THE NAICA CAVES AND HUMAN PHYSIOLOGY

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Naica Crystal Cave is an extremely hostile environment for human beings. However, it is also the most beautiful place on the planet for cavers. Any speleologist would like to visit it at least once in his lifetime. The caver's body is accustomed to physical efforts and the hostile conditions of the environment he explores, but this is not sufficient for survival in the Naica caves. In this place the temperature exceeds 45° C and humidity is well over 90 %. No human being can survive in these conditions for more than 15-20 minutes. A group of speleologists has planned and realized a simple and intelligent strategy that has allowed the exploration of this cave.

In this project, the medical aspects have assumed an important role, involving:

- a program of progressive adaptation for the speleologist to high humidity and temperature;
- a program of prevention and treatment of possible accidents, and;
- survey and analysis of the cardio-vascular, neurological and metabolic physiological activities.

The experience resulting from in this project has produced many data that will be analyzed statistically. Moreover, such data will support future analyses regarding human behaviour and physiology in caves and in extreme environmental conditions.

1. Analysis of the Induced Physiologic and Pathologic Phenomena on the Human Organism

Exposed at the Naica Cave

During the period of exploration activity carried out between 2006 and 2008, we gathered a series of clinicians and instrumentals data. The main purpose of the physicians was to oversee the involved people to ensure their safety. Subsequently, the recorded parameters were collected in a data base for a careful analysis. Various people were investigated: professional speleologists, photographers, video operators, electricians, and others. According to their assignments, the approach modalities of everyone in the cave differed as a precise and scientific medical analysis would have taken too much time. It was not possible because it would have hindered the documentation and exploration plans, which were the main objectives of the expedition. However, everybody was subordinated to a clinical and instrumental examination. We made some tests and evaluations at rest, before the activity of body weight and body mass index (BMI), body's temperature, heart pulse and respiratory rate, blood oxygen saturation levels, blood pressure, glycemia and urine analysis (proteins, specific gravity, and ketones), and electrocardiogram (EKG). Moreover, everybody was submitted to a neuropsycological test of the attention's evaluation (Wassler's test: test of numerical memory). The same assessments, tests and evaluations were repeated with every exit from the cave, considering: time of permanence, type of equipment used and amount of beverages drunk. Moreover, records were made of the appearance of symptoms like: dyspnea, palpitations, chest pain, dizziness, muscular pains, nausea, cefalea, weakness, and heavy legs' sensation. A visual-analog rating scale, was used to define the subjective suffering degree. The data were analyzed with SPSS, statistic program, and the analytical results will be published elsewhere. However, from these data we can understand that the use of a system of body's cooling, like the *Tolomea suit,* associated by a system of inspired air cooling , *Sinusit,* improve the endurance during the exploration and recovery upon exiting. Thank to this equipment, it is possible to survive for over an hour in the Naica caves. Survival for over 15 minutes is not possible without it. No important changes of hemodinamyc parameters, occurred. Sometimes, the body's temperature at exit was elevated but it never reached dangerous levels and all parameters (blood pressure, temperature, heart rate) in few minutes were readily restored. Nobody required important care beyond quick cooling with vaporized water, rest, and application of ice packs at the neck, axillae, and groins. No significant variations of body weight were detected because, in the environmental conditions of the Naica cave, the human body can not evaporate by sweating. However, the people were invited to drink constantly throughout the working day. There were many people that made many short stays in the cave without equipment. At each exit, they sweated so much because the temperature and humidity in principal tunnel (37°C and 70%, respectively) facilitated it. Unfortunately, these people were not monitored but only observed.

2. Emergency Planning

Base camp included a tent with conditioned air and contained a camp bed and equipment for medical emergency. Available inside was an oxygen tank, intubation and resuscitation kit, surgical kit, drugs, kit for intravenous infusion, electrocardiograph, and immobilization systems for limbs and vertebral column. Moreover, a basket stretcher and a truck were available for immediate transportation outside the mine.

A rescue team composed by a doctor and three people, all expert cave rescuers, was always ready . The team was equipped with light suits, special boots, helmets, protective gloves, a small cool-breather, a bandoleer of flat tape, and four non-locking carabiners. They also had to bring:

- A little backpack containing a tank with 110 liters of oxygen, emergency scissor, four flat tapes 4 cm x 4 m, one cervical collar;
- A small cool-breather for the injured;
- 2 portable radios for communication, one of these for the doctor; and,
- The stretcher.

If an accident should take place

- In the place of the accident;
  - o alert rescue team immediately;
  - o if the injured has fainted, lay him on a side, his head lower than his feet;
  - o check if the breather is working correctly and set it for maximum air flow rate;
  - o wait for the rescue team; and,
  - o always consider the BLS procedure (Basic Life Support).

- At the base camp
  - o stop any work activity;
  - o in case of fainting, immediately alert an ambulance and start the chronometer;
  - o get the rescue team ready;
  - o follow the doctor's instructions; he is the head of the rescue;
  - o the doctor's assistant stays in the medical station;
  - o the members of the "human chain" transport team, get ready to enter at the doctor's call; (This a team of eight people with light suit, helmet, boots, and protective gloves ready to execute a rapid transport hand-to-hand of the stretcher, from the last area of the cave out to the base camp.) and,
  - o remove all obstacles to transport the injured from the medical station to the ambulance parking site.

3. Response of the Organism to the Heat, Acclimatization, and Recovery

The human body is a homoeothermic system able to guarantee an internal constant temperature between 36.5°C and 37.5°C. This is possible thank to a correct thermal balance between the heat acquired and lost. The heat acquired derives from the metabolism and the environmental heat; the heat lost depends from the body's capacity to eliminate the heat, through systems of conduction, convection, radiation, and evaporation. The metabolic heat result by the sum of basal metabolic rate (BMR), muscular exercise, and possible diseases. Excluding diseases, the BMR, at rest, increase the body temperature of about 1.1°C each hour, whereas the muscular activity can increase the metabolism of 15 times, at least, coming to 1000 Kcal/hour. As regard to heat loss, it depends on the utilized system. Conduction is the transfer of heat via direct physical contact with a cooler object; it accounts for 2% of the body's heat loss. Convection is the dissipation of heath from the body to the air and water vapor surrounding the body; it accounts for 10% of the body's heat loss (when air temperature exceeds body temperature, the body gains heath energy). Radiation is the transfer of heat to the environmental via electromagnetic waves; it accounts for most heat dissipation. As long as there is a temperature gradient between the body and the air, 65% of the body's heat is lost by radiation. Evaporation is the transfer of heat by transformation of perspiration and saliva into a vapor; it accounts for 30% of the body's heat loss. Now, the principal forms of body's heat loss in a hot environment are: radiation and evaporation. However, when air temperature exceeds 35°C, radiation of heat from the body ceases and the evaporation becomes the only mean of the heat loss. But evaporation is maximally efficient in a dry environment and if humidity reaches 100%, evaporation of the sweat is no longer possible and the body loses its ability to dissipate heat.

In the Naica caves, the temperature is 47°C and relative humidity nearly to 100%! When the heat gain exceeds heat loss, the body temperature rises and, if it exceeds 41.1°C, the situation becomes very dangerous. To promote blood cooling, the cardiovascular system increases its activity by shifting the blood from inside to the skin, which is the more important system for heat dissipating. In the skin, the sweat glands are stimulated to produce more sweat. In this way the vital organs are protected from overheating. This effect is associated to increase of cardiac activity, but the increase of the internal temperature produces also other effects. The central vasoconstriction can cause intestinal ischemia with release of toxins, but at the same time inflammatory proteins with protective action called *heat shock proteins* are released. These effects are person-related and a regular acclimatization procedure can significantly change the result. In fact, acclimatization training improves adaptation and endurance of the organism in hot and humid environments, reducing the risk of heat damage. This is a process that requires several days (7-8 days) to achieve the following effects:

- earlier onset and increased production of sweat that will contain less mineral salts;
- enhanced vascular output and cardiovascular performances;
- the endocrine apparatus ensures a salt conservation and the expansion of plasma volume;
- the renal apparatus increases the filtration rate of the blood; and,
- heat shock proteins are produced to increase the resistance at the toxics products.

The clinical manifestation that can be observed after prolonged exposure to the heat, heat exhaustion and heatstroke, are described in Table 1.

To improve the physical performances of the explorers and reduce the risk of hot damage, the following protocol was proposed:

- 90 minutes of daily of exercise in hot conditions for at least one week and gradually increasing exercises for intensity and duration
- Take a bath or hot shower before the exposure
- Drink before the exposure, 400–500 cc of cold fluids (200mOsm/L, enriched of mineral salts)
- Monitor body weight before and after exposition:
  - For reduction of 2–3% rehydrate / proceed to work
  - For reduction of 5–6% rehydrate to normal weight / proceed with light work
  - For reduction over 7% rehydrate to normal weight /stop the work and rest
- Immediately stop activity at the appearance of one of the following symptoms
  - Nausea, vomiting
  - Headache, dizziness
  - Shiver, piloerection
  - Fainting feeling, Tachycardia, 90-100/bpm at rest
- Constant control of the physical activity: slow movements and reduced workload

The program of recovery after exposure to the cave and in presence of symptoms was as follows:

- Slowly oral rehydration with prepared solutions (enriched of mineral salts, 200 mOsm/l)
- Remove clothes
- Physical rest
- To spray on the body tepid water and expose it to a powerful fan
- Apply ice packs to the neck, axillae, and groins
- Cover the body with a wet sheet

SYMPTOMS OF HEAT DAMAGE

Tc ≤ 41°C HEAT EXHAUSTION	**Tc ≥ 41°C HEATSTROKE**
Fatigue, weakness, fainting	Central Nervous System disfunctions
Nausea and vomiting	-impaired judgment
Headache, myalgias, muscle cramps	-bizarre behavior
Dizziness	-hallucinations, confusion, disorientation
Irritability	Cerebral edema, coma
Tachycardia, blood pressure change	Decreased cardiac output, shock, hypercoagulation
	Respiratory distress, pulmonary edema, renal failure

- o Insulation in air-conditioned environment at 30° to 32°C
- o It is necessary to avoid the immersion in cold water because it could lead a reverse of the blood torrent from the periphery at the core of the body. This action will cause a shiver reaction that could cause further increase of the temperature and the complete loss of the control system

Despite all the attention, the call for caution, and the respect of rules, two accidents occurred. Both were due to human error. The first happened to an excellent speleologist during an exploration of a remote and not already known area of the cave where he was found alone. The cool-breather apparatus has broken and was found quickly to breathe the warm air of the cave at 48° C. He quickly suffered the symptoms of heatstroke: weakness, dyspnea, near fainting, and he was unable to call for help because he did not have a transceiver radio. He moved very slowly in the direction of the exit and only when it was possible to view him with a camera positioned in the last area of the cave, did he receive the aid. With a correct cooling and rehydration, he was recovered without consequence. The second accident occurred to a technician at the end of a day of intense work. He had to exit the cave to retrieve filming equipment. He went alone, without adequate boots and without his helmet secured. In these conditions and without experience, he fell down for five meters and suffering an head injury that resulted in confusion, disorientation, and temporary memory loss. He was accompanied to the hospital and discharged, fortunately, two days later without consequence.

4. Communications

An efficient system of communication is fundamental for ensure rescue support. We used a transceiver system constituted by a station allocated in the base camp. An omnidirectional antenna, vertical rod, was positioned in a high place in the cave. Each person must use a handheld transceiver battery powered and equipped with laringophonic microphone. The handheld transceivers were allocated a little space inside the cool-breathers to ensure their cooling. Indeed, the overheating of the radios occurred when used without protection from the heat, causing numerous failures.

5. New technologies

The Department of Bioengineering in the University of Milan (Italy) designed a telemetric system for monitoring of the vital sign. This system uses technology called "smart shirt" and makes it possible to monitor several parameters. Conductive fibers are incorporated into the design of a specialized T-shirt that can detect: heart rate, EKG, respiration, temperature, and more. The detected signals are transmitted via radio to a personal computer where they can be analyzed, noting if there are problems. The system that we used was experimental and capable to measure: heart rate, EKG, respiration, temperature and more. For the first time, it was utilized in caving activity. In this particular environment, it had demonstrated limitations especially on the transmission of data and requires placement of many radio repeaters and antennas. However, it was shown to be an interesting technology for surveillance of people employed in activities at risk in extreme environments.

6. Conclusions

Once again the caving meets science and experimentation by providing a valuable aid in the development of technologies and analysis of physical and human environment. On this occasion, the team used the beauty of the Naicas caves to get involved by tackling the risks. This could be the beginning of a new era where caving is not only adventure and geographical records, but a new way to experience a fascinating sport, even if not for all.

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