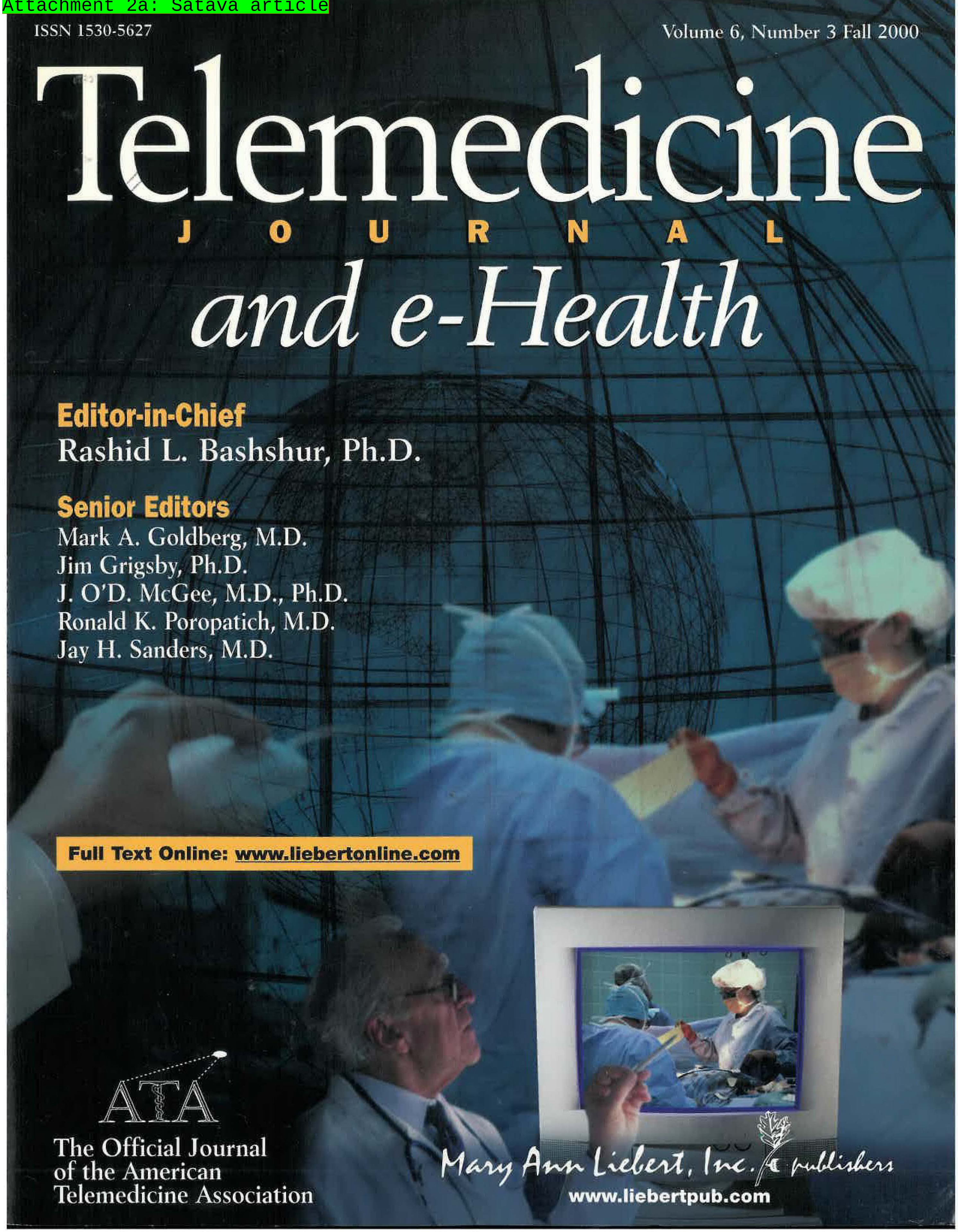

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The Physiologic Cipher at Altitude: Telemedicine and Real-Time Monitoring of Climbers on Mount Everest

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ABSTRACT

Advanced wearable biosensors for vital-signs monitoring (physiologic cipher) are available to improve quality of healthcare in hospital, nursing home, and remote environments. The objective of this study was to determine reliability of vital-signs monitoring systems in extreme environments. Three climbers were monitored 24 hours while climbing through Khumbu Icefall. Data were transmitted to Everest Base Camp (elevation 17,800 feet) and retransmitted to Yale University via telemedicine. Main outcome measures (location, heart rate, skin temperature, core body temperature, and activity level) all correlated through time-stamped identification. Two of three location devices functioned 100% of the time, and one device failed after initial acquisition of location 75% of the time. Vital-signs monitors functioned from 95%–100% of the time, with the exception of one climber whose heart-rate monitor functioned 78% of the time. Due to architecture of automatic polling and data acquisition of biosensors, no climber was ever without a full set of data for more than 25 minutes. Climbers were monitored continuously in real-time from Mount Everest to Yale University for more than 45 minutes. Heart rate varied from 76 to 164 beats per minute, skin temperature varied from 5 to 10°C, and core body temperature varied only 1–3°C. No direct correlation was observed among heart rate, activity level, and body temperature, though numerous periods suggested intense and arduous activity. Field testing in the extreme environment of Mount Everest demonstrated an ability to track in real time both vital signs and position of climbers. However, these systems must be more reliable and robust. As technology transitions to commercial products, benefits of remote monitoring will become available for routine healthcare purposes.

INTRODUCTION

FIVE CLIMBERS DIED during their May 1996 climb of the summit of Mount Everest. This tragedy brought into focus the extraordinary risks all individuals endure in remote and extreme environments. The accounts, popularized by Jon Krakauer in *Into Thin Air*[1] and Brougton Coburn and David Beshears in *Everest, Mountain Without Mercy*,[2] described in detail the hardships and circumstances leading to disaster. Incredibly in that episode, two climbers died

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during a snowstorm within proximity of the safety of the camp. Another was left for dead but actually survived to walk into camp the following morning with frostbite so severe that he lost his nose, right hand, and fingers. Had the expedition members known that two of their colleagues were fallen at a position just outside their tents, or had it been known that one was severely hypothermic but alive with barely detectable vital signs, the outcome may have been more positive. These three tragedies could have been avoided if current technology had been available to the expedition.

A physiologic cipher is a noninvasive identifying tool to measure physiologic status of an individual in real time, through monitoring of vital signs, biochemical, and other parameters with sensors worn by the individual. When concerned with remote locations, such as expeditions or the battlefield, such monitoring also includes geolocation using the Department of Defense global positioning satellite (GPS) system.

The military sector has been developing a number of wearable systems for location and vital-signs monitoring (VSM).[3] These systems consist of three principal components:

1. The vital sign sensors, including heart rate, temperature, respiratory rate, electrocardiogram (EKG), motion (accelerometers) and pulse oximeter, are currently worn at various sites on the body. They are typically strapped across the chest or wrist or swallowed in pill form.
2. The GPS device is commercially available and accurate to within 0.75 meters longitude and 1.01 meters latitude.
3. The telecommunications system, usually a radio frequency (RF) transmission system, is also commercially available but repackaged into a miniaturized wearable configuration.

In remote environments, strategically placed transceivers are required to receive and transmit the signals from the wearable systems to a base station containing the receiver, signal processor, and computer workstation (or laptop computer). Some systems, such as the Sarcos Personnel Status Monitoring or PSM™ system (Sarcos, Inc., Salt Lake City, UT) also have a hand-held "medic unit" (Fig. 1) that permits a member of the expedition to be in the field and still monitor the vital signs and location of other individuals or members of the squad. During the Mount Everest climbing season in May 1999, an Everest Extreme Expedition was conducted by a team from Yale University School of Medicine in collaboration with the Yale University–NASA Commercial Space Center for Medical Informatics and Technology Applications, Millennium Healthcare Solutions, and The Explorers' Club. The mission had three objectives: (1) to provide advanced medical support to the climbing expeditions from a base camp at 17,800 feet at Mount Everest Base Camp (EBC) from a telemedicine clinic, (2) to test an emerging VSM system for monitoring a physiologic cipher and vital signs of climbers as they ascend toward the summit of Mount Everest, and (3) to assess the cardiovascular adaptation to hypoxia at high altitude. This report concerns the VSM system and the medical implications of a physiologic cipher.

FIG. 1. The medic unit from the Sarcos, Inc. Personnel Status Monitor (PSM) system being developed for the military. (Courtesy of Dr. Stephen Jacobsen, Ph.D., Sarcos, Inc., Salt Lake City, Utah.)

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