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The Current State of Telemonitoring: A Comment on the Literature

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ABSTRACT

Telemonitoring, is defined as the use of information technology to monitor patients at a distance. This literature review suggests that the most promising applications for telemonitoring is for chronic illnesses such as cardiopulmonary disease, asthma, and heart failure in the home. Fetal heart rate monitoring and infant cardiopulmonary functions have also been monitored at a distance, as well as coagulation, or the level of activity of elderly people, assessed by the intelligent home monitoring devices. Hospitals, clinics, and prisons all have used telemonitoring, as have ambulances equipped with systems connected to the receiving hospital. Telemonitoring allows reduction of chronic disease complications thanks to a better follow-up; provides health care services without using hospital beds; and reduces patient travel, time off from work, and overall costs. Several systems have proven to be cost effective. Telemonitoring is also a way of responding to the new needs of home care in an ageing population. Real-time monitoring of patients in ambulances reduces the time to initiate treatment and allows the emergency crew to be better prepared. The obstacles to telemonitoring development include the initial costs of systems, physician licensing, and reimbursement. In the future, virtual reality, immersive environments, haptic feedback and nanotechnology promise new ways in improving the capabilities of telemonitoring.

INTRODUCTION

SIMPLY DEFINED, telemonitoring is the remote monitoring of patients, including "the use of audio, video, and other telecommunications and electronic information processing technologies to monitor patient status at a distance."[1] Telemonitoring is still overshadowed by telediagnosis and teleconsulting and we have yet to understand fully its current achievements and potential for the future. A more restrictive term used for telemonitoring is biotelemetry, which consists of the transmission of biologic or physiologic data from a remote location to another location for data interpretation and decision-making.[2]

Telemonitoring can be traced back to 1905, when Dr. Einthoven transmitted electrocardiograms (ECGs) from a hospital to his laboratory by directly connecting immersion electrodes to a remote galvanometer via telephone lines.[3] In 1921, Winters transmitted heart sounds over a marine radio link.[2] Radiotelemetry for patient monitoring was reported by the journal *Anesthesiology* in 1961; ECGs and x-rays were transmitted in 1965 from ship to shore; and a few years later, existing voice radio channels were used to transmit ECGs from fire–rescue units

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to Jackson Memorial Hospital in Miami, Florida.[1] The Space Program provides good illustrations of telemonitoring, tracking the signals of the human body under extreme conditions from remote locations. As early as the Mercury and Gemini programs (1961–1966), astronauts wore torso coveralls in which biosensors measured blood pressure, pulse, ventilation and ECG data continuously.[4]

MATERIAL SELECTION

An extensive literature search was conducted during the years 2001 and 2002, using the following terms: telemonitoring, telemedicine and monitoring, remote sensing, remote monitoring, distant monitoring, and biotelemetry. Documents that were retrieved came from academic literature, MEDLINE, library databases, conference proceedings, and Internet websites. This collection of literature was then reviewed for its value and for the development of a global view of telemonitoring.

RESULTS

Table 1 lists all the medical conditions found in the collected volume of literature that can be successfully telemonitored. The most prevalent and promising location for telemonitoring is in the individual's home. Cardiopulmonary diseases, such as asthma, chronic obstructive pulmonary disease, and chronic heart failure, are the most common applications in telemonitoring. Moreover, telemonitoring ranges from monitoring blood pressure,[5] and pregnant women,[6] to cardiopulmonary monitoring of chronically ill patients.[7] Patients with asthma have been telemonitored with digital spirometry devices,[8,9] as have cardiac patients with pacemaker and ECG monitoring.[10,11] ECG monitoring may use a very simple and inexpensive device.[12] Pediatric cardiology patients use digital stethoscopes.[13] Patients with severe congestive heart failure use an electronic scale to telemonitor weight, combined with a display to answer relevant questions, and a communication device to transmit data.[14] Fetal heart rate telemonitoring can be delivered at home in high-risk pregnancies,[15] and infant cardiorespiratory functions can be telemonitored for observation during sleep at home.[16] Metabolic diseases such as diabetes also are telemonitored. Diet telemonitoring, via a computerized Diabetes Monitoring System in Hong Kong, uses a handheld electronic diary[17] or the DIABTel Telemedicine system.[18] It was developed in Spain for the intensive management of

TABLE 1. WHAT THE LITERATURE HAS DEMONSTRATED TO BE SUCCESSFULLY TELEMONITORED

Cardiovascular:	Metabolic:
Heart rate[7,16,27,31,34]	Body weight[14]
Fetal Heart rate[15]	Basal metabolic rate[4]
Blood pressure[5–7,16,26,27]	Blood glucose[18]
ECG[7,10-12,16,22,26-28,34]	Blood lactate[34]
Pacemaker parameters[10,11]	Blood ethanol[34]
Stethoscopy[13]	Diet[17,18,48]
Hematologic:	Physical activity[18]
Coagulation (INR)[19]	Temperature[7,31,34]
Respiratory:	Urologic:
Pulse oximetry[16,26,27]	Intravesical pressure[2]
Spirometry[8,9,45]	Obstetrics-gynecology:
Respiratory rate[7,26,28,31]	Intrauterine pressure[20]
CO_2 production[4]	
O_2 consumption[4]	
Neurologic:	Others:
EEG[30]	Movements[28,34]
EMG[35]	Drug therapy[18]
Intracranial pressure[23]	Geographical location (GPS)[31,34]
	Home activity[21]

ECG, electrocardiogram; INR, international normalized ratio; EEG, electroencephalogram; GPS, global positioning system.

patients with diabetes. Using a palmtop computer, patients enter their diet, treatment, physical activity, and alarm symptoms. Patients are also equipped with a portable glucometer to measure blood glucose. Physicians are notified when data with associated alarms are received. Subsequently, they can consult patient information by a complete outpatient Electronic Medical Record system. Other functions also have been monitored, such as a home coagulation monitoring system that measures the International Normalized Rate (INR),[19] the detection of premature labor after intrauterine surgical interventions with implantable devices,[20] or the intelligent home monitoring system,[21] which is a combination of passive infrared movement detectors, contact sensors in the refrigerator and front door, as well as room temperature sensors distributed throughout the home of elderly people to assess their level of activity and critical signs.

Hospitals, clinics and prisons all have used telemonitoring. Critical-care patients' physiologic data can be accessed remotely through the Internet and handheld computers,[22] and intracranial pressure telemonitoring has been used by a neurosurgery team to evaluate shunt systems in hydrocephalus treatment.[23] Telemonitoring in the neonatal intensive care unit allows concerned parents to see photographs and videos of their infants.[24] Prisons use telemonitoring to transmit data to outside healthcare professionals, representing 30% of the nonradiology telemedicine programs in the United States.[25]

Ambulances are equipped with systems connected to receiving hospitals, such as Mobimed[26] in Sweden or the Lifepack 12 in Singapore.[27] Other portable systems are the Wireless Intelligent SEnsor (WISE),[28] a wearable device for monitoring multiple physiologic signals with intelligent sensors connected to a wireless Personal Area Network (PAN), and the SmartShirt System,[29] which resembles a regular T-shirt. It is made of a soft and washable fabric with optical and electrical fibers woven into it, enabling integration of a large variety of sensory parameters. EEGs were also measured with a portable system developed to study possession trances in the field.[30]

NASA has developed advanced telemonitoring techniques since the first manned missions. Devices like Telemedicine Instrumentation Pack (TIP) were validated during the Space Shuttle Program.[4] Telemonitoring of future astronauts in long-term space missions to Mars will be tested with "terranauts." It will include a 22-minute delay in transmission to simulate the longest possible delay of communications between Mars and the Earth.[31] The U.S. Army is developing the Warfighter Physiological Status Monitoring (WPSM), a suit of external sensors to monitor a soldier's vital signs and condition (hydration, thermal strain, etc.) and allow remote triage (wound condition, alive/dead status).[32] A commercial device, the VitaLink® 1200 (VitaLink, Brampton, Ontario, Canada),[33] has been used by in a nonstop balloon flight around the world, by the U.S. Department of Defense, and by the Federal Bureau of Investigation (FBI).

Telemonitoring has been used mostly to monitor sick patients. But it can benefit healthy patients including athletes and astronauts to improve training and to watch over them in severe environments.

Physiologic functions are monitored by peripheral devices, which distinguish them from simple videoconferencing systems. Peripheral devices enable the clinician to better approximate an onsite examination. They include electronic versions of the standard tools as well as other sense extending electronic implements. Peripheral devices are designed to capture data on physiologic functions by measuring electrical signals (ECG,[7,10–12,16,22,26–28,34] electroencephalogram [EEG],[30] electromyogram [EMG][35]) or by using transducers to measure other types of data, such as movement, pressure, volume, flow, serum chemistry, etc. Some of these measure only one variable or physiologic function, others integrate many devices to monitor more than one function, and often combine cardiopulmonary functions.[7,26,27,33] Modern biotelemetry emphasizes two concepts: mini- and micropower. The two allow the development of implantable or ingestable devices.[2] Imaging devices are used for imaging lesions, x-rays, ECGs, etc. Portable ultrasound machines, microvascular imaging cameras, digital ophthalmoscopes, otoscopes, microscopes, and dermascopes also have been used.

Once collected by peripheral devices, data can be transmitted through guided or wireless media. The simplest way to use guided media (e.g. wires) is the Personal ECG transmitter,[12] which has to be less than several dozen centimeters from a standard telephone microphone and with ambient noise of less than 75 dB. The Internet is used for publishing and retrieving information. Its ubiquitous acceptance has pushed software developers to create standardized platforms in client–server applications. The advantage of using a standardized communication platform is substantial for both customers and providers alike, and is progressively resulting in Internet-based telemedicine applications for several different pathologies.[36] Wireless satellite communications are used by many systems, such as the Tracking and Data Relay Satellite System (TDRSS) of NASA that allows real-time communication of biomedical information from the Space Shuttle crews to mission control,[4] or the Everest Extreme Expeditions (E3) that used a satellite connection between the Mount Everest base camp and the Yale University School of Medicine.[34,37] Numerous techniques are used to transmit information with radiofrequency electromagnetic waves, such as amplitude modulation (AM), frequency modulation (FM), and pulse modulation. Frequency or time multiplexing is used to allow for the simultaneous transmission of several physiologic signals.[2] Sweden and Singapore (Mobitex) use a wireless telephone network for telemonitoring in ambulances.[26,27] In-flight continuous telemonitoring via the Internet is used with a portable vital signs monitoring device and a laptop computer connected to the seat-back telephone aboard aircrafts to send data and graphically display a patient's vital signs.[38]

Infrared communication transmits data that has a wide field of applications. Its main limitation is the short range and restriction to a single room. But it is also a way of avoiding electromagnetic interference caused by radio waves to medical devices especially cardiac pacemakers and infusion pumps.[2] Finally, ultrasonic communication uses acoustic energy, and is the best available means to transmit information in water. This means of communication is very efficient and operates with low energy loss.[2]

Standards are required in almost every means of communication to ensure that different hardware and software can work together, and to allow the development of networks. Standards may be formally, developed by an official organization (HTML, IP, Ethernet, etc.) or *de facto*, emerging in the marketplace and supported by several vendors without official standing.[39] Telemedicine technologies have evolved rapidly but in an unstructured manner. Certain devices have been developed in isolation. However, their advantages are becoming more and more obvious. Consequently, there is an important need for standardization and the development of common protocols, which would enhance their use and acceptance in the medical community. For instance the, digital Imaging and Communications in Medicine (*DICOM*) published by the American College of Radiology/National Electronic Manufacturers Association (ACR/NEMA) is the dominant standard for Picture Archiving and Communication Systems (PACS) and other medical images exchange applications internationally.[40] Health Level 7 (*HL7*) was first published in 1987 for electronic healthcare data exchange. The current version 3 uses an XML (eXtensible Markup Language) syntax, and improves the standard by adding specifications for data management.[41] The European Standardization Committee (CEN) published many standards such as *VITAL* (*ENV 13734*) that provides a definition of a common (device independent) representation of vital signs information,[42] and the *Standard Communications Protocol for Computer-Assisted Electrocardiography (ENV 1064)* to ensure proper ECG data and report exchanges between systems.[43] Some authors also have proposed other solutions including the Standardized Data Interchange Format,[44] using XML or a Generic Data Schema to accommodate various types of data.

Data gathered in distant locations are processed and analyzed to offer accurate information and automatic alert rather than consultations only. For instance, a digital spirometer coupled to a PC-based terminal was used in Belgium to monitor patients after lung transplantation. Data were gathered and then analyzed by calculating indexes and comparing them to a personal baseline. Three consecutive sessions showed a decrease in one of the variables from baseline that exceeded the personal Value for a Significant Change (VSC) and generated an alarm, which led to the transplant physician calling the patient.[45]

DISCUSSION

Telemonitoring allows patients to be maintained in their home.[14] Better follow-up of patients reduces the complications of chronic diseases such as diabetes, hypertension, or chronic heart failure. Telemonitoring may reduce patient travel, time off from work, and overall costs. Several systems have proved to be cost effective, such as home monitoring of high-risk pregnancies,[15] infants,[16] pediatric pacemaker patients,[11] and patients suffering from chronic diseases.[7] The cost of simple telemonitoring was evaluated to be approximately $70 per month.[5,11] A standard emergency room charge is $260.[11] Telemonitoring also responds to the emerging needs for home care. The National Research Council[46] reported that, "since 1975, the number of hospital beds per 1000 enrollees has declined from 51 to 28. Similarly, the number of patients receiving home care nearly tripled between 1982 and 1994."

Telemonitoring provides accurate and reliable data,[11] which results in stabilization and often improvement of chronic diseases,[5–8,17] and avoids unnecessary treatments because of the "white-coat" effect.[48] It also gives patients a feeling of security.[8] Real-time telemonitoring of patients transported in ambulances reduces the time for initiating treatment and allows the emergency crew to be better prepared.[27]

Further diffusion of telemonitoring would depend on the availability of low-cost high-bandwidth communication, security, and ubiquity. Although licensing of physicians remains an issue, 20 states have adopted statutes addressing licensing requirements for out-of-state physicians. Payers have yet to accept fully the reimbursement for such services. Currently, Medicaid reimburses for telemedicine services in only 18 states.[49] Medicare accepts claims for teleconsultation, telepsychotherapy, and drug management, and in rural areas exclusively, but legislation that would expand the coverage is pending.[50]

Virtual reality, immersive environment, haptic feedback, and nanotechnology promise a new stage in the evolution of telemonitoring. The first three will allow information to be transmitted to all our senses. New technologies will be developed such as handheld biosensors, holographic three-dimensional imaging, biologically inspired technologies, nanotechnologies, human-centered autonomous robotic telemedicine systems, and augmented human machine interaction with haptic devices.[4]

CONCLUSION

Although telemonitoring is still at an early developmental stage, the possibilities are promising. The supervision of physiologic data from a remote location is a possibility that may improve health care dramatically. Technological advances in miniaturization and nanotechnology, together with progress in wireless communication allow for the development of miniaturized devices, integrated with clothes, or even implanted in the human body. Unobtrusive monitoring makes it feasible in almost all situations and locations. Haptic devices and imaging sensors are the bases of virtual reality environment monitoring, provide new opportunities to bridge distance issues between patients and health care providers.

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