Rescue techniques during AustroMars -- a report on four different scenarios

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Rescue techniques during AustroMars – a report on four different scenarios.

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ABSTRACT

The first human expedition to Mars is planned for about 2030. The flight to the red planet might take approximately 10 months. After this long period in zero gravity the astronauts will suffer from osteoporosis and amyotrophia. In addition, the crew will have to face considerable strain due to a large number of experiments to be done within a very short time span. Therefore, we have to assume to be confronted with an increased accident risk and consequent injuries. The planning of a Mars expedition should include the development of rescue techniques´ procedures and the treatment of injured astronauts.
In the Mars Desert Research Station in the desert of Utah, simulations of the first human expedition to Mars were performed. In addition to geophysical, microbiological and psychological experiments, various potential accidents and their consequent injuries were simulated for the very first time during "AustroMars" in April 2006. This work points out which injuries future astronauts may have to cope with, which rescue techniques might be suitable for recovery of survivors and the limited possibilities for treating injured astronauts.

Keywords: Space medicine, emergency medicine, AustroMars, rescue techniques.

INTRODUCTION

AustroMars – a simulated expedition on Mars

AustroMars is a research project of the Austrian space forum during which a manned Mars landing was simulated at the Mars Desert Research Station in the desert of Utah in April 2006. The crew consisting of 6 Austrian participants was selected in a months-long procedure from about 200 volunteers. They conducted experiments in co-operation with the US Mars Society in a Mars-similar environment in complete isolation of the external world for two weeks. The experiments included geophysical attempts, microbiological investigations as well as medical and psychological experiments as they are expected to be performed during a real Mars expedition in the future. During this simulation different accidents and injuries were brought in as anomalies for the first time. The different scenarios were trained in the preparatory phase. The aim of these trials was:

- to develop rescue techniques for fallen astronauts and treatment procedures for various injuries,
- to determine to what extend the analogue astronauts can perform medical procedures after previous training in the case of emergency under Mars-similar conditions,
- to study the challenges and limitations of rescue techniques and medical treatment during planetary sojourns and to develop solutions.

Consequences of weightlessness

The first human expedition to Mars is planned for about 2030. The NASA has defined the largest risks of a human expedition on the red planet [1]. Besides constant radiation, extremes in pressure and temperature and new physical and chemical conditions, it is the low gravity that leads to serious consequences for human beings during a longer stay in space.

It is known that weightlessness during space flight causes osteoporosis. Low or even zero gravity leads to a continuous loss of bone- and muscle mass, which is persisting during the space stay. Data from the space station MIR show that after a six month's stay in space the bone density in the calcaneus of an astronaut decreased by 13.2% [3]. Bone mass changes are site-specific and bone loss seems to be greater in cancellous bone than in cortical bone [7]. Despite constant training, the bone mineral density (BMD) in the spinal column, in the pelvic and in the proximal femur is reduced by 1-2% monthly during a space flight [8]. Thus, astronauts lose as much bone mass in the weight-bearing areas of the skeleton in one month as postmenopausal women do in one year! (Fig.1).

Furthermore, due to the inactivity of the musculoskeletal system the muscle power of the lower extremities decreases up to 25% and the muscle mass up to 30% [4, 5]. The reduced bone mass together with the loss of muscle power increases the risk of fractures.

Accidents on Mars?

The red planet got its name due to its colouring by ferric oxide. It is about half as large as the earth and approximately 230 million kilometres distant from the sun. Its atmosphere consists of 95% CO_2 and it has only approximately 1% of the terrestrial air pressure. At the Mars surface temperatures of -100° to 0° C prevail and the gravity is only about a third of the earth [2, 12]. Thereby, surviving without aids is not possible for humans.

A crewed flight to Mars might take approximately 10 months. Due to the long outward flight duration the astronauts will have a decreased bone density and, thus, an increased risk for fractures on their arrival on the Red Planet. Moreover, during excursions on the Mars surface (extra vehicular activity, EVA) the astronauts have to wear a space suit and a life support backpack system (LSBP) of at least 20 kg weight also with Mars gravitation (this is about 60 kg on earth). This causes a higher balance point of the body and, therefore, increases the risk of stumbling and falling. This could particularly lead to ankle fractures by spraining. Due to the unknown terrain with uncertain ground conditions, accidents and injuries can also happen during excursions on the Mars surface by fall or by accidents with an all terrain vehicle (ATV).

Further risks are caused by activities outside the surface station like the establishing of a radiation protection shield or other engineering and construction tasks. In addition, astronauts can be hurt inside the space station, e.g. within the laboratory area when working with reagents and tools (burns, chemical burns, lacerations, micro lacerations with risk of infection).

As the crew will be so far from the earth that constant communication can be severely delayed or even not available, the astronauts should be trained in being able to deal with any medical situation on their own at the beginning.

METHODS – Simulated accidents under Mars-analogue conditions

Preparatory phase

Keeping that in mind the following experiments and/or injuries were defined:

1) Rescue and transport of a fallen astronaut
2) Ankle injury by spraining during EVA
3) Burn injury during work in the laboratory area
4) Laceration of the head and the lower arm by a fall within the Habitat.

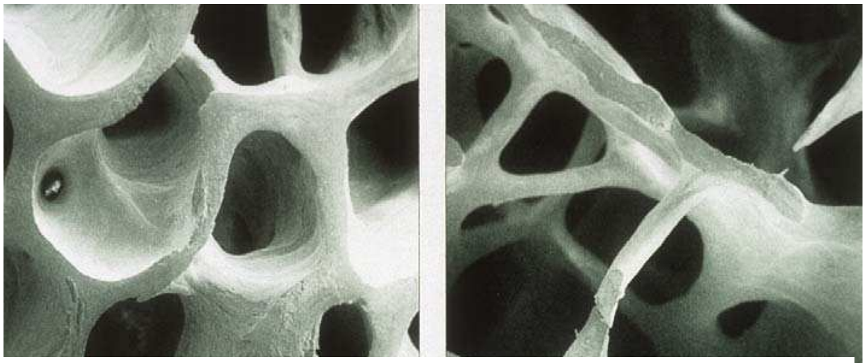

Fig. 1: *electron micrograph of normal bone (left) and decreased bone density in osteoporotic bone (right) Remark: Bone density is site-specific and depends on sex and age.*

The crew trained roping and rescue techniques by using a „bipod" under guidance and supervision of the Tyrolean Mountain Rescue Service. The basics of fracture and wound treatment were taught at the University Hospital's Department for Traumatology in Graz/Austria. Additionally, the crew was instructed in first aid by emergency medical technicians.

Simulation phase
During the two-week AustroMars simulation these emergencies were brought in to the flight plan as anomalies by the AustroMars Mission Control Center as follows: One analogue astronaut was mandated over mail to simulate a defined accident. The medical treatment of the "patient" by the crew was filmed or photographed for a detailed later evaluation. Additionally, the course of actions was observed live over webcams in the Habitat. After the simulation each crew member was interviewed in detail during the post-simulation debriefings on the basis of a questionnaire to detect problems in the workflow and to find solutions.

Fig. 2: *Bipod of the Tyrolean Mountain Rescue Services*

EXPERIMENTS

1) Rescue and transport of a fallen astronaut

Experimental setup and actions
During an EVA to obtain geological samples an astronaut slips and slides over a cliff about 12 m down into a canyon. Four colleagues mount the bipod of the Tyrolean Mountain Rescue Service. One crew member is let down the rope to the "injured astronaut" (IA) and ropes him up using a climbing harness which can be attached to the EVA-suit. Afterwards, first the IA and then the rescuer are pulled up (Fig. 2, 3). Subsequently, 2 variants for the transport of the IA are tested:
a) A carrying net is knotted from 100 m rope, at which carabiners are hung up as hand grips. The IA lays on it in prone position and is carried by four rescuers.
b) A 5-step-ladder is padded with an isolating mat and the IA is fixed on it in prone position with bungee cords. Afterwards, the ladder is fastened on an ATV and the IA is brought to the Habitat at walking speed (Fig.4).

Fig. 3: *The Health and Safety Officer (left) secures the IA (right) before tilting the Bipod to move him over the edge of the canyon.*

Results - Discussion
In this experimental setup the crew had the rescue equipment already on site. During a real expedition on the Mars surface the astronauts will probably not carry along the entire equipment. In the case of an accident this must be retrieved from the space station and brought up to the scene of accident. This could be lasting for hours and, therefore, increases the risk of injured astronauts extremely.
The mounting of the bipod is a further time factor. Due to the reduced mobility in the space suit and the lack of tactile sensitivity in the EVA-gloves (knot technique!) the assembling of the bipod took about 1 hour in the experiment (to

Fig. 4: *Four crewmembers carry the patient in a prone position*

compare: a well trained team of the Tyrolian Mountain Rescue Service is able to do this in about 10 min – without gloves). Due to unfavourable geological conditions and a surface crew which is potentially out-of-training the duration of these salvage operations can be even longer.

The examination of an injured astronaut is limited to very few measures. Mobility and sensitivity can only be tested roughly through the space suit and the gloves [6]. To evaluate respiration and circulation the rescuer is completely dependent on the data from the standard monitoring of the astronaut (pulse, blood pressure, temperature, oxygen and CO_2 in the breathing air). Emergency treatment of the injured astronauts is also only possible within certain limits.

The rescue of the IA with the bipod could be mastered in about 15 min. In our experiment the climbing harness was already assembled, as this would not have been possible with gloves. A future space suit should have inserted appropriate devices, e.g. eyes for fastening ropes or carabiners, to save time.

For pulling up a hurt astronaut from the depth he must be conscious in order to support himself at the cliff with his legs. An unconscious or dazed astronaut would push against the wall and, thereby, risk to damage his helmet or to loosen tubes of his PLSS. For rescuing an unconscious astronaut it would be necessary to pull him up together with the rescuer. However, this may be complicated by the heavy-weight equipment. It is to be considered how e.g. an ATV could be used for support.

An unexpected problem concerned the technical equipment: The desert sand made the ropes rigid and stiffened the guide rollers of the Bipod. As the sand on Mars is more fine-grained than on earth the equipment would be even more damaged. Therefore, better materials have to be developed.

When carrying an injured astronaut one of the problems is his rescue position:

Fig. 5: *Close-up of the simulated space suit of the US Mars Society with the personal life support system backpack (= PLSS). Note, that it takes an assistant to take off the life support rack. Undonning the suit during an emergency situation takes 15-20 minutes under AustroMars procedures*

Fig. 6: *First assessement of an ankle injury during EVA*

a) Transportation in spine position is hardly possible because of the PLSS. This reaches up to the middle of the lumbar spine, so that the pelvic and the legs overhang in a very unpleasant hollow back position. Moreover, in this position an unconscious astronaut would be in danger of aspiration.
b) Transportation in prone position makes it necessary that the astronaut holds up his head actively, because this is freely hanging in the helmet. Otherwise, the astronaut would strike with his chin or even his throat against the metal ruffle of the helmet constantly and, thereby eventually sustain further injuries (fig. 5). It has to be investigated how e.g. pads in the helmet or special „airbag" systems could mitigate this problem. In addition, the weight of the PLSS on the back makes breathing in prone position difficult.
c) In our experiment, the bedding in side position was the most pleasant one for the IA. This corresponds to the recovery position of an unconscious patient and is, therefore, to be preferred. Transportation in a sitting position or rather with increased torso would be likewise comfortable. In this position the space suit and helmet cannot slip at the body and, therefore, the astronaut is not "hanging in the suit". It remains to be investigated whether the transport in these positions is practicable. Again, this is only possible for conscious astronauts.

Carrying the IA with the knotted net worked well and is suitable for short distances of about 100-200 m. However, this technique is very exhausting for all the involved persons. Thus, due to high energy consumption and oxygen demand, this is not a practicable method for longer distances.
The use of the re-designed ladder has proved to be uncomfortable and difficult for both the IA - who was cut by the fixing bungee cords - and the aids - who could not keep the ladder because of the sharp edges. A simple spine board (e.g. with carabiners for fastening the board on the ATV) or even a „multi-function" ladder with grasps and eyes, which can be altered as stretcher would be more suitable. By attaching the stretcher on the ATV it is also possible to transport an injured astronaut over large distances.

The major problem in our scenario was the long salvage time. From the astronauts fall to his attachment on the ATV approximately 2 hours passed (approx. 1 h bipod mounting, approx. 15 min rescue and roping, approx. 45 min transport to and adjustment at the ATV). The time for getting the equipment from the Habitat and for the transport of the IA with the ATV back to the Habitat is not yet included. As an injured astronaut on Mars lies on an underground of about -80°C [2], one can imagine that the danger of hypothermia increases with the rescue time. Heating of the suit is not possible due to electric current requirements. The development of special isolation materials, possibly integrated in the space suit, is recommended. A further problem with long rescue times is the limited oxygen supply. Oxygen depots as e.g. usual in the diving sports could increase the astronauts range. At present the NASA is developing air supply systems with back respiration. Currently 2-3 l „air" provides adequate oxygen supply for approximately 60 hrs in experiments.

2) Sprained ankle during EVA:

Experimental setup and actions

During an EVA an astronaut stumbles across a stone and hurts his right ankle (fig. 6). The accompanying astronaut sends a call for assistance to the Habitat. Subsequently, he examines the IA and applies a simulated painkiller (2 ml lemon juice) over the tube system of the helmet. When two further astronauts arrive from the Habitat for help, they entwine belts of the mountain rescue service around their shoulders and the IA is seated in their center. By this way the IA is carried back to the Habitat. Afterwards, the space suit is taken off and the helpers apply a lower leg cast.

Results - Discussion

The difficulties of examining an injured astronaut in his space suit have already been discussed.

A lot of time has passed until the rescue team arrives to the scene of accident. Under normal conditions the tightening of the space suit lasts about 45 min. In case of emergency a crew manages this within 30 min. Further 10 min in the air lock and the advance time to the accident scene (about 15 min walking time for 500 m) must be added. The problems arising from the long rescue time (hypothermia, oxygen supply) have already been mentioned.

In our experiment the IA was administered a painkiller-placebo before transport by bringing in a liquid over the water supply tube which was connected to an external valve. On Mars this procedure is a significant challenge, because with 10 mbar pressure each liquid would evaporate immediately. The installation of a kind of „emergency cap" into the space suit, which can be activated if required, could be an approach. Moreover, the development of a space suit with separated sections which can be blown up if necessary similar to a pneumatic splint is thinkable. Partitioning of the suit would also be advantageous in case of damages of the cover material, because thus, a pressure loss would not concern the entire suit.

Carrying the IA with the belts was rather difficult. The belts were nearly too short to loop them around the shoulders over the space suit. Moreover, they were only 2-3 cm broad and, therefore, cutting into the skin. This kind of transport is only possible with the assistance of the IA. The „patient" must be able to hold on to his rescuers actively. Thus, he must be conscious and be able to move at least his arms. Over all, this technique is only suitable for very short distances (approximately 30 m) because of the high energy consumption of all parties involved.

When applying the cast the rescuers kept the trained procedures. However, the result was insufficient. The cast showed a foot pointed position and was altogether too thin and too instable. In addition, the IA complained about pressure points in the cast. Correct treatment of extremity injuries is impossible without sufficient experience and regular training. Prefabricated splints would be simpler to use, however, they do not fit well with swollen extremities and they provide insufficient stability in case of fractures. In addition, radiography would be indispensable for adequate diagnosis and therapy of skeleton injuries. This facility should be demanded for a space station of the future.

The mobility of the IA with the cast in the Habitat was clearly difficult. Especially the ladder between ground floor and upper deck could hardly be mastered with the immobilized leg. When constructing a future space station situations like this should be considered.

3) Burn injury during work in the laboratory area

Experimental setup and actions

During laboratory work with the Bunsen burner a disinfectant in the proximity inflames and an astronaut sustains a second-degree burn injury of the left arm. Another astronaut renders first help with cold water. A further astronaut

Fig. 7: *Treatment of the burn injury (surveillance webcam picture from the Habitat/Laboratory deck)*

deletes the fire and switches off the fire alarm, monitors the air quality monitoring system for hazardous gases and sends an emergency dispatch to the AustroMars Mission Control Center. Subsequently, the rescuer puts on an oxygen mask to the IA and covers the wounds with an aluminium dressing, controls the blood pressure and applies an infusion (Fig. 7).

Results - Discussion

The medical treatment of the IA in this experiment followed classical first aid guidelines. This treatment may be sufficient for minor wounds. With large surface burns and/or chemical burns, however, the rescuers will face high volume loss and accompanying shock conditions which can lead to significant problems due to limited resources. The treatment of major burn injuries requires a great quantity of infusions for volume substitution, antibiotic prophylaxis of wound infections and alleviation of pain. Moreover, intensive care measurements are necessary to avoid after burning problems and toxic pulmonary oedema. Furthermore, the cleaning of the wounds demands sterile conditions and a comprehensive wound management with regular dressing changes is necessary in order to reach as complication less healing as possible. On earth, this extensive therapy of burn injuries is performed in specialized clinics. As this kind of treatment is not possible in a space station, it is assumed that the mortality rate of major burn injuries of astronauts would be very high.

A slight CO poisoning after fire accident, however, could be relative simply treated by a hyperbaric oxygen therapy in the air lock.

4) Laceration of the head and lower arm

Experimental setup and actions

a) An astronaut hits his head at the ladder to the upper deck of the Habitat and sustains a laceration at the back. Another astronaut fastens a sterile artificial skin on the head of the IA with tape, covers “the wound” with sterile cloth, disinfects the wound and closes it with clamps using a surgical stapler. Then he takes an impression preparation (sterile sample patch for microbiological analysis) of „the wound” and puts on a sterile adhesive tape.

b) An astronaut stumbles across an object within the working area and sustains a laceration of the forearm by falling at a n open metal drawer. Another astronaut renders first help and puts on a pressure bandage. Subsequently, he fastens a sterile artificial skin on the lower arm with tape and covers „the wound” with sterile textile layer. Then he dresses in sterile surgical clothing and closes „the wound” by suture. In the end he takes an impression preparation and applies a plaster (fig. 8).

Results - Discussion

The wound closure with clamps is simpler than with sutures. However, it is not suitable for deep wounds and it is not possible for every body site. Keeping sterile conditions in wound treatment is difficult as there is no sterile area in the Habitat and it is altogether crowded. Nevertheless, there was no germ growth on the impression preparations of “the wounds” after 48 hours incubation with 37° C. Thus, sterile wound treatment is possible even under the restrained conditions of the Habitat or rather of a space station.

Fig. 8: *Wound closure of the artificial skin on the Command Deck of the Mars Desert Research Station*

In our experiment, the preparation of all necessary implements for the wound closure (sterile cloths, sterile coat, gloves, mask, instruments, suture material, dressing material…) was the biggest problem for the participants. Everything in the sterile packing looks equivalent for the medical layman. An easement would be e.g. number- or colour-coded packing and large inscriptions without medical terms.

At the beginning, as the last training has already been some time ago, the implementing analogue astronaut had difficulties with the wound closure – above all with the knot technology - and was dependent on assistance. This shows that refresher courses in the medical skills are necessary on a regular basis as only skilled astronauts are able to act efficiently in case of emergency. Furthermore, all crew members should be proficient in wound closure.

The medical waste is another challange. Large quantities of waste material accumulate and one can neither burn it (too little oxygen) nor leave it on Mars (contamination). Thereby, re-useable materials should be preferred as far as possible in contrast to the single use articles used at present. However, this requires the possibility of cleaning and sterilization. For materials not to be sterilized in autoclave, the plasma sterilization could be a possible alternative [9, 11].

Overall, wound closure is only possible inside the space station. Any wound sustained outside during an EVA goes along with damaged space suits and would immediately cause pressure loss. Emergency measurements could be special tapes to cover cracks immediately or segmented space suits with the possibility to seal off the damaged site.

The major problems concerning accidents and injuries during an expedition on Mars are summarized in the following table:

• misanthropic environment (pressure, temperature, radiation, …)
• limited resources (oxygen supply, medicines, technical equipment, …)
• long rescue times with surface expeditions on Mars
• difficult transport of an injured astronaut
• danger of hypothermia
• technical equipment impaired by sand/dust
• communication with time delay
• space suit (reduced mobility, risk of damage and pressure loss)
• hygiene lacking
• medical waste
• regular training of medical skills

CONCLUSIONS

The challenge of medicine in astronautics is the maintenance and support of the health, the well-being and the workability of the astronauts during their space travel and on their return to the earth [10].
When planning a manned Mars mission the eventuality of various accidents has to be considered. For the case of injuries easily comprehensible procedures for rescue techniques and for the medical treatment of injured astronauts have to be developed.
Minor injuries can surely be mastered by laymen with appropriate training. In the case of serious medical problems, however, comprehensive knowledge is necessary. Since communication with an experienced physician on earth is only possible with the problem of time delay due to the large distances, help will come too late in case of emergency. It is, therefore, to be demanded that with longer lasting expeditions an experienced physician or specially trained paramedic is a permanent member of the crew.

Moreover, as the resources and technical equipment for the medical treatment in a space station on Mars will be very limited, the prevention of accidents should be in the center of attention from the medical point of view. This starts with the construction of the space station, which should include a medical center, and includes the design of the equipment and methods for the health maintenance of the astronauts as well as safe operational procedures.

Additionally, as various unexpected problems emerged during our experiment, there is a need of testing all medical procedures under Mars-analogue conditions in order to avoid as many problems as possible for an actual expedition.

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