Telemedicine Applied to Disaster Medicine and Humanitarian Response: History and Future

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Abstract

During the past decade, the military, space programs, and various governmental agencies have progressively developed telemedicine applications and tested them in real and simulated civilian disaster emergencies. This paper reviews the history of telemedicine activities during actual disasters and related situations, provides insight into issues that must be addressed, and summarizes innovations that are likely to improve future disaster outcomes.

1. Introduction

Disaster management utilizes diverse technologies to accomplish a complex set of tasks. Despite decades of telemedicine experience, there are few reports of telemedicine applied in disaster and humanitarian assistance situations. Telemedicine encompasses the diagnosis, treatment, monitoring, and education of patients, and provides convenient, site-independent access to expert advice and patient information. Transmission modalities include direct wired connections over standard phone lines and specialized data lines, and "wireless" communications using infrared, radio, television, microwave, and satellite-based linkages. This paper reviews the history of telemedicine activities in actual disasters and similar scenarios, as well telemedicine innovations that may be applicable to disaster situations in the future. Improved space- and ground-based technologies now form a communications infrastructure that is evolving to address ongoing disaster management needs. Emergency care providers must begin to plan effectively to utilize telemedicine applications to improve future outcomes.

2. Civilian Experience with Telemedicine in Disasters

The National Aeronautics and Space Administration (NASA) first used

telecommunications technology to furnish disaster aid following the 1985 earthquake in Mexico City. The Advanced Technology-3 (ATS-3) communications satellite provided voice communications support for the international rescue and relief efforts of the American Red Cross and the Pan American Health Organization. The ATS-3 communications link was crucial because the earthquake disrupted all land-based forms of communication in Mexico City, except for ham radio operators. Within 24 hours of the disaster, ATS-3 gave priority to satellite communications traffic involving disaster assessment and emergency rescue operations.[1]

The US/USSR Space Bridge Project provides the strongest example of global telemedicine disaster assistance. The Space Bridge was employed after the Armenian Earthquake of 1988.[2,3] The project used satellite communications (Intelsat and Comsat) to provide clinical consultation to several Armenian regional hospitals, linking them with four US medical centers (The Uniformed Services University of the Health Sciences, Bethesda, MD; Maryland Institute for Emergency Medical Services Systems, Baltimore, MD; The University of Texas Health Sciences Center, Houston, TX; and LDS Hospital, Salt Lake City, UT). The program utilized two-way interactive audio and unidirectional full motion video transmissions from Armenia to the United States.

The Space Bridge Project provided consultation in the areas of neurology, orthopedics, psychiatry, infectious disease, and general surgery. A separate link permitted consultations for the Russian town of Ufa, where a gas explosion caused a large number of casualties. Slow-scan black and white video was transmitted from Ufa to one of the Space Bridge sites in Armenia (Yerevan) which provided the satellite uplink.[2,4,5,6] Over a 12 week period, the Space Bridge program augmented care for 209 Armenian patients. Diagnoses were changed for 54 patients, new diagnostic studies were recommended for 70 patients, and treatment plans were changed for 47.[5]

The technical and political linkages developed during the original Space Bridge project continued throughout the 1990s. Capabilities were activated in times of crisis. For example, during the attempted coup in Moscow in 1993, NASA took advantage of existing capabilities to provide consultations for casualties of small arms fire. The project linked four US medical centers with the Clinical Hospital of the Medical Department of the Ministry of the Interior in Moscow. Each participating site had a television studio with two-way full motion color video and two-way audio. Eighteen separate clinical consultation sessions involved internal medicine, disaster and trauma management, surgery, and public health (including epidemiology and preventative medicine).[7] Consultations also involved telepathology and teleradiology systems developed by the United States Department of Defense’s Medical Diagnostic Imaging Support System.[8]

The US/USSR Space Bridge has since become the “Space Bridge to Russia”. Project physicians now use a common web browser to create and consult on clinical case records stored in a relational database.[9] The project currently provides a test-bed for evaluating Internet-based telemedicine infrastructures, and for developing insight into potential clinical care methodologies leveraging the Internet.[10] It employs multimedia e-mail, the World Wide Web, and interactive video conferencing, and supports education as well as consultation, developed for ongoing telemedicine support for astronauts involved in joint US-Russian space missions, as well as for applications here on Earth.

“Staged” disasters can help to estimate the usefulness and performance of telemedicine systems. Several telemedicine experiments and simulations have utilized ACTS, NASA’s Advanced Communication Technology Satellite, which was launched in 1994. ACTS transmits medical records, images and live video at up to T-1 (1.544 mbps) data rates[11] and has made delivery of quality clinical and information services to remote areas faster and more cost-effective than previously possible.

The 1996 ACTS Montana Telemedicine Demonstration involved a staged disaster at an Exxon refinery remote from hospital facilities.[11,12] This simulation used a modified version of the ACTS Ultra Small Aperture Terminal (USAT) with a portable Telemedicine Instrumentation Pack (TIP) developed for the Johnson Space Center. The TIP provides a compact, integrated suite of tools (acquisition devices for ENT and skin imaging, ECG, blood oxygen saturation, heart and lung sound auscultation). The TIP, packaged as a briefcase-sized diagnostic system, was used in Space Shuttle missions. Together with USAT and ACTS, the TIP proved capable of providing basic medical services to any location.[13] It allowed on-site telemedical examinations in the field by capturing, displaying, and transmitting patient audio, video, and laboratory data for remote consultations.[14]

3. Military Experience with Telemedicine in Disasters

During the late 1980s and early 1990s, technological progress provided the military with the ability to establish integrated health care delivery networks in many areas of the world.

When Hurricane Hugo devastated the Virgin Islands in March 1990, the Alabama Army National Guard Mobile Army Surgical Hospital (MASH) deployed to St. Croix. They used the prototype Battlefield Computed Radiography scanner, a digitizer, and an International Maritime Satellite (INMARSAT) terminal to transmit images acquired in the Virgin Islands via satellite to Walter Reed Army Medical Center (WRAMC) in Washington, D.C. and to Dwight D. Eisenhower Army Medical Center in Augusta, Georgia. This relief effort was the first to demonstrate the value of deployable teleradiology systems in times of crisis.[15,16]

In 1991, advanced telecommunications technology was integrated into mobile health units during the Persian Gulf war, demonstrating that such systems can function under difficult geographic and climatologic circumstances and in combat operations.[15-18] Two computerized tomography (CT) scanners were installed in transportable modular Army evacuation hospitals in the Saudi desert south of the Iraqi and Kuwaiti borders. Using an INMARSAT terminal, CT images were transmitted via satellite and the

International Telephone Network to Brooke Army Medical Center in San Antonio, Texas for expert consultation.

In late 1992, US forces were deployed to Somalia as part of a United Nations humanitarian relief effort. Somalia's population had been devastated by civil war, famine, and infectious diseases.[19] In addition, the country's communications, transportation, and public works infrastructures were severely depleted by the prolonged civil war. Medical care was in short supply and limited. Medical units supporting US troops in Somalia depended on a deployable field hospital for medical care. However, not all medical specialties and essential technologies could be represented locally. Therefore, in early 1993, the Remote Clinical Communications System (RCCS) was deployed to transmit still, digitized images and voice messages from a portable INMARSAT terminal to WRAMC.[20]

The RCCS used low bandwidth (9600 bps) telecommunications to send CT images back to the US for neurosurgical and neuroradiological consultation. Color, high-resolution images of medical conditions facilitated dermatology, infectious disease, CT/radiology, and preventive medicine consultations.[15,16] During 13 months of operation, 74 cases involving 248 images were transmitted from Somalia. For several patients, air evacuation or on-site surgical intervention were avoided because of telemedicine. The system also demonstrated that expensive video teleconferencing (VTC) capabilities were not essential for many types of telemedicine consultations. Overall, this experience emphasized the potential value of international telemedicine.[20]

In 1994, the US military gained additional experience by sending a telemedicine team to support US troops in Haiti. Patients included military personnel and Haitian civilians. Telemedicine capabilities included video teleconferencing, and transmission of high resolution still digital images. Video-enabled diagnostic equipment were connected to the teleconferencing equipment for consults based at WRAMC.[21]

The initial telecommunications from Haiti used a 56 Kbps Maritime Satellite linked to a switched 56 Kbps commercial line at WRAMC. Later, the Army Space Command allocated use of a T1-VSAT earth station (Very Small Aperture Terminal) for telemedicine access to the NASA ACTS satellite system. The satellite provided full T1 bandwidth connectivity to WRAMC using a commercial line for a high band-width, full-motion video link between the Combat Support Hospital and WRAMC. One Oral Surgery, one neurology, and three dermatology consultations took place over this improved communications link. Interactive remote telepathology and full motion orthopedic joint examinations were also conducted as concept validation tests using various data rates.[15,21] Physicians concluded that deployment of the telemedicine unit in Haiti made a significant difference for a small number of patients. In 15 of the 30 telemedicine consultations, the remote advice was rated as having a significant effect upon treatment. In 5 cases, the advice had a possible or significant effect on medical evacuation plans. The most frequently used consultants were dermatologists, radiologists, orthopedists and hand surgeons.[21]

Operation Primetime, established in 1993, provided telemedicine support to medical units in Macedonia and Croatia. The operation was upgraded (Primetime II) in 1995 with a 30-fold increase in communications bandwidth that substantially improved the transmission of medical images for diagnostic consultations. T1 Asynchronous Transfer Mode (ATM) technology was used for several integration tests that included ultrasound with color Doppler at T1 rates.[15]

In 1996, the US Department of Defense established a medical network in Bosnia that connected Army field physicians with physicians at five regional military medical centers in the US (Washington, Texas, California, DC, and Hawaii). The telemedicine segment of this project (Primetime III) utilized communication satellites to allow military physicians to consult with one another using real-time voice and video.[22] Front line physicians (in deployed units and small clinics at forward areas) transmitted X-rays, ultrasound, CT scans, other medical images, and full motion videos to remote field hospitals for diagnostic support. They also used the system to access computerized medical records, and to track patient evacuations. They obtained forward delivery of laboratory and radiological results, prescription support, and utilized digitized medical logistics support, teledentistry, online clinical information/e-mail, and medical command and control/situational awareness technologies.[15,23]

For Primetime III, the communications infrastructure changed from ATM to an integrated frame relay-ISDN (integrated services digital network) architecture. The main telemedicine hub was at the Landstuhl Regional

Medical Center (LRMC) in Germany, integrated into the Internet and a commercial ISDN gateway linked to the world. Large telemedicine nodes were installed at the Combat Support Hospital (CSH) in Taszar, Hungary, and the MASH unit in Tuzla, Bosnia. The CSH was connected to Landstuhl via dual T1 terrestrial circuits and the MASH was connected to Landstuhl via two T1 satellite circuits. Physicians could establish video telemedicine sessions anywhere within the theater, and could connect with medical centers in the United States after normal working hours in Germany, or when specific clinical expertise was not immediately available for urgent situations in Bosnia.[15] Connection to medical centers positioned in varying time zones around the globe facilitated 24-hour, 7 days per week support without requiring additional medical staffing.[24,25]

The military's efforts are especially relevant in that large-scale deployments were rapidly accomplished despite the complex and dangerous environment (characteristics often encountered in disaster or humanitarian relief settings).

4. Communication Pathways

Telecommunications infrastructures support information movement among geographically dispersed locations. The pathway a given telemedicine program will utilize is determined by required capabilities and available infrastructures. The bandwidth (bits per second) of the transmission medium limits the types of telecommunication systems that can be used.

Direct (“land”) lines over metallic twisted pairs are the most common transmission media for telephone networks,[26,27] but where fiber is available, it offers superior service. The disadvantages of direct lines for disaster responses are that they are “point to point”, cannot support mobile operations, cannot be extended on short notice to reach remote locations economically, and can only with great difficulty broadcast a signal simultaneously to all parts of a continent. To overcome these limitations, wireless broadcast media (e.g., radio and satellite) are employed.[27]

Wireless transmission links utilize the entire frequency spectrum from about 10 KHz to several GHz. Wireless linkages (most commonly via radio) can provide communications independent of local telephone and electric infrastructures. Consequently, damage to infrastructures by disasters has minimal effect on wireless communications. However, damage to radio towers, base stations and repeaters can disable communication.[26,27,28] Satellites offer a method of long distance communication when other means, such as land lines or cellular telephone services, are destroyed by disaster or, as in many developing countries, are inadequate.[27,29,30]

Most current commercial communication satellites are placed in a geosynchronous Earth orbit (GEO) -- 22,300 miles (42,164 km) above the earth’s equator. Geostationary satellites occupy fixed positions in the sky because they orbit synchronously with the earth’s rotation.[30,31] Due to long transmission distances between Earth and geostationary satellites, broadcast facilities must be relatively powerful -- requiring fixed facilities with large antennas.

Currently, satellite terminals can cost thousands of dollars, with additional costs for satellite services and maintenance.[29,32] Consequently, only large governments, very large aid organizations, and the media have primary access to satellite resources. Some communities and even some developing countries cannot afford their own emergency equipment and, therefore, must rely on outside agencies for satellite assistance. Fortunately, more portable satellite terminals will cost less over the next few years.[30,33]

Two approaches to future satellite systems are emerging to address the portability issue. One approach embeds larger, more powerful transmitters and receivers in geostationary satellites, to permit smaller, hand-held earthbound terminals.[30,34] The other approach utilizes an array of non-geostationary satellites in low Earth orbit (LEO).[30] Since LEO satellites are much closer to Earth than geostationary satellites, earth-based transmitter/receiver power requirements are reduced. Hand-held terminals the size and weight of portable cellular telephones can suffice for communicating with LEO satellites.[35,36] In the context of disaster communications, such a system could offer immediate and reliable communications for disaster responders, regardless of the severity and magnitude of the surrounding damage.

The advent of LEO communications satellites is a significant event. They can knit the world together, providing basic communications better than any wired terrestrial system (however, the intent is not to replace terrestrial systems). Individuals with LEO connectivity can have one cell phone that will operate anywhere in the world. In the midst of a disaster, even if surroundings are totally leveled, a LEO pocket cell phone could make a call for help to any phone on Earth. Future disaster management efforts will no longer be paralyzed by the lack of communications.

5. New Communication Tools

To better manage, analyze, and communicate information during a disaster, systems must reduce the burden of information management. They must facilitate rapid entry and retrieval of notes; rapid ordering and reporting of findings; and, easy and timely access to current literature and databases. The increasing prominence of the Internet, World Wide Web, and computer miniaturization, promise to improve administration and resource management related to disasters.

5.1 The Internet and World Wide Web

The Internet offers unprecedented facilities for the creation, storage and communication of information. Through the Internet, users can now exchange text, sound, images (including video), and software.

1) Disaster Management Networks

Ideally, a global resource linking all nations would facilitate sharing of critical disaster-related information and expertise. Indeed, many individual nations have already established their own disaster-related WWW-accessible networks.[37]

One effort, the Global Health Network (GHNet), has attempted to establish a gateway for global public health information.[38] GHNet hopes to establish a network that can provide immediate information in disaster situations. GHNet is an alliance of experts in health and telecommunications (University of Pittsburgh, Pan-American Health Organization, the World Bank, World Health Organization, National Aeronautics and Space Administration, and the US Agency for International Development) who share an evolving health information architecture. GHNet goals include liaison among agencies, fostering global health tele-prevention and tele-education, and program development. GHNet has also initiated a “Cyberdoc Training” effort to encourage individuals trained in both telecommunications and epidemiology (or Public Health) to provide simple, online medical expertise.

A Global Health Disaster Network (GHDNet) has been started in Ehime University, Japan, as part of the Global Health Network and is becoming an important global web site for disaster medicine. It lists organizations and individuals involved in disaster relief worldwide, and provides links to databases on past disasters. GHDNet enrolls individuals and organizations voluntarily, irrespective of country or official status. Participants share information resources and communicate with one another during disasters.[39,40]

The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) has established Relief Web as a global, WWW-based information system to support and improve humanitarian relief efforts through timely dissemination of reliable information on prevention, preparedness, and disaster response. Relief Web supports 24-hour access, accomodates user language preferences, and provides maps, daily updates, and links to websites of other humanitarian agencies. The intent is to provide "one-stop shopping" for timely and reliable information on situations and resources.[41]

2) Web Based Telemedicine

The WWW provides an efficient platform for medical education, access to medical knowledge, and conducting telemedicine consultations.[42-48] An ideal WWW-based telemedicine system would integrate existing technologies, providing access to diverse application programs and utilizing multimedia modalities; deliver information to access points, independent of hardware platform (e.g., desk-top PCs, portable lap-tops, or pocket-sized computers); and, be protocol-driven, with Store-and-Forward (SAF) or real-time teleconsulting capability. The system would promote cost-efficient transfer and sharing of clinical information throughout the world, even in remote areas.

5.2 Computer Miniaturization

1) Personal Digital Assistants

Recent computer miniaturization has produced pocket-sized Personal Digital Assistants (PDAs) with personalized interfaces. PDAs can support keyboard, pen, touch, and voice inputs, and provide information management, portability, connectivity (via phone modem, wired LAN, radio frequency LAN, and diffuse infrared transmission), and to varying degrees, e-mail, fax, graphics, digital photography, and voice recording capabilities. The ability to use a single small communicator to transmit a variety of information anywhere in the world would be ideal for the disaster field worker. A small "pocket telemedicine" unit equipped with WWW browsing capability, digital camera, phone, and computer, could conduct on-site, real-time assessment and consultations whenever necessary.

The US Military is incorporating hand-held PDA computers into its telemedicine communications efforts for combat casualty care.[49,50] It is envisioned that a front-line medic could use a PDA to read the patient's medical history, printed on a digital dog tag, and transmit information about a casualty's wounds back to a field hospital via the medic's helmet-mounted camera and a throat microphone. The PDA would link all these modalities via Broadband Code Division Multiple Access (an advanced form of wireless telecommunications) to the field hospital. Physicians at the field hospital would use the video and data input to assess the casualty and make suggestions (via an earphone PDA attachment) to the medic for immediate patient care.[51,52]

2) Wearable Computing

Miniaturization of components has enabled the development of personal computer systems that are lightweight, unobtrusive, and wearable. Both the military and the civilian sector are investigating such systems that allow hands-free operation, enhanced mobility, access to information, and shared visual experiences.

Miniaturization will continue to incorporate greater levels of functionality into smaller spaces, and may eventually allow computers to disappear into clothing and eyeglasses.[53] A military objective is to make this type of system small enough to be undetectable.[54] Wearable devices equipped with a wireless Internet connection and camera would make it possible to transmit a sequence of images to other individuals, who, watching remotely, can see what the wearer sees and interact via voice, data, and video messages.[53]

Wearable computing will, in the future, incorporate the advantages of a PDA, but in a more compact, "hands free" form that allows the worker to communicate while helping disaster victims. This will become the ultimate wireless communications/support system for the disaster responder.

6. Summary

Historically, providing telemedicine capabilities to local disaster sites has been costly. Accessibility has been limited to sites where land line or satellite linkages can be established, and where sophisticated, bulky equipment can be deployed. Traditionally, only large governments and commercial enterprises have been able to acquire such systems and infrastructures. For relief teams in remote and/or severely devastated areas, satellites played a significant role in providing mobility and land-line independence for telemedicine. Soon, new communications technologies, and miniaturization of computers will enable a far greater variety of users to engage in field level use of telemedicine during large-scale and complex scenarios.

In the future, the operating methods and systems utilized during this historical journey will seem slow, cumbersome, and crude. New technologies on the horizon will greatly simplify disaster communications, enhance telemedicine capabilities, and make telemedicine accessible to a greater number of users.

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