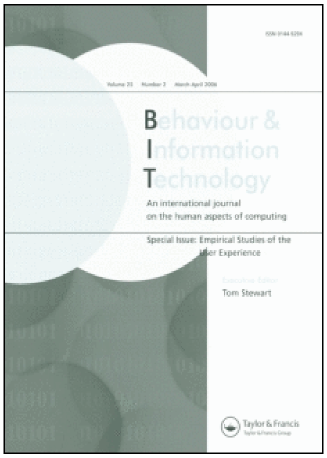

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David V. Beard [a]; Brad M. Hemminger [b]
[a] Department of Computer Information Systems, College of Business, Idaho State University, Pocatello ID 83209-8020,USA; email beard@isu.edu.
[b] Department of Radiology, Old Clinic Bldg, University of North Carolina, Chapel Hill, NC 27599-7510, USA.

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Remote ultrasound using cooperative video: a field study

DAVID V. BEARD† and BRAD M. HEMMINGER‡

†Department of Computer Information Systems, College of Business, Idaho State University, Pocatello ID 83209-8020,USA; email beard@isu.edu

‡Department of Radiology, Old Clinic Bldg, University of North Carolina, Chapel Hill, NC 27599-7510, USA

Abstract. In this ultrasound field study, patients were examined by a technologist in a separate room from the radiologist. Two-way audio and the NTSC video signal from the ultrasound probe were provided to the remote radiologist. Data were collected using observation, surveys, and interviews. Of particular interest was how often the radiologists felt it clinically necessary to walk to the examination room and interact directly with the patient, indicating a failure of the technology. The system was judged viable with no cases requiring hands-on viewing during the last 3 weeks of the 5-week study. Based on this experience, such video technology has been purchased and is currently in use in the clinic. Similar pilot studies are recommended during introduction of remote consultation facilities to improve technology interaction, develop new organizational procedures, and insure minimal interpersonal conflicts.

1. Background

Ultrasound imaging provides a low-cost method for viewing a patient's anatomy. In use (figure 1), specially trained ultrasound technologists or physicians point one of several ultrasound probes—held either outside the patient's body or within a cavity—at the anatomy in question and the ultrasound machine generates a two-dimensional fan-shaped real-time analog-video grey-scale image. Colour is also used with some ultrasound machines to show the flow direction and rate for blood and other fluids. Because of ultrasound's non-invasiveness and lack of radiation, it is particularly useful for obstetrics and other cases in remote family medicine clinics.

1.1. *Conventional ultrasound operations*

1.1.1. *Preparation:* Most cases follow the same basic procedure. A referring physician orders an ultrasound examination by generating an ultrasound requisition form containing some patient information and stating one or more clinical questions to be addressed. Based on the requisition form, the radiologist selects one of several standard ultrasound examination *protocols* that will image the anatomy well enough to allow the radiologist to answer the clinical questions.

1.1.2. *Examination:* When the patient arrives for the examination, the technologist directs the patient into the examination room, and then—following an 'examination protocol' selected by the radiologist—uses a specific ultrasound probe and machine to capture a series of select static images on film from the live NTSC video feed generated by the ultrasound machine. For a given anatomical area and clinical situation, a particular examination protocol will specify what portions of anatomy are to be filmed and from what approaches and angles. Most often, technologists rather than radiologists conduct the exams.

Figure 1. Patient being imaged with ultrasound.

1.1.3. *Examination sign-off:* For more complicated examinations or depending on the background, training, and department policy, the on-duty radiologist often must approve the resulting images generated by the technologist before the patient is released. Therefore, while the patient remains in the examination room, the static films—showing the selected images from the ultrasound study—are developed and brought by the technologist to the radiologist in the reading room. The radiologist examines these images using a lightbox (figure 2) to insure that the anatomy has been imaged sufficiently well to allow the referring physician's clinical questions to be addressed. If the images are sufficient, the radiologist directs the technologist to release the patient. However, sometimes the static film images are insufficient due either to the difficulty of the case or the inexperience of the technologist. In this case, the radiologist goes to the examination room and re-examines the patient themself, generating new static film images and/or better visualizing the real-time data on the ultrasound machine's realtime display monitor.

1.1.4. *Interpretation:* At some later point—typically when the radiologist has a lull in their activity—they take the patient's ultrasound images, display them on the lightbox in the reading room, examine the imaged anatomy and dictate an interpretation report addressing the referring physician's clinical questions. If abnormal or interesting results are found or if the referring physician has requested rapid feedback, the radiologist will call the referring physician and discuss the case verbally.

1.1.5. *Is the examination sign-off necessary?:* Examination sign-off will theoretically improve interpretation quality, for it provides an additional viewing of the data by the radiologist and insures full coverage of the anatomy. It also may provide faster feedback of anomalies to the referring physician than if initial radiologist viewing were delayed until the interpretation. On the other hand, the sign-off is expensive. A radiologist must either be interrupted every 10 minutes to come to the clinic and sign-off on a case, or they must stay in the clinic during operating hours waiting to sign-off on the cases. If few or no examination sign-offs were conducted, the radiologist would spend considerably less time in the clinic interpreting the cases and thus would have more time to spend on other clinical or academic duties. Further, the operation of the clinic is greatly disrupted by examination sign-off, for patients, technologists and ultrasound examination rooms may have to wait for 2 – 15 minutes until the radiologist is available to sign-off on an examination.

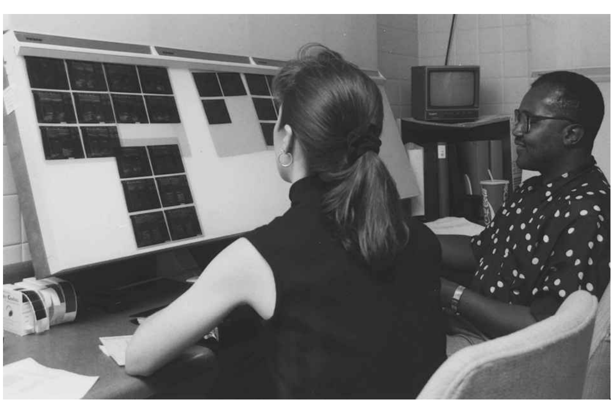

Figure 2. Radiologist and resident viewing ultrasound images arrayed on a lightbox.

While either a static-image review or hands-on realtime review will be conducted by the on-duty radiologist for some cases at all institutions, the frequency of this review varies widely. Some institutions insist that an examination sign-off be conducted for every examination, while others have a policy of having a radiologist sign-off only for a few specific types of cases, with junior technologists, or when a senior technologist decides it is necessary.

1.2. *Anatomical context*

A raw ultrasound image can be difficult to mentally position relative to the patient's anatomy, so technologists and radiologists use a number of different methods to help understand the anatomical context of a static or real-time ultrasound image. First, ultrasound machine operators can use *kinesthetic positioning* using their eyes, their hands containing the probe, and the real-time image displayed on the ultrasound machine's video monitor, to help understand what portions of the patient's anatomy are being imaged. High-quality imaging requires well-trained, experienced operators to integrate in real time several sources of information, including video display from the probe, kinesthetic feedback, pressure and touch sensations when positioning the probe on or within the patient, and verbal and visual feedback from the patient. Operators spend time searching through the anatomy to properly understand what they are currently seeing, and understanding how to locate what they wish to image next. Second, viewing the real-time images while being able to see the technologist move the probe also provides *visual positioning* of the images relative to the patient. Third, a *real-time* video image of the probe moving over the anatomy will typically show a larger area possibly containing easier-to-see anatomical landmarks that provide 'hooks' into the viewer's mental understanding of the anatomy. Fourth, static ultrasound images contain *text labels* (figure 3)—added by the technologist—that state the anatomy being imaged (e.g. 'left ovary') to help provide anatomical context. Fifth, the static images are generated using a *standard examination protocol* so that for example, a *standard pelvic examination* would result in a carefully prescribed set of images from various predefined positions and orientations; when the static images for a case are generated using a standard protocol familiar to the radiologist, they have an expectation of what anatomy is on an image.

1.3. *Remote ultrasound*

Hospital service functions, such as radiology, are extending to remote geographical sites as hospitals develop satellite facilities, and expert radiological consultation is required in remote rural settings hundreds of miles from the nearest tertiary-care centre. The scarcity and cost of highly-trained ultrasound radiologists, together with the lower number of cases encountered in many remote sites, prohibit stationing a radiologist with each ultrasound machine. Thus, there is a growing demand for remote radiological ultrasound consultation.

Such a situation currently exists at The University of North Carolina at Chapel Hill's hospital. To provide better outpatient service, they have opened an Ambulatory Care Centre (ACC) about half a kilometre from the main hospital. Many cases can be conducted by an ultrasound technologist at this remote site, but a final viewing by a radiologist specializing in ultrasound interpretation is essential for at least some cases. While there is sufficient case volume to justify stationing a technologist and ultrasound machine at the ACC, cost containment and the shortage of radiologists specializing in ultrasound interpretation require the radiologist to remain in the main hospital. Patients are often unwilling or unable to take the time to travel to the main hospital for examination by the radiologist.

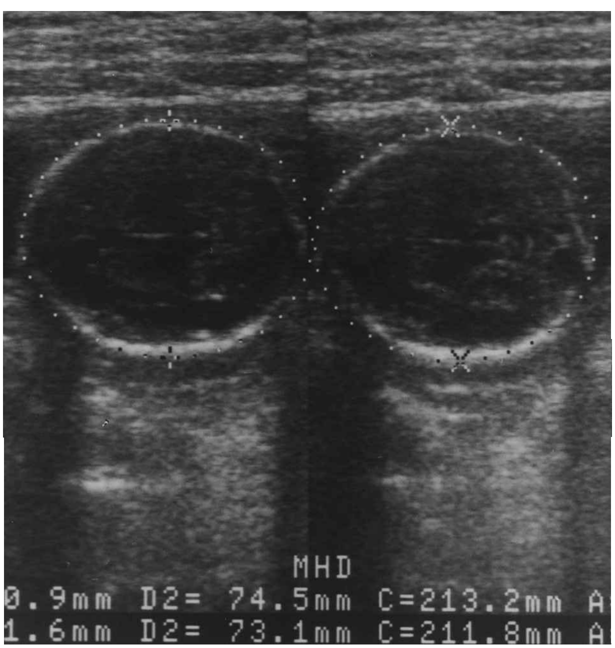

Figure 3. Static ultrasound image.

1.4 *Computer solutions*

As computer and communication technology costs continue to decrease, radiological images in general, and static ultrasound images in particular, are being acquired, moved, stored, and viewed electronically and eventually, real-time images will be dealt with using commodity-price computer equipment. Such PACS (Picture Archive and Communication Systems) should improve medical image access, increase productivity (Arenson *et al.,* 1990), allow electronic image enhancement (Pizer 1985, Pizer *et al.,* 1987), and—like a number of remote conferencing situations (e.g. Tang 1990)—facilitate remote radiology with potentially hundreds of miles between referring physician, radiologist, technologist, and imaging machine. Computer-based force-feedback technology (Brooks *et al.,* 1990) might even be used eventually to provide the radiologist with 'telepresence', and thus kinesthetic control of the ultrasound probe.

A typical radiology lightbox (figure 2) can display up to 16 000 by 8 000 12-bit pixels, though this resolution is not needed for ultrasound. Considerable experimental and field work has examined radiologists' film navigation (Kundel and Wright 1969, Kundel and La Follette 1972, Judy *et al.,* 1982), workstation contrast and resolution requirements (Pizer 1985, Chakraborty 1986, MacMahon 1986, Pizer 1987, Rogers 1987, Pizer 1989, Roehrig *et al.* 1990), and single-user image navigation (Foley *et al.* 1990, Horii *et al.* 1991). A remote-consultation electronic lightbox would also facilitate discussions between radiologists and remote referring physicians about medical images. Such a computer-supported-cooperative-work tool would be similar to several such systems for real-time cooperative writing and software development (Smith and Lansman 1989), drawing (Tang 1990, Minneman and Bly 1991), and meetings (Mantei 1988).

1.5. *Near-term solution*

Static ultrasound images can be cost-effectively displayed by computer for clinical interpretation (e.g.

Foley *et al.* 1990, Beard *et al.* 1993a, 1995, 1996) and commercial personal-computer-based systems have become available. But the high quality *real-time* video required for ultrasound hands-on examination sign-off is still problematic with cost effective computer technology. However, real-time ultrasound images can be carried on conventional TV distribution mediums, allowing less expensive solutions for the specific problem of examination sign-off of remote ultrasound. NTSC TV signals can be carried on baseband and broadband coaxial cable, fibre optics, airwaves broadcast via TV transmitters, narrowcast via satellite or microwave receivers.

One low cost solution that was investigated for implementing only the examination sign-off problem of remote ultrasound, involves transmitting one or more analogue NTSC signals over the campus broadband. A broadband cable system is simply a scheme to divide the possible range of usable frequencies on a cable into many different channels (e.g. most cable TV systems). Each TV signal requires one broadband cable channel. With this approach the real-time images from the ultrasound machine at the ACC—containing the real-time images generated by the ultrasound probe—are transmitted and shown to the radiologist in the main hospital using a conventional TV monitor. Additionally the radiologist and technologist can verbally communicate using 'phone lines and headsets. If necessary, additional NTSC signals can be used to show the radiologist's face to the patient and technologist, and the patient and technologist, including the ultrasound probe's location, to the physician. Scrambling would be used to insure confidentiality. Because of limited available bandwidth on this campus broadband, this study was initially constrained to working with only a single NTSC channel from the ultrasound machine at the ACC to a monitor in the radiology reading room in the main hospital.

2. Field study

To help in determining whether to purchase the proposed video technology, a field study, simulating remote ultrasound from the ACC to the main hospital, was conducted between the ultrasound reading room, and one of the ultrasound examination rooms in the radiology department (Beard *et al.* 1993b). These two rooms are about 10 metres from each other. There were a number of advantages to first running a field study: First, it provided clinical, rather than laboratory conditions for a realistic test environment. Second, because the rooms were close together, the radiologist could always walk from one room to the other and conduct the examination in person, thus assuring acceptable patient care and—by counting the number of times the radiologists walked to the examination room—provide a measure of remote-consultation failure. Third, the field study tested remote consultation with a single NTSC video connection with real situations and users, but under 'clinically safe conditions', that is, under conditions in which no harm could come to the patients due to the remote consultation field study. Fourth, it provided a safe training environment for the technologists and radiologists to adapt their methods, procedures, and personalities to remote work.

Two measures of success were decided upon. First and most importantly, whether the radiologists and technologists were satisfied with their ability to conduct a remote examination and view and understand the anatomy was determined. Second, how often the radiologists feel the remote consultation was inadequate was determined by measuring how often they were willing to use the remote video and how often they walked to the examination room and imaged the patient directly.

2.1. *Method*

2.1.1. *Equipment:* The examination room and the ultrasound reading room were adapted for the field study. A telephone with a headset was installed in the examination room to allow the technologist hands-free conversation with the radiologist in the reading room. The NTSC output connection on the Acuson ultrasound machine was connected by a coaxial cable to a 10" monitor in the reading room near the lightbox (figure 4). An additional monitor was available in the examination room to allow the patient to view the output from the ultrasound probe.

Figure 4. NTSC monitor for remote cooperative ultrasound.

2.1.2. *Cases:* Cases likely to occur at the ACC (obstetrics and pelvis cases) as well as a mixture of all other case types were scheduled for the remote-consultation examination room. Department practice at the time of the study required that all cases have an examination sign-off by a radiologist prior to releasing the patient.

2.1.3. *Participants:* Four ultrasound radiologists and five technologists participated in the study. Radiologists 1, 2, and 3 were female faculty members with 8 – 20 years experience. These three were very familiar with the procedures and protocols. The remaining radiologist was a male who had experience with ultrasound interpretation, but was less familiar with department protocols and procedures. The vast majority of cases were read by radiologists 1 and 2. All the technologists were females, each with over 5 years of experience with ultrasound in general and department procedures and protocols in particular.

Depending on training, personalities, work habits, etc. there can be a considerable variation among radiologists at the same institution as to the desired frequency of examination sign-off. The two primary ultrasound radiologists who participated in the experiment illustrated the two examination sign-off extremes commonly found in radiology ultrasound departments. Radiologist 1 typically spent her clinic days in the ultrasound reading room interpreting cases and waiting to be called by a technologist to sign off on an examination. She often would not find the static images sufficient and would therefore go to the examination room and examine the patient herself. She concurred with the department policy that required examination sign-off on every case. Before the study she had expressed the opinion that a radiologist would have difficulty controlling an ultrasound operation remotely. She said she would be unwilling to conduct ultrasound operations at the ACC unless either the video system worked to her satisfaction or a second ultrasound radiologist was stationed at the remote location which was her preference.

Radiologist 2 represented the other extreme. She had been trained at an institution that did not require ultrasound examination sign-off for most procedures and was somewhat unhappy about having to frequently drop what she was doing elsewhere in the hospital, travel to the ultrasound clinic, and view an examination that she felt the technologist could have handled. On the other hand, when she felt it necessary, she would spend considerable time viewing the real-time images and manipulating the probe herself. Because a second remote video monitor could be installed in her office in addition to one in the reading room, she saw the remote video as potentially allowing her to work in her office and view the video when called by the technologist. However, she was somewhat sceptical that the video would be able to replace hands-on probe manipulation. Radiologists 3 and 4 fell somewhere in between radiologists 1 and 2 with respect to examination sign-off procedures.

2.1.4. *Procedure:* The following approach was used. The technologist prepared the room and moved the patient into position. Then the radiologist was paged or called. The radiologist might or might not watch the exam depending on her current workload. If during the exam the radiologist wanted to modify the procedure she could call the technologist and give her directions over the 'phone. At the conclusion of the protocol, the technologist would again contact the radiologist (if they were not already in contact). The radiologist would talk with the technologists while reviewing the images over the remote video link, and decide whether she was willing to do an examination sign-off without physically studying the patient in the exam room.

2.1.5. *Data collection:* Observation by two experienced observers, surveys and structured interviews were used to collect data during the field study. First, 25 cases were observed directly by the observers with the observer sitting with the radiologist in the reading room and listening to the conversation between the radiologist and technologist. Second, the radiologists were asked to fill in a survey form for each case conducted remotely. The survey form provided details on whether the case would be a likely ACC candidate, ultrasound case type, radiologist, technologist, the extent of the examination sign-off, and categorization of how well the participants felt the remote consultation worked for that case. Space was also provided for comments. Additionally, the survey logged several logistical items (date, time, patient identification) so that additional comparisons could be made as needed. Third, the technologists and all radiologists were interviewed by the observers to determine how much confidence they placed in the remote operation. Technologists were interviewed separately from radiologists (for whom they work) to insure unbiased opinions about the technologies, methodologies and personalities. The radiologists answered questions on how well they felt the system worked, what they felt were the problems with the system, whether the current system would be usable in the proposed situation, their preferred interaction method, and several detailed questions relating to the findings on the survey form or noted from direct observations. The technologists were asked similar sets of questions, with special emphasis given to level of comfort since the radiologists were on the 'driving' end of the remote communication and the technologists were on the 'receiving' end of the directions.

2.1.6. *Quality assessment of remote video:* Measuring the quality of a data point by the opinion of the subject is generally considered a marginal way to evaluate a new technology. However, radiologists are non-standard subjects who, during medical school, residency and fellowship, have been 'trained to the asymptote' of what is required to generate a clinically acceptable interpretation, even if that means slowing down, obtaining additional images, recalling the patient, or even walking down the hall to manipulate the probe themselves; thus we anticipated that the metric of walking down the hall would be a sufficient measure of the clinical effectiveness of the remote video to allow us to make the decision as to whether we should purchase this technology. Note that an interpretation with the static images which resulted in an official dictated interpretation report was conducted for each case subsequent to examination sign-off, serving as a safety check and an additional measure of the quality of the sign-off.

2.2. *Results*

2.2.1. *Data:* The field study was conducted during a 5 – week period. A total of 77 cases were recorded, 30 from radiologist 1, 39 from radiologist 2 and four each from radiologists 3 and 4. Since radiologists 3 and 4 had very little experience with the system, their data were not included in the results, though observation of their behaviour is described. In 11 of 34 cases examined by radiologists 1 and 2 during the first 2 weeks of the study (32%) the radiologists felt it clinically necessary to walk to the examination room and personally examine the patient. For the final 3 weeks of the study, the radiologists used the video system for all cases and did not walk to the examination room (0%).

Assuming that the data point events are independent, then the difference between the 32% of the first two weeks and the 0% of the last three weeks is clearly significant. However, the assumption of independence is not justified. Nevertheless, the difference is striking, and they are willing to move forward based on an assumption of a decrease in the perceived need for direct intervention. There were insufficient data to comment about individual radiologists, but no patterns were visible.

2.2.2. *Observations:* During the first 2 weeks of the study, one radiologist was initially observed doing small amounts of 'human robot arm control' in which the radiologist used tedious verbal instructions, such as 'please move a bit to the right', to spatially direct the imaging. This behaviour disappeared by the third week. After this, all the radiologists would state goals, such as 'please image the left ovary' and trust the technologist to move the probe to image the desired anatomy. The authors suspect that the combination of experienced technologists, and radiologists who became willing to trust the remote operation and the senior technologists, allowed the radiologist to navigate by goal rather than by 'human robot arm control.' Radiologists did not report any difficulty in maintaining anatomical context with the real-time ultrasound images displayed on the remote NTSC monitor.

By the end of the first month, the technologists were only calling the radiologists toward the end of the exam to verify the results. The methods each of the radiologists developed for viewing during examination sign-off varied considerably.

Radiologist 1 typically requested the technologist to go back and re-image most of the critical anatomy for her to view on the monitor. While this re-imaging required less time than the technologist's initial imaging, it lengthened the total time for the examination as compared with the non-remote situation, because it took longer for the technologist to move the probe to the new anatomy, than it would take the radiologist to view the static image displayed on the lightbox. However, this time increase would be mainly for the technologist, rather than the radiologist. Since it is anticipated that at the present time there will be insufficient case load to saturate the technologist stationed at the ACC, the additional time required to re-image the anatomy for the radiologist will be of less consequence. However, as the case load increases at the ACC, the increased technologist time per examination could become significant. At the other extreme, radiologist 2 would often listen to the technologist describe the examination results on the 'phone, and might not even look at the images before releasing the patient.

By the end of the field study, the technologists generally liked the remote consultation environment. The remote consultation environment seemed to allow the technologists more responsibility, control and independence. The remote operation also seemed to have some interesting interpersonal ramifications. The remote operation encouraged the radiologists to give the technologists more responsibility and autonomy in conducting the examinations. Technologists said they felt better about their work and liked the increased trust shown in them. Less experienced technologists and/or radiologists might not have managed as well, and it is suspected that the remote environment might exacerbate any existing interpersonal conflicts.

The small black and white monitor placed in the reading room provided sufficient image quality for the ultrasound NTSC signal. Its size was sufficient for a single radiologist to view the ultrasound images. However, a larger monitor would have been useful when two or more radiologists or residents wished to simultaneously view the ultrasound signal. The 'phone headsets did allow the technologists to conduct a conversation with the radiologist that the patient could not overhear. However, a cord was used, rather than a cordless headset on the technologist's 'phone, and they had considerable problems with becoming tangled with the cord, or with the cord pulling the headset off their heads. A cordless headset will be used in future.

There was also some difficulty with the limited luminance available on the NTSC monitor (figure 4). Lightboxes can generate up to 500 foot-Lamberts, while current monitors can only generate up to 50 foot-Lamberts (Rogers *et al.* 1987). Since the lightbox was adjacent to the monitor, its luminance could overwhelm the NTSC display and make it difficult to see the real-time images. The radiologist can turn off the lightboxes, but a solution that allows the radiologist to simultaneously view NTSC or computer monitor images and films on lightboxes would be superior, for it would allow the radiologist to compare older film images in the patient's folder with currently generated electronic images.

2.3. *Further unexpected results*

Conducting this study caused the topic of examination sign-off to be 'brought into the open.' Technologists, while being interviewed by the experimenters without the presence of the radiologists, stated that they felt that the vast majority of the sign-offs were unnecessary and disruptive to clinical operations. Several of the radiologists also stated that having to sign-off on every examination was a waste of time, and caused the patients to stay in the examination rooms longer than was necessary. Sign-off on every case was felt to be demeaning to senior technologists and irritating to many radiologists.

3. Discussion

The proposed remote ultrasound between the Ambulatory Care Centre (ACC) and the main hospital seems to be an acceptable low-cost method for providing examination sign-off, without having to station an underused radiologist at the remote clinic. The study indicated the need for a number of new protocols and procedures for sending the patient to the main hospital when the remote video is felt insufficient and for dealing with referring physician interruptions during examination sign-off. However, in the course of doing the study, it became clear to everyone, including Radiologist 1, that examination sign-offs for all cases were often unnecessary, time consuming and disruptive to clinical operations. Subsequent to this study, the radiologists and technologists reviewed examination sign-off for each type of case and changed department policy to have examination sign-off only for selected types of cases, when requested by a technologist, or for junior technologists. However, it was felt that examination sign-off was still essential for ultrasound operations, and that a video system would be sufficient additional function to justify the cost.

3.1. *Purchased system*

As a result of this study, a small ultrasound PACS system implemented using personal computers for managing and viewing static ultrasound images has been purchased. This system runs over an ethernet between the ACC and the main hospital. This PC-based system, however, does not allow for real-time video and examination sign-off. Thus, despite the fact that examination sign-off is no longer performed for each case, a remote video system allowing the radiologist in the reading room to view the realtime images from any of the department's ultrasound machines in the examination rooms has been implemented.

3.2. *Cost effective tool evaluation*

Evaluating electronic remote collaboration tools can be troublesome, expensive and time consuming. While this field study was inexpensive and involved relatively few subjects, it allowed a consensus to be formed with respect to purchasing a remote video system and changing the examination sign-off policy. A similar initial study—using a local simulation of the remote operation—will help determine the effectiveness of many remote environments, and may provide a safe environment for training the potential participants. Such an environment will be all the better if it can be conducted under field conditions with real users performing real work. By allowing the participants to 'vote with their feet' (e.g. walk to the remote room) a measure of the remote consultation's effectiveness can be obtained with relatively little expense.

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