Review Paper ■

Applications of Telemedicine and Telecommunications to Disaster Medicine:

Historical and Future Perspectives

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Abstract   Disaster management utilizes diverse technologies to accomplish a complex set of tasks. Despite a decade of experience, few published reports have reviewed application of telemedicine (clinical care at a distance enabled by telecommunication) in disaster situations. Appropriate new telemedicine applications can improve future disaster medicine outcomes, based on lessons learned from a decade of civilian and military disaster (wide-area) telemedicine deployments. This manuscript reviews the history of telemedicine activities in actual disasters and similar scenarios as well as ongoing telemedicine innovations that may be applicable to disaster situations. Emergency care providers must begin to plan effectively to utilize disaster-specific telemedicine applications to improve future outcomes.

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Emergency responses to disasters routinely employ information and telecommunication technologies. However, use of telemedicine (providing clinical services remotely through telecommunication-based digital information exchange) has been reported relatively infrequently. During the last 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 manuscript 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.

Telemedicine systems aim to provide quality health care services to persons whose access is otherwise restricted by geography or environment. 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 hard-wired connections over standard phone lines and specialized data lines (single/twisted pairs of metallic wires, coaxial lines, fiberoptic cable) and "wireless" communications using infrared, radio, television, microwave, and satellite-based linkages. Improved space- and ground-based technologies now form a communications infrastructure well suited to addressing ongoing disaster management needs.

Historical Perspective and Lessons Learned

Telemedicine was first applied in disasters during the mid-1980s. At its inception, a potpourri of inconvenient, bulky, uncooperative systems caused technical difficulties. Subsequent learning through trials and tribulations resulted in the improved technologic systems of today. Looking back provides perspective on what worked well and what did not and allows developers to extrapolate how telemedicine could evolve to meet future disaster needs. Pioneering projects illustrated the potential benefits of telemedicine

systems and emphasized the need to institutionalize such capabilities nationally and internationally so that they could be activated on demand. Most important, these efforts fostered a global telemedicine disaster assistance mentality.

Civilian Experience with Telemedicine in Disasters

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

The U.S.–U.S.S.R. Space Bridge project, developed for ongoing telemedicine support for astronauts involved in joint U.S.–Russian space missions, provides a primary example of global telemedicine disaster assistance over time. Space Bridge was employed after the Armenian earthquake in 1988.[2,3] The project used satellite communication (Intelsat and Comsat) to provide clinical consultation to several Armenian regional hospitals, linking them with four U.S. medical centers (The Uniformed Services University of the Health Sciences, Bethesda, Maryland; Maryland Institute for Emergency Medical Services Systems, Baltimore, Maryland, The University of Texas Health Sciences Center, Houston, Texas; and LDS Hospital, Salt Lake City, Utah). The program utilized two-way interactive audio and unidirectional full-motion video transmissions from Armenia to the United States. Separate data and fax transmission lines provided additional bandwidth.

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 images were transmitted from Ufa to one of the Space Bridge sites in Armenia (Yerevan), which provided the satellite uplink.[2,4–6] Over a 12-week period in 1988, 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 technologic and geopolitical linkages developed during the original Space Bridge project expanded 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 U.S. 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 U.S. Department of Defense's medical diagnostic imaging support system.[8]

Space Bridge is now called "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.

"Staged" disasters can help 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] ACTS made delivery of quality clinical and information services to remote areas faster and more cost-effective than was previously possible.

The 1996 ACTS Montana telemedicine demonstration involved a staged disaster at an Exxon refinery remote from hospital facilities.[11,12] This high-fidelity 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 (data acquisition devices for ear, nose, and throat and skin imaging, electrocardiography, blood oxygen saturation levels, and 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]

The ACTS experimental model is the forerunner of a new generation of satellite telemedicine systems. Such systems provide new infrastructures that will significantly change the way disaster responses are viewed and carried out.

Military Experience with Telemedicine in Disasters

The U.S. armed forces have had a long-standing interest in mobile health and telemedicine services. During the late 1980s and early 1990s, technologic 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) was 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 telecommunication technology was integrated into mobile health units during the Persian Gulf war, demonstrating that such systems can function under difficult geographic and climatologic circumstances.[17,18] Two computerized tomography 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. This demonstrated the value of teleradiology in combat operations.[15,16]

In late 1992, U.S. 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 a variety of infectious diseases, including malaria and dengue fever.[19] In addition, the country's communication, transportation, and public works infrastructures were severely depleted by the prolonged civil war. Medical care was limited and in short supply. Medical units supporting U.S. 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 (9,600 bps) telecommunications to send CT images back to the U.S. for neurosurgical and neuroradiologic consultation. High-resolution color images of medical conditions facilitated dermatology, infectious disease, computed tomography and 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 was avoided because of the telemedicine consultations. Physicians on site characterized the RCCS as reliable, easy to use, and flexible and a valuable tool for clinical support. The system also demonstrated that expensive video teleconferencing capabilities were not essential for many types of telemedicine consultations. Overall, this experience emphasized the potential value of international telemedicine.[20]

In 1994, the U.S. military gained additional experience by sending a telemedicine team to support U.S. troops in Haiti. Patients included military personnel and Haitian civilians. Telemedicine capabilities included video teleconferencing and transmission of high-resolution still digital images (including digitized radiographic films). Video-enabled diagnostic equipment, including otoscopes, ophthalmoscopes, and dermscopes, were connected to the teleconferencing equipment for consultations 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 T-1/VSAT earth station (1.54 Mbps, very small aperture terminal) for telemedicine access to the NASA ACTS satellite system. The satellite provided full T-1 bandwidth connectivity to WRAMC using a commercial line. Using this technology, a high-bandwidth, full-motion video link was established between the combat support hospital and WRAMC. One oral surgery, one neurology, and three dermatology consultations took place over this improved communication 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 five 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] Telemedicine best facilitated care when the attending health provider at the remote location had sufficient clinical expertise to carry out the recommendations of the consultant.[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 communication bandwidth that substantially improved the transmission of medical images for diagnostic consultations. T-1 asynchronous transfer mode (ATM) technology was used for several integration tests that included ultrasound with color Doppler at T-1 rates.[15]

In 1996, the U.S. Department of Defense established a medical network in Bosnia that connected army field physicians with physicians at five regional military medical centers in the United States (Washington, Texas, California, District of Columbia, and Hawaii). The telemedicine segment of this project (Primetime III) utilized communication satellites to allow military physicians to consult one another using real-time voice and video.[22] Using commercially available technology, frontline 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. The same frontline physicians used the system to access computerized medical records and to track patient evacuations. They obtained forward delivery of laboratory and radiologic results and 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 communication 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 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 in Taszar, Hungary, and the MASH unit in Tuzla, Bosnia. The CSH was connected to Landstuhl via dual T-1 terrestrial circuits, and the

Table 1 ■

Operation Primetime III: Preliminary Findings

Primetime III Objectives	Preliminary Findings
Maintain patient accountability	85% patient accountability (substantial improvement over paper records).
Minimize evacuations	Of 63 documented teleconsultations reviewed, one resulted in evacuation. Of 153 evacuations reviewed, 11% could potentially have been avoided with a teleconsultation.
Provide rapid, definitive response to trauma	Data do not support use for trauma care. No teleconsultations conducted during first hour for the 200 documented trauma cases.
Deliver highest quality care to soldiers, leveraging on specialty medical support	More than 80 clinical video teleconferences, more than 650 teleradiology consultations (4,000+ images) and more than 40,000 clinical e-mails were conducted.
Provide medical leadership with "eagle's eye" view	A dedicated medical control network was created. More than 100 medical video conferences and 5,000 e-mails were conducted. Visibility of patients and facilities from outside the area was greatly improved.

MASH was connected to Landstuhl via two T-1 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 in different time zones facilitated 24-hour, 7-days-a-week support without requiring additional medical staffing.[24,25]

Table 1 summarizes preliminary findings as they relate to operational objectives.[26] Reports from those who used the systems in Bosnia indicate problems with the telemedicine equipment and with the training. Table 2 summarizes the problems, the lessons learned, and the guidance these lessons provide for disaster telemedicine efforts.[27,28] The military's efforts are especially relevant in that large-scale deployments were rapidly accomplished despite the complex and

Table 2 ∎

Operation Primetime III: Lessons Learned and Relevance to Disaster Telemedicine

Problems Reported	Lessons Learned	Relevance to Disaster Medicine
Equipment downtime: Systems non-operational for extended periods (mainly because of signal pre-emption and weather disturbances).	Telemedicine equipment must be tested and stressed across the full array of operational scenarios prior to deployment	Equipment must be independent of environmental influences, interference, or power interruption and protected from "other user" pre-emption.
VTC connections often of poor quality and at times could not be established. This was the intended method but system had multiple problems.	Provide basic (simpler), mature, tested, reliable capabilities first.	Equipment must be reliable and tested to ensure high-quality connection in a variety of circumstances. Should be rugged, utilitarian, maintenance free and quick to repair (e.g., directions written on back panels of units).
Physicians preferred store-and-forward (e.g., stored e-mail forwarded at provider's convenience) approach over video teleconferencing.	This was realized early, prompting store-and-forward to be aided by Lotus Notes–based software that allowed clinical consultation forms to be transmitted electronically.	Provide flexible telemedicine systems that offer e-mail, voice, image, fax, etc. for sending medical and disaster situational data. Provide choice of real-time or store-and-forward modes (to use as needed).
Insufficient training (and information) for users: Clinicians in theater had trouble dealing with technical difficulties, producing reluctance to use telemedicine technologies. Clinical training was inadequate to persuade physicians to use telemedicine in their practice.	Standard operating procedures for maintenance and repair of telemedicine systems and hardware should be provided (e.g., integrated logistics support package deployed with telemedicine systems). Develop uniform clinical practice guidelines and train providers.	Telemedicine use and simulated applications should be a routine part of the disaster training exercise. Systems should be simple and easy to use, requiring minimal technical training. Systems with familiar or common-use aspects would be ideal (enabling "instant" use).
Insufficient case load (data) for evaluation: Telemedicine use was shifted to disease and non battle injury cases due to smaller than anticipated number of trauma cases.	Identify user requirements prior to and throughout deployment. In some situations telemedicine capability may not be needed and data not collected.	Broaden data collection to capture a wider array of field medical data for evaluation (both anticipated and nonanticipated cases). Emphasis should be placed on collecting data in support of civilian populations most in need during disasters (e.g., trauma in natural disasters, severe communicable diseases in complex emergencies).
Protocols for telemedicine consultations not established early, creating inconsistencies in scheduling and conducting consults.	Well-defined protocols and procedural guidelines should be provided to physicians prior to telemedicine implementation.	Protocols should be provided, and they should be well defined and clinician-driven, with procedural guidelines.
An aggressive time line for rapid deployment enhanced overall risks. Difficult to foresee needs and events.	Build flexibility into the system, tailor to changes in operational missions.	Equip relief workers with systems that are mobile and immediately deployable/adaptable; capable of "doing the job" through advanced planning, testing, and simulation; flexible with choice of modality to accompany changing situations.

dangerous environment (characteristics often encountered in disaster or humanitarian relief settings).

Communication Information Pathways

Simple systems for disaster telemedicine can often deliver benefits. The main challenge is to match the right communication and contingency systems with a given disaster medicine plan or scenario. Another important challenge is to interpret and manipulate abstract acquired information and communicate essential results to where they are needed, when they are needed.

Telecommunication 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,[29,30] but fiber, where available, offers superior service. The disadvantages of direct lines for disaster responses are that the lines 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.[30]

Wireless transmission links utilize the entire frequency spectrum, from about 10 KHz to several gigahertz. Wireless linkages (most commonly via radio) can provide communication 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.[29–31] Satellites offer a method of long-distance communication when other means, such as land lines or cellular telephone services, are destroyed by disaster or are, as in many developing countries, inadequate.[30,32,33]

Most current commercial communication satellites are placed in a geosynchronous earth orbit, 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.[33,34] Because of long transmission distances between earth and geostationary satellites, broadcast facilities must be relatively powerful, requiring fixed facilities with large antennas.

However, the advantages of satellites come at a great cost. Currently, satellite terminals can cost thousands to tens of thousands of dollars, with additional costs for satellite services and maintenance.[32,35] 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, evolving, more portable satellite terminals will cost less over the next few years.[33,36]

Although satellite terminal research has created more convenient, portable products, even the smallest satellite terminals today lack the personal-level utility of portable cellular products. Two approaches to future satellite systems are emerging to address the portability issue. One approach embeds larger, more pow-erful transmitters and receivers in geostationary satellites to permit smaller, hand-held earthbound terminals.[33,37] The other approach utilizes an array of nongeostationary satellites in low earth orbit (LEO).[33] Since LEO satellites are much closer to earth than geostationary satellites, earth-based transmitter and receiver power requirements are reduced. Hand-held terminals the size and weight of portable cellular telephones can suffice for communicating with LEO satellites.[38,39] In the context of disaster communications, such a system could offer immediate, effective, reliable, and personalized communication for disaster responders, regardless of the severity and magnitude of the surrounding damage.

The advent of LEO communication satellites is a significant event. They can knit the world together, providing basic communication better than any wired terrestrial system. On the most basic level, a person with LEO connectivity can have one cellular telephone that will operate anywhere in the world. In the midst of a disaster, even if surroundings are totally destroyed, a LEO pocket telephone could easily make an immediate call for help to any telephone on the planet. Future disaster management efforts will no longer be paralyzed by the lack of communications.

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, databases, and knowledge. The increasing prominence of the Internet, World Wide Web, virtual reality, computer miniaturization, and smart/advanced materials will improve administration, resource management, and scientific research related to disasters.

The Internet and World Wide Web

The Internet emerged unexpectedly as a global phenomenon in the mid-1990s, although its history goes back three decades. It offers unprecedented facilities for the creation, storage, and communication of information. The rapid increase in Internet use has both catalyzed and benefited from increased computer literacy by end users, the availability of inexpensive powerful computer hardware and software, and better, nearly ubiquitous access. Through the Internet, users can now exchange text, sound, images (including video), and software (as Java applets, plug-ins, and executable binary native programs).

Disaster Management Networks

Ideally, a global resource linking all nations would facilitate sharing of critical disaster-related information and expertise. Many individual nations have established their own disaster-related Web-accessible networks.[40]

One effort, the Global Health Network (GHNet), has attempted to establish a gateway for global public health information.[41] GHNet is an alliance of experts in health and telecommunications agencies (University of Pittsburgh, Pan-American Health Organization, the World Bank, World Health Organization, National Aeronautics and Space Administration, and the U.S. Agency for International Development) that share a developing health information architecture. GHNet goals fall into three main categories: liaison among agencies, the fostering of global health tele-prevention and tele-education, and specific program development. GHNet has initiated a "cyberdoc training" effort to encourage persons trained in both tele-communications and epidemiology (or public health) to provide simple, online medical expertise. GHNet hopes to establish a network that can provide immediate, accurate information in disasters.

A global health disaster network (GHDNet) has been started at Ehime University, Japan, as part of the GHNet. GHDNet is becoming a key global Web site for disaster medicine. It lists organizations and individuals involved in disaster relief worldwide and provides comprehensive links to databases on previous disasters. A goal is to establish a new, official network to transmit information for disaster and emergency medicine. GHDNet enrolls individuals and organizations voluntarily, irrespective of country or official status. Participants share information resources and communicate with one another during disasters.[42,43] GHNet has set up short-term training courses in Japan and the United States to support this goal.[44]

The United Nations Office for the Coordination of Humanitarian Affairs has established Relief Web as a global, Web-based information system to support and improve humanitarian relief efforts. It fosters timely dissemination of reliable information on prevention, preparedness, and disaster response. Relief Web supports 24-hour access, accommodates user language preferences, and provides maps, daily updates, and links to Web sites of other humanitarian agencies. It provides "one-stop shopping" for timely and reliable information on situations and resources.[45]

The U.S. Department of Defense is also developing a "one-stop" source of disaster-relevant information and assistance with its Virtual Information Center (VIC). The VIC will integrate existing information management technologies and existing information sources (Internet, selected Web links, rapid search engines, predictive modeling tools, and remote sensing monitors). This effort, under the direction of the U.S. Pacific Command in Hawaii in cooperation with the Joint Battle Center, Suffolk, Virginia, and the Center of Excellence for Disaster Management and Humanitarian Assistance, Hawaii, will support military and nongovernmental, private volunteer and international organizations participating in humanitarian assistance or disaster management operations.

The VIC will be an interactive resource, able to request and coordinate electronic and manual assistance from a wide variety of sources—including open-source military and commercial information agencies, businesses, and global and local organizations—relevant to a disaster scene. The VIC would coordinate efforts by performing first-level analyses of information and then passing data and summaries to the field liaison almost continuously. Testing of the VIC began in a series of experiments starting in April 1998 that will continue through 1999.[46]

Multilingual considerations during global disaster communication must be addressed. Multinational relief workers, whether sent to a foreign site physically or connected to it electronically, often encounter language barriers. Ideally, an online multilingual interview system would assist with foreign language interviews as part of a global disaster information system. The U.S. Naval Operational Medicine Institute has developed the Rapid Health Assessment Module, which provides a microcomputer or laptop-based phrase-conversion program for rapid health assessment, refugee registration, and various medical queries.[47] It is intended for use in military efforts involving local populations, prisoners of war, refugees, civil action programs, and multinational troops. It also can support related nongovernmental activities. Using the module, an interviewer chooses an English phrase and the computer speaks that phrase in another language (recorded by a native speaker). The system supports a limited, focused, two-way conversation without a human interpreter (the subject responds with "yes," "no," pointing, and multiple-choice selections). Languages can be changed quickly, and the system accommodates illiterate people. Mounting such a multilingual interview system on the Internet would permit workers equipped with wireless laptop computers to query disaster victims on site in a variety of locations worldwide.

Web-based Telemedicine

The Web provides an efficient platform for medical education, access to medical knowledge, and telemedicine consultations.[48-54] An ideal Web-based telemedicine system would integrate existing technologies, providing access to diverse application programs and utilizing multimedia modalities. It would also deliver information to a single access point, independent of hardware platform (e.g., desktop PC, portable laptop computer, or pocket-sized computer), and be protocol-driven, with store-and-forward or real-time teleconsulting capability. The system would promote cost-efficient transfer and sharing of clinical information throughout the world, even in remote areas.

Virtual Reality

Virtual reality immerses a user in a synthetic world, creating a sensory-based environment that interactively responds to, and is controlled by, the user's behavior. The more efficient and natural the flow of data—the sights, sounds, and sensations that mimic actual experience—the more persuasive the sense of reality.[55,56] Virtual environments can effectively train individuals for disaster medicine and clinical battlefield management procedures, in a manner analogous to flight simulators for pilots, by providing opportunities to perfect skills and rehearse procedures before entering a hostile or chaotic environment.

The MediSim trainer, already in use, combines distributed interactive simulation with virtual reality. The Defense Advanced Research Projects Agency sponsored its development to train combat medics in preparation for stressful battlefield environments.[57] High-fidelity virtual-reality battlefield simulations present medic trainees with "casualties" that manifest physiologic changes of various wounds and "respond" to medics' interventions. Trainees interact with virtual casualties through spoken commands, requests for information, and manipulation of virtual medical instruments. MediSim provides feedback to the trainee on the state of the casualty and the status of procedures being performed until the condition of a wounded casualty is stabilized. The MediSim project also provides a context in which advanced battlefield medicine technologies can be prototyped and tested.

Similar high-fidelity virtual-reality training tools are needed for training skilled care providers to manage complex disaster-related situations, in order to give them predisaster, higher-level conceptual understanding and experience.

Computer Miniaturization

Personal Digital Assistants (Pocket Telemedicine)

Recent computer miniaturization has produced pocket-sized personal digital assistants (PDAs) with personalized interfaces. These small computers can support keyboard, pen, touch, and voice inputs and provide information management, portability, connectivity (via phone modem, wired or radio-frequency local area network, 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 different types of information anywhere in the world would be ideal for the disaster field worker. A small "pocket telemedicine" unit equipped with Web-browsing capability, a digital camera, telephone, and computer could be used to conduct on-site, real-time consultations whenever necessary.

The U.S. military is incorporating hand-hand PDA computers into its telemedicine communication effort for combat casualty care.[58,59] It is envisioned that a frontline medic could use a PDA to read a 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.[60,61]

Wearable Computing (Personal Imaging)

Miniaturization of components has also 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.

Early prototypes for wearable wireless computers utilized video images sent to a remote supercomputing facility over a high-quality microwave communication link. The computing facility sent back the processed image over ultra-high frequency communication links. Newer versions incorporate commercial head-mounted displays and cellular communications. Miniaturization will continue to incorporate

greater levels of functionality into smaller spaces and may eventually allow computers to disappear into clothing and eyeglasses.[62] A military objective is to make this type of system small enough to be undetectable.[63] Wearable devices equipped with a wireless Internet connection and camera would make it possible to transmit a sequence of images to other persons who, watching remotely, could see what the wearer sees and interact via voice, data, and video messages.[62] For example, someone anticipating danger might trigger a distress signal to others nearby.

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-communication support system for the disaster responder.

Advanced Sensors and Medical Monitoring

The U.S. military is developing innovative applications for advanced sensors and smart materials. The Personnel Status Monitor (PSM), a miniaturized device resembling a wrist watch, will be worn by all soldiers as part of the combat uniform. It combines advanced environmental sensors and nonintrusive physiologic sensors with a CPU, geopositioning receiver (interacting with global positioning satellites), and low-power wireless radio. The PSM will monitor the soldier's vital signs (pulse rate, temperature, respiration, and blood pressure) continuously. The PSM

remains passive until queried, when it replies with the soldier's geographic location and vital signs. However, if the soldier's vital signs depart significantly from established norms, the PSM would transmit location and vital signs until shut down by a medic.[59,63] PSMs can reduce combat mortality by precisely locating stranded or wounded soldiers; commencing triage within moments after a soldier is hit; detecting and warning about chemical and biological warfare agents; and identifying dead soldiers to prevent dangerous evacuation attempts in hostile environments.[59,61]

When a soldier is wounded, a PSM alert would be transmitted to the closest medic, who would locate him and then stabilize his condition using a "trauma pod." The Life Support for Trauma and Transport (LSTAT) unit[59,63] micro-miniaturizes and embeds into a stretcher the advanced life support capabilities of a medical center intensive care unit. Using it, remote physicians can monitor the patient and administer various fluids and medications. A next-generation clothing-based body sensor system is being developed ("the sensate liner") to provide vital signs for the medic or the LSTAT. Such advanced sensors have obvious applications in disaster medicine.

The navy has incorporated microelectronic noninvasive monitors and medical information technology capabilities into a rugged mobile medical monitor (M3) for field use.[64] The M3 helps deliver of state-of-the-art diagnosis and treatment to far-forward deployed

Table 3 ■

Summary Time Line of Military and Civilian Disaster and Wide-Area Telemedicine Deployments

	Project Area or Name	Infrastructure	Capabilities
1989	U.S./U.S.S.R. Telemedicine Space Bridge (civilian)	INTEL-SAT, COMSAT	1-way video, 2-way audio, fax
1990	Hurricane Hugo (military)	INMARSAT, land lines	CT
1991	Gulf War (military)	INMARSAT, land lines	CT
1992	Somalia (military)	INMARSAT, land lines	CT, still image
1993	Primetime I, Macedonia and Croatia (military)	Orion satellite	CT, still image
	Space Bridge, Moscow (civilian)	GTE Spacenet, G-Star II, WSDRN satellite (Russian)	2-way video, audio, telepathy
1994	Haiti (military)	INMARSAT, ACTS satellite	CT, video, still image, digital acquisition devices
	Space Bridge to Russia (civilian)	Internet, land lines	Video, audio, text, whiteboard
1995	Primetime II, Croatia (military)	Orion satellite, ATM technology	CT, still image, ultrasound, color Doppler
1996	Primetime III, Bosnia (military)	Orion satellite, ISDN	CT, still image, ultrasound, color Doppler, store-and-forward
	ACTS Montana Demonstration (civilian)	ACTS satellite	On-site acquisition devices (audio, video, data)

NOTE: INTEL-SAT indicates international telecommunication satellite; COMSAT, communication satellite; INMARSAT, international maritime satellite; CT, computed tomography; GTE, General Telephone and Electronics Corporation; WSDRN, Western Satellite Data Relay Network; ACTS, NASA Advanced Communication Technology Satellite; ATM, asynchronous transfer mode; ISDN, integrated services digital network.

forces and has applicability in operations other than war. The advanced M3(B) provides clinical and informational support by integrating a standard U.S. military battlefield personal computer, and a lightweight computer unit that hosts a suite of clinical sensors. The sensors monitor parameters such as noninvasive blood pressure, electrocardiography, pulse oximetry, and medical imaging (e.g., scopes, ultrasound/Doppler imaging, and color photography). The M3(B) information support capabilities include communication software and interfaces; local and remote patient data storage, transmission, and retrieval; access to general clinical databases; office automation software; Theater Medical Core Services functionality; and theater-based report generation.

The First Medical Battalion, Camp Pendleton, San Diego, California, participated in the field testing of the M3(B) as part of the Cobra Gold exercise (Thailand). Users commented that the clinical sensors worked well and allowed easy data storage. They noted that the packaging should be condensed and that assemblies could be made more rugged. A key point was that special training is required prior to field use, regarding the Windows environment and use of several of the peripherals (e.g., GPS and ultrasound). The current M3 requires one-on-one monitoring (i.e., one computer per patient), and the requirement for multipatient monitoring was noted. It is important for the clinician to obtain patient demographic and historical data from a central relational database source once and have those data distributed to all the software applications that require them. Other applications should be able to access the database, extract or summarize information, and forward that information for use in command and control, medical logistics, or clinical reports. Future development of the system will incorporate these recommendations from the users. Such a rugged system may find utility in disaster field operations as a first on-site telemedicine link capable of operating in the most harsh or devastated environments.

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 or severely devastated areas, satellites played a significant role in providing mobility and land-line independence for telemedicine. This flexibility is especially important. Soon, new communication technologies and miniaturization of computers and biosensors will enable a far greater variety of users to engage in field-level use of telemedicine during large-scale and complex scenarios.

Sophisticated, formal, real-time video teleconferencing was not always required or useful. The time flexibility of store-and-forward teleconsultation has been appreciated and should be provided to accommodate cases where real-time is not needed. Internet and multimedia e-mail are evolving. In complicated disaster scenarios, easy-to-use Internet-based consultation systems may be ideal.

Historically, technical difficulties have been problematic in telemedicine. Systems must be reliable and able to withstand environmental conditions, interference, and power interruptions. Telemedicine equipment should be quick and easy to repair. Lack of adequate training has hampered deployment of many systems. Telemedicine systems should minimize the amount of technical training required. Where they are to be used in disaster relief efforts, hands-on training in simulated disasters should be routine.

Table 3 summarizes the last decade of military and civilian disaster-related telemedicine deployments. The operating methods utilized during this historical journey will seem slow, cumbersome, and crude in the future. New, less costly technologies now 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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