

Fig 1. Software components of the imaging stations. The software on each workstation is identical.

At the time of project design, it was decided to use a semi "point-to-point" transmission methodology rather than internet solutions so as not to compromise on patient confidentiality. Primary rate ISDN lines were selected. These link up to 30 ISDN lines (transmission rate 64 kbs) although only six linked lines were used. A staged solution, combining "store and forward" and conferencing software, was specified to circumvent the problem of large image files. Five lines were used for image data transmission; the sixth line was used for the teleconferencing. Conference patient files are transmitted overnight (taking advantage of cheaper rates) approximately 24 h prior to a conference. In an emergency, patient files may also be sent immediately and arrive in SJH within 30 min. The system is designed to link databases, and when the conference takes place patients may be selected at either SGH or SJH and the workstation at the other end automatically loads the same patient image files. During the conference control signals are exchanged in real-time so that the workstations on both sides are showing the same imaging sequences with the same processing applied, etc. The software allows a synchronized, fully interactive teleconference. Either side is allowed take control of the workstations during a conference. An audio link is also provided with standard phone conferencing technology. Apart from the conferencing software, all components are off-the-shelf (Fig 2). The system was designed with cardiac applications in mind, but could be readily adapted to work with other imaging modalities.

RESULTS

Technical Evaluation

The system achieved design objectives (1)–(4) listed above. The potential to meet objective (5) was built into the system, but this could not be properly assessed with a two-point conference design. There was no perceived loss of image quality during the image capture, storage, and transmission. This was verified during the commissioning phase of the project by carrying out image-quality measurements pre- and posttransmission, using images of standard test objects and test patterns.[15,16] In addition, the display technologies utilized ensured optimum image quality based on standard PC display technologies. The feedback from cardiologists was uniformly positive, with specific improvements on displayed image quality of the current system over that of the older methods being articulated.

The system incorporated patient management, data transfer, and conferencing functions within a single software package. Worklists for conferencing are assigned from the set of patients on the database, and scheduled for overnight transfer. Transfer is automated so that worklists can be scheduled during the day, but transfer overnight at the lower cost line rates. Image display and controls provides standard interface capability for cardiac image review. A sample of the screen display is shown in Figure 3.

Technical difficulties were concentrated in the commissioning phase and in the first 6 months of operation. Most of the problems were related to programming communications routers to allow transmission of data and ensuring such programming was maintained through software or hard-

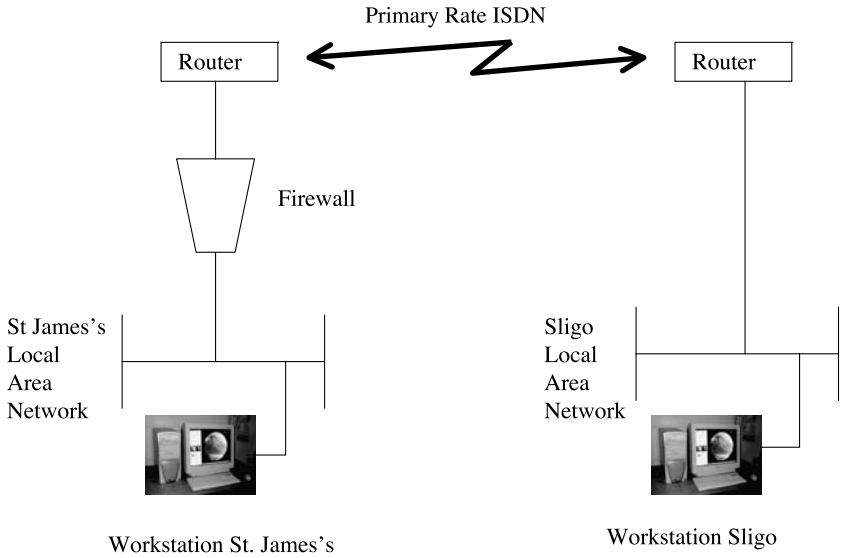

Fig 2. The teleconferencing network.

Fig 3. Example of screen display.

ware upgrades. As soon as these difficulties were resolved, system function was stable. A summary of technical performance is shown in Table 1.

Clinical Results

The mobile angiographic service in Sligo began in March 2001. Prior to this, all patients who required angiography in the region were transferred to Dublin. In the last year that full data are available (1999), 257 patients had to travel to SJH for angiograms: the actual number to move outside the region would be higher than this as patients may have visited hospitals other than SJH as well.

Table 1. Summary of technical performance

	Conferences missed due to system failures	Minor problems	Total number of conferences
First 6 months of operation	2	8	20
Subsequent 15 months of operation	1	1	64

Starting in March 2001 a mobile angiography service was provided at Sligo General Hospital. In January 2003, the teleconferencing system was added to this facility. Primary diagnosis can be performed locally, and in approximately 70% of the cases there is no further requirement to travel to a main center for additional work. Workload increases are apparent from year to year as the service developed. Extrapolating from 2004 figures gives a total workload of 556 patients for 2004 (Table 2).

The addition of the teleconferencing station in 2003 brought management and diagnosis of the patients in Sligo fully into the conference and decision-making process at the referral center. This increased the quality of care by providing a forum for the full team (e.g., referring cardiologists, cardiologists at referral center, and the surgical team at referral center) to assess patients. A key benefit

of the teleconferencing system is its impact on decision time. Analysis of 2003 figures demonstrated time to decision post angiograms was positively effected, with 70% of decisions obtained within 24 h, and 88% within 1 week of their procedure. Delays encountered in conference discussion were usually caused by the angiographic procedure occurring the day after the conference. Rapid decision making reduces patient anxiety and, if subsequent intervention is required, can improve prognosis. Although precise data prior to the implementation of the system is not available, it is estimated by clinical users that "time to decision" has been reduced by 60–70%. Of the inpatients referred for angioplasty, 66% were transferred within 7 days of the conference and 88% within 10 days. Of the patients referred for cardiac surgery 53% were transferred within 10 days of the conference and 65% within 1 month.

The software is designed to create a worklist for the conference, facilitating management of the workflow. Preparation for the conference is performed by the administrative staff: staff at SGH enter patient cases on their workstation and create and send the worklist; at SJH this worklist is then selected prior to the conference commencing. Notes on outcomes can be made during or after the conference and the results can be printed out.

DISCUSSION

The teleconferencing system implemented between St. James's and Sligo General hospitals represents a considerable advance in telemedicine. Workstations are linked at Sligo and St. James's providing, for the first time, a fully synchronized and interactive teleconferencing facility for use in "real-time" with digital cardiac patient image sequences. The solution is patient focused and designed to support the way hospitals operate in diagnosing and treating patients. It offers patients at remote locations the same range of diagnostic services available to patients attending a main cardiac center, while maintaining the link with the expertise and patient knowledge of the local cardiology team. It overcomes or circumvents key problems that have prevented cardiac imaging becoming part of telemedicine solutions.

Images transmitted over primary rate ISDN provide an easily managed solution for a dial-up variable bandwidth link between the two hospitals networks. Based on current usage, and exploiting overnight rates, this also provides a cost-effective solution. The data transfer is set to use five channels on the primary rate ISDN that can be increased with data transmission demands, and the conferencing link uses one ISDN channel. This method was selected to guarantee bandwidth availability and eliminate exposure of the system to general internet access thus ensuring security of patient data. This solution allows full scalability and the potential for multiple sites to participate in a conference.

This system has a number of potential economic benefits. Local access to angiography has been improved, which reduces the cost of patient transport.

Improved local access and rapid decision making shortens hospital stays and for outpatients may promote a more rapid return to the workplace. There has also been a reduction in the diagnostic workload of St James's Hospital, which means that more angiographic laboratory time can be dedicated to percutaneous intervention.

One of the main design aims of the project was to ensure ease of use; this was achieved by close collaboration between the design team and the cardiology teams at both institutions. The workstation is easy to understand, and similar to those used by standard angiographic viewing software. An extremely useful feature is that users at either workstation can take control of precisely what image is being viewed, which ensures a truly interactive discussion of the relevant data. The linked control signals continually ensure that both parties are looking at the same image.

Table 2. Angiography performed at regional centers, with breakdown of subsequent referrals

	2001	2002	2003	2004 (to Sept)
Total angiograms	328	369	438	417
Total normal or medical management	207	254	303	281
% Referred to tertiary center	36.89%	31.17%	30.82%	32.61%
Number referred	121	115	135	136
Breakdown of referrals				
Angioplasty	82	72	83	110
CABG	39	43	41	26

The teleconferencing system augments regional angiography services by more effectively merging the diagnosis process of the local and tertiary centers. From the perspective of Sligo General, this arrangement allows swift decision making, while ensuring peer review and best quality patient care. It also provides an innovative educational environment for the staff and improves the cooperation and communication between the two institutions. From the viewpoint of St James's, the active participation of the referring cardiologist has greatly enhanced the utility of the cardiac conference.

CONCLUSION

We have successfully implemented this novel system to facilitate rapid and effective clinical decision making. Participants at both centers have expressed a high degree of satisfaction with the system.

The application of this system has been beneficial to clinicians in both institutions. Cardiology is a rapidly changing field and close interaction between cardiologists, which is facilitated by this system, ensures dissemination of knowledge and builds important professional relationships. The teleconferencing process ensures both audit and peer review, which are necessary to achieve the highest standards of clinical care.

This is the first fully integrated system that allows real-time conferencing and ensures that both parties are looking at the same image at the same time. Being able to discuss each case as if both parties are in the same room leads to more efficient information transfer between the referring cardiologist and the tertiary center. Patients benefit from this in two ways: (1) as more information is available better decisions are made and, (2) as soon as the decision is made, their doctor is aware and can pass the information to the patients. This leads to shorter hospital stays but more importantly reduces waiting times for patients and so reduces uncertainties and keeps the patient informed. The system has broadened patient access to angiography and enhanced the quality of the decision-making process. Both patients and clinicians have expressed high degrees of satisfaction with the system.

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