Medical Issues Associated with Winter Survival Training

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INTRODUCTION: During active phases of manned spaceflight there is a possibility of a spacecraft landing at any point traversed by its orbital path on the Earth. Survival training after emergency landing is an important and vital part of pre-mission preparations. In this paper we analyze medical issues associated with winter survival training in marshy and forested terrain.

METHODS: From 2011 to 2019, 50 International Space Station crews participated in winter survival training. Crewmembers included Roscosmos, NASA, CSA, ESA, and JAXA astronauts, spaceflight participants, and instructors. Medical protocols and training final reports were analyzed for conditions and medical events.

RESULTS: The health status of crewmembers during training was nominal. Temperature sensation was reported as comfortable or moderately cold during daytime and moderately cold or cold during nighttime. S_pO_2 (blood oxygen saturation) and heart rate recorded during training did not exceed normal values. S_pCO (blood carbon monoxide saturation) generally was within normal limits. All participating crewmembers lost some bodyweight, from 0.1–5.5 kg (average 2.1 kg). Over the course of winter survival training there were 32 medical and environmental events requiring medical intervention. For two of the crewmembers requiring medical intervention, training was subsequently canceled.

DISCUSSION: Winter survival training has successfully prepared spaceflight crews for the possibility of off-nominal landings in challenging terrain under adverse conditions. As this training involves high fidelity flight-like survival equipment and assigned flight crewmembers, the medical problems described here should closely reflect type and prevalence of events during an actual contingency scenario.

KEYWORDS: medical support, survival, spaceflight training.

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During active phases of manned spaceflight (launch and landing), failures in control systems, such as guidance or propulsion, or other emergencies such as spacecraft fire or leak, may prompt the execution of an emergency return, with a possibility of landing at any point traversed by the spacecraft's orbital path on the Earth. In the history of spaceflight there have been several cases where emergency or off-nominal landings resulted in spacecraft crews landing in unplanned locations and sometimes challenging environmental conditions.[2–4]

Training for survival after emergency landing is an important and vital part of premission preparations. The purpose of training in different climatic and geographical zones is to ensure crews have the resources and knowledge to survive in a myriad of possibly hostile landing environments until the arrival of search and rescue teams for evacuation. While a favorable outcome from such an event depends on many internal and external factors, survival skills are crucial. Survival skills ensure a proactive implementation of practical actions designed to preserve life. These actions include stress management, resourcefulness, innovation, and effective usage of survival gear to improve upon the environmental situation and build survival advantages from locally provided opportunities.[6] Cosmonaut and astronaut training for spaceflight is rigorous and intensive. Survival training includes actions that will be effective across a wide range of climatic and geographical zones. For the Russian Human Spaceflight Program, this

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training has been conducted by the Gagarin Cosmonauts Training Center (GCTC) since the 1960s.[1]

Located in Star City just outside Moscow, the GCTC survival training program consists of theoretical lectures, practical classes in the field, and 2 d of simulated autonomous survival experience in real environmental conditions. Training is conducted during the summer for desert survival and during the winter for mountain, prairie (tundra), marshy, and forested terrain survival techniques. Historically, survival training in marshy and forested terrain was mostly conducted in eastern parts of Russia. Since 2011, winter survival training has taken place in a forested area within the confines of GCTC in the Moscow Region. Sea survival training is conducted during the summer and includes helicopter rescue.

Cosmonaut candidates and Russian cosmonauts must complete all phases of survival training and serve as Soyuz commanders. National Aeronautics and Space Administration (NASA), Canadian Space Agency (CSA), European Space Agency (ESA), and Japan Aerospace Exploration Agency (JAXA) astronauts and nonagency spaceflight participants receive training in those areas needed to support their assigned mission. Crewmembers assigned to International Space Station (ISS) missions train together as Soyuz crews, participating only in marshy and forested terrain (wintertime) and water surface (sea survival) training.

During training crewmembers practice correct usage of communication tools and visual signaling equipment in search and rescue team interactions, and psychologically prepare for 2 to 3 d of independent existence in an extreme environment. Experienced medical trainers familiarize crew with the main symptoms of relevant diseases and their prevention, learning approaches and principles of self and mutual care, and appropriate usage of medications and supplies from the medical kit. There are three stages of winter survival training: 1) preliminary preparations consisting of classroom lectures by experts; 2) direct preparations in the field (terrain practice and hardware familiarization), 6 h; and 3) autonomous complex training, 48 h.

Field training typically takes place in a mixed coniferous-deciduous forest. For this series, training was conducted during the winter season (January–February) from 2011–2019, when weather conditions varied widely. Snow cover varies from absent to 1 m. Ambient temperatures can range from −35°C to +3°C with wind conditions from calm (no wind) to near gale force (10–15 $m \cdot s^{-1}$) and potential precipitation of light snow showers to full-blown snowstorms. In 2012 the weather conditions were extremely severe (ambient temperature −35°C, heavy winds) and this was the only time that training was temporarily suspended. Based on the medical team's recommendation, the crew continued normal training until 20:30 local time when they were brought in from the field to spend 1 night in an observation post with resumption of training the following morning at 08:30.

During autonomous complex training only flight-like survival garments and equipment are allowed. The Soyuz space vehicle crew's personal survival kit (PSK) is designed for 3 d of crew life support at the site of an emergency landing. The PSK comprises three very compact bundles, which are located in the Soyuz descent module. The PSK component elements may be divided into the following categories: emergency radio and light signaling devices, camping gear, water/food items, first-aid kit, personal flotation device and water survival suit ("Hydrosuit", three sets), and thermal survival clothing (three sets). Survival clothing includes undergarments, woolen flight suit, and a thermal protective suit. The first-aid kit contains medications and bandages. Medications in the kit are located inside a sealed package. The entire contents of the kit are stowed in a box with a lid.

Winter Survival Training Timeline

Training in the field starts at noon. Three crewmembers don Sokol spacesuits and take their seats in a realistic mock-up of a Soyuz descent module to simulate a landing event. The training begins with the crew doffing their spacesuits and donning survival clothing as environmental conditions dictate, assisting each other in the tight confines of the module for positioning and manipulation of clothing and supplies. This activity is quite strenuous and can build considerable metabolic heat. After leaving the descent module they choose a suitable site to build a shelter to protect themselves from the wind and cold. They can use the descent module as a base or build a lean-to or other primitive shelter for protection during the quickly advancing first night using the natural resources of their selected site and the contents of the standard PSK. On the second day, the crew improves their survival situation by constructing a more substantial type of shelter such as a teepee. During training, interactions with a search and rescue team are simulated. At the end of training the crew performs a foot march toward a rendezvous point to meet up with rescuers. After simulated recovery by search and rescue forces and training completion, the crew proceeds to the observation post for a medical checkup.

Medical Support

The GCTC Survival Training Team who organizes and conducts the training includes a medical team who are responsible for the health status of operators. While GCTC and NASA flight surgeons are always members of the medical team, flight surgeons from other international partners may also participate when astronauts from JAXA, ESA or CSA are involved. All participating crewmembers undergo medical checks the morning prior to the beginning of field training and at its completion. Pre- and post-training evaluations are conducted by an internist, an ophthalmologist, and an ENT specialist. Medical checks include, but are not limited to:

- questionnaire for general sense of well-being, health status, work-rest cycle, and food regimen;
- evaluation of emotional status (affect, behavior);
- mucosal evaluation;
- blood pressure (BP) and heart rate (HR);
- body temperature; and
- bodyweight.

The following medical conditions warrant additional evaluation: 1) medical complaints regarding overall health status; 2) work and rest cycle disorder; 3) symptoms of chronic or acute disease; 4) blood pressure and/or heart rate abnormalities; 5) body temperature greater than 36.9°C. To date, no operator has been disqualified from training after completion of the pre-training medical checkup.

During field training the crew is given maximum possible autonomy to simulate an actual survival scenario. For safety purposes, a 24-h observation post is maintained, located far enough away from the training site to preserve the crew's autonomy, but close enough for rapid ground response. The training team monitors crewmembers with visual observation and radio communications from the post. A GCTC flight surgeon is always present at this post with an emergency medical kit and equipment. Other participating flight surgeons are on call when not present at the observation post.

The training timeline requires crewmembers to report their actions and well-being to the observation post every hour by radio. At any time, the survival training team can go to the site to monitor and evaluate the crewmembers' performance, actions, and well-being. Visual medical checks are nominally conducted twice per day (morning and evening evaluations). If the ambient temperature is less than −20°C, the checks are performed four times per day or as clinically indicated. Historically during these evaluations crewmembers were questioned about their state of health, sense of temperature (cold perception), and given brief exams of visible skin and mucosa. Because of the typical practice of building fires in small shelters with possibly poor ventilation, there are concerns of carbon monoxide toxicity. Beginning in 2012, measurement of HR, blood oxygen saturation (S_pO_2), and blood carbon monoxide saturation (S_pCO) (Rad-57, Masimo, Irvine, CA, USA)[5] was proposed by NASA flight surgeons and has been routinely performed since.

Criteria for premature training termination include:

- personal request by the crewmember;
- failure of descent module systems or equipment;
- sudden changes in weather conditions which could adversely affect crew safety; and
- disease, severe trauma, disturbance of the general sense of well-being, or deterioration of psychophysiological indicators.

METHODS

From 2011 to 2019, 50 ISS crews participated in winter survival training. Roscosmos, NASA, CSA, ESA, and JAXA astronauts, as well as spaceflight participants and instructors, took part in winter survival training. For medical permission to participate in training all crewmembers had medical clearance. During training crewmembers spent 2 d in field conditions. Medical protocols and training final reports were analyzed. The data were collected noninvasively during training.

RESULTS

During this period, 50 ISS assigned and surrogate crews—a total of 150 participants (13 women, 8.7%)—passed medical clearance and took part in winter survival training. Subsequently, 40 of these crews performed successful spaceflights (**Table I**).

Table I. Winter Survival Training Operators (Field Training Participants).

AGENCY	QUANTITY	%
Russian cosmonauts	50	33.3
NASA astronauts	33	22
GCTC instructors	27	18
Candidate cosmonauts	16	10.7
ESA astronauts	9	6
JAXA astronauts	7	4.7
CSA astronauts	4	2.7
Spaceflight participants	2	1.3
Others	2	1.3

NASA: National Aeronautics and Space Administration; GCTC: Gagarin Cosmonauts Training Center; ESA: European Space Agency; JAXA: Japanese Aerospace Exploration Agency; CSA: Canadian Space Agency.

In general, the health status of crewmembers during training was nominal. Temperature sensation was reported as comfortable or moderately cold during daytime and moderately cold or cold during nighttime. S_pO_2 and HR recorded during training did not exceed nominal values. S_pCO generally was nominal (near 0%). In several cases the S_pCO was found to be 1–2% (not exceeding 3%) without any symptoms or complaints and in all cases determined to be the result of the shelter being constructed with poor ventilation. In these instances, the crew remained in the open air outside the shelter until their S_pCO returned to near 0% and the shelter's ventilation system was reconstructed under an instructor's guidance. Medical checks after training did not reveal any substantial deviation in body temperature, BP, or HR data.

All participating crewmembers lost some bodyweight to varying degrees, from 0.1–5.5 kg over the 2 d of field training. Average bodyweight loss was 2.1 kg. This variation was likely the result of multiple factors, including individual constitutional particularities, different weather conditions, water and food consumption regimens, physical activity levels, and cold-induced diuresis. Extreme bodyweight losses were observed in particularly cold weather due to intensive physical activity with excessive perspiration and intentional reduction of water consumption to decrease diuresis.

Overall, no clinically significant deviations in health status were revealed by this data. All variations were transient and self-resolving with no long-term effects. There were 32 cases requiring medical intervention (**Table II**). For two of the crewmembers requiring medical intervention, training was subsequently canceled based on the medical team's recommendations.

Table II. Medical Conditions Identified During Winter Survival Training.

DIAGNOSIS	QUANTITY	%
Skin injury	20	62.5
Eye injury	7	21.9
Mucosal injury	3	9.3
Tenosynovitis	2	6.3

Medical Cases by Diagnoses

Table II shows the overall distribution of injuries incurred during the field training portion. These are further broken down by type: skin injury: first and second-degree burns of the fingers (1), first-degree frostbite (1), contact dermatitis (1), lacerations (2), abrasions (3), and chaffing (12). Eye injury: allergic/toxic conjunctivitis (3), foreign bodies in the eyes (3), and superficial keratitis (1). Mucosal injury: rhinitis (2) and pharyngitis (1).

Some of these events have led to specific changes in pretraining instruction, medical monitoring, and training procedures as described below.

A) During post-training medical checks one operator was found to have first and second-degree burns of the second, third, and fourth fingers of the right hand. Questioning revealed that the burn occurred while the operator was handling the heated water cannister (used for preparing hot drinks over a campfire) with his bare hands. Presumably due to reduced skin sensitivity in the cold weather, he did not feel the heat of the tank in time to prevent injury. Subsequently, during pretraining briefings, mandatory use of protective equipment (wool gloves) when handling the water cannister has been emphasized. Since then there have been no additional cases of burns.
B) Contact dermatitis of the right wrist was observed in a crewmember secondary to the wearing of a watch with a metal strap during training.
C) Skin abrasions and chafes, mainly on the fingers and wrists, due to injuries sustained during firewood collection.
D) Foreign bodies in the eyes (3) complicated by superficial keratitis (1) due to debris created during wood chopping. Such cases ceased after instructors began emphasizing the use of goggles and more attention to safety during chopping of wood.
E) Mucosal irritation from smoke manifested as allergic/toxic conjunctivitis (3), rhinitis (2), and pharyngitis (1). Causes of excessive smoke exposure included weather conditions (high humidity, rain) and poor shelter ventilation for campfires.
F) Tenosynovitis of the wrist extensor due to repetitive strain injury during wood chopping.

Two cases described below required cancellation of training.

First degree frostbite of the nose. During the second day of field training the crew commander reported to the observation post that a crewmember had skin blanching at the tip of the nose. Weather conditions were not severe. On the first day of training, ambient temperature was −12°C with a 3–4 $m \cdot s^{-1}$ wind; on the second day, temperature was −18°C, with a 2–3 $m \cdot s^{-1}$ wind. The afflicted crewmember was temporally removed from training for a thorough medical evaluation. The crewmember had no symptoms, vital signs were normal, and the only physical finding was light skin blanching at the tip of the nose. After discussion inside the medical group, it was decided to stop training for this crewmember. The affected crewmember was advised to go to the sauna and take greater precautions for exposed skin during the cold weather. Training for the remainder of the crew continued with an instructor replacing the injured crewmember and was successfully completed the following day. It should be noted that the professional and proactive actions by the crew commander in mutual crew support helped to preclude a serious deterioration in crew health.

Laceration of the third finger of the right hand. On field training day 1, the crew donned their Sokol space suits and prepared to enter the mock-up descent module. During entry, one crewmember injured his right hand, suffering a finger laceration inside the mock-up, resulting in bleeding. The crewmember was evacuated from the descent module and the medical exam revealed a partial thickness laceration of the medial surface of the middle and distal phalanges of the middle finger, extending partially through the nail. After cleaning the wound with an antiseptic, the bleeding was stopped with a pressure dressing and the crewmember was evacuated to the observation post. After administering an intralesional anesthetic, the wound was closed with an atraumatic suture and covered with a sterile dressing. Tetanus vaccination was verified as up to date in the medical record. Wound healing was normal and the sutures were removed on the seventh day postinjury. At the time of injury, training was cancelled for the entire crew and an examination of the mockup was conducted to search for the source of the injury. None was found and it was concluded that the injury was sustained when the crewmember accidentally lodged his finger between the hatch and opening while trying to assist the close-out crew. Pretraining briefings of crews now discuss this episode, emphasizing adherence to proper close-out procedures, and all crew are instructed to use textile gloves before entering the mock-up descent module.

Both of the injured crewmembers in the events cited above subsequently performed successful spaceflights on the International Space Station.

DISCUSSION

From the early years of manned spaceflight to the present time, winter survival training has successfully prepared spaceflight crews for the possibility of off-nominal landings in challenging terrain under adverse conditions. In this paper, we have specifically reviewed the medical support provided as well as the occurrence of medical problems during winter survival training at GCTC since 2011. The medical cases discussed herein have been incorporated into the medical team briefing that is presented to subsequent participating crewmembers during the classroom phase of survival training. An analysis of these cases has also resulted in changes to the training protocol to enhance the overall safety of the training environment.

Because this training involves flight assigned crewmembers using high fidelity flight-like hardware, clothing, and survival equipment, the incidence of medical issues seen should closely anticipate those that might occur in an actual postlanding survival event. The success of this training and its medical support is reflected in the number of crews that have safely completed this physically challenging exercise, often during adverse environmental conditions, to go on to complete spaceflight missions to support and maintain our human presence in space. Thanks are due to the professionalism of the cosmonauts, astronauts, and other participants, including crewmembers and instructors, and to the dedication and skill displayed by the medical support group.

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