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An Overview of NASA Telehealth

INTRODUCTION

The National Aeronautics and Space Administration (NASA) has been a pioneer in telemedicine research and utilization since the Agency's inception in 1959. Telemedicine, defined by the Agency as "the integration of telecommunications technologies, information technologies, human-machine interface technologies, and medical care technologies for the purpose of enhancing health care," is a critical factor in the success in the Agency's ability to sustain a human crew in a remote, extreme environment—space. In the earliest days of the U.S. space program, telemedicine enabled scientists on the ground to observe the human body's reactions to microgravity. As the space program progressed, NASA's telemedicine activities evolved from a basic one-way monitoring function into today's interactive program of *telehealth*. While physiological monitoring is still a fundamental part of space missions, telehealth combines state-of-the-art telecommunications technology and medical knowledge to provide a wide range of additional services and abilities, including teleimaging, telepidemiology, telescience (research), and teleducation.

NASA's telehealth program has successfully contributed to a number of applications on the Earth's surface. These terrestrial testbeds have enabled rapid medical response to natural disasters and war-torn areas, as well research into the workings of the human body in extreme environments. These testbeds have in turn expanded NASA's telehealth abilities, improving the Agency's operations in space.

As NASA moves into the International Space Station (ISS) era, the Station itself will become a testbed for telehealth technologies designed to enable space travel beyond Earth orbit. Crews of these missions will require interactive and autonomous medical capability as real-time communications with Earth become an impossibility. As NASA embarks on this effort, the Agency looks to the history of telehealth for directions for the future of space medical care.

ROOTS OF TELEHEALTH

The roots of telehealth may be traced back centuries, when time and space played a large role in driving the costs and constraining the quality of health care. Prior to the mid-eighteenth century, health care across any distance was impossible; to deliver treatment, patients and providers had to be co-located. The cost of the messenger used to summon the doctor and the need to reimburse the physician for travel, in addition to the actual costs of treatment, inflated the price of health care beyond what many could afford. These same travel costs also kept physicians from extraneous travel, preventing their exposure to a variety of conditions and ultimately limiting the quality of care. Distance, further constrained the quality of care. Instantaneous response to an emergency situation was impossible. Distance also prevented physicians from conferring and collaborating, limiting the experience base of physicians and further constraining care quality. In other words, health care was limited by the need to physically manipulate people and equipment across geographic distance.

Beginning in the eighteenth century, technological advances changed the nature of health care and laid the foundations for telehealth. In 1789, Linnaëc's newly-invented stethoscope provided medical information to a provider across a distance (albeit only a few centimeters), the first instance of telehealth utilization. Advances in transportation and communications soon followed, resulting in decreasing costs and increasing quality of care. As the speed of transportation increased and the cost of transportation decreased, first with the locomotive, and later with the automobile and airplane, the distance barrier fell. Physicians could come to their patients—or patients to their physicians—with relative ease. With new communications technologies—the telegraph and telephone—patients were able to summon physicians quickly and inexpensively. In addition, physicians could now easily confer with one another, facilitating collaboration and expanding their mutual knowledge base. Rapid-response medical care became possible. Although the transformation was by no means complete, a shift had begun: medical care could now focus on the transfer of information, rather than the physical transfer of patient to provider.

Today, it is tempting to say that the transformation is complete. The advent of fiber optic cable, the world wide web and Internet, and satellite communications, coupled with concomitant decreases in computing cost, allowed a greater number of users to transfer specialized medical information at high speeds. As the technology progressed and became incorporated into the medical community at large, health care providers gained the ability confer and provide care to patients located in some of the most remote locations on the planet. But the computer revolution is yet only in its infancy. Virtual. reality, immersive environments, haptic feedback, and nanotechnology promise a new stage in the evolution of telehealth.

ROLE OF TELEHEALTH IN NASA

NASA's primary telehealth goal is the assurance and enhancement of the health and well-being of astronauts during space flight. This goal may be broken down further: to *monitor* the health and status of astronauts, to *prevent* disease and injury from occurring, and to *treat* disease and injury when they occur. Secondary telehealth goals provide for in-flight research and continuing education.

Evolution of Telehealth in Space

Initially, NASA accepted certain limitations on in-flight medical care systems, counting on the fact that their astronauts were selected from a discrete population of healthy and experienced military pilots. As missions expanded in duration and complexity, however, the Agency required new protocols to protect the health of and provide medical care for astronauts in space flight.

In the beginning of the space program, researchers were still uncertain as to whether or not a human could actually survive and function efficiently in microgravity. Project Mercury (1961-1964) quickly settled this question. Astronauts were connected directly to biomedical instrumentation, allowing for the recording of important physiological data.

Health care monitoring during these projects relied solely on voice communication transmission of basic medical data—heart and respiration rates, blood pressure, and EKG telemetry.

These techniques continued into the Gemini Program (1964-1967). For the first time, NASA conducted in-flight biomedical experiments. Gemini astronauts served as test subjects for studies in sleep patterns, balance disturbance, and nutritional changes. Although the resulting medical data was collected and recorded, the information was not downlinked during the mission.

By the first Apollo flight, NASA added new elements to its telehealth program. NASA began to utilize video monitoring and metabolic expenditure monitoring during extravehicular activity (EVA). NASA equipped its astronauts with a biosensor harness, a mechanism that gathered critical physiological data for transmission back to Earth. Crewmember health information was transmitted to ground stations at varying locations throughout the world. Through the harness, NASA could monitor various vital signs, including oxygen consumption, carbon dioxide levels, changes in temperature, and heart rate. Like their Mercury predecessors, Apollo astronauts did not conduct intensive in-flight medical investigations.

By the time the Skylab program launched its first mission in May 1973, and NASA resumed in-flight medical testing, the Agency had added an important component to its telehealth program – the ability to communicate biomedical data from the spacecraft to the ground in a timely manner. Investigators on the ground received downlinked health information concerning their astronauts within 12 to 24 hours post experiment. In addition, investigators and crew members engaged in scheduled weekly real-time meetings during which they could discuss the modification of protocols (if necessary) to rectify health and experiment concerns. For Skylab, NASA's first extended stays in space, the Agency developed the In-flight Medical Support Unit, a dedicated rack with a host of equipment for diagnostic and therapeutic capabilities for medical and dental issues.

Many of the same techniques and technologies from Apollo were incorporated into the subsequent Space Shuttle program. The Tracking and Data Relay Satellite System (TDRSS) allows the communication of biomedical information from Shuttle crews to mission control in real-time, a significant step for modern telehealth. NASA also employs continuous indirect monitoring (the monitoring of voice and video transmissions) and direct monitoring (monitoring downlinked biomedical data and conducting Private Medical Conferences, or PMCs). Through these technologies, relevant and life-saving biomedical information concerning everything from an astronaut's suit pressure to a crewmember's ECG data may be transmitted virtually instantly.

The ISS Phase 1/Shuttle-*Mir* program was a learning opportunity for NASA and the Russian Space Agency. Telehealth in the Shuttle/*Mir* program included regular meetings between ground personnel in Moscow and in Houston, as well as private medical conferences between the crew and the ground. Telemedicine equipment installed at

Gagarin Cosmonaut Training Center in Star City, Russia, supported medical operations activities between the astronauts in *Mir* training, resident flight surgeons, and the medical staff in Houston.

Development of Telehealth Testbeds
Although NASA telehealth activities primarily focus on the welfare of astronauts, the ultimate purpose in the development and application of telehealth technologies and applications is to support *all* humans in remote, extreme environments—on Earth or off. Since the early 1970's, NASA has contributed its telehealth capabilities to terrestrial situations, allowing the Agency to test its technologies and provide feedback for its space operations.

NASA carries out the majority of its terrestrial telehealth activities in collaboration with other organizations. NASA's primary partner in telehealth is the Medical Informatics and Technology Applications Consortium (MediTAC, formerly MITAC) Commercial Space Center located at the Virginia Commonwealth University. MediTAC was established to develop, evaluate, and promote information and medical technologies for space and ground applications, while leveraging partnerships with academia and industry. The East-West Space Science Center (EWSSC) and the Uniformed Services University of the Health Sciences (USUHS) are also frequent collaborators in NASA telehealth activities.

The telehealth activities of NASA and its partners have brought medical care, disaster relief, and demonstration projects to remote locations across the globe.

Medical Care in Remote Locations
In 1972, NASA teamed with the U.S. Department of Health, Education, and Welfare, the Bureau of Indian Affairs, and the Lockheed Corporation on the Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC), the first large-scale telehealth project. A mobile health unit (MHU), traveling on an established route, carried diagnostic laboratory and radiology hardware. Staffed by physician assistants, the STARPAHC MHU transmitted the medical information of patients on the Papago Indian reservation in Arizona to health care providers in Sells, Arizona, Phoenix, Tucson, and Santa Rosa via microwave. The same technology was later used in ambulances for emergency response.

In 1998 and again 1999, MediTAC (then MITAC) led an intensive test of telehealth technologies in one of the most extreme environments on Earth—Mount Everest. Encamped at 17,700 feet above sea level at Everest Base Camp, a group of Yale physicians and researchers supported telemedicine activities, monitored climbers during their ascent to the summit, and evaluated new technology. Together, the two Everest Extreme Expeditions validated new technologies (including a vital signs monitor) and gathered a wealth of physiological information on the body's reaction to extreme high altitude. The Everest expeditions also provided teleducation opportunities. Video teleconferences were conducted between Base Camp and school children on both coasts of the U.S. In addition, daily activities of Everest team members were posted on the Internet, collecting over one[1] million hits during the course of the mission.

More recently, a MediTAC team traveled to the Dominican Republic to provide surgery and medical care at the Hospital of Samana. Connected over the Internet, patients in the Dominican Republic were monitored and diagnosed by physicians at the Virginia Commonwealth University. Data was gathered from the patients and entered into a database. Collaborating surgeons in the Dominican Republic and Virginia were then able to share database tools and whiteboards during live videoconferencing. The project successfully tested the feasibility of sending live images over low-bandwidth connections.

Disaster Relief
In 1985, NASA teamed with the Pan American Health Organization to provide disaster relief logistics support via the ATS-6 following an earthquake in Mexico City. The satellite-based communications facilitated the distribution of food, water, and medical supplies.

Three years later NASA provided telehealth capabilities following an earthquake that destroyed much of the medical care capability in the then-Soviet Republic of Armenia. Under the auspices of the US/USSR Joint Working Group on Space Biology and Medicine, NASA offered medical assistance via the Spacebridge to Armenia, a communications system providing consultations between Armenian physicians at the Diagnostica Center in Yerevan and medical personnel at several locations in the U.S. During the 12 weeks of operation, U.S. clinical specialists "saw" 209 patients in Armenia. Using one-way, full-motion color video, two-way audio, telephone, and fax machine, U.S. physicians assisted in the treatment of infections disease, psychological reactions to the earthquake, and surgical consultation. The Spacebridge was extended to Ufa, Russia, to provide medical consultation following a train collision and explosion. The Spacebridge to Armenia/Ufa was the first large-scale use of international telehealth for disaster relief.

Demonstration Projects
Following the success of the Spacebridge to Armenia, NASA, the US/Russian Joint Working Group on Biomedical and Life Support Systems, and Medtelecominform, developed and operated the Spacebridge to Moscow via two satellites, the U.S. Spacenet Gstar II and Russia's Loutch. Over the nine-month span of this project, Russian and American physicians collaborated in the treatment and diagnosis of over 70 patients, some in highly specialized areas such as hyperbaric and emergency medicine. These interactions highlighted the need for reliable, inexpensive medical communications that are available on demand, rather than tailored to specific events. The Spacebridge to Moscow was also an opportunity to investigate how cultural and linguistic differences may affect telehealth practices—a necessary understanding for the multicultural efforts of the ISS.

As a follow-on to the Spacebridge to Moscow, the Spacebridge to Russia was developed to demonstrate the use of the world-wide-web, Internet, and multicasting in terrestrial telehealth activities. Participating physicians conduct clinical consultations via electronic media, digitize the data, and transmit it across the Internet as data, still images, audio, and video. Collaborating physicians may then access the data. Patient privacy is protected by a number of safeguards. Spacebridge to Russia workstations also offer real-time video teleconferencing ability. Recently, the Spacebridge to Russia interface was modified to become the Telecollaboration On-Line Database (TOLD), a key component of MediTAC's operations.

The Virtual Collaborative Clinic (VCC), a joint effort of NASA-Glenn Research Center, Stanford University, Salinas Valley Memorial Hospital, Northern Navajo Medical Center, and NASA-Ames Research Center, was first demonstrated in May 1999. The VCC enabled physicians at remote sites to interact with each other and with 3D visualizations of patient data via a high-speed multicasting system. In addition to bringing specialized care to remote locations, the VCC system allows surgeons to plan and practice delicate operations in a virtual environment. Following the successful first demonstration, MediTAC announced that it will fund VCC operations, beginning in June 2000.

DIRECTIONS IN NASA TELEHEALTH

The past success of NASA's telehealth activities ensures the delivery of medical care to individuals remote locations—from climbers on Mount Everest to astronauts on the Shuttle or ISS in low-Earth orbit. As NASA plans for the future, however, medical care providers find themselves again facing the same barriers that inspired the development of telehealth: time and distance.

As crews venture beyond low-Earth orbit for the first time since the Apollo missions, they will find themselves millions of miles from health care, unable to return to Earth in the event of emergency. Crews will have to rely on on-board equipment and expertise for medical maintenance and emergency procedures. Long-distance exploration crews will also face communications delays. A message sent from a mission *en route* to Mars, for instance, will take almost 20 minutes to reach Earth, with another 20 minutes spent waiting for a reply. Traditional forms of teleconsultation will no longer be sufficient. Again, NASA must ensure that crews have a high degree of self-sufficiency in exploration medical systems.

To plan for the future, NASA has already embarked on an intensive, cross-cutting research program to develop telehealth technologies that will provide onboard capability while delivering high-speed communications ability. These technologies will converge to create compact medical delivery systems supported by a crewmember physicians, an integrated telemedicine capability, and computer-aided diagnosis. In the very near future, the ISS will begin to serve as a testbed for these technological advances. Miniature, portable equipment, such as handheld biosensors, will provide detection and diagnosis capability, while saving power, weight, and volume—precious resources on spacecraft. Nanotechnology, technology on the scale of billionths of a meter, will supply additional diagnostic and life support capability, as well treatment by delivering targeted therapies to the site of injury. Information systems, decision-support systems, and computer-based medical training and record systems will allow astronauts to make informed, knowledgeable health care choices. Holographic and 3-D imaging will allow crewmember physicians to assess medical matters in detail. Genetic and DNA therapies will offer detection, diagnosis, analysis, and treatments for a wide range of illnesses. Biologically-inspired technologies, machines that mimic the properties of biological systems, will contribute a wide range of necessary characteristics to future telehealth. Because they are adaptive, anticipatory, collaborative, curious, guided, self-modeling, and self-repairing, biologically-inspired technologies are key to building human-centered and robotic telehealth systems. Wireless communications will provide astronauts with hands-free access to information and communications, imparting greater ease and freedom of movement. Together, these technologies will create a telehealth system that provides on-board medical capabilities to crews millions of miles from Earth-based care.

CONCLUSION

Telehealth has played an integral role in NASA's human space flight program and in terrestrial efforts to bring medical care to patients in remote locations. In the near future, the research of today will combine to become tomorrow's "smart", interconnected, autonomous, self-replicating, self-repairing telehealth systems—essential elements of NASA's plans for long-duration exploration. As NASA's telehealth capabilities advance, the Agency's ability to care for remotely-located patients—whether on Mount Everest in Nepal or Olympus Mons on Mars—will improve the quality of health care for all patients, on Earth and in space alike.