Advanced Trauma Life Support for the Injured Astronaut

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Third Edition

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BACKGROUND

Space travel will continue to become more and more common over the next decade with growth of the Space Shuttle program and construction of the International Space Station (ISS). Lunar and even Mars habitation is also becoming a definite reality. In addition, several private corporations are preparing to transport civilians into low-altitude space orbits within the next decade.

Such travel is not without potential for traumatic injury. Astronauts and ground personnel are subject to unique injuries as a result of the conditions and chemical substances that are inherent to space travel. The standard principles of Advanced Trauma Life Support (ATLS) are directly applicable to the care of the injured astronaut. Microgravity environments also present a variety of physiologic changes that may complicate both patient assessment and treatment. To provide appropriate patient care, knowledge of the unique injuries, chemical exposures, and equipment associated with space travel is essential. This monograph summarizes a variety of information sources and is intended to provide the trauma surgeon with the essential information necessary to appropriately treat individuals injured in the course of space exploration.

As the closest Level I Trauma Center to Kennedy Space Center (KSC), NASA considers ORMC to be a "definitive medical care facility" (DMCF) and relies upon its physicians to provide care to injured astronauts and staff when necessary. Joint training exercises several times each year ensure that both NASA and ORMC are prepared to handle any injuries that might occur during space travel-related activities. Whereas Space Shuttle launch and landing-related injuries are feared most, non-flight-related ground accidents associated with maintenance and refueling of the Space Shuttle are much more likely to occur. KSC also has a fully functional airport (the Shuttle Landing Facility or SLF) from which NASA aircraft takeoff and land throughout the day, presenting the potential for traditional aircraft-related incidents. The potential for injury among the many thousands of spectators who witness each Space Shuttle launch as well as the thousands of motor vehicles present at such events must also be considered. NASA's Emergency Medical Services respond to an average of 2 medical emergencies among the spectators at each launch. Potential mass casualty events at KSC therefore include:

- Space Shuttle launch and landing incidents
- Space Shuttle maintenance / refueling incidents
- Aircraft crashes at the Shuttle Landing Facility (SLF)
- Spectator motor vehicle collisions

ADVANCED TRAUMA LIFE SUPPORT IN SPACE

During each Space Shuttle flight, one astronaut is designated the "crew medical officer". This individual is rarely a physician. Flight surgeons at Johnson Space Center (JSC) in Houston are available to the astronauts 24 hours a day during spaceflight should a medical emergency arise. These physicians also have a daily medical conference with each astronaut to answer questions and ensure that they remain healthy.

Resuscitation equipment on board the Space Shuttle is limited as a result of space and weight restrictions. NASA's goal is to be able to provide at least Advanced Life Support (ALS) care while in orbit, not unlike that available in an ambulance on the ground. In the event of an in-flight medical emergency, however, NASA's intent would be to rapidly bring the Space Shuttle back to Earth with a return time of less than 12 hours. Only basic medical equipment is available on the Space Shuttle. This includes intravenous fluids, basic medications, an Ambu bag, and dressings. On certain missions, a defibrillator has been included as well. Drugs available to the astronauts in-flight include: NSAIDS, Acetamino-phen (Tylenol), Scopolamine (Scope-Dex), Promethazine (Phenergan), Zolpidem (Ambien), Zaleplon (Sonata), Neosynephrine (Afrin), Guafenesin / phenylpropanolamine (Entex LA), and Bisacodyl (Dulcolax).

With the manning of the ISS, return to Earth will be more difficult and prolonged. As a result, astronauts inhabiting the ISS have more advanced medical training better preparing them to handle a medical emergency should it occur. Expanded medical supplies including an EKG monitor, defibrillator, intubation equipment, ventilator, chest tubes, and ACLS medications are available. NASA has also designed a "telemedicine instrumentation packet" that includes two-way video teleconferencing, 12 lead EKG, pulse oximetry, ultrasound, and a fiberoptic scope. Astronauts on the ISS can use this technology under the direction of flight surgeons on the ground to remotely "examine" the injured astronaut and prescribe appropriate care until the victim can be returned to Earth for definitive care.

Should the need arise, the ISS crew will be able to evacuate and return to Earth using the X-38 Crew Return Vehicle. The return time will be 6-24 hours. Based upon the MIR space station and US Space Program experiences, it is estimated that:

- there will be a medical emergency requiring use of the on-board medical equipment every 2.4 years
- an astronaut will need to be evacuated back to Earth for a medical reason every 5 years
- a catastrophic medical event involving an unconscious astronaut will occur every 8-12 years

LAUNCH AND LANDING CONTINGENCIES

The following will familiarize the Trauma Team with the various scenarios possible and to define the terms that may be used during conversations with NASA officials. In the event of a launch-related emergency contingency, the following options are available to the Space Shuttle crew:

- **Mission Profiles**
  - **Return to Launch Site (RTLS)**
    Only possible within the first 4.5 minutes after launch (and after SRB separation), the flight crew has the ability to return to KSC for a landing at the SLF. This maneuver requires approximately 25 minutes from launch to landing.

  - **Transoceanic Abort Landing (TAL)**
    This option is executed once the orbiter has traveled too far to return to KSC, but does not have sufficient power to reach orbit. The external tank is jettisoned and the orbiter glides to a landing at designated landing sites in Europe or Africa. This requires approximately 35 minutes from launch to landing. The decision to perform a TAL must be made in the first 10 minutes of the flight. DoD emergency medical teams are deployed and available at each of the designated TAL sites for each shuttle launch.

  - **Abort Once Around (AOA)**
    This option is declared once the opportunity for a successful TAL has passed and there is insufficient power to reach orbit. The shuttle will make one revolution around the Earth, reenter, and land at KSC, Edwards AFB, or White Sands Space Harbor. This option requires approximately 1¾ hours from launch to landing.

  - **Abort Temporary Orbit (ATO)**
    This option is declared if the shuttle can achieve a temporary orbit that is lower than the nominal mission orbit. It allows the crew time to evaluate existing problems and resources. They may decide to terminate the mission or attempt to boost the shuttle to a higher orbit.

- **Contingency Response Modes**

The following scenarios describe evacuation and rescue of the Space Shuttle crew in the event of a launch or landing contingency.

Launch Pad Modes

- **Mode I** – Unaided egress from the launch pad. The crew will egress the Shuttle and use the slidewire system to escape from the launch pad.
- **Mode II** – Aided egress from the launch pad. The closeout crew will assist the flight crew in egressing the Shuttle. The slidewire system is used to escape from the launch pad.
- **Mode III** - Aided egress from the launch pad. The fire/crash/rescue crew will assist the flight crew in egressing the Shuttle. The slidewire system is used to escape from the pad.
- **Mode IV** - Aided egress from the launch pad. The fire/crash/rescue crew assists both the flight crew and the closeout crew in egressing from the launch pad. The slidewire system is used to escape from the launch pad.

Astronauts escaping from the Space Shuttle during a Mode I contingency drill

Landing Modes

- **Mode V** – Landing mishap on or near runway (Unaided Egress / Aided Escape). Flight crew egresses the Shuttle and the fire/ crash/rescue crew aids them in escaping from the landing area.
- **Mode VI** - Landing mishap on or near runway (Aided Egress / Escape) and accessible to ground crews. Fire/crash/rescue crew enters Shuttle to aid the flight crew in egressing from the Shuttle and escaping the area.
- **Mode VII** - Landing mishap off the runway (Aided Egress / Escape), not accessible to ground crews. Fire/crash/rescue crew, transported by helicopter, enters the Shuttle to aid the flight crew in egressing from the Shuttle and escaping the area.

Flight Mode

- **Mode VIII** – Bailout of the Shuttle crew during controlled gliding flight or following a catastrophic breakup, which the crew compartment survives.

SEARCH AND RESCUE

NASA has an extensive array of rescue services in place in the event of injury. The KSC Fire/Rescue department is tasked with providing a variety of emergency medical services for the space center including:

- EMS ambulance services for spectator injuries and minor environmental exposures
- Fire suppression, HAZMAT, and Incident Command for Shuttle-related activities
- Search and Rescue (SAR) for downed astronauts and pilots within 20 miles of KSC

Self-extrication and evacuation from a damaged Space Shuttle, the launch pad, or the Vehicle Assembly Building following a Space Shuttle launch, landing, or refueling mishap will be difficult, especially for astronauts returning from space due to muscular deconditioning (see below). Astronauts and ground personnel will be dependent upon the SAR teams to evacuate and bring them to medical care. The toxic chemicals and propulsion fuels utilized in the shuttle program require specialized equipment and protective suits that further complicate and prolong the prehospital course.

During Space Shuttle launch and landing, the Department of Defense (DoD) provides an extensive array of aircraft, personnel, and world-wide resources to assist with KSC's emergency medical response capabilities. In the event of a mishap occurring outside the 20 mile radius of KSC, DoD forces, supplemented by United States Navy vessels and United States Coast Guard aircraft and vessels, are responsible for all SAR efforts.

Multiple triage sites and landing zones have been designated at KSC in preparation for an emergency situation. Triage sites are utilized for initial resuscitation, decontamination, and stabilization prior to transfer to a DMCF such as ORMC. NASA believes that all astronauts should receive equal medical care should the need arise. Traditional concepts of triage, in which patient care is based upon expected likelihood of survival, is not considered appropriate by NASA.

TRANSPORT TO ORMC

Following decontamination and initial assessment and stabilization, astronauts and ground personnel injured at KSC will almost always be transported to ORMC by helicopter. The Air Care Team has a 16-minute transport time from KSC to ORMC and is able to transport one patient at a time. Two flight nurses staff this aircraft. NASA's UH-1 "Huey" helicopters have a slightly shorter transport time and can usually transport one patient each. One to two paramedics and occasionally a flight surgeon staff this aircraft. Like the Air Care Team's BK-117, the UH-1 helicopters are able to land on the ORMC rooftop helipad. The primary aircraft used for SAR efforts at KSC are HH-60 "Blackhawk" helicopters from Patrick Air Force Base. These aircraft can transport two patients at a time and are staffed by two paramedics and a flight surgeon. Due to weight restrictions, the Blackhawk helicopters cannot land at ORMC. After initially landing at Orlando Executive Airport, casualties will be transferred to ORMC by ground ambulance, or by helicopter (Air Care Team or Orange County Firestar). All casualties from KSC will be accompanied by a NASA flight surgeon familiar with space physiology and toxic chemical exposure. They will bring with them specialized medications pertinent to the patient's potential injuries (such as large doses of pyridoxine - see below).

HH-60 "Blackhawk" helicopter preparing to evacuate casualties from a remote crash site while DoD flight surgeons begin initial assessment of an injured astronaut

MECHANISMS OF INJURY

Astronauts and ground personnel are subject to a variety of injuries, many of which are typical of what surgeons see on a daily basis in their practice of trauma. Astronauts and NASA ground personnel are also subject to many unique injuries as a result of the conditions and chemical substances that are inherent to space travel. Casualties transferred to ORMC from KSC have the potential to be injured in a number of ways. The most common etiologies of injury include (in descending order of likelihood):

- **Toxic Chemical Exposure**
  - Toxic chemical exposure represents the most likely etiology of casualties that may be transported to ORMC from KSC. Whereas the malfunction and explosion of the early rockets, the Apollo 1 fire, and the Challenger accident are most likely to come to mind, industrial accidents related to toxic chemical exposure are much more common. There are approximately 400 compounds within the confines of the shuttle cabin which have potentially toxic effects at high concentrations.
  - Since 1983, there have been over 1200 incidents at KSC in which workers sought medical care. This includes the 1981 deaths of two KSC workers who were asphyxiated when they entered a nitrogen-purged compartment following a Space Shuttle main engine-firing test. A similar mishap occurred several years ago in the European Space Agency program. In 1994, 80 individuals were injured when 16 gallons of nitrogen tetroxide was accidentally released at Johnson Space Center in Houston resulting in a brownish-red vapor cloud. Toxic chemical exposures can also occur during spaceflight. In 1975, astronauts returning during the last Apollo-Soyuz mission were exposed to nitrogen tetroxide and monomethylhydrazine during re-entry. All three crewmembers developed chemical pneumonitis despite rapidly donning oxygen masks. All three required intensive care management for subsequent pulmonary edema. There was no permanent injury. Eye irritation from lithium hydroxide canisters has been reported on at least 6 shuttle missions as well as nausea from ammonia and formaldehyde.
  - The toxic chemicals used at KSC can be divided into two basic types: **hypergolic fuels** and **non-hypergolic agents**. Hypergolic fuels are used to propel the Space Shuttle and other missiles into space while the non-hypergolic agents are commonly used to support the daily activities at KSC.

Hypergolic Fuels and Oxidizers

The hypergolic fuels include hydrazine, monomethyl hydrazine, and dimethyl hydrazine. These agents ignite on contact when mixed with oxidizers such as nitrogen tetroxide and nitrogen dioxide. Hypergols, together with other flammable agents such as liquid hydrogen, liquid oxygen, and solid rocket motor propellant, are of the greatest concern with regards to potential for injury. The hypergolic agents are used as propellants in the main shuttle tank as well as the auxiliary power units and orbital maneuvering system on the shuttle itself. They are also used in the Atlas and Delta rockets. Personnel involved in handling these agents must wear protective clothing and use breathing equipment due to their corrosive nature. Hydrazines are colorless, odorless liquids that have an ammonia or fishy odor when vaporized. They are corrosive and will burn the skin and eyes. Ingestion or absorption can cause seizures and death.

Oxidizers such as nitrogen tetroxide and its breakdown product nitrogen dioxide are also corrosive liquids that form a brownish to reddish gas at room temperature. They have a bleach-like odor. Nitrogen dioxide combines with water to form acids that can cause significant burns to exposed skin and eyes. Inhalation can cause pulmonary edema.

The solid rocket motor propellant consists of a mixture of ammonium perchlorate and powdered aluminum. When ignited, these compounds release large volumes of gases containing aluminum oxides, carbon monoxide, and hydrogen chloride gas. The latter forms an acid when mixed with water. In the event of a catastrophic launch accident or a ground processing accident involving the solid rocket motors, these vapor clouds could represent a significant threat to those downwind.

Table 1 lists the basic hypergolic fuels and oxidizers, the signs and symptoms of exposure, and the treatment of such exposures.

Table 1: Hypergolic Fuels and Oxidizers

	Hydrazines	Nitrogen Tetroxide / Dioxide
Use	Rocket fuel	Rocket fuel oxidizer
Properties		
Color	clear, colorless, liquid	green to brown (liquid) clear to orange-brown (vapor)
Damage potential	corrosive	highly corrosive
Odor	ammonia or fishy odor	“sweetish, acrid, bleach” odor
Signs/Symptoms		
Onset	Symptoms may not appear until 12 hrs post-exposure	Symptoms may initially be mild followed by a symptom-free period of approximately 5-12 hrs
Cardiovascular	Hypotension	Tachycardia, bradycardia
Respiratory	Coughing, dyspnea, airway irritation, pulmonary edema, respiratory failure	Coughing, dyspnea, delayed pulmonary edema, chemical pneumonitis, respiratory failure, sudden death from severe spasm of the airways or larynx
CNS	Headache, dizziness, narcosis, CNS depression, muscle tremors, seizures	Headache, narcosis, vertigo, somnolence, fatigue, loss of consciousness
GI	Nausea, vomiting, hematemesis	Nausea, vomiting, burning of GI tract
Eye	Conjunctivitis	Conjunctivitis
Skin	Dermatitis, chemical burns	Dermatitis, chemical burns
Renal	Kidney damage	
Hepatic	Liver damage	
Endocrine	Hyper - / hypoglycemia	
Blood	RBC hemolysis, methemoglobinemia	Methemoglobinemia
Treatment issues		Close observation during first 24-48 hrs since pulmonary edema may be delayed.
Decontamination	Disrobing and washing if not already done prior to arrival	Disrobing and washing if not already done prior to arrival
Respiratory	Supplemental oxygen, intubation prn	Supplemental oxygen, intubation prn
Fluids	Normal saline	Normal saline
Medications	Administer pyridoxine* (Vitamin B_6) 25 mg/kg IV if exposure suspected to prophylax for seizures.	
	For seizures: Ativan 2 mg IV prn or Valium 10 mg IV. If seizures persist, Cerebryx 15-20 mg/kg IV. If no response, consider pentobarbitol coma.	Decadron 10 mg/kg IV q 6hrs or Solumedrol 30 mg/kg IV q 6 hrs
	If methemoglobin > 30%, give 1-2 mg/kg 1% methylene blue solution IV	If methemoglobin > 30%, give 1-2 mg/kg 1% methylene blue solution IV

* Pyridoxine inhibits gamma-aminobutyric acid (GABA) and increases the seizure threshold. Its use is based on anecdotal experience in animals.

Non-hypergolic agents

There are over 17,000 agents used at KSC that are potentially hazardous. Although they are not as toxic as the hypergolic agents, the non-hypergolic agents are still capable of causing significant injuries. Those listed below are commonly used in the Space Shuttle program.

Name	Use
Anhydrous Ammonia	refrigerant
Chlorine	waste water cleaning agent
Halon 1301	fire extinguishing agent
Freon 21	refrigerant
Helium gas	pressurant gas
Hydrogen gas	purge gas
Liquid Argon	inert gas
Liquid Helium	pressurant gas
Liquid Hydrogen	cryogenic fuel
Liquid Nitrogen	pressurant gas
Liquid Oxygen	cryogenic oxidizer
RP-1	hydrocarbon fuel
JP-5	hydrocarbon fuel

Many of the gases are used to purge oxygen from engine compartments and other areas in an attempt to decrease the risk of fire. As evidenced by the 1981 accident, workers entering these areas without adequate protective equipment are subject to injury. The cryogens such as Anhydrous Ammonia and Freon 21 present hazards such as frostbite and potential asphyxiation from oxygen displacement as they vaporize. Protective clothing and breathing equipment should be used in the handling of all of these agents.

- **Fire**
  - Fire has long been a major concern in space travel dating back to the Apollo I pad disaster. This prompted changing the cabin atmosphere from 100% oxygen to approximately 30% oxygen. An oxygen-generating canister fire aboard the MIR space station in 1997 almost resulted in the crew having to abandon the station. In the confined space of a shuttle or the ISS, fire is highly lethal.
  - Although the outer layer of the Advanced Crew Escape (ACE-2) suit is constructed of fire-resistant Nomex™, it would provide little protection in a major fire. During a Mode I-IV mishap, fire suppression sprinklers on the 195-foot crew level of the launch structure would provide some protection.

- **Blast / Explosion**
  - The periods of greatest concern during space travel are the initial launch and landing of the spacecraft back on Earth.. The thrust generated by the Space Shuttle's main engine is equivalent to that of 39 train locomotives, but this is insufficient to place the Space Shuttle into orbit. Solid rocket boosters (SRB's) are attached to the orbiter to provide the necessary propulsion to reach space. The motors burn for just over 2 minutes, each generating 3.3 million pounds of thrust - equivalent to 35 Boeing 747's on takeoff. Unlike the Space Shuttle's main engines, the SRB's cannot be shut down once ignited and ignition commits the Space Shuttle to launch. The combustion gases from the SRB's achieve temperatures of 3,371 degrees Centigrade (two-thirds the temperature of the surface of the sun) and a plume of flame 500 feet long.
  - Although significantly redesigned in the aftermath of the Challenger incident, the SRB's continue to pose significant risks to astronauts and NASA staff both before and during launch. During the 2 minute 5 second period of SRB firing, no airborne abort attempts are possible. Also of major concern is premature ignition of the SRB components during "stacking" in the Vehicle Assembly

Building (VAB) which would create both a significant explosion as well as release of volumes of toxic fumes.

- **Deceleration / Impact**
  - Sudden deceleration injuries typical of high-speed motor vehicle collisions may occur should the Space Shuttle crash upon returning to Earth. During return, the orbiter is essentially a glider and the landing must be perfect on the first attempt- a “go-around” and second attempt is not possible. Upon landing the Space Shuttle has a speed of 250 mph, well above the typical commercial airliner landing speed of 150-160 mph. The orbiter itself is very fragile and designed to break apart upon impact with the protected crew compartment intact.
  - The deceleration forces that astronauts would be exposed to in an impact situation would be great and the potential for blunt aortic injury and spinal fracture great.

KSC Fire / Rescue Team members evacuating astronauts from the side emergency egress hatch during a Mode VII drill. Rescue personnel wear fire resistant suits and oxygen packs to protect them from hypergolic fuels and other toxic chemicals.

- **Hypothermia**
  - The Space Shuttle’s main engine burns liquid hydrogen (-253 degrees Centigrade – the second coldest liquid on Earth) and liquid oxygen (-183 degrees Centigrade) generating main engine combustion temperatures of 3,316 degrees Centigrade. Exposure to these fuels leads to significant potential for hypothermia. Anhydrous ammonia is used for cooling and can also cause hypothermia. The frigid temperatures of outer space similarly place the astronauts at risk for hypothermia during space walks or EVA’s (extravehicular activities).
  - Hypothermia as a result of high altitude exposure and prolonged salt-water immersion are also significant concerns. In the event of a Mode VIII bailout over the Atlantic Ocean, the shuttle crew would be spread out over a distance of some 6 miles. It is highly likely that rescue of any individual astronaut from the water and return to medical care would require 2-3 hours. Toxic fuel decontamination with water and removal of the astronaut’s space suit will only serve to further expose them and predispose them to marked hypothermia.

- **Decompression**
  - Sudden decompression of a spacecraft during launch, spaceflight, or landing may cause barotrauma, decompression sickness, or arterial gas embolism. The latter would require recompression in a hyperbaric chamber. Frequent space walks or “EVA’s” also place the astronaut at risk for gas embolism or “the bends”.
  - Loss of cabin pressure within a spacecraft is catastrophic. When recognized quickly, appropriate corrective manuevers can be instituted (such as occurred on the MIR space station when a portion of the station had to be abandoned). Decompression of during return of one Russian spacecraft resulted in loss of the entire crew.

- **Radiation Exposure**
  - Early Space Shuttle missions occasionally carried satellites that were nuclear powered. No radioactive payloads have been carried aloft for several years. Future missions, however, may require that potential sources of radiation exposure be involved.
  - Long-term space travel, such as has occurred on the Russian MIR space station and will occur with the ISS, is also associated with radiation exposure as a result of solar flares. Astronauts who resided on the MIR station for several months received approximately 13 rems of radiation exposure (the equivalent of 780 standard chest radiographs).

ASTRONAUT PHYSIOLOGY

A number of physiologic changes occur with spaceflight that may directly impact the traumatically injured astronaut. These changes can occur even with a short Space Shuttle flight of 14 days and may require a month or more of recovery. As a result, the typical astronaut who presents for care following a Space Shuttle contingency will be:

- hypovolemic
- anemic
- osteopenic
- orthostatic
- weak
- easily fatigued
- neurologically unsteady

Each of these findings may mimic shock or injury and will potentially confound accurate diagnosis and treatment of traumatic injuries. They may also adversely affect a crewmember's ability to egress from the orbiter during contingency operations. As a rule, astronauts should be considered to have physiologic derangements consistent with a American Society of Anesthesia (ASA) Class III patient. Pertinent physiologic adaptations will be discussed by organ system.

- **Fluid and Electrolytes**
  In microgravity environments, astronauts experience a cephalad and central shift in fluid volume. The ensuing increase in blood pressure results in a spontaneous diuresis. Astronauts are therefore initially fluid overloaded for the first few days in space until the excess fluid is diuresed off. Upon return to Earth, however, both intravascular and extracellular fluid volumes are decreased by as much as 10%. Interstitial volume is preserved. Astronauts also demonstrate decreased fluid intake during spaceflight as a result of space motion sickness (SMS). Motion sickness medications may also make the astronauts nauseated and less likely to drink fluids. Twenty-four hours prior to landing, astronauts consume 8 salt tablets and 32 oz of fluid in an attempt to restore their total body volume. Such maneuvers are only partially successful. Injured astronauts will likely be intravascularly volume depleted beyond that expected based upon their injuries. Shock will be more pronounced and early resuscitation essential. Astronauts must have both their shock-related and dehydration-related fluid deficits restored rapidly following arrival in the Trauma Center.

  Astronauts may also demonstrate marked electrolyte abnormalities. Antidiuretic hormone (ADH) secretion is decreased in microgravity and diuresis of the centrally mobilized intravascular fluid ensues. Serum osmolarity decreases by an average of 4%. Serum sodium falls by an average of 6% resulting in hyponatremia. Aldosterone secretion will increase in response, increasing potassium excretion by 32% and placing the astronaut at risk for hypokalemia. Hypomagnesemia is also common.

- **Cardiovascular**
  Decreased intravascular volume leads to reductions in central venous pressure (CVP), stroke volume (SV), cardiac output (CO), and left ventricular end-diastolic volume (LVEDV). SV upon return to Earth

has been documented to be approximately 75% of that pre-flight. LVEDV demonstrates similar reductions. A compensatory tachycardia is common. Vasomotor tone is decreased during spaceflight and astronauts cannot acutely increase their systemic resistance upon return to gravity. As a result, astronauts tend to be orthostatic and markedly tachycardic, both of which may mimic shock and complicate resuscitation. Careful attention to the need for invasive hemodynamic monitoring and assessment is necessary.

As a result of both volume and electrolyte changes, rhythm disturbances may also occur including:

- premature ventricular complexes (PVC's)
- supraventricular tachycardia (SVT)
- bradycardia with increased PR interval
- atrial fibrillation
- atrial flutter

Development of SVT in an astronaut on the MIR station resulted in early termination of a mission. EKG changes have also prevented a MIR astronaut from proceeding with a scheduled EVA.

- **Pulmonary**

  Microgravity has profound influences on alveolar size, ventilation, and perfusion. As a result, four changes occur in pulmonary physiology during spaceflight:

  - Thoracic blood volume increases
  - Hydrostatic pressure changes are absent
  - Blood is redistributed within the lung
  - Pulmonary alveolar ventilation is altered by changes in ribcage and abdominal wall mechanics

  Gravity normally results in differences in perfusion, ventilation, and gas exchange within the lung. Such changes can be described using West's lung zones I, II, & III. With loss of gravity, West's lung zones are abolished, and pulmonary perfusion, ventilation, and gas exchange are largely equalized throughout the lung. Whereas on Earth areas of increased perfusion are associated with areas of increased ventilation, in microgravity this is reversed (i.e., increased perfusion is associated with decreased ventilation). Gravity thus improves ventilation-perfusion ratio while microgravity decreases the ratio making the lung less efficient. The effects of prolonged spaceflight on pulmonary function and respiratory muscle strength remain largely unknown.

  Of further concern is that the astronauts are breathing within a very enclosed space and are exposed to a number of chemical substances. Small aerosols may become deposited in alveoli and cause respiratory dysfunction. Astronauts exposed to the hypergolic agents can manifest significant respiratory compromise as a result of the exposure. Such dysfunction, however, may not be immediately apparent and respiratory collapse may not occur for 6-24 hours post-exposure. Bronchiolitis obliterans may develop several months post-exposure.

- **Neurologic**

  Neurovestibular changes are common in spaceflight. "Space motion sickness" (SMS) occurs in approximately 50% of astronauts with symptoms similar to that of air or seasickness. Posture and locomotion are both abnormal during space travel and such tendencies may continue after return to Earth. Coordination may be altered and is a significant concern for astronaut pilots. NASA's standing rule is that no astronaut who has been in space for more than 20 days may pilot a spacecraft back to Earth. Proprioceptive illusions are common including perceptions of moving walls and floors. Visual illusions are also common. Many astronauts report orientation illusions such as feelings of being inverted. All of these findings may obscure mental status evaluation and mimic brain injury / dysfunction.

- **Musculoskeletal**

  The loss of positive muscle resistance in microgravity results in loss of muscle size and strength. Rapid muscle fatigue, hyperreflexia, and reduced neuromuscular efficiency are common. These changes are directly proportional to the duration of space travel. As a result of muscular deconditioning, 50% of the astronauts would have trouble evacuating themselves from the Space Shuttle, 15% could not climb out the cockpit roof escape hatch, and 5% could not even crawl out the side evacuation hatch. Astronauts are typically 1-2 inches taller in microgravity due to unloading of the spinal column. As a result, back pain is common upon return to gravity and may confound physical examination of a possible spine injury. The shuttle pilot and copilot are required to exercise every other day throughout the mission and every day for the three days before landing in order to maintain muscular and cardiovascular conditioning.

The astronaut who has been in space for 4-6 months will return to Earth having lost 20% of their upper extremity strength, 50% of their lower extremity strength, and 50% of their paraspinal muscle strength.

- **Bone Metabolism**
  Reduced mechanical stress on bone during spaceflight reduces osteoblast activity and increased osteoclast activity. Urinary calcium losses are significant and further exacerbated by reduced intestinal absorption of calcium. These findings are of particular concern with prolonged space travel as will occur with the ISS. During prolonged spaceflight, 1-3% of an astronaut's total body calcium is lost per month. Development of renal calculi as a result of the increased urinary calcium concentrations is a significant concern and almost required that a MIR mission be terminated early due to symptomatic nephrolithiasis in a Russian astronaut. Astronauts may be more prone to fractures during spaceflight. It is postulated that fractures may not heal well in microgravity as a result of the reduced osteoblast function.

- **Hematologic**
  Erythopoetin secretion is reduced in microgravity resulting in an "anemia" of spaceflight. Further, there is increased red blood cell (RBC) destruction by the spleen. As a result, RBC mass is decreased by 7-17% and hemoglobin and hematocrit by 3-26%. These changes compound the effects of traumatic injury.

- **Immune function**
  Space travel appears to be immunosuppressive. Cortisol levels are increased and interleukin-1 levels decreased. Neutrophil count is elevated, but all other cell lines are decreased. Astronauts appear to be at risk for infection. Development of urosepsis / prostatitis in a Russian astronaut has resulted in termination of a MIR mission.

- **Pharmacology**
  Astronauts may not respond as one would anticipate to medications administered during care and resuscitation for a number of reasons:

    - decreased bioavailability
    - slower gastric emptying
    - faster intestinal transit
    - reduced enzyme activity
    - altered gut flora
    - increased volume of distribution
    - increased renal excretion of many drugs

ASTRONAUT IDENTIFICATION

Prior to each Space Shuttle launch, the classified medical records of each crewmember are delivered to ORMC and maintained by Dianna Liebnitzky, Trauma Coordinator. In the event of a Space Shuttle contingency, these records will be made available to the ORMC Trauma Team. They include a complete history and physical examination on each crewmember. Astronauts may not have their name on their flight suit. Identification will be by a color-coded tag located on the helmet, flight suit, and boot. The tag contains a letter and a number, such as "A1" or "E4", which corresponds to their role (i.e., "A" = commander, "E" = mission specialist).

ADVANCED CREW ESCAPE (ACE-2) SUIT REMOVAL

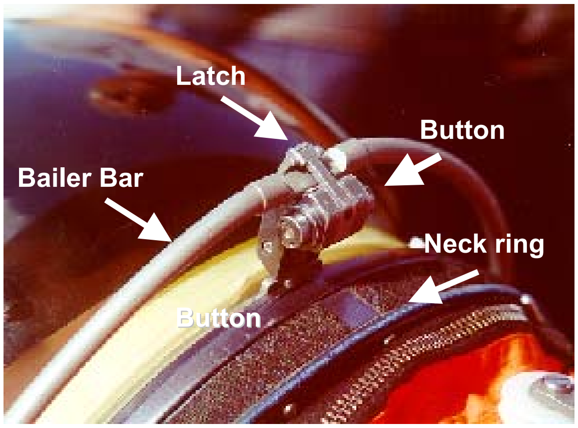
The Advanced Crew Escape (ACE-2) Suit is a pressurized flight suit that weighs approximately 80 pounds. It came into widespread use following the Challenger incident. It is a one-piece flight suit and is constructed of fire-resistant Nomex™. To enter the suit, the astronaut must assume a fetal position and pull the suit on by entering it through a zipper on the back. A specialized helmet, modified military anti-gravity suit, and canvas boots complete it. During re-entry, the "G-suit" is inflated to counteract the orthostatic hypotension / autonomic dysfunction that occurs with spaceflight. Astronauts therefore essentially have military anti-shock trousers (MAST) in place and inflated upon re-entry. This fact must be taken into consideration when removing the astronaut's flight suit. It may be of more use left in place until the astronaut's shock state is reversed. Underneath the ACE-2 suit is an undergarment cooling suit, which contains an extensive array of plastic tubes sewn into a fabric garment. This suit can be easily cut.


The ACE-2 Advanced Crew Escape Suit (left)
Cooling suit (right)

The water within the cooling tubes contains a small amount of silver nitrate ($AgNo_3$) as a bacteriostatic agent; this represents minimal threat to patient or healthcare personnel. Under the cooling suit is worn a pair of thermal-type underwear.

Portions of this ensemble may or may not have been removed and/or cut open prior to arrival at ORMC. Bandage scissors are all that is needed to removal the suit, but this is a very involved process and can take upwards of 20 minutes to accomplish. There are actually five separate layers to cut to fully expose the astronaut and many portions of the suit contain wires or cables that must be avoided. For immediate access to the astronaut in order to perform emergency procedures, the following points should be kept in mind:

- The helmet faceplate and visor must be opened to gain access to the astronaut's face. This should be done immediately on arrival if not already done in the field. This is performed by first pushing down on the bar and pulling out the upper clasp of the latch. The two buttons on the "bailer bar" latch must then be squeezed simultaneously. At this point the bailer bar will elevate itself (unless jammed) and the faceshield may be opened and locked into place.



Bailer bar of astronaut helmet

- After opening the helmet faceplate, the communications cable must be either disconnected or cut. This is located in the right mandible area. This cable connects the helmet and the skullcap. Failure to disconnect the cable will result in the astronaut's head being pulled during removal of the helmet.

- The helmet connects to the rest of the suit via a locking “neck ring”. The helmet-neck ring latch is opened by pulling it out and sliding it forward.
- The neck ring contains a rubber diaphragm or “dam” which fits snuggly around the neck. Its purpose is to maintain positive pressure within the suit. The dam can be stretched, while the helmet is still in place, to check for neck trauma and/or tracheal deviation. Radial cuts in the rubber dam will allow access to the internal jugular veins until the astronaut’s suit can be removed further. Complete access to the neck, such as for a cricothyroid-otomy, can be achieved by cutting through the fabric of the suit just below the neck ring.

- The head and neck are fairly well immobilized in good, in-line traction as long as the helmet is left in place. Intubation is very difficult, however, unless the helmet is removed. This is performed by unlocking the latch on the right side of the neck ring, disconnecting the helmet from the neck ring. An alternative to removing the helmet is to cut the fabric circumferentially immediately below the neck ring and above the oxygen supply hose, removing the helmet and neck ring as one piece. This allows a thorough evaluation of the head and neck as well as placement of a cervical collar.

- Removal of the helmet requires three people. As with a common motorcycle helmet, the first person reaches into the helmet and holds the head and neck in manual in-line traction while the remaining two remove the helmet. Once the helmet is removed, a towel needs to be placed under the head in order to maintain the head and neck in neutral position. The neck ring will preclude placement of a cervical collar until it is removed by cutting the fabric around the ring circumferentially.

- A survival vest will likely be present. This contains a life raft, flotation device, two oxygen cylinders, and other survival equipment. Cutting through this vest is difficult and may be hazardous due to the presence of the cylinders. Unzipping or cutting the vest down the midline will allow the vest and its contents to be folded laterally and out of the way. If the flotation device is still inflated, it can be punctured and deflated to facilitate access to the patient.

- Holes can be cut in the fabric over the clavicles and groins in order to allow emergency access to the subclavian or femoral vessels for vascular access.
- Access to the chest and abdomen can be obtained by cutting the fabric across the neck from one shoulder to the other and then extending down each side of the chest (see dashed lines to the right). The fabric can then be folded down onto the abdomen allowing access for line placement, tube thoracostomy, and focused abdominal sono-graphy for trauma (FAST) exam.

- Gloves are removed by cutting the fabric just proximal to the wrist disconnect ring or lining up the “I” with the “III” on the wrist disconnect ring and removing the glove. This allows IV’s to be started in the hand or wrist. The fabric just above the wrist disconnect ring can also be cut longitudinally to gain access to the entire arm.

- The controller for the anti-gravity suit is located on the left leg.

- A “biomedical instrumentation port” is located in a pocket on the inner right leg just below the knee. Through this port, physiologic monitoring cables and even arterial or venous access cables may pass depending on the shuttle mission experiments which were performed. Care must be taken when cutting the suit in this area. Complete access to the astronaut’s legs can be achieved using longitudinal cuts in the fabric of each leg.

- Shoes are canvas and can be easily cut.

INITIAL RESUSCITATION

- Initiate ATLS principles as for any trauma victim.
- Protect yourself at all times with protective gown, eyeshields, and gloves. Although the patient will likely have been already decontaminated at the scene, small amounts of hypergolic fuel may still reside on the victim's clothes. If you are not adequately protected, you may well become a victim yourself and further stretch the staff and facilities resources. If a burning sensation is felt when caring for these patients, immediately change gloves and wash your hands. Standard gloves will provide short-term protection from the hypergolic agents, but they should not be relied upon for long-term protection. If strong chemical odors are present, the victim's clothes are likely "off-gassing" toxic fumes and all clothing should immediately be removed from the Emergency Department. In severe situations, healthcare personnel may need to don respiratory protective equipment. Patients who do not appear to have been adequately decontaminated prior to arrival at ORMC should be washed off for 20 minutes outside the Ambulance Entrance before entering the Trauma Bay.
- Due to the concern for pulmonary dysfunction, supplement oxygen and follow arterial oxygen saturations closely. Consider intubation as needed to protect the patient's airway and ensure adequate oxygenation and ventilation. Watch for acute airway compromise and laryngospasm.
- Obtain large bore IV access and remember that astronauts will be significantly volume depleted.
- EXCEPT FOR A TRAINING SESSION, do not hesitate to cut away the victim's flight suit to gain access for invasive procedures and physical examination. Do whatever is necessary to obtain the most rapid exposure of the patient possible. If you have difficulty cutting through a portion of the suit, do not waste further time – find another way to gain access.
- On the orange ACE-2 suit, a **yellow stain** indicates that the astronaut was exposed to **hydrazine** while a **black stain** on the suit indicates exposure to **nitrogen tetroxide**.
- On the blue cooling suit, a **black stain** indicates that the astronaut was exposed to **hydrazine** while a **white stain** on the cooling suit indicates exposure to **nitrogen tetroxide**.
- If hypergolic fuel exposure is suspected, administer pyridoxine to prophylax against seizures (see Table 1).
- Remember to treat the patient's traumatic injuries simultaneously.

SUGGESTED READING

- Kennedy Space Center Spaceflight Medical Support Training Course (SMSTC) 2000 syllabus

- Extreme Critical Care: Space Travel in the 21st century. 29th Society of Critical Care Education and Scientific Symposium. February 2000. Orlando, FL.
  - Introduction to Space Travel. Smith Johnston, MD
  - Cardiovascular Physiology. Victor Convertino, Ph.D
  - Gravity and the Lung: Lessons from Microgravity. G. Kim Prisk, Ph.D
  - Surgery in Space. Mark Campbell, MD
  - Crew Return Vehicle. Smith Johnston, MD
  - "Houston, we have a problem…". Phillip Scarpa, MD

- Space Shuttle Solid Rocket Booster Retrieval Ships. KSC Form 2-203NS (Rev. 11/92).

- NASA Casualty Fact Sheet, Department of Surgical Education, Orlando Regional Medical Center.

- Countdown! NASA Launch Vehicles and Facilities. IS-1997-10-03-KSC. October 1997