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High Performance Connectivity and Communications

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High Performance Connectivity and Communications

This report describes high performance connectivity and communications at the Lister Hill National Center for Biomedical Communications (LHC), especially as they relate to the goals and activities of the Office of High Performance Computing and Communication (OHPCC) and its Collaboratory for High Performance Computing and Communication (Collab). Special attention is given to high performance computing and communications in the areas of telemedicine and distance learning, two focal points of Collaboratory work. NLM funded external research under three High Performance Computing and Communication initiatives is summarized to provide a context for understanding the Collab's origins and the focus of its research. Collaboratory research and other activities are described in relation to four major goals and relevant research on telemedicine and distance learning is reviewed. The report concludes with a discussion of problems related to conducting collaboration research, the direction of future work, and with questions for the Board.

1. Background

High performance computing and communications (HPCC) is often equated with super computing and advanced research and education networks, such as Internet2 and National Lambda Rail. Although these forms of computing and communication constitute much of HPCC, high performance computing and communication is broader than raw processing power and bandwidth. Bandwidth affects network reliability, technically known as quality of service (QoS), because greater bandwidth reduces congestion that can cause problems. Bandwidth does not guarantee QoS, however, since a network can have sufficient capacity and still have packet loss. For video, the result can be increased latency, jitter, pixilation, or lost connections affecting the ability to communicate. Moreover, part of the effort of high performance communication is to obtain high or acceptable levels of performance in situations where bandwidth may be challenging (e.g., at disaster sites, remote areas, or on mobile devices).

A collaboration technology could be any tool enabling people to work together, including the telephone. Limiting collaboration technology to online tools is not very helpful because email and programs allowing file sharing should be included. Consequently, the focus on collaboration technology at OHPCC has been on online tools allowing users to exchange video and other data synchronously in real time. The technology not only includes videoconferencing but ways to share applications and control devices remotely. Some need significant bandwidth, while others are less demanding. They all, however, require a degree of network QoS to avoid latency and other artifacts that can intrude upon communication.

1.1 HPCC @ NLM

The NLM, as the designated lead government agency for high performance computing and communications in health, joined the Departments of Defense and Energy, the National Science Foundation, and eight other agencies in researching advance network applications in different domains. The OHPCC Collaboratory was developed in response to the needs of three research initiatives sponsored by the NLM and administered by the Office of High Performance Computing and Communications under the government's High Performance Computing and Communications Program. Nineteen projects were funded under the 1996-1999 Telemedicine Initiative, fifteen in the 1998-2002 Next Generation Internet Initiative, and eleven in the 2003-2007 Scalable Information Infrastructure Initiative. The initiatives were outgrowths of three NLM/OHPCC sponsored reports by the National Research Council and Institute of Medicine.[1,2,3] Projects funded under the initiatives were multimillion dollar, multiyear efforts. A list of primary institutions having projects that used interactive video for either telemedicine, distance learning, or disaster management is shown in Table One. The degree of use implied by the figure is understated because some projects had multiple videoconferencing applications and most worked with other institutions that are unlisted.

Table 1: NLM HPCC Initiatives with Collaborative Video

Telemedicine
Beth Israel Deaconess Medical Center, Brigham & Women's Hospital, Carnegie Mellon University, Children's Hospital – Boston, Columbia University, East Carolina University, Georgetown University, Indiana University, Johns Hopkins University, Northwestern Memorial Hospital, Oregon Health Sciences University, University of Alaska – Anchorage, University of California – San Diego, University of California – San Francisco, University of Chicago, University of Illinois – Chicago, University of Iowa, University of Maryland, University of Missouri, University of North Carolina, University of Pennsylvania, University of Pittsburg, University of Southern California, University of Washington, Washington University, West Virginia University, Yale University
Distance Learning
George Mason University, Stanford University, University of Chicago, University of Colorado, University of Illinois – Chicago, University of Michigan, University of Washington
Disaster Preparedness
Georgetown University, Johns Hopkins University, University of Alabama – Birmingham, University of California – San Diego, University of Chicago

1.2 HPCC Profiles

Three projects underscore the use of interactive video and collaboration tools for telemedicine, distance learning, and disaster preparedness.

The Indianapolis Telemedicine Test Bed Project[4] researched the use of spontaneous videoconferencing to provide 24/7 coverage of patients in a nursing facility by physicians in their clinic or homes. Encrypted video was transmitted wirelessly from a mobile cart that could be moved to patient's rooms. Transmission to the physicians' homes was asymmetrical, with a higher transfer rate for the patient's video than the physician's.

Videoconferencing sessions were archived and linked into patients' electronic medical records. During the day, physicians consulted with patients first by video and then at the bedside, while evening use of video or phone consultation was documented. Although more orders were generated after face-to-face examination, physician subjective assessments indicated video still adds value when in-person examination is not possible. After hours, video was used more for older, infirm patients, especially in cases where patients' vital signs worsened, patients were injured or fell, or patients had pain or skin problems. It was not used for nurses' inquiries or for routine patient monitoring.

The Remote Real-Time Simulation for Teaching Human Anatomy and Surgery Project[5] explored the use of videoconferencing, 3D imaging, and haptic (tactile) feedback in distance learning. The haptic focus concerned how one might feel a real or virtual object remotely. Stereographic 3D models of the entire Visible Human Male and a human hand were developed to do virtual dissections and simulated operations. Haptic client-server programs were developed that monitor the user's location in a visual space and send appropriate haptic data. End to end performance data were collected on the videoconferencing, 3D resources, and haptic applications, not only in terms of packet loss, latency and other measures, but also in relation to user perceptions. 3D and other applications, including a haptic pelvic exam simulator, have been incorporated into the Stanford University medical curriculum and have been used in distance learning sessions with UCLA, the Northern Ontario School of Medicine, and others.

The Wireless Internet Information System for Medical Response in Disasters Project[6] explored the use of mobile video, electronic triage, ad hoc networks, and global positioning systems to monitor disasters and track victims. Portable wireless routers are deployed at the disaster site with GPS capabilities, wireless triage tags and blood pressure monitors communicate with the routers about victim location and status. First responders also used handheld devices to record and communicate victim information and wore head mounted cameras to send video of victims and the disaster scene to command centers. Electronic capture of victim data was as good as paper capture and superior for tracking victim transport and destinations. Video and global positioning improved commander situational awareness.

1.3 HPCC and Collab Research Themes

Ten themes representing the current landscape of healthcare applications using advanced networks and computing were identified in a retrospective review of NLM OHPCC research initiatives.[7] The *diversity* theme indicates that the projects, taken as a whole, provide evidence that advance networks are relevant for supporting a wide range applications in many areas of healthcare. The *specificity* theme indicates that HPCC is only appropriate for solving a subset of problems in each area, however, and that much routine care can be handled with conventional computing and networks. The *quality* theme underscores the quality of service a network offers is as important or even more important than its capacity. The *effectiveness* theme acknowledges that while most projects were proofs of concept, many documented application effectiveness and additional, unanticipated benefits. The *enabling* theme stresses the fact that advanced networks make it possible to create applications and provide services that were previously not possible and that the projects created infrastructure that could be leveraged. The *visualization*, *collaboration*, and *presence* themes indicate many HPCC projects involved imaging and that they enabled people to work together and communicate in real time at a distance in virtual environments where participants felt they were either co-located or physically at some other location. The *mobility* and *integration* themes emphasize the importance of healthcare communication while in motion, either when moving about clinics, while in transit to emergency departments, or at disaster sites, and that the communication is contingent on getting different devices and software working together.

The OHPCC Collab was originally established so OHPCC staff could develop first-hand knowledge of the technology they were funding and collaborate with investigators and demonstrate their work, but it has evolved into a resource for internal research and, when appropriate, for supporting NLM programs. The collaboration research focus concerns mainly the *collaboration* and *presence* themes but also the *enabling*, *effectiveness*, *mobility*, and *integration* themes identified from the research initiatives. The collaboration program carries on this research on a more modest scale, with more limited funding and a focus on telemedicine and distance learning.

2. Collab Goals and Activities

The OHPCC's Collab goals are 1) to provide a collaboration infrastructure for supporting OHPCC work and demonstrating collaboration technologies that NLM has internally or externally funded, 2) to maintain knowledge about current and emerging collaboration technologies of possible interest to the Library, 3) to research applications of collaboration technologies in telemedicine and distance learning, and 4) to leverage infrastructure to support other programs of the Library. Although the Collab has specific telemedicine and distance learning research projects related to the third goal, research has been conducted related to the other goals as well.

2.1. Demonstrations and Infrastructure

The Collab has infrastructure for demonstrating applications that have been internally or externally developed. Selected demonstrations are listed in Table Two.
Formal demonstrations have not only been done in the Collab, but between the Collab and national conferences. Sometimes the Collab has served as terminal point for receiving and sending video from other venues at NLM, such as its auditorium, and occasionally the Collab has participated in demonstrations of network applications conducted by others. It is important to note, that demonstrations involve more than setting up a computer in a room or exhibit booth at a national conference. Demonstrations previously conducted at the annual meeting of the Radiological Society of North America were tutorials that ran the entire week and that required extending Internet2 from its point of presence in downtown Chicago to McCormick Place, the meeting site, as well as multiple displays with 3D imaging. A demonstration of high definition video from the Collab to the Interent2 Member Meeting last year involved setting up a dynamic network

connection, a very new, experimental network technology, allowing variable bandwidth to be reserved on demand.

Table 2: Selected Demonstrations

NLM Board of Regents
Federal Communications Commission Panel on Rural Telehealth
University of Missouri Virtual Site Visit
Radiological Society of North America Annual Meetings
American Society of Clinical Pathologists
American Medical Informatics Association
Internet2 Member Meetings
National Association for Equal Opportunity in Higher Education
Slice of Life/International Association of Medical Science Educators
Kids on the Grid

2.2. Maintaining Knowledge

The need to understand technologies used in OHPCC funded research was a motivating factor in establishing the Collab. From the start, this involved more than reading trade journals and going to trade shows. It meant obtaining first hand experience by actually installing and using technology. Although some of the technologies were off-the-shelf commercial products, open source and experimental technologies were tested as well. The latter require active participation in open source developer and user communities and working with those actively researching video over IP.

Quality of service is important given the nature of video. Video is comprised of a series of individual pictures or frames that when captured and played back at the rate of thirty per second, create the illusion of full motion. A standard definition screen consists of 640 x 480 pixels, each of which could have up to 32 bits of color information, while high definition video has 1280 x 720 or 1920 x 1080 pixels. Transmitting individual frames with so many pixels overburdens networks so a number of strategies are applied.

One strategy is to use coders/decoders (codecs) that are either software or firmware to compress the video. Codecs can reduce the video by shrinking the picture into a smaller window (e.g., 320 x 240 pixels), reducing the information within individual frames (intraframe compression), or between frames (interframe compression). Intraframe compression is accomplished by reducing the amount of color information associated with each pixel and/or sampling different blocks of pixels and encoding the color information for the block instead of individual pixels. Interframe compression is accomplished by only encoding the differences between the images in successive frames.

Another strategy is to use varied protocols for transmitting the data. The Internet most commonly uses the transport control protocol (TCP) to send information in units (packets) from servers to client computers. The protocol involves checking packet reception and resending packets that are dropped. Video, in contrast, uses the user datagram protocol (UDP) where packets are transmitted without the error checking that introduces delay. In addition, it is possible in some cases to increase packet size so fewer packets have to be processed. Finally, unicast or multicast can be employed (Figure 1). In unicast, a separate stream of data is sent to each participating videoconferencing end point. In multicast, the video is transmitted as one stream to a unique multicast address to preserve bandwidth. End points requesting the address can send video to and receive video from the address, much like tuning into a television broadcast frequency. Since many routers are not multicast capable or many capable routers do not have the feature enabled, unicast is more common. Multipoint conferencing units (MCUs) are needed to manage the streams when more than two end points participate in unicast conferences. The conferences can be set for continuous presence, where video from all end points is allocated within a single stream so that all sites are seen at all times, or voice activated switching, where the video information is changed from site to site depending on which site is talking.

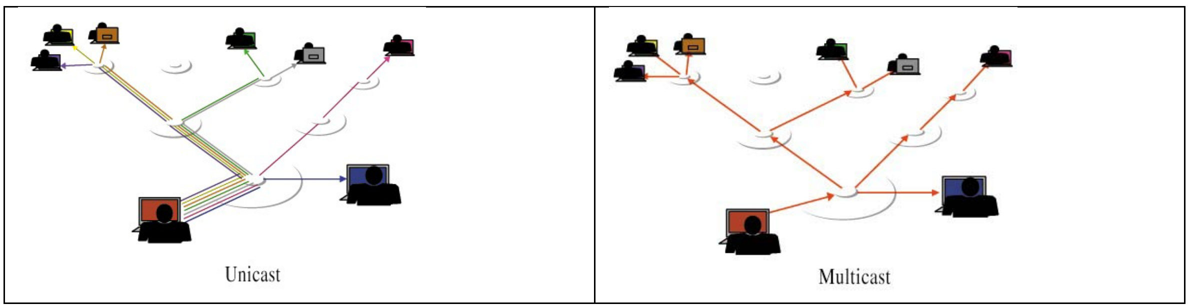

Figure 1: Transmission Types.

There are interactions between codecs, transfer rates, and image resolution. A codec can be standard definition or high definition, with the latter having higher resolution. Still the image could have lower quality than a standard definition video if transmitted at a lower data rate because more compression is applied. The minimal data rate for full screen, full motion standard definition video is considered to be 384 kbps and most commercial videoconferencing products can be set to transmit from 128 kbps to 2 mbps. The minimal high definition transmission rate for full screen, full motion high definition video is considered to be 512 kbps for 720p and 1024 kbps for 1080p. Most commercial products can be set for transmission rates up to 4 to 6 mbps. Even these highest rates are below those used for HD television broadcasts. Camera inputs (high or standard definition) and lens quality also affect resolution.

Other aspects of quality of service in videoconferencing and collaboration are the ability to share applications (documents, slides, device controls) and security. Sometimes applications are shared as video, but at a higher resolution, with the presenter appearing picture in picture. Other times, applications are shared separately, using different protocols. Encryption can be applied to the video streams and it is possible to send video over virtual private networks to provide added security.

Experimental programs are a challenge, but even commercial, "standardized" products can pose problems. Early videoconferencing products based on the H.323 standard for doing videoconferencing over IP, for example, could not interoperate. Moreover, some products comply with different standards. For example, some manufacturers employed MPEG2 compression rather than the kind used in H.323 products. While these MPEG2 products used the same compression, their different methods for initiating communication made them non-interoperable. Finally, standards are not static, but change over time. The most widely adopted standard used by commercial videoconferencing producers, H.323, has been modified many times for application sharing, camera control, and the accommodation of high definition video. Each iteration produces new implementations and prospects for incompatibility. H.323 technology can range from simple desktop or laptop implementations to telepresence systems (Figure 2).

Figure 2: A Telepresence System

Collaboration technologies tested by Collab staff are listed in Table Three. Some are proprietary, some standardized, and some open source. Some are very experimental, in the alpha or beta stages of development. In general, Collab policy has been to ignore proprietary technology, since these developers and manufacturers anticipate capturing market share and becoming the default standard, which seldom happens. The only exception is when the Collab has a special need that can be uniquely filled by a niche, proprietary product. Collab tests show that many products complying with standards initially may have different implementations or bugs that are eventually worked out. Open source and experimental technologies have varied users, but some, like the AccessGrid, have a large installed user base at research institutions and active developer communities adding enhancements. There is often cross-over between the open source and experimental groups so that experimental programs get incorporated early into open source products.

Table 3: Selected Collab Conferencing/Collaboration Technologies

Proprietary/Quasi Proprietary
Motion JPEG - ICOSM MPEG2 – StarValley, vBrick Wavelet – Session Other – vSee
Standardized/Open Source
H.323 - Polycom, Tandberg (Cisco), LifeSize, VCON and others H.26X & Windows Media - AccessGrid, ConferenceXP
Open Source Experimental
iHDTV, UltraGrid, HD ConferenceXP
Cloud
Vidyo, Vissimeet, Movi (Cisco), Blue Jeans, EVO, Scopia (Radvission), CMA (Polycom)

Collab staff published a review of selected videoconferencing and collaboration tools that they have tested.[8] They have developed improved implementations for sharing browsers and slides for the AccessGrid and software for remotely controlling cameras that can be used with open source and experimental programs. They are currently conducting a review of so-called cloud software-based videoconferencing and collaboration tools, starting with those available for testing through the Internet2 Commons. Preliminary product tests have been done with most of these and the plan is to test others with an eye toward publication. Initial findings are that there are wide variations in what constitutes "cloud" conferencing ranging from typical client-server applications to more distributed ones employing multicast as a network backplane. Overall, the applications are very new, assume desktop videoconferencing by single individuals instead of groups, and have pricing models suitable only for enterprise deployments. Consequently, while continued testing is warranted, no deployment of cloud conferencing and collaboration tools is planned at this time.

In-depth evaluations of experimental programs using high definition and/or uncompressed video are in progress. The Collab has acquired commercial high definition products and new open source programs that can do high definition video for the AccessGrid that use the H.264 compression standard. The digital video transport system (DVTS) has been used to packetize and transmit standard definition video uncompressed at data rates of 30 mbps. An HD version (HDVTS) has been used to transmit an early form of HD video which is natively compressed also at 30 mbps. Three experimental programs using uncompressed true high definition video at transfer rates of 1.5 gbps are of greatest interest because of their potential relevance to telemedicine. One program, iHDTV, transmits two 750 mbps streams for each half of the picture. Another, UltraGrid, transmits a single 1.5 gbps stream in 12 bit color and has an option for compressing the stream to 250 mbps. A third, HD Conference XP, transmits a single stream in 32 bit color at 1.99 gbps, has an option for transmitting 16 bit color at just under 1 gbps, and options for compressing video to 50 or 11 mbps. Some of these programs have tested successfully and others have not. Until recently, the programs could only be tested between computers in-house because of difficulties transmitting outside the building. Ten gigabit Ethernet has been installed in the Collab and successful uncompressed video has been transmitted between NLM and Masaryk University in Brno, Czech Republic.

3D video is becoming more common. Although 3D televisions and camcorders have not proved as popular as anticipated, the technology should be investigated, given the evidence for the benefits of viewing 3D images for anatomy education[9] and surgical training. Current 3D video technology focuses on recording and playback, not real time bidirectional or multidirectional transmission. The challenge will be to determine how these technologies or those for regular 2D HD video can be adapted for 3D videoconferencing. 2D standard definition video images have been displayed as 3D within the Collab, but the technology has not been tested with distant sites because of unique camera, configuration, and projection requirements.

2.3 Collaboration Research

Collab staff has researched collaboration technology and evaluated its use in ongoing distance learning programs, but also has conducted formal research on telemedicine and distance learning applications. This research has been targeted to address telemedicine or distance problems that have not been researched before or areas where the research is inconclusive. Since NLM lacks patients and students, these efforts necessitate building alliances with other institutions.

2.3.1 Telemedicine Research

Telemedicine is the use of telecommunications technology for diagnoses, monitoring, and medical decision making when distance separates the users. The most thorough reviews of telemedicine research are, perhaps, those prepared for the Agency for Healthcare Research and Quality (AHRQ) by the Oregon Evidence-Based Practice Center.[10,11] The original report and update and other reviews[12,13,14,15,16,17,18] underpin this discussion about telemedicine generally and about videoconferencing for so-called live-interactive videoconferencing telemedicine applications specifically. The AHRQ reports cover store and forward, home based (monitoring), and office/hospital based telemedicine where videoconferencing is substituted for in-person examination. The update examined each in terms of diagnostic reliability and accuracy, clinical outcomes, and access, while the original report also examined these factors and costs. Although interactive videoconferencing is most relevant for office/hospital based telemedicine, store and forward telemedicine is discussed to some extent because real time telemedicine applications are sometimes compared to it. The corpus of research is too diverse for meta-analysis, but specific studies cited in the research summaries involving videoconferencing are reviewed in greater detail as well as more recent telemedicine studies using interactive video.

Specialties like radiology and pathology were excluded from the AHRQ reports because these specialists rarely see patients in-person. Cost were dropped from the AHRQ update because of the diverse and sometimes unmeaningful ways they were calculated in the research originally reviewed or because the more solid research showed a trend toward cost savings given quantities of scale. Otherwise, the AHRQ update report's findings generally mirror those of the original one. Although telemedicine may be warranted when there is no alternative for providing care, it still is deployed in many areas where there is insufficient evidence to justify it use. There are insufficient rigorous studies, many lacked a "gold standard" for making meaningful comparisons, and outcome studies are lacking except in the area of home based telemedicine. The AHRQ update acknowledges that accuracy tests may be useful because clinicians can agree and still be wrong and accuracy can often be checked in reference to another standard, such as histopathologic review of biopsied tissue. The most appropriate telemedicine standard, however, is agreement because accuracy can be low even when diagnoses are done face-to-face. The standard is to prove telemedicine's equivalency, not superiority, to healthcare provided in-person.

The AHRQ reports find the best evidence for telemedicine, especially live interactive office/hospital based telemedicine, is from specialties such as psychiatry and neurology where verbal interaction is a key component of patient assessment. Telemedicine's benefits in other areas of healthcare and in other specialties are more uneven. Teleophthalmology has high rates of diagnostic agreement and accuracy, but only for certain eye conditions (e.g., diabetic retinopathy), while teledermatology concordance rates are highly variable and have mostly compared remote to in-person diagnosis without the concordance of two or more dermatologists who have diagnosed the same patient face-to-face. Wound management was identified as a potentially promising area for telemedicine needing additional research. Additional evidence for diagnostic accuracy for telemedicine interventions in chest pain, gynecology, gastroenterology, pulmonology, otolaryngology, and urology assessment also were found in the AHRQ reviews. Store and forward and office/hospital based telemedicine improve access to the extent healthcare was absent prior to telemedicine's introduction, but store and forward interventions have only had modest impact on reducing the need for subsequent evaluations in-person, at least in certain specialties such as dermatology. There is weak evidence office/hospital based telemedicine increases access and reduces travel in rural settings when patient assessments can be made adequately by videoconferencing. Overall, telemedicine may best serve as an adjunct to care centered on the in-person visit, at least initially.

More recent reviews of telemedicine in specialty areas generally support AHRQ findings related to psychiatry,[12] neurology,[13] trauma and surgery,[14] obstetrics,[17] and, to some extent, dermatology. Two teledermatology reviews[15,16] acknowledge concordance variability but one[15] concluded teledermatology agreement was adequate, mainly based on two studies[19,20] (one each for store and forward and live interactive) where more than one dermatologist did an in-person assessment. This review discounted the conclusions of the original live interactive study researchers,[20] while the AHRQ reviewers accepted it. The AHRQ call for more in-person to in-person comparisons in teledermatology is substantiated because the in-person comparisons in that live interactive study were for an entirely different sample of patients than the one used for telemedicine and a more recent teledermatology review reports the agreement range for videoconferencing is only 57 to 78 percent.[16]

Agreement in teledermatology may depend on type of disease, especially when diagnosis requires palpation. Less diagnostic confidence in teledermatology is evidenced by the fact that more tests are ordered.[16] Lower diagnostic confidence for teledermatology was confirmed in two studies[21,22] and increased testing confirmed in one.[22] It is supported also by studies cited in the AHRQ update showing most teledermatology patients eventually need to be seen in-person. There are far more studies of diagnostic concordance than confidence. Still, there is some evidence confidence may be lower for other telemedicine specialties as well. For example, studies in teleobstetrics indicate there is less satisfaction with transmitted images and remote exams[17,23] and a proclivity to order more tests[21], even if remote and in-person diagnoses are similar.[23,24] One obstetric study of telecolposcopy done asynchronously, with images stored on a workstation, and synchronously, by network transmission, found equal concordance and confidence, but visualization and exam satisfaction was superior in the network condition, even though image quality was not considered as good.[25] Higher satisfaction was attributed to the real time nature of the communication and the ability to adjust focus, magnification, and other parameters as exams progressed,[25] controls that are enhanced in newer, digital video colposcopes and through the use of additional techniques.[26,27] Real time interaction may affect physician and patient satisfaction with teleophthalmology[28] and patient satisfaction in a range of specialties.[29]

A review of some of the original research for office and hospital telemedicine cited in the AHRQ update and more recent research in specialties other than psychiatry and neurology illuminates two additional reasons for using live interactive videoconferencing in clinical contexts other than those emphasizing verbal interaction. Many telemedicine studies in gastroenterology,[30,31] obstetrics,[17,23,24,32,33] ophthalmology,[28,34-37] otolaryngology,[38-43] rheumatology,[44] cardiology,[45-50] and surgery[14,51-52] used endoscopes, colposcopes, laproscopes, slit lamps, audiometers, and ECG print outs that are commonly used in face-to-face exams. The only differences in telemedicine are that the information is being transmitted over greater distances and that, sometimes, the remote specialists may have to direct trained local operators while exams are preformed. One reason telemedicine may work in these specialties is that technologies and procedures are identical or congruent with those used in regular practice. Endoscopic images are video images, ultrasound (while not strictly video) is typically viewed on video displays, and paper is paper whether seen locally or remotely. A second reason, at least as live interactive video and store-and-forward telemedicine are concerned, is the adequacy of the visualization and image resolutions employed. A scanned tiff image of a radiograph may be sufficiently like those stored digitally in PAC systems or like the original film to provide clinically relevant information. High resolution still images, for example, appear to be adequate for most wound management[53-57] and video may work as well.[58]

Telemedicine's usefulness, even in areas where it has been shown to work, depends on quality of service. Although none of the studies reviewed explicitly evaluated QoS, several mentioned network performance problems. These studies cut across specialties and included gastroenterology,[31] obstetrics,[17,23] otolaryngology,[42,43] ophthalmology,[35,37] and cardiology.[47,49,50] Even transmission of less bandwidth consuming electrocardiograms at low bandwidth can affect usefulness and the amount of compression applied to information transmitted can be a factor.[37,42]

2.3.1.1 Telemedicine Research Summary

1. Telemedicine is used more widely than can be justified by research evidence.
2. Studies are often inadequate and lack a gold standard.
    - While comparisons with definitive lab results are fine to check accuracy, equivalency with in-person assessment, not superiority, should be the standard.
    - Clinical comparisons should have more than one physician doing in-person assessments.
3. There may be less diagnostic confidence and increased use of tests in telemedicine, at least in some specialties.
4. Telemedicine is probably best as an adjunct or follow up to in-person evaluation.
5. Telemedicine, especially live interactive, works best in specialties where assessment involves interpersonal interaction.
6. Telemedicine may work well in specialties where the technologies used for examinations are congruent with those used in-person or where they provide information of adequate resolution for clinical decision making.
7. Conversely, telemedicine can be more challenging in specialties, such as dermatology, where there are technology/procedural disconnects and visualization and other clinical data may be inadequate.
8. Quality of service can greatly impact the adequacy of telemedicine interventions, even in specialties where it works well.

2.3.2.2 Collab Telemedicine Research

Collab staff worked with the Medical University of South Carolina to research the use of videoconferencing for medical interpretation.[59,60] The only previous study identified used a single health provider and interpreter, had too few patients for statistical comparison, and used older videoconferencing technology over ISDN lines at a bit rate insufficient for full motion. One Collab study[59] involved interpretation services provided in-person, by video and by phone to limited English proficient patients in a post partum clinic (Figure 3). Video was transmitted wirelessly at a rate of 384 kbps for full screen, full motion. Data were collected on 240 clinical encounters over a seven month period where patients, provider, and interpreters independently rated encounter quality and could write comments on the scales. Seven interpreters and twenty four providers participated who also were interviewed at the conclusion of the study.

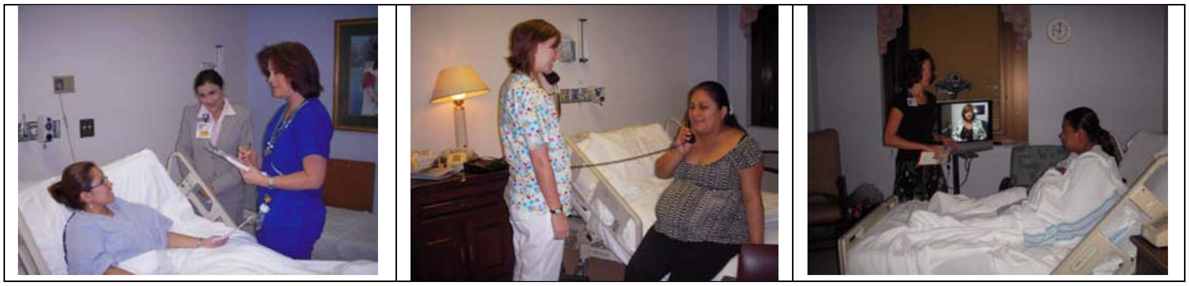
Figure 3: Medical Interpretation Research

In-person encounters were rated higher than those provided remotely with the differences due to interpreter and provider ratings. Patients rated encounters high no matter how services were provided and were exposed to only one method. Providers and interpreters used all methods and although there were no statistical differences in ratings for remote methods, remote video encounter ratings approached significance. Moreover, in written comments and interviews there was a distinct order of preference for in-person, video and then phone. Video allowed remote interpreters to see body language and what was happening to patients during encounters. Providers could easily move about the room and still be seen and heard and their hands were free to demonstrate baby care. Phone encounters were significantly shorter, a disturbing outcome considering that more conversation may have been needed to compensate for the loss of the visual channel.

Another Collab study involved providing video interpretation at a pharmacy in an out-patient free clinic using cellular networks.[60] The plan was to replicate the methodology of the first study, but the research was terminated after several months because of insufficient volunteers. There were several reasons for the low volunteer rate. First, the clinic was for out-patients who may have been pressed for time. Second, no compensation was offered. Third, many patients were chronically ill repeat visitors who once vetted for participation could not be recruited again. Forth, another study commenced in the clinic's examination area shortly after the research started, so patients were recruited for that study prior to being asked to participate in the pharmacy's study. Finally, the South Carolina legislature was considering, and has since passed, an Arizona-like immigration law. The research's targeted Latino patient population may have been reluctant to sign the consent form stating the research was subject to South Carolina law.

Valuable information was collected despite problems. The feasibility of using video over cellular networks was established providing steps are taken to ensure QoS. Remotely controlled pan-tilt and zoom (PTZ) cameras, essential in the post partum clinic, were unnecessary in this context, since the pharmacist and patient were stationary. Prescription names and dosages were complex and a problem for interpreters. The video helped pharmacists detect times when interpreters were having problems understanding. Holding labels to the camera were adequate for seeing drug names but not dosage and other information. There was a need to provide this information in written form to interpreters before the encounter.

A teledermatology study is planned with the Medical University of South Carolina that addresses limitations of previous ones. 240 patients will be examined in-person, by video, and by store and forward methods. Each patient will experience all three methods. Four dermatology residents (second year or higher) and a board certified dermatologist will participate. The dermatologists will rotate using the different methods to avoid confounding method and expertise. The exception will be the board certified dermatologist who will always exam in-person with one of the residents. Their agreed upon diagnosis will be the gold standard for judging diagnoses made by other methods. Any decisions to biopsy will be based on in-person exams and these results will be used to calibrate diagnostic accuracy for all exams. Recommendations for biopsy will be used to gauge confidence. Moreover, provider diagnostic confidence will be directly measured and provider and patient satisfaction with the exam encounter will be assessed well. Half the patients will be examined by compressed high definition video and half by uncompressed high definition video, the highest video resolution possible.

2.3.2 Distance Learning

Distance learning involves formal education in circumstances where teachers and students are separated in place, time, or both. Typical examples include classrooms where teachers and students interact in real time and other students simultaneously participate by videoconference from remote sites or where interaction occurs through web based courses. These synchronous and asynchronous distance learning applications roughly correspond to live interactive and store and forward telemedicine. Distance learning research is more amenable to meta-analysis than telemedicine. Student populations studied in distance learning tend to be larger than the patient populations studied in telemedicine. Multiple choice and other tests used to measure learning are more objective than the subjective measures used in medical diagnosis. The time pressures typical in clinics are usually absent, so tests can be comprised of many items, increasing measurement reliability. Finally, testing and evaluation is part of normal educational workflow, whereas data gathering in clinical research can intrude upon normal practice.

The most thorough review of distance and online research is, perhaps, one funded by the U.S. Office of Education.[61] Its meta-analysis of the research found that students in online learning performed the same as those in classrooms, but performance was better when classroom and online learning were combined. Such blended learning approaches have been strongly advocated in medical education.[62] The meta-analysis authors are cautionary about generalizing the results to K-12 education, since most of the studies were from medical and higher education, and they noted that none of the studies analyzed accounted for attrition. In addition to blended learning, the meta-analysis found greater effects when students learned collaboratively instead of independently, that inclusion of more media or online quizzes is no more effective than other tactics such as assigning homework, that providing learning support is more effective with individual learners than groups, and that strategies getting students to monitor and reflect on their learning are beneficial.

These findings are generally consistent with those of earlier meta-analyses and research reviews that examined other variables[53-70] and are confirmed by current research.[72-74] In addition to showing no significant differences between classroom and distance learning,[63-65] they indicate students prefer learning in-person,[63,72] and document reasons for higher dropout rates in distance courses (e.g., poor time management and self learning skills),[63] the social nature of interactivity at a distance,[68] and benefits for asynchronous distance learning courses over synchronous ones because they extend instructional time.[70] They also show improved performance with interactive video over one way broadcasts,[69] greater satisfaction with live interactive communication than with written,[67] and that satisfaction, persistence, and other outcomes are linked to a strong sense of presence in distance learning.[66,71,73,74] Blended learning provides much of the social interaction of meeting face-to-face with and the extended time for learning afforded by asynchronous instruction.

2.3.2.1 Distance Learning Summary

1. There are no differences in learning when students learn in classrooms or at a distance.
2. There is more attrition in distance learning.
3. Students prefer learning in-person than at a distance.
4. Distance learning strategies supporting collaboration and reflection are more effective.
5. Creating a sense of presence improves satisfaction, persistence, and other factors affecting learning.
6. Asynchronous distance learning is slightly better than synchronous because it extends learning time.
7. Students are more satisfied with live interactive communication and interactive video is better than one way.
8. Blending classroom and online learning has the highest benefits, extending learning time while providing the kinds of interaction and sense of presence students prefer.

2.3.2.2 Collab Distance Learning Research

Video and sense of presence in distance learning was the focus of Collab research working with the University of Alabama at Birmingham.[75,76] In the first study[75] students participated in a distant tele-lecture and were then asked to collaborate doing a follow up exercise involving the search of a telemedicine web site under conditions where they were either co-located in a computer lab or dispersed in different rooms. Students then rated the quality of instruction. Students in the dispersed group rated the experience as significantly more interactive and observations showed that they did, in fact, interact more. The way that videoconferencing channeled communication forced everyone to participate in the collaborative activity. Co-located students, if they interacted at all, did so with the person next to them. The expectation was sense of presence and, consequently, satisfaction with instruction would have been higher in the co-located group, but the video brought students closer together. The study provides some evidence that videoconferencing might be substituted for face-to-face interaction in blended learning when it is not possible to bring students together in-person.

A second study was done with co-located and dispersed students who experienced the lecture by webcast and who could communicate by chat.[76] Results were compared to those of the earlier study, the hypotheses being that sense of presence and ratings would be lower because the communications media were not as natural or rich. There was weak evidence to support the hypothesis. The students did not rate the experience as interactive as those having a videoconference, but they felt the instructor encouraged them to learn more own their own. Ironically, this finding may have been an indicator that the learning experience was not as rich. There were technical problems with the web site during the collaborative exercise in the second study that made it impossible to draw definitive conclusions about the degree of interaction.

2.4 Supporting NLM Programs

OHPCC staff has used videoconferencing technology routinely to make virtual presentations to others online. After 9/11, the Internet2 Member Meeting was conducted virtually online and the Collab became a site in the Washington area for people to participate. In addition to similar ad hoc uses, the Collab supports two ongoing educational programs.

2.4.1 Bioinformatics Training

The Bioinformatics Training Program is a series of real time interactive tele-courses for graduate students, MDs, PhDs, and post-docs providing hands on instruction in the use of the information resources and analysis tools developed by the National Center for Biotechnology Information and others. The program, an outgrowth of recommendations by the Lister Hill Center Board of Scientific Councilors, presented a number of challenges. The first was that 3D molecular modeling tools had to be shared at a distance and manipulated with little latency. The second was that instructor needed to access student desktops. The tools are complicated, multiple windows usually are open, and often information in one window must be transferred to another. Student desktop access has proved essential in providing individual assistance during hands on practice. Experiments were done with the University of Puerto Rico Medical Campus to find solutions to the latency and access issues and the results have been published.[77] The program has been offered at several medical schools (see Table Four) and it has been possible to conducted classes simultaneously with two different sites and provide hands on assistance at each.

Table 4: Bioinformatics Training Sites

University of Puerto Rico Medical Campus
University of Michigan
Charles R. Drew University of Medicine and Science
University of North Carolina
University of Maryland
University of Tennessee at Memphis
Virginia Commonwealth University

2.4.2 High School Career Education

The Presentations in Medicine Program is geared to minority high school students interested in health science careers at three geographically distinct high schools and is part of the Specialized Information Services Division's (SIS) outreach effort. SIS provides funding and is responsible for speakers and content; OHPCC provides technology support and is responsible for program evaluation. Information is presented by videoconference on health science careers and different specialties and problem areas in medicine, often by health professionals who represent the minority high school target populations. Related information sources are part of each class and the presenting health professionals not only discuss their problem and specialty areas, but their career choices. SIS funds and OHPCC hosts teachers and staff from each school for one week over the summer to plan the program, discuss technology, and cultivate collaboration.

The program started with the King Drew Medical Magnet High School in Los Angeles and its neighbor, the Charles R. Drew University of Medicine and Science. At first, the predominately African American and Hispanic students at the school had to be brought to the university's heavily scheduled auditorium for the distant learning sessions, but a network link between the high school and university, initially installed for OHPCC sponsored telemedicine research, was re-activated extending Internet2 access from the university to the school.

The program was evaluated the first year and expanded four years ago to include Kotzebue Middle-High School in Kotzebue, Alaska. These initial evaluation and expansion efforts were published[78,79] and two years ago the program was expanded again to include a health academy at Farrington High School in Honolulu, Hawaii (Figure 4). The Alaskan school serves predominately Native Alaskan students, while the Hawaiian school serves Native-Hawaiian and range of other Pacific Rim ethnic minorities.

Some sessions originate at NLM, some at either the Los Angeles or Honolulu high schools, and some from other health science institutions or universities linked into the videoconferences. Students rate each session. The overall ratings have been high and ratings of sessions that were face-to-face have been compared to those distant. Some years the in-person sessions are rated higher and sometimes the distance ones are, but the differences are so low and the overall ratings so high as to be essentially the same, an outcome consistent with other distance learning research.

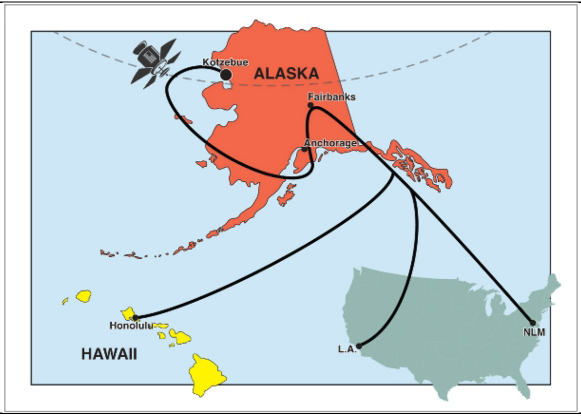

Figure 4: Locations of Participating High Schools

Kotzebue (a.k.a. Kotz), Alaska presents a special challenge because it is 30 miles north of the Arctic Circle and is reached by satellite link. The video transmission rate has to be dropped to 384 kbps, the minimum for full motion, lowering quality. While there is a special link for satellite video transmission, once video reaches the school district's Internet service provider's downlink in Anchorage it traverses the commodity Internet until it reaches the University of Alaska's Internet2 service. The sharing of presenter slides and browsers traverses a different satellite link accommodating all Kotz Internet traffic and it has proven unreliable. In addition to differences in connectivity, Kotz varies from the magnet and academy schools whose students have self-selected into programs helping them prepare for health careers. Kotz students are more general science. This summer, faculty and staff created a Facebook page to foster interaction amongst students outside class sessions. A qualitative evaluation of the program involving individual and focus group discussion of students and teachers is underway to determine how the program can better meet the varied needs and interests.

Two additional publications about education were generated in addition to those describing these educational programs. One addressed the issue of media effectiveness in education that drew upon media's impacts in telemedicine.[80] The other addressed the role of educational technology in medical and health science education.[81]

3. Collaboration Observations

Collaboration at a distance is very difficult. First, the technology is complex. One has to know the computer technology, operating systems, and applications that may be employed; how to use a range of audiovisual devices and application sharing tools; and how networks operate. Computing, audiovisual, and network devices have to be integrated for collaboration to work. Second, it is difficult to find collaborators. They must not only share an interest in the distance learning or telemedicine program being fielded or researched, but they need to have the requisite computational and network infrastructure. Third, collaborative research involves human subjects. Institutional review board approval must be obtained, even for distance learning research. For OHPCC, it means IRB approval must be sought not only at the collaborating institution, but at NIH. The problem is compounded in telemedicine where a clinical exemption must be requested from an Office of Management and Budget regulation requiring all government agencies to obtain OMB approval before collecting data from the general public. These approvals take time and often have to be obtained prior to issuing contracts to the institutions helping perform the research. Finally, security is an issue. Collaboration requires NLM access to others' networks and their access to NLM's; access that network security technologies are designed to block. Collaboration technologies are being designed to better accommodate network security constraints, but the underlying purposes of the technologies and those who manage them are antithetical and have to be dealt with.

4. Future Work

Future work was alluded to within the context of the Collab's four goals and will be summarized here. *First, there are no formal plans to conduct formal demonstrations.* There may be demonstrations if the need arises, but there are no formal plans to conduct them because other goals have higher priority. *Second, there are plans to conduct ongoing studies of the technology.* Staff plans to conclude their review of cloud conferencing technology and continue to experiment with uncompressed video. Minimally, this means getting all three systems for uncompressed video to work in the Collab and with outside end points. It may also become more deeply involved in the development of these tools. In the longer term, it means starting work with 3D HD video technology that currently is geared for recording and playback for possible adaptation to real time HD video. Conversely, this effort may involve adapting 2D HD real time video to create a 3D effect. *Third, there are plans to continue studying the technology in telemedicine and distance learning contexts.* Staff will continue to explore other mobile, wireless uses of video for healthcare. Uncompressed HD video has not been studied in telemedicine and there are few studies of compressed HD video. Consequently, the clinical application of each will be researched in dermatology, a domain where telemedicine results have been criticized and where video has not shown itself as good as store and forward methods. As staff become more familiar with 3D HD video, there may be an effort to test it in a telemedicine or distance learning contexts as well, for diagnostic effectiveness and as a technology for providing training (e.g., in surgery). *Fourth, there are plans to continue supporting NLM programs.* Support will continue for ad hoc uses of the technology to make presentations or virtually participate in meetings on an "as needed" basis. Support for the biotechnology training and high school distance learning outreach programs also will continue. The latter was only assessed with one school after the first year. The plan is to conduct a qualitative assessment to augment the numerical ratings collected after each presentation and to do this with all three participating schools.

References

1. National Research Council. *Networking health: prescriptions for the internet*. Washington, DC: National Academy Press, 2000.

2. National Research Council. *For the record: protecting electronic health information*. Washington, DC: National Academy Press, 1997.

3. Institute of Medicine. *Telemedicine: a guide to assessing telecommunications in healthcare*. Washington, DC: National Academy Press, 1996.

4. Laflamme M, Wilcox D, Sullivan J, Schadow G, Lindbergh D, Warvel J, Buchanan H, Ising T, Abernathy G, Perkins S, Daggy J, Frankel R, Dexter P, McDonald C, Weiner, M. A pilot study of usefulness of clinician-patient videoconferencing for making routine medical decisions in the nursing home. *J Am Geriatr Soc* 2005; 53:1380-5.

5. Dev P, Montgomery K, Senger S, *et al.* Simulated medical learning environments on the Internet. *J Am Med Infrom Assoc* 2002; 9:437-47.

6. Buono C, Chan T, Killeen J, Huang R, Brown S, Lui F, Palmer D, Griswold W, Lenert L. Comparison of the effectiveness of wireless electronic tracking devices versus traditional paper systems to track victims in a large scale disaster. *Proc AMIA Symp* 2007: 886.

7. Ackerman M, Locatis C. Advanced networks and computing in healthcare. *J Am Med Inform Assoc* 2011; 18:523-528.

8. Liu W, Zhang K, Locatis C, Ackerman M. Internet-based videoconferencing coder/decors and tools for telemedicine. *Telemedicine and eHealth* 2011; 17(5), 1-5.

9. Garg A, Norman G, Sperotable S. How medical students learn spatial anatomy. *Lancet* 2001; 357: 363-364.

10. Hersh WR, Hickam DH, Severance SM, Dana TL, Krages KP, Helfand M. Telemedicine for the Medicare Population: Update. Evidence Report/Technology Assessment No. 131, AHRQ Publication No. 06-E007. Rockville, MD: Agency for Healthcare Research and Quality. February 2006.

11. Hersh WR, Wallace JA, Patterson PK, *et al.* Telemedicine for the Medicare Program. Evidence Report/Technology Assessment No. 24, AHRQ Publication No. 01-E012. Rockville, MD: Agency for Healthcare Research and Quality. July 2001.

12. Nelson E, Bui T, Velasquez S. Telepsychology: research and practice overview. *Child Adolesc Psychiatric Clin N Am* 2011; 20:67-79.

13. Audebert H, Schwamm L. Telestroke: Scientific results. *Cerebrovasc Dis* 2009; 27 (suppl 4): 15-20.

14. Augestad K, Lindsetmo R. Overcoming distance: videoconferencing as a clinical and educational tool among surgeons. *World J Surg* 2009; 33:1356-1365.

15. Whited J. Teledermatology research review. *Int J Derm* 2006; 45:220-229.

16. Johnson M, Armstrong A. Technologies in dermatology: teledermatology review. *G Ital Dermatol Venereol* 2011; 146: 143-153.

17. Magann E, McKelvey S, Hitt W, Smith M, Azam G, Lowery C. The use of telemedicine in obstetrics: A review of the literature. *Obstet Gynecolo Survey* 2011; 66(3): 170-178.

18. Jarvis-Selinger S, Chan E, Payne R, Plohman K, Ho K. Clinical telehealth across disciplines: lessons learned. *Telemed eHealth* 2008; 14:720-725.

19. Whited J, Hall R, Simel D, Foy M, Stechuchak K, Drugge R, Grichnik J, Mayers S, Horner R. Reliability and accuracy of dermatologists' clinic-bases and digital image consultations. *J Am Acad Dermatol* 1999; 41:693-702.

20. Lesher J, Davis L, Gourdin F, English D, Thompson W. Telemedicine evaluation of cutaneous diseases: A blinded comparative study. *J Am Acad Dermatol* 1998; 38:27-31.

21. Edison K, Ward D, Dyer J, Lane W, Chance L, Hicks L. Diagnosis, diagnostic confidence, and management concordance in live-interactive and store-and-forward teledermatology compared to in-person examination. *Telemed eHealth* 2008; 14:889-895.

22. Pak H, Harden D, Welch M, Poropatich R. Teledermatology: An intraobserver diagnostic correlation study, Part II. *Cutis* 2003; 71(6): 476-480.

23. Ferris D, Macfee M, Miller J, Litaker M, Crawley D, Watson D. The efficacy of telecolposcopy with traditional colposcopy. *Obstet Gynecol* 2002; 99: 248-254.

24. Etherington I. Telecolposcopy – a feasibility study in primary care. *J Telemed Telecare* 2002; 8(Suppl2): S2: 22-24.

25. Ferris D, Litaker M, Miller J, MacAfee M, Crawley D, Watson D. Qualitative assessment of telemedicine network and computer-based telescolposcopy. *J Lower Genit Tract Dis* 2002; 6(3): 145-149.

26. Louwers J, Kocken M, ter Harmsel W, Verheijen R. Digital colposcopy: Ready for Use? An overview of the literature. *Brit J Obstet Gynecol* 2009; 116: 220-229.

27. Tan J, Wrede C. New technologies and advances in colposcopic assessment. *Best Prac Res Clin Obstet Gynecol* in press.

28. Wu Y, Wei Z, Yao H, Zhao Z, Ngoh L, Deng R, Yu S. TeleOph: A secure real-time teleophthalmology system. *IEEE Trans Info Tech Biomed* 2010; 14(5): 1259-1265.

29. Mair F, Whitten P. Systematic review of studies of patient satisfaction with telemedicine. *BMJ* 2000; 320: 1517-1520.

30. Kim K, Etemad B, Glenn T, Mackey H, Viator G, Wallace M, Mokhashi M, Cotton P, Hawes R. Remote clinical assessment of gastrointestinal endoscopy (tele-endoscopy: An initial experience. *Proc AMIA Annul Symp* 2000:423-427.

31. Wildi S, Kim C, Glenn T, Mackey H, Viator G, Wallace M, Hawes R. Tele-endoscopy: A way to provide diagnostic quality for remote populations. *Gastro Endo* 2004; 59(1): 38-43.

32. Adriaanse B, Tromp C, Simpson J, van Mieghem T, Kist W, Kuik D, Oepkes D, van Vugt J, Haak M. Inter-observer agreement in detailed prenatal diagnosis of congenital heart disease by telemedicine using four dimensional ultrasound. *Ultrasound Obstet Gynecol* in press.

33. Ferris D, Macfee M, Miller J, Litaker M, Crawley D, Watson D. The efficacy of telecolposcopy compared with traditional colposcopy. *Obstet Gynecol* 2002; 99(2): 248-254.

34. Bowman R, Kennedy C, Kirwan J, Sze P, Murdoch I. Reliability of telemedicine for diagnosing and managing eye problems in accident and emergency departments. *Eye* 2003; 17: 743-746.

35. Dawson E, Kennedy C, Bentley C, Lee J, Murdoch I. The role of telemedicine in the assessment of strabismus. *J Telemed Telecare* 2002; 8:52-55.

36. Crowston J, Kirwan J, Kennedy C, Murdoch I. Evaluating clinical signs in trabeculectomized eyes. *Eye* 2004; 18: 299-203.

37. Constable I, Barry C, Eikelboom R, McAllister I, Tay-Kearney M. Telemedicine screening of diabetic retinopathy using a hand-held fundus camera. *Telemed J* 2000; 6(2): 219-223.

38. Urquhart A, Antoniotti N, Berg R. Telemedicine – An efficient and cost-effective approach in parathyroid surgery. *Laryngoscope* 2011; 121: 1422-1425.

39. Smith A, Dowthwaite S, Agnew J, Wootton R. Concordance between real-time telemedicine assessments and face-to-face consultations in paediatric otolaryngology. *Med J Australia* 2008; 188: 457-450.

40. Dorrian C, Ferguson J, Ah-See K, Barr C, Lalla K, van der Pol M, McKenzie L, Wootton R. Head and neck cancer assessment by flexible endoscopy and telemedicine. *J Telemed Telecare* 2009; 15: 118-121.

41. Givens G. Internet application to tele-audiology – "Nothin' but Net". *Am J Audiology* 2003; 12: 59-65.

42. Zhu Y, Witt R, MacCallum J, Jiang J. Effects of the voice over Internet protocol on perturbation analysis of normal and pathological phonation. *Folia Phoniatr Logop* 2010; 62: 288-296.

43. Ullah R, Gilliland D, Adams D. Otolaryngology consultations by real-time telemedicine. *Ulster Med J* 2002; 71(1): 26-29.

44. Leggett P, Graham L, Steele K, Gilliland A, Stevenson M, O'Reilly D, Wootton R, Taggart A. Telerheumatology – Diagnostic accuracy and acceptability to patient, specialist, and general practitioner. *Brit J Gen Prac* 2001; 51: 746-748.

45. Chen K, Yen D, Chen C, Young M, Yin W. Effect of emergency department in-hospital tele-electrocardiographic triage and interventional cardiologist activation of the infarct team on door-to-balloon times in ST-segment-elevation acute myocardial infarction. *Am J Cardiol* 2011; 107: 1430-1435.

46. McCrossan B, Sands A, Kileen T, Cardwell C, Casey F. Fetal diagnosis of congenital heart disease by telemedicine. *Arch Dis Child Fetal Neonatal Ed* in press.

47. Grant B, Morgan G, McCrossan B, Crealey G, Sands A, Craig B, Casey F. Remote diagnosis of congenital heart disease: The impact of telemedicine. *Arch Dis Child* 2010; 95: 276-280.

48. Scalvini S, Zanelli E, Conti C, Volterrani M, Pollina R, Giordano A, Glisenti F. Assessment of prehospital chest pain using telemedicine. *J Telemed Telecare* 2002; 8: 231-236.

49. Wang S, Gross H, Lee S, Pardue C, Waller J, Nichols F, Adams R, Hess D. Remote evaluation of acute ischemic stroke in rural community hospitals in Georgia. *Stroke* 2004; 35: 1763-1768.

50. Terkelsen C, Norgaard B, Lassen J, Gerdes J, Ankersen J, Romer F, Nielsen T, Andersen H. Telemedicine used for remote prehospital diagnosing in patients suspected of acute myocardial infarction. *J Int Med* 2002; 252: 412-420.

51. Seemann R, Guevara G, Undt G, Ewers R, Schicho K. Clinical evaluation of tele-endoscopy using UMTS cellphones. *Surg Endosc* 2010; 24: 2855-2859.

52. Endean E, Mallon L, Minion D, Kwolek C, Schwarcz T. Telemedicine in vascular surgery: Does it work? *Am Surg* 2001; 67(4): 334-340.

53. Braun R, Vecchietti J, Thoma L, Prins C, French L, Gewirtzman A, Saurat J. Telemedical wound care using a new generation of mobile phones. *Arch Dermatol* 2005; 141: 254-258.

54. Kim H, Lowery J, Hamill J, Wilkins E. Accuracy of a web-based system for monitoring chronic wounds. *Telemed J eHealth* 2003; 9(2): 129-140.

55. Halstead L, Dang T, Elrod M, Convit R, Rosen M, Woods S. Teleassessment compared with live assessment of pressure ulcers in a wound clinic. *Adv Skin Wound Care* 2003; 16(2): 91-96.

56. Jones O, Wilson D, Andrews S. The reliability of digital images when used to asses burn wounds. *J Telemed Telecare* 2009; 9(Suppl.1): S22-S24.

57. Houghton P, Kincaid C, Campbell K, Woodbury G, Keast D. Photographic assessment of the appearance of chronic pressure and leg ulcers. *Ost Wound Manage* 2000; 46(4): 20-30.

58. Gardner S, Frantz R, Pringle Specht J, Johnson-Mekota J, Wakefield B, Flanagan J. How accurate are chronic wound assessments using interactive video technology? *J Gerontol Nurs* 2001; 27(1):15-20.

59. Locatis, C, Williamson D, Gould-Kabler C, Zone-Smith L, Detzler I, Roberson J, Maisiak R, Ackerman M. Comparing in-person, video, and telephonic medical interpretation. *Journal of General Internal Medicine* 2010; 25(4): 345-350

60. Locatis C, Williamson D, Sterrett J, Detzler I, Ackerman M. Video medical interpretation over 3G cellular networks: A feasibility study. *Telemedicine and eHealth* in press.

61. Means B, Toyama Y, Murphy R, Bakia M, Jones K. *Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies*. Washington, DC: U.S. Department of Education Office of Planning, Evaluation, and Policy Development, 2010.

62. Ruiz J, Mintzer M. Leipzig R. The impact of e-learning in medical education. *Acad Med* 2006, 81: 207-212.

63. Schlosser C, Anderson M. *Distance education: Review of the Literature*. Washington, DC: Association for Educational Communications and Technology, 1994.

64. College of Engineering, Engineering Outreach. Distance education: Research. Moscow, Idaho: University of Idaho, 1995.

65. Simonson M. In case you're asked: The effectiveness of distance education. *Quart Rev Dist Ed* 2002; 3(4): vii-ix.

66. Moore M. What does research say about the learners using computer-mediated communication in distance learning? *Am J Dist Ed* 2002; 16(2): 61-64.

67. Allen M, Bourhis J, Burrell N, Mabry E. Comparing student satisfaction with distance education to traditional classrooms in higher education: A meta-analysis. *Am J Dist Ed* 2002; 16(2): 83-97.

68. Bannan-Ritland B. Computer-mediated communication, elearning, and interactivity: A review of the literature. *Quart Rev Dist Ed* 2002; 3(2) 161-179.

69. Machtimes K, Asher W. A meta-analysis of the effectiveness of telecourses in distance education. *Am J Dist Ed* 2000; 14(1): 27-46.

70. Barnard R, Abrami P, Lou Y, Borokhovski E, Wade A, Wozney L, Wallet P, Fiset M, Huang B. How deos distance education compare with classroom instruction? A meta-analysis of the empirical literature. *Rev Ed Res* 2004; 74(3): 379-439.

71. Garrison R, Anderson T, Archer W. Critical inquiry in a text-based environment: Computer conferencing in higher education. *Int High Ed* 2000; 2(2-3): 87-105.

72. Paechter M, Maier B. Online or face-to-face? Students' experiences and preferences in e-learning. *Int High Ed* 2010; 13: 292-297.

73. Kim J, Kwon Y, Cho D. Investigating factors that influence social presence and learning outcomes in distance higher education. *Comp Ed* 2011; 57: 1512-1520.

74. Online university students' satisfaction and persistence: Examining perceived level of presence, usefulness and ease of use as predictors in a structural model. *Comp Ed* 2011; 57: 1654-1664.

75. Locatis C, Berner E, Hammack G, Smith S, Maisiak R, Ackerman M. An exploratory study of co-location as a factor in synchronous, collaborative medical informatics distance education. *BMC Research Notes* 2010; 3:30.

76. Locatis C, Berner E, Hammack G, Smith S, Maisiak R, Ackerman M. Communication and proximity effects on outcomes attributable to sense of presence in distance bioinformatics education. *BMC Medical Education* 2011; 11(10).

77. Locatis C, Vega A, Bhagwat M, Liu W, Conde J. A virtual computer lab for biomedical technology education, *BMC Medical Education* 2008; 8:12.

78. Locatis C, Gaines C, Liu W, Gill M, Carney J, Foster J, McCall V, Woods M. (2006). A blended training approach using videoconferencing for distance education. *Journal of the Medical Library Association* 2006; 9(4): 464-468.

79. Locatis C, Gaines C, Liu W, Gill M. Extending a blended education programme to Native American high school students in Alaska. *Journal of Visual Communication in Medicine* 2009; 32(1): 8-13.

80. Locatis C. Why media matter: Media effectiveness from a performance perspective. *Perf Improv Quart* 2007; 20(1), 9-22.

81. Locatis C. Performance, instruction, and technology in healthcare. In R. Reiser and J. Dempsey (Eds.) *Trends and Issues in Instructional Design and Technology*, 3rd Ed., Boston: Pearson, 2012.