Human Space Flight Emergencies in the Prehospital Environment

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This guideline provides an overview of the prehospital management of injuries and illnesses associated with human space flight mishaps throughout the continuum of care.

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Background

This clinical practice guideline (CPG), developed in coordination with NASA's Space Medicine Operations Division, Johnson Space Center (JSC) and the Office of the Command Surgeon, United States Space Command, Peterson Space Force Base, is designed to ensure Department of War (DoW) forces understand the unique injuries, illnesses, and launch/landing operational considerations while conducting human space flight support (HSFS) operations or when responding to related space flight contingencies.

First Responder Guides

Each spacecraft poses its own unique risks and hazards to first responders. Guidelines to vehicle hazards for many of these spacecraft have been developed, should be sought and are available, as needed. Information in these guides include:

- Notes to the Incident Commander and rescuers
- Types of hypergolic gases
- Composite Overwrapped Pressure Vessel (COPV) and thruster hazards
- Batteries and ordnances
- Vehicle access and egress
- Spacesuit removal
- Spaceflight mishap response (Spaceflight Mishap Investigation Flight Surgeon Handbook)

All first responder actions during a spacecraft contingency should be coordinated through the Air Force Rescue Coordination Center (AFRCC) at (800) 851-3051, (850) 283-5955, or Defense Switched Network (DSN) 523-5955.

Contact 1AF/Det3, HSFS at (321) 853-9161 or DSN 467-9161 during a contingency or (321) 494-5116 or DSN 854-5116 during normal duty hours

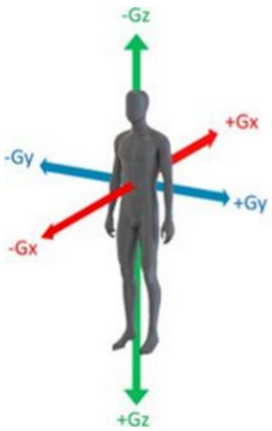
Kinetics of Trauma & Mechanisms of Injury

ABORT

When the rocket-powered Launch Abort System is activated during launch countdown or during flight, the crew may experience significant G forces. The injuries associated with these aborts depend on the level, axis and duration of G force.[1]

Potential injuries can include[2]:

- Head, neck and spine injury
- Blunt trauma
- Internal organ collision
- Musculoskeletal trauma



Acceleration	Perceived Direction
+Gz	Head to Foot
-Gz	Foot to Head
+Gx	Front to Back
-Gz	Back to Front
+Gy	Right to Left
-Gy	Left to Right

CONTINGENCY LANDING

Considerations based on the type of contingency landing include[3]:

- Exposure to extreme temperatures with resulting hyper- or hypothermia
- Exposure to toxic gases
- Cabin fire with thermal and inhalational injuries
- Loss of cabin pressure
- Flying debris inside cabin
- Extreme G-forces

Hard landings can occur when the parachute system fails to deploy correctly, the capsule encounters a high rate of wind speed or if it lands at an unusual attitude. Injuries are comparable to an aircraft impacting the ground or water. Factors include[4]:

- Capsule's rate of descent
- Capsule's angle at impact
- Number of inflated canopies
- Correct function of the restraint system
- Correct function of energy absorbing structures of seat

Hazardous Gas Exposure

All currently supported spacecraft utilize hazardous materials for systems operation. Some that are commonly utilized include:

- Hydrazine (N2H4), a fuel that can be used with derivatives like monomethyl hydrazine (MMH), unsymmetrical dimethylhydrazine (UDMH), and Aerozine 50 [5]
- Nitrogen tetroxide (N2O4), an oxidizer that can be used with hydrazine and its derivatives
- Ammonia (NH3), used for spacecraft cooling and heat transport[6]

Illness and/or injury depend on the duration of exposure and the concentration of the gas and include[7]:

- Inhalation: May cause nasopharyngeal and tracheal burns, upper airway edema and pulmonary edema, which may develop gradually
- Skin and eye contact: Injuries range from irritation to severe cutaneous burns or corrosive damage
- Central nervous system: Can cause lethargy, seizure, neuritis, and coma

Treatment

Follow standard patient assessment protocols starting with scene size-up and the donning of PPE. Consider the following interventions:

- Move crew from contaminated environment
- Remove contaminated clothing
- After initial assessment, begin copious skin and eye irrigation for at least 20 minutes
- Treat dermal irritation or burns with standard prehospital protocols
- Consider warm humidified O2

- If signs or symptoms of inhalational injury, consider aerosolized bronchodilator and early intubation
- Consider corticosteroids and antihistamines
- Consider methylene blue for methemoglobinemia
- Consider pyridoxine (B6) for seizures
- Monitor for hypotension and dysrhythmias

Methemoglobinemia: a very rare disorder affecting how blood cells deliver oxygen throughout the body that may occur after exposure to a medication or chemical, such as hydrazine.[8] It presents with dyspnea or cyanosis and hypoxemia that is refractory to supplemental oxygen. SpO2 may appear normal. Blood will appear chocolate brown in color. Methemoglobinemia can be treated with methylene blue which accelerates the reduction of methemoglobin to hemoglobin.

- Methylene blue: 1 mg/kg intravenously over 5 minutes. Repeat dose after 1hr if needed. Use only with caution in those with known G6PD deficiency or those taking serotonergic medications as this may increase the risk of hemolytic anemia and serotonin toxicity, respectively, in this subset of patients.[9,10]

Seizures: Exposure to small amounts of hydrazine and its derivatives can cause seizures and coma.[11] Hydrazine exposure can prevent benzodiazepines from being effective. High-dose intravenous pyridoxine has been suggested as treatment for hydrazine-related neurologic toxicity.

- Benzodiazepines per protocol
- Pyridoxine: 25 mg/kg, slow IV over 30-60 minutes

Decompression Illness: Decompression Sickness / Air Gas Embolism

Decompression Illness (DCI) is the umbrella term for the constellation of symptoms associated with Decompression Sickness (DCS) and Air Gas Embolism (AGE). DCS occurs when rapidly transitioning from high-pressure to low-pressure environments, such as during rapid cabin depressurization at altitude or failure of pressurized spacesuits.[12] AGE is the result of barotrauma from trapped gas (e.g., lungs) expanding when transitioning to lower pressures, leading to intravascular bubbles.[12] Both DCS and AGE can present with overlapping symptoms and patient care is similar – thus will be discussed in tandem. However, it is important to recognize that DCS and AGE are different pathologies.

Symptoms of altitude-related DCS often, but not exclusively, occur during active phases of flight (i.e. during a sortie). An AGE often occurs within 10-mins of active ambient changes to lower pressure and is frequently associated with breath-holding or On-Board Oxygen Generating System overpressurization.[13,14]

Common Symptoms[15]*:*

- Musculoskeletal Joint Pain (e.g., shoulders, knees, elbows, etc.)
- Extreme Fatigue
- Numbness / Tingling Sensation
- Confusion or “Brain Fog”
- Skin Rash, or Mottling

Less Common, but More Severe Symptoms[15]*:*

- Chest Pain / Cough / Shortness of Breath ("Chokes")
- Limb Weakness or "Stroke-like" Symptoms
- Urinary Retention

Suggested Treatment

First-Line[13]

- ABCs (Airway/Breathing/Circulation Primary and Secondary Survey)
- Immediate ground-level oxygen via 15L/min O2 face mask or demand valve
- Transport to closest Hyperbaric Oxygen Therapy Chamber for recompression
- Supine position preferable (*avoid* head down positioning)

Adjunct/Secondary Treatments[13]

- Oral rehydration with water, if conscious
- IV fluids (*avoid* glucose-containing fluids and *avoid* overhydrating)
- Nonsteroidal Anti-Inflammatory Drugs - NSAIDs (e.g., ibuprofen, naproxen)
- Avoid overheating (i.e., limit sun exposure, removal from spacesuit, etc.)

NOTE: Evidence for use of aspirin, corticosteroids, and lidocaine for DCI treatment is lacking and therefore not recommended as standard of care for adjunctive therapy.

Special Considerations

Flying, and subsequently exposing patients to lower ambient or cabin pressures, can worsen symptoms of DCI. When transporting a patient suspected of DCI by a helicopter or unpressurized aircraft, evacuation should attempt to fly as low as reasonably achievable based on operational or safety limitations. Flight altitudes below 1,000-ft are preferred for unpressurized cabins and pressurized cabins should be maintained as close to 1-atm (760-mmHg) as able. However, evacuation should not be terminated strictly due to inability to maintain these recommended altitude restrictions.[15]

Low-pressure fabric altitude chambers (e.g., Gamow bags) are *not* sufficient to reach the partial pressure of oxygen required for therapeutic hyperbaric oxygen, and thus, should *not* be considered definitive treatment. However, utilization of the Emergency Evacuation Hyperbaric Stretcher or SOS Hyperlight hyperbaric stretcher can be considered for transport.[15]

Resources

Contact the nearest hyperbaric chamber facility or the following for support:

Divers Alert Network (DAN) Emergency 24/7 Hotline
+1.919.684.9111

Brooke Army Medical Center Hyperbaric Medicine On-Call Provider:

During the duty day, call +1.210.539.8000
After hours, call +1.210.916.2500, option 2, option 1, ask for the Undersea & Hyperbaric Medicine physician on call

University of California San Diego, Hillcrest Hyperbaric Medicine Emergency Center:

Call 858-657-7000

Long-Duration Space Flight Physiology

The weightlessness experienced during long-duration spaceflight causes physiological changes in the human body as it adapts to this unique environment. Upon return to Earth, these changes may raise concerns if they are unanticipated by first responders.

NEUROVESTIBULAR SYSTEM

The neurovestibular system provides a sense of balance, position, and motion. Sensory inputs are immediately and radically altered in weightlessness with the loss of gravitational force. This alteration of inputs leads to central sensory conflict, known as space motion sickness.[16] The body adapts to Space within 72hrs. Returning to Earth with the neurovestibular system adapted to microgravity causes "entry motion sickness". All crew members will be affected to some degree with vertigo, unstable gait, nausea and vomiting. Returning astronauts may have been treated with meclizine, or promethazine prior to reentry.[16]

Suggested treatment

- Avoid rapid head movements
- Consider Meclizine
- Consider Promethazine at half the normal dose
- Replace fluid and electrolytes, PO or IV

Special considerations

- If the patient is conscious and responsive, ask about what prophylactic medications he or she may have taken prior to reentry, in order to reduce the risk of toxidrome that might occur if further doses of medication are given during treatment of symptoms.
- Promethazine may cause urinary retention due to its anticholinergic effects
- Scopolamine transdermal patch is effective but has a slow onset of system relief
- As entry motion sickness is like motion sickness, medications such as ondansetron are not as effective

ORTHOSTATIC INTOLERANCE

In microgravity, the hydrostatic pressure gradient is lost, leading to redistribution of blood and body fluids from lower parts of the body towards the head. The body's adaptation to the redistribution is a reduction in circulating intravascular volume by around 15%. When crewmembers return to Earth, the diminished intravascular volume coupled with the gravitational pooling of fluid in the lower extremities, leads to reduced venous return, decreased cardiac output, and orthostatic intolerance. Orthostasis is triggered by upright positioning as the body is unable to maintain arterial blood pressure and cerebral perfusion, resulting in presyncope or syncope.[17] When crewmembers are reintroduced to gravity, the vomiting caused by neurovestibular dysfunction and decreased circulating volume increases the likelihood of orthostatic intolerance.

Suggested treatment[18]

- Oral fluids if tolerated
- IV isotonic crystalloids
- Rest
- Appropriate clothing to prevent fluid loss through sweating and peripheral venous dilation

Special considerations

If blood loss is suspected due to trauma, initiate resuscitation with blood products given the similarities between shock physiology and orthostatic intolerance. Refer to TCCC guidelines.

URINARY SYSTEM

Urinary tract infections (UTI) have been reported on space flight missions as multiple factors experienced in the microgravity environment increase the likelihood of a UTI. Urinary retention has an increased incidence as a side effect of anticholinergics and anticholinergic-like medications used during spaceflight to include promethazine, scopolamine and meclizine[19].

Suggested treatment:

- Catheterization may be required due to urinary retention
- Consider antibiotics for known or suspected urinary tract infection

MUSCULOSKELETAL SYSTEM

Reduced skeletal loading in microgravity will result in muscular atrophy and bone demineralization without effective countermeasures with the weight bearing regions being most affected. Even with countermeasures, crew members reintroduced to normal gravitational forces on Earth will have weakness, fatigue, and impaired physical abilities upon their return.[20]

Treatment

- Aid with ambulation
- Rest

Special considerations:

Crew may have spent 5 hours or more in the seats before a launch, causing nerve compression that may cause paresthesia characterized by tingling, numbness and/or burning pain in the outer thighs. Additional skin inspection should include evaluation for pressure ulcers.

ALTERED IMMUNE FUNCTION

Physiological stress, disruption of the circadian rhythm, radiation, and microgravity may cause dysregulation of the immune system, making crew members vulnerable to infections.[21] Prevention and early detection are important.

Treatment

- Use proper hygiene and sanitation techniques
- Use proper aseptic techniques and infection control during procedures
- Have a high index of suspicion for infection as possible cause of illness

BEHAVIOR AND PERFORMANCE

Spaceflight mishaps related to behavioral manifestations of mission-related operational stressors and mental health problems have been quite low, though the incidence may be underestimated due to the reluctance of astronauts and space flight participants to report issues. Mental health decrements and stressors impacting behavioral coping mechanisms can lead to performance-related effects that compromise the crew's ability to function as a team, especially under abnormal or emergency conditions.[22] The crew may have sleep-shift changes required, prior to undocking, to align with the primary landing site time zone and mitigate what otherwise would have been significant duty day extension. The physical toll from re-entry and landing while deconditioned, coupled with altered sleep cycles and a sleep deficit, can lead to profound exhaustion.[23]

Special considerations

Failure to follow simple instructions may be a "red flag" of some other underlying condition.

Medical Equipment and Supply Considerations

The most likely scenario that would involve DoD response to a crewed spacecraft off-nominal recovery will be one that occurs in a maritime environment. The USAF 913N medical assemblage is a long-range maritime medical assemblage that consists of waterproof medical bags and air droppable bundles containing supplies and equipment to support 4 injured crew members for up to 72 hours. This assemblage can be found in Defense Medical Logistics Standard Support (DMLSS) or contact 1AF/Det3 at 1afdet3.hsfs.medical@us.af.mil

Available Training

USSPACECOM Space Medicine 101

- A familiarization course intended for first responders and medical personnel to gain a basic understanding of HSFS during astronaut rescue and recovery operations. It is available on JKO Platform Course Number DHA-US1341. https://jkodirect.jten.mil/html/COI.xhtml?course_prefix=DHA&course_number=-US1341

Pre-Hospital Space Medicine Care Course (PHSMCC)

- An advanced course for DoD rescue forces tasked in support of HSFS operations. It is taught as a part of the Rescue Forces Qualification Course (RFQC).

Artemis Landing and Recovery Medical Operations (ALARMO) Course

- An advanced course for USN medical forces, to include search and rescue medical technicians (SAR Med Tech), en route care (ERC) teams and fleet surgical teams (FST) tasked in support of NASA's Artemis Program landing and recovery operations. The ALARMO Course is taught while the medical forces are underway in support of an Artemis return mission.

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