FOCUS ON YALE MEDICINE:
THE EVEREST EXTREME EXPEDITION

Advancing Technologies in Clinical Medicine:
The Yale-Mount Everest Telemedicine Project

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PUSHING THE LIMITS OF MEDICAL TECHNOLOGY ON THE ROOF OF THE WORLD

In the spring of 1999, just before the monsoon descended upon the Himalayas, physician-climbers and scientists brought a novel telemedicine program from the Yale School of Medicine to the remote and harsh environment of the Base Camp of Mount Everest. They implemented and tested new telemedicine technologies in a high-altitude environment well-known to push humans to the limits of their physiological adaptability.

Telemedicine, which “utilizes electronic information and communications technologies to provide and support health care when distance separates the participants” [1] was rigorously evaluated in the Himalayas. The high-altitude environment of Everest Base Camp, at 17,500 feet above sea level, set an ideal stage for evaluating telemedicine’s provision of advanced medical care in an isolated and distant location. The atmospheric conditions on the mountain stresses the physiology of climbers considerably in their quest for the summit. Taking into consideration the oxygen cascade from atmosphere to mitochondria, it is truly remarkable that elite climbers can respire sufficiently to travel at these extremely high-altitudes at all. By quantitatively considering the requisite factors for effective respiration, such as the convective ventilation from atmosphere to alveolus, diffusion across the gas-blood barrier, uptake by hemoglobin in pulmonary capillaries, convective flow of oxygenated blood to peripheral capillaries, gas exchange between hemoglobin and tissues, and finally the diffusion of oxygen to mitochondria for utilization in the electron transport system, it has been calculated that at the summit of Mount Everest, a climber breathes oxygen that is very near the absolute lowest partial pressure tolerable for a human [2]. Extreme demands, both physiological and environmental,
strained this Yale telemedicine project, also known as the Everest Extreme Expedition, or E3.

A BRIEF HISTORY OF TELEMEDICINE

The nascent steps in what would become the field of telemedicine were taken in 1959 at the University of Nebraska [3]. Here, psychiatrists developed a one-way video conferencing system used in real-time psychiatric ward consultation; their program was dubbed “telepsychiatry.” In the same year, doctors in Montreal were practicing “teleradiology” for the first time by transmitting high resolution x-ray images to consulting radiologists. At the start of the 1960s, then, two divisions of telemedicine had been born: interactive video and still-image transmission. In the next decade, the federal government funded fifteen telemedicine projects.

The field was advanced considerably in the 1960s by NASA scientists; pioneering technologies were first developed to monitor the vital signs of astronauts, with the goal of attaining the ability to broadcast other critical medical data from a remote patient to a local physician.

In parallel with the explosion in information technology and the advancement of satellite communications in the last two decades, telemedicine has progressed tremendously. The commonplace use of current telemedicine technology is seen today in the consultation of radiologists anywhere on the globe with transmission of nearly all types of radiological images over the internet. Another well-established application is in the evaluation of implanted cardiac pacemakers; a patient can transmit operative data from their pacemaker to a distant technician by simply placing the telephone handset on the skin above the implanted device. Until recently, however, projects in the field have not

Figure 1. E3 Expedition team members. Mount Everest base camp, May 1999.
utilized telemedicine technology to its fullest potential.

THE YALE MOUNT EVEREST PROJECT

NASA and the Yale School of Medicine have been working in partnership since 1997 toward developing commercial applications of telemedicine. It was recognized that issues facing the high altitude mountaineer, including profound physiological stress and consequent adaptation, represented medical challenges not unlike those faced by an astronaut in space. A new standard was founded in 1998 when the capacity of telemedicine technology was demonstrated with the inaugural E3 Yale telemedicine project. The project established the first-ever telemedicine clinic that linked leading medical and research centers in North America to the exceptionally remote Everest Base Camp. With the objectives of both evaluating current technologies and pushing the limits of the exchange of medical information, the E3 project readied advanced medical and communication technologies in an extreme environment. Importantly, it validated telemedicine's capability to connect a team in a remote and severe environment with a major medical center to effectively provide advanced medical care.

Mount Everest, being both one of the most remote and one of the harshest environments on the planet, proved to be an ideal locale for the project. At high altitude and in this remote mountain range, telemedicine was pushed to new limits, in terms of the technological demands placed on the project, the physical limitations of the equipment, and the physiological demands placed on the team members. The E3 team lived and worked at Base Camp, at 17,500 feet, where the partial pressure of oxygen is about half that of sea level and where weather conditions can be prohibitively inhospitable. Challenges mandated by the remoteness and severe climate of the Everest Base Camp were ever-present and introduced the requirement to find creative solutions for this evolution of telemedicine technology.

THE 1999 EVEREST EXTREME EXPEDITION

The three-fold goals of the current 1999 E3 project were developed and supported by the Yale/NASA Commercial Space Center for Medical Informatics and Technology Applications (CSC/MIT), Millennium Healthcare Solutions, The Explorers Club, with participation by the National Institutes of Health and with the financial support of Olympus America and other partnerships. First, the E3 project endeavored to provide modern medical care at Base Camp through the utilization of global telemedicine technology. Secondly, efforts were made to evaluate a novel physiological monitoring system (the Personal Evaluation Device [PED]) worn by climbers into extreme climates, and under extreme physiological demands, on the flanks of the highest and one of the most remote mountains in the world. Third, the E3 team labored to perform new experiments designed to investigate specific aspects of high-altitude human physiology.

On April 23, a group of fifteen physicians, climbers, and scientists left the United States for Katmandu, Nepal. Team members and equipment were then shuttled by Twin Otter STOL aircraft to the village of Lukla, at 9,000 feet above sea level. From here, the team began their ten day trek to the base camp of Mount Everest aided by approximately one hundred Sherpas, and with thousands of pounds of equipment. Yaks were later used to transport the massive loads at higher elevations, but were not effective at the relatively low elevation of Lukla village. The E3 team made stops along their trekking route to see patients, perform their high-altitude research projects, and to acclimatize as they ascended.
Upon reaching Base Camp at 17,500 feet above sea level on May 8, the team began work with their telemedicine resources and made the first connection with the Yale support group on May 9. Two satellite telephones (64 kbps each) were patched together to achieve a bandwidth so that video and audio could be transmitted from base camp, via a folding satellite dish, to the INMARSAT satellite in fixed orbit above the Indian Ocean. From here, the signal reached ground links in Malaysia and in France and was subsequently transmitted to an ISDN bridge in Dallas from where video conference locations could access the signal. This series of connections brought high-resolution images, real-time interactive video and audio communication to New Haven on at least a daily basis while the E3 team worked at Base Camp. The team also established the E3 medical clinic soon after their arrival, preparing to treat the international group of over 150 climbers, Sherpas, and other personnel at Base Camp and in nearby areas. The Yale clinic with its telemedicine capabilities currently represents the most advanced medical facility ever assembled at Base Camp, and was very well-utilized during its occupancy there.

An early case involved a 42-year-old hypothyroid female climber with significant previous experience at high altitude who experienced increasing lethargy and weakness while ascending to high altitude on the mountain. She adjusted her oral synthroid dose from 0.5 µg daily to 1.0 µg daily and subsequently was able to ascend to Camp Three at 23,000 feet where her symptomatology again worsened. She then increased her synthroid dose to 1.5 µg daily, began oral dexamethasone 24 mg twice a day, and rapidly descended to Base Camp where she continued to be lethargic and weak. The patient took no other medications. The patient was afebrile, not tachycardic, and all other vital signs were found to be within normal limits. Examination of the thyroid revealed a normal sized and textured gland, without masses or nodules, with the right lobe slightly larger than the left. While serum thyroid function testing was unavailable at Base Camp, the patient's thyroid vascular flow was imaged with Doppler ultrasound and found to be unremarkable. The patient's dexamethasone administration was discontinued while the thyroid replacement was sustained.

MEDICAL CONSULTATION TO THE OTHER SIDE OF THE WORLD

The first goal of E3 1999, to deliver advanced medical care through telemedicine capabilities, was achieved on a daily basis; the Base Camp team presented daily morning rounds to the medical support group at Yale by way of interactive video conference. Typically, cases seen over the past twenty-four hours were presented and discussed. While most cases treated by the team at base camp were of non-emergency patients with difficulties such as high-altitude headache, gastroenteritis, and uncomplicated pneumonia, several complex cases were discussed with consultants at Yale.

At morning rounds on May 16, another patient benefited from discussion made available through telemedicine technology. In this instance, the 41-year-old patient was an E3 team-member. The patient, who
reported a history of red-green color differentiation deficiency, but no other significant past medical history, was found to have changes in routine ancillary grid testing as well as in visual acuity, from 20/20 to 20/25 in the right eye. During the interactive morning rounds, the patient reported that he had not noticed any change in his vision, but that the "right eye was not performing correctly with the left eye shut" and that "as I walk around now, I have no problem whatsoever." Extra-ocular movements were intact and the pupils were equal and reactive to light bilaterally. On dilated exam, two retinal hemorrhages were evident in the right eye; one was imaged at 5 o'clock near the disk, and the other at 3 o'clock, close to the macula, but not impinging on the fovea. No papilledema was observed. The patient was diagnosed with high-altitude retinopathy. Images from the Olympus digital ophthalmoscope were transmitted to Yale for detailed evaluation.

At the next morning rounds, Dr. Bruce Shields, the Chairman of the Department of Ophthalmology, attended for consultation. Dr. Shields suggested that the patient suffered from high-altitude retinopathy and should not ascend any higher. He further commented that if the hemorrhage progressed as evident on later exams, the patient would be required to descend to a lower altitude, but on a non-emergency basis. Through the utilization of telemedicine’s transmission of high-resolution digital fundoscopic images as well as live consultation with Dr. Shields, medical support was again effectively dispensed on a timely basis from the Yale medical center to one of the most harsh and remote places on earth, 12,000 miles away and 17,500 feet up into the troposphere.

On several dramatic occasions, physicians at Yale were required to actively participate in the real-time evaluation and treatment of emergency patients at Base Camp; on May 15, as morning rounds were being conducted, word reached the E3 clinic that a climber with severe respiratory distress was being carried into Base

![Figure 2. Organizing medications and materials for medical tent. Left to right: Jennifer Kreshak, Ken Kamler, Jennifer Grin, Javier Davila, and Nick Craig.](image-url)
Camp. This patient was a young Dutch climber with a past medical history of both high-altitude pulmonary edema and high-altitude cerebral edema who had been to the summit of Everest two days earlier. Throughout his struggle to ascend the summit ridge, he experienced severe respiratory distress, and after summitting the highest peak on the planet, he descended as rapidly as possible to Camp Four at 26,000 feet. Here his respiratory difficulties did not remit and he quickly as possible descended to Camp Two at 20,000 feet where he experienced worsening shortness of breath.

As soon as the climber was delivered to Base Camp, the clinic team reacted in a coordinated manner with the medical support group at Yale. The patient was evaluated as he arrived in the clinic tent, with Dr. Peter Angood, Director of Yale's Surgical Intensive Care Unit, and Dr. Richard Stahl, Co-chair of the Yale Telemedicine Committee, looking on from New Haven, asking questions, observing the patient's condition, and making recommendations. Vital sign data including a temperature of 99.1°F, pulse 111 beats per minute, and arterial oxygen saturation of 72 percent on room air were displayed for the Yale team, who could also see the patient's exhausted visage throughout the evaluation.

An I-Stat portable device measured the patients serum chemistries and complete blood count. A digital stethoscope transmitted the pulmonary auscultatory examination to New Haven; decreased breath sounds and crackles were heard in the lower lung fields bilaterally and a question of fluid in the left lung was raised. Ultrasound images were transmitted as radiologists directed the exam from New Haven. A parasagittal view of the left lung by Dr. Kamler was read by radiologist Dr. Leslie Scoult at Yale, demonstrating consolidation with possible fluid collection. Exam of the right lung also confirmed the consolidation heard on auscultation and revealed a small effusion. The patient was administered 4 liters of oxygen per minute, and his arterial oxygen saturation increased to 91 percent. The patient was started on Cefazolin and Acetazolamide. Sputum samples were obtained, and Gram-stained images were transmitted to Yale, which illustrated organisms whose morphology was consistent with Streptococcus pneumoniae. The patient's shortness of breath began to subside approximately 30 min after treatment began. He became able to ambulate and breathe comfortably without supplementary oxygen after spending the next 24 hr under observation in the E3 clinic tent.

Cases such as this illustrated the utility of telemedicine in the provision of medical care. Real-time consultation with physicians at Yale for the diagnosis and treatment of this emergency patient dramatically demonstrated the robustness of telemedicine to all of those who were involved on this day.

An interesting case seen by the E3 physicians late in the expedition illuminated the conditions that strongly affect the realization of medical care in Nepal. This patient was a 32-year-old Sherpa yak driver who had suffered a shoulder injury after a loaded yak collapsed upon him. The patient presented several days later to Dr. Ken Kamler of the E3 team with tenderness to palpation at the gleno-humeral joint and with a limited range of motion.

An ultrasound exam of the shoulder was performed by Dr. Christian Macedonia, and high-resolution still images were transmitted to Yale Vice-Chairman of Radiology, Dr. James Brink. Impingement of the supraspinatus and minimally displaced bone avulsions were then identified, as well as a small hemorrhage in the sub-deltoid bursa. Dr. Kamler administered intra-artrophic steroids and local anesthetic. He stated that the recommended treatment in the third world, where surgical repair of rotator cuff injuries was unavailable, included immobilization for several weeks followed by six months of rehabilitation exercises. He explained,
however, that the Sherpa refused immobilization since he needed to continue working on a daily basis to support his family. This case demonstrated the differences in the realities of medical care between Nepal and North America, and some of the limitations that telemedicine faces in bringing advanced medical care to the third world. This large gap between North America and Nepal is difficult for telemedicine to bridge; without simple social and economic support structures in place, patients cannot comply with even the most basic medical care. This compelling case rendered the real limitations of the E3 team effort with telemedicine to bring advanced health care to Nepal.

MONITORING CLIMBERS' PHYSIOLOGY AS THEY STRUGGLE TO ASCEND THE ROOF OF THE WORLD

A second focus of the Everest Extreme Expedition involved the remote monitoring of climbers performing in extreme climates and altitudes where significant danger is always an issue. In 1996, eight climbers were caught in a fierce storm high on the mountain and were killed while trying to descend. This well-publicized tragedy, which occurred on the south side of Mount Everest, was fresh in the minds of those developing the plans for the 1998 E3 project. This reminder served as a backdrop to the proposal that physiological monitoring devices might be used to provide a new margin of safety to personnel in remote and harsh environments. Monitoring heart rate, surface and core temperatures, exact location, and whether an individual is moving or stationary would have significant value in attempting to save the lives of hapless climbers. The PED was developed and tested by the U.S. Army's Natick laboratories and taken to Mount Everest by the E3 team for evaluation. The PED measures cardiac pulse rate, skin temperature, and extremity motion by way of skin electrodes, body core temperature from a 1 cm capsule swallowed by the climber, and position through a Global Positioning System unit. This information was relayed by radiofrequency transmission through repeaters on the mountain to Base Camp, and then onto New Haven. The PEDs were tested both along the trekking route as the team ascended the lower flanks of the mountain, and in Base Camp.

The devices were ultimately worn by those western climbers and Sherpas who ascended above Base Camp to Camp One. Their physiologic condition and their location was carefully monitored as they wound their way for nine and a half hours beneath the teetering seracs and ever-threatening deep crevasses of the Khumbu Icefall, one of the most dangerous sections of the route to the summit on the south side of Mount Everest. Real-time access to the PED data provided continuous reassurance as to the climbers' conditions and progress, and could be used to assess and locate the climbers in the event that a rescue became necessary. This evolving application of telemedicine will be invaluable in helping to insure the safety of personnel in extreme environments, whether it be on the flanks of far-away mountain ranges or beyond the earth's atmosphere altogether.

HIGH-ALTITUDE PHYSIOLOGICAL INVESTIGATIONS

Physiologic research was carried out by investigators on the E3 team; data were collected from individuals as they were strained by and adapted to the high-altitude environment. While the respiratory response to hypoxia has been thoroughly investigated and is well-understood, the cardiovascular adaptation to high altitude is less extensively studied, primarily due to the difficulties inherent in measurement. The invasive techniques used to measure cardiac output, for example, are
prohibitively difficult to carry out in remote high-altitude conditions. The ability to measure cardiovascular function in remote mountain locales would be a major step toward understanding the cardiovascular adaptation to high altitude. In 1999, E3 researchers used a portable Doppler ultrasound instrument to quantify blood flow in the carotid, brachial, and posterior tibial arteries of subjects at high altitude. Blood flows were measured in team members as they ascended to high altitude and while they underwent the physiologic adaptation to the low partial pressures of oxygen in such a lofty atmosphere. These measurements of blood flow were recorded, using ruggedized laptop computers. These data were followed for both Western climbers as they acclimatized to the high-altitude environment and for Sherpas who typically exhibit a somewhat different response to exposure to low partial pressures of oxygen. Yale ultrasound radiologist Dr. Leslie Scoult, on reviewing the ultrasound images of a Sherpa climber, commented the images were significantly different than those of the E3 team members: a “whopping diastolic flow through the posterior tibial artery” was revealed in the Sherpa.

On May 20, Dr. Macedonia had the unique opportunity to examine Babu Sherpa, several days after he set the astounding record of spending twenty-one hours at the summit of Mount Everest without supplementary oxygen. This almost incomprehensible feat of physiologic adaptation spurred those high-altitude physiologists present to wonder with awe at the facets of this man’s physiology that made his effort possible. Ophthalmological research was also undertaken, using an Olympus digital ophthalmoscope. Fundoscopic images were collected from E3 team members, as well as from others, on a regular basis. Other routine ophthalmological testing was performed and resultant data recorded. Hematological, biochemical, and vital sign data were additionally collected and followed for a small cohort of subjects on the expedition. The data, when analyzed after transmission back to Yale School of Medicine, will undoubtedly deliver useful information with respect to high-altitude physiology in several different fields of interest.

EDUCATION PROGRAMS

In addition to the advanced medical care brought to Everest by telemedicine, the evaluation of the physiologic monitoring systems and the basic high-altitude research performed by the E3 project, educational objectives were also undertaken. On May 17 and 18, interactive videoconferences linked high-school students in New Haven, Los Angeles, and Long Island with E3 team members in New Haven and at Base Camp. The presentations were also made available live on the internet through broadcast.com. Live expositions were made from Olympus America headquarters, from Yale University, and from other sites to hundreds of students at interactive sites, and to approximately 10 million internet viewers. Dan Biondi, corporate liason for Olympus America, enticed students with his anticipation of Mars exploration; he impressed upon those students around the country that the current average age of the future Mars mission team is thirteen-years-old. Such exploration will rely heavily upon developing telemedicine technology.

After the presentation, hundreds of students and teachers were able to interact in real time with the E3 1999 team members at Mount Everest. Questions put forth by students regarded issues ranging from recollections of the 1996 tragedy on Everest to the Sherpa reaction to the mass of technology assembled at Base Camp and stimulated a lively discussion between those on the mountain and the participants across America. As Biondi closed the session with the (actual and literal) statement that Mount Everest is the closest one can get to the red planet on foot, all were again reminded that the
future goals of telemedicine lie far beyond even the summit of Mount Everest.

Through telemedicine technology, a powerful link between Yale and the Mount Everest Base Camp enabled the implementation of clinical care, research, and education. With these three facets of the academic medical center brought to Base Camp's remote and unforgiving environment, participants were challenged with new ideas concerning the future of medical practice. While telemedicine could not overcome basic social problems in the third world to deliver health care, it has shown great promise for the future of rural health care, as well as for space exploration. Undoubtedly, the technology examined at Mount Everest will be a cornerstone in the structure of America's health care in the coming decades as we become able to provide patients in all locales with the best clinical care available.

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