Overview

Regardless of mission length or objectives, all human spaceflight requires some degree of in-mission medical support. The transition from a gravitational environment to microgravity, coupled with living in a closed-loop environment, can result in variable physiological effects and health risks. For example, anticipated physiological impacts of the microgravity environment include fluid redistribution and subsequent head congestion, particularly during the space adaptation phase. Such effects typically occur within a predictable timeframe and will affect all crewmembers to some degree.

To ensure mission success and a positive spaceflight experience, known physiological effects of the spaceflight environment must be anticipated and mitigated where possible. Integration of varied strategies, including crew selection processes, pre-mission quarantine, in-mission medical capabilities, and ground medical support, are necessary to ensure crew health and optimal performance. Simultaneously, vehicles must be designed to optimize crew health and performance and accommodate any necessary medical capabilities, equipment, crew training, and physical space.

The knowledge and tasking of medical actions can be distributed among crewmembers, medical devices or aids, artificial intelligence systems, robotic systems, or similar. Additionally, incorporating ground medical support is key to many medical capabilities during flight and requires streamlined integration of variable technologies, ground communications, and support systems. Integration of these systems enables the provision of medical care and ensures crew health during a mission.

Pre-mission		In-mission	Post-mission	
Selection Standards				
	Health Stab. Program			
		In-mission Medical Treatment & Capabilities	***Immediate Post-landing Care***	
Longitudinal Health Surveillance				

The table displays the interaction between five key elements necessary to promote crew health and performance:

1. Crew Selection Standards – discussed in this technical brief
2. Health Stabilization Program (HSP) – reference Health Stabilization Program technical Brief
3. In-mission Medical Treatment & Capabilities – discussed in this technical brief
4. Immediate Post-landing Medical Care i.e., care provided immediately upon return to Earth – discussed in this technical brief
5. Longitudinal Health Surveillance – reference Longitudinal Health Surveillance technical brief

Relevant Standards

This technical brief is inclusive of **NASA-STD-3001 Volume 1, Rev B** as a whole. A list of Volume 1 Standards is included at the end of this technical brief and the full document can be found at the following link: *https://www.nasa.gov/offices/ochmo/human_spaceflight/standards101*

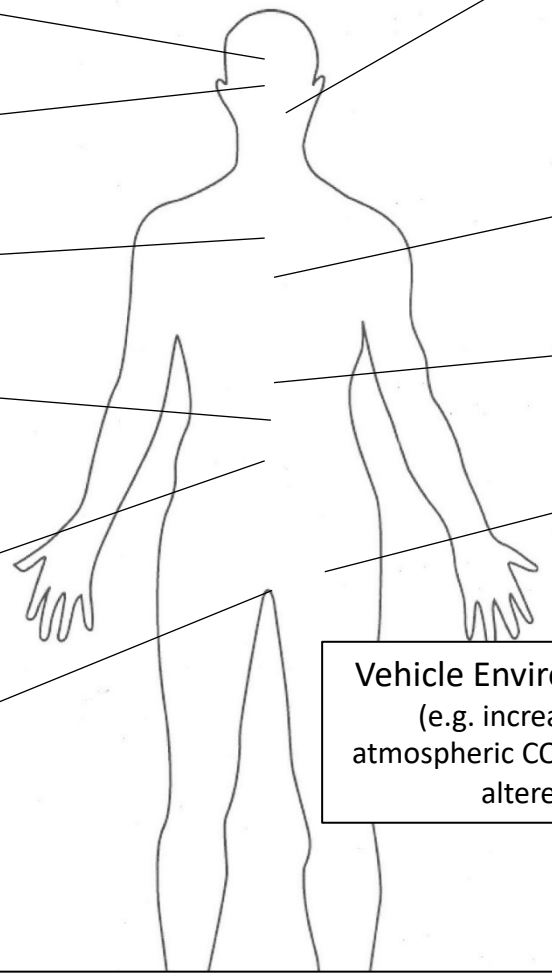
NASA-STD-3001 Volume 2, Rev C

[V2 3001] Selection and Recertification

[V2 3002] Pre-Mission Preventive Health Care

Changes During Spaceflight

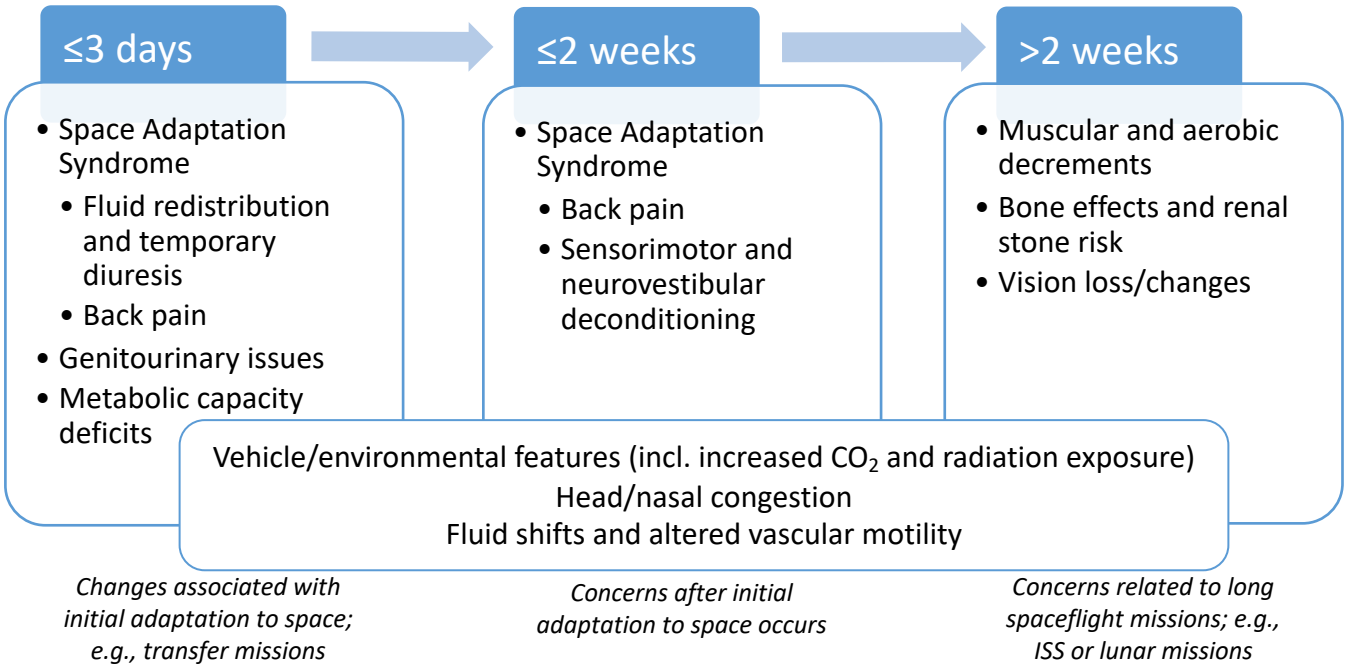
Prevalent Physiologic Changes Experienced due to Microgravity and Vehicle Design



- Vision Changes/Loss
- Head and/or Nasal Congestion
- Muscular and Aerobic Decrements
- Lower Back Tightness & Pain
- Fluid Shifts, Altered Vascular Motility, and Orthostatic Intolerance
- Genitourinary Issues
- Sensorimotor Deconditioning
- Metabolic Capacity Deficits
- Space Adaptation Syndrome
- Bone Remodeling and Renal Stones
- Vehicle Environmental Considerations (e.g. increased radiation exposure, atmospheric CO_2, toxic chemicals, and VOCs; altered pressures & DCS)

All crewmembers experience the above effects to some extent. Minimizing the potential for communicable disease transmission through screening and effective pre-flight quarantine in the Health Stabilization Program (HSP) lessens potential in-mission impacts of infectious disease. Subsequent in-mission medical support is critical for the mitigation of the above effects and maximizing crew performance and experience. Finally, NASA crewmembers are selected through a rigorous set of procedures in order to minimize some of the above effects. For example, certain cardiac, musculoskeletal issues, and osteopenia are selected out to enhance mission success.

Physiologic Timeline



≤3 Days – *changes associated with initial adaptation to space; e.g., transfer missions*

Space Adaptation Syndrome (SAS) – neurovestibular adaptation to microgravity; symptoms include nausea, emesis, headache, malaise, vertigo; cephalad shift of fluid, resulting in facial "stuffiness"

- Affects 50-70% of crewmembers
- Treatment: pharmaceutical options, inactivity, head movement exercises, head restraints, 1g orientation and pre-mission training / prophylaxis

Head/nasal congestion – space adaptation or CO_2-related

- Affects >50% of crewmembers
- Treatment: pharmaceuticals (congestion or allergy meds)
- Leading cause of prolonged medication use in-mission

Fluid redistribution – 12-15% reduction in whole body volume, temporary diuresis with polyuria

- Affects all crewmembers
- In-mission treatment is not needed; vehicle must accommodate temporary increased urine output
- Subsequent euvolemia, but continued third spacing of fluids throughout the mission

Genitourinary issues – subset of crew who experience urinary retention with space adaptation

≤2 weeks – *concerns after initial adaptation to space occurs*

Lower back tightness & pain (i.e., Space Adaptation Back Pain, SABP) – back pain associated with the physiological changes in spaceflight; SABP is distinguished from other types of back pain if it develops within the first few days of the mission

- Affects 52% of crewmembers
- Positioning, exercises, and pharmaceutical options to manage (≥85% pain relief effectiveness for all treatments)

Physiologic Timeline

>2 weeks – *concerns related to longer missions; e.g., ISS or lunar missions*

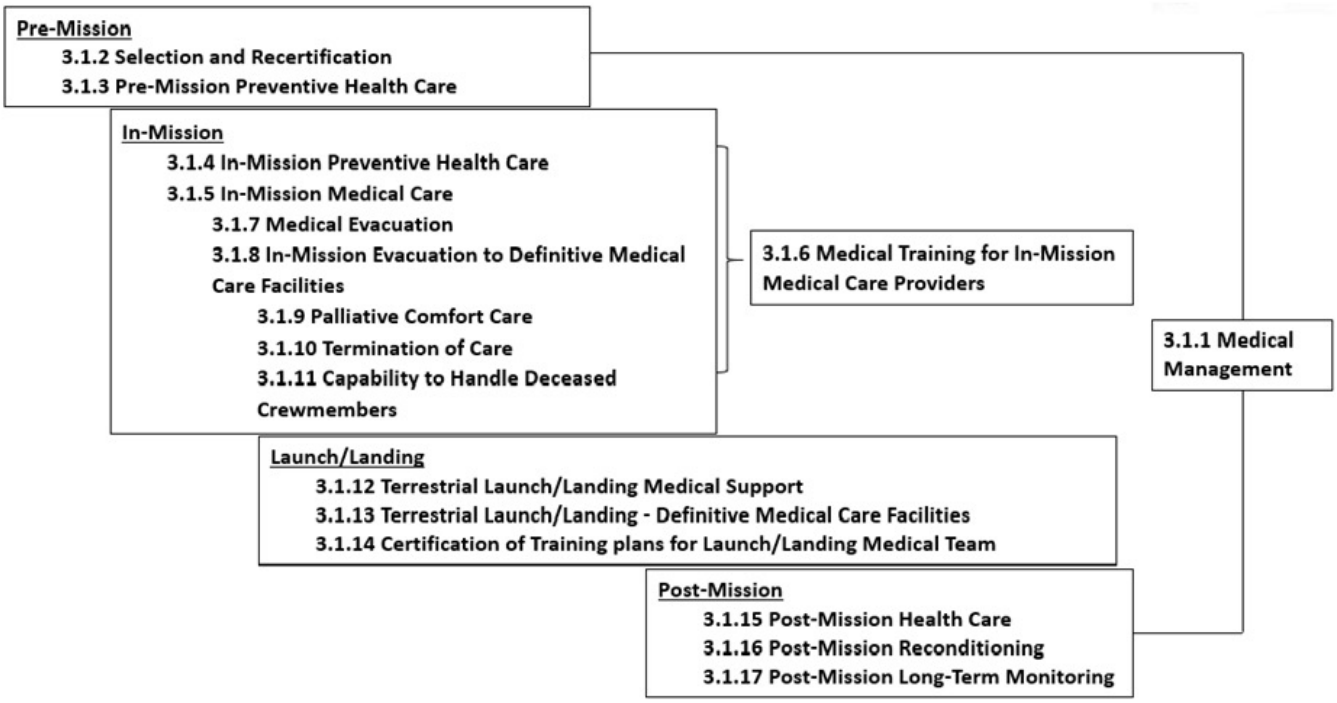
- Aerobic and muscular decrements – decrease in aerobic capacity and muscle mass and tone over the mission
  - Begin for all crewmembers upon exposure to microgravity, but are mainly a concern for longer missions: more muscle & aerobic capacity are lost the longer the crew is in microgravity
  - Countermeasures/treatment: exercise – resistive and aerobic, can be highly effective
  - Upon re-exposure to gravity, decrements incurred due to spaceflight must be accounted for
- Bone effects and renal stone risk – microgravity induces bone atrophy, approximated at 1.5%/month; almost fully mitigated by exercise; bone loss increases circulating calcium, which impacts renal stone risk
  - Bone effects begin for all crewmembers upon exposure to microgravity, but are mainly a concern for longer missions – more bone is lost the longer the crew is in microgravity, which leads to a increased renal stone risk
  - Countermeasures/treatment: pharmaceutical options and exercise
- Vision alterations (Spaceflight-Associated Neuro-Ocular Syndrome (SANS)) – ocular changes including disc edema, choroidal folds, globe flattening, and/or hyperopic shifts in refractive error; believed to be associated with cephalad fluid shifts and possibly with diet or environmental factors. Vision changes could impact performance.
  - 16% of crewmembers show disc edema during/after long-duration missions; most findings subclinical, some require corrective lenses
  - Treatment: corrective lenses, and adjustable glasses can be flown to aid vision adjustments; potential countermeasures: pharmaceuticals, environmental/dietary considerations
- Altered vascular motility – stagnant or reverse flow in the internal jugular vein has been observed in 6 of 11 crew members (55%) tested in mission on approximately flight day 50; one crewmember was found to have an occlusive internal jugular vein thrombus. This is an emerging finding and has potential impacts on flight participants with cardiovascular conditions.
- Increased radiation exposure – an increased risk of developing cancer post mission
  - Space Environment radiation exposure – increased exposure outside of low-Earth orbit
  - Shielding is effective against some radiation exposure (solar particle events (SPE), but does not mitigate Galactic Cosmic Radiation (GCR) exposure
  - Primary risk is for carcinogenesis (post-mission); additional risks for cataract development and potential cardiovascular or neurological sequelae (reference the Design for Radiation Protection technical brief)

Upon re-entry to 1g: descent and landing

- Sensorimotor and neuro-vestibular deconditioning – the brain and neurological systems that control balance and motor skills adapt to microgravity within 2 weeks of spaceflight missions; it takes hours to days for the body to readapt to gravity upon landing, with associated balance issues and visual inconsistencies
- Affects all crewmembers post-landing to some extent; may be severe enough that crew cannot perform functional/ operational tasks (e.g., fall recovery)
- Impacts vehicle design (e.g., displays and controls)
- Prevention: in-mission exercise provides some benefit
- Treatment for symptoms similar to SAS

Health and Medical Care Standards for Astronauts

NASA updated the Health and Medical Care Standards for Astronauts. The following requirements reflect this comprehensive approach to astronaut health and well-being, addressing screening, preventive health strategies, medical care, contingencies during launch and landing, and post-mission Healthcare, reconditioning and long-term monitoring. These detailed standards can be found in NASA-STD-3001, Volume 1, Revision B at https://www.nasa.gov/offices/ochmo/human_spaceflight/index.html



Comprehensive set of Health and Medical standards from crew selection to post-mission health care.

Medical Program Design Guidance Overview

- The importance of the interaction between crew selection, health stabilization programs, longitudinal health surveillance, in-mission medical capabilities, and immediate post-mission medical care cannot be overstated. These program aspects, in conjunction with vehicle design, work together to maximize crew health and performance over the mission, while helping to minimize resource footprint and wasted time during the mission.

  Medical Program Design begins with crew selection but is maintained throughout the pre-flight and mission cycle.

- By employing selection criteria and selecting out certain conditions, healthier individuals are flown and less risk is present in-mission.

  If the selection criteria is broadened, in-mission medical capabilities need to accommodate the anticipated conditions and if the conditions are exacerbated by spaceflight.

- Crewmembers should participate in a health stabilization program (HSP) to promote success over the full length of the missions.

  HSPs help reduce the burden of spaceflight adaptation by ensuring the crew begin missions with good health & minimize risk of communicable diseases.

- To reduce the need for in-mission medical care and mitigate the risks of spaceflight, activities should be performed pre-, in-, and post-mission to help the crewmember achieve maximal health (i.e., longitudinal astronaut health surveillance, training, countermeasures, and reconditioning should be employed).

  By taking a preventive approach rather than a reactionary one, total onboard resources and required mission capabilities can be reduced and optimized.

- Based on the most common conditions expected and seen during missions, NASA tailors in-flight medical capabilities and skillsets to ensure that the most likely or impactful medical or physiological events can be managed and crew health can be optimized. There are additional conditions and capabilities that may be applicable after an overall mission architecture assessment is completed; these are similarly tailored to every program.

Crew Selection

NASA 2021 Astronaut Class

Crew selection is the starting point for predicting subsequent medical care. While the chance of medical events for every person is non-zero, a person who is selected through rigorous medical and psychological selection standards should require less in-mission medical care, be more productive, and have a more positive experience. As a result, the overall mission risk and probability of a medical event causing a loss of crew event and/or diminished performance are reduced. When considering which selection criteria are most impactful, parameters that should be considered include: potential impact on the in-mission health and productivity of the individual if a condition occurs or reoccurs; whether or not a condition will be exacerbated by spaceflight exposure (e.g., gravity, pressure changes, atmospheric constituents, etc.); limitation of treatments in a vehicle with restricted capabilities and resupply; and the long-term health and operational effectiveness of the individual. Examples of conditions that may require further evaluation or assessment of risk during selection due to their potential exacerbation in spaceflight include:

- Altered / partially obstructed nasal passages – this condition(s) could lead to complications when considering a vehicle's atmosphere, microgravity-induced cephalad fluid shifts, and incidence of head/nasal congestion
- Orthostatic intolerance/hypotension – spaceflight-induced fluid redistribution may lead to exacerbation of the condition during and/or after the mission and landing
- Musculoskeletal, neuro-vestibular, and/or sensorimotor deficits and abnormalities – due to changes occurring in all three of these systems, pre-existing conditions may increase in-mission risk
- Pre-existing back pain and/or abnormal curvature of the spine – spinal elongation and space adaptation back pain may cause further issues in-mission
- History of kidney stones and/or osteopenia – as bone loss is known to occur and renal stones are considered high risk, selecting out a predisposition to these conditions may increase mission success
- Disc edema, choroidal folds, globe flattening, hyperopic shifts in refractive error – these findings are associated with Spaceflight-Associated Neuroocular Syndrome (SANS); if preexisting, these conditions may exacerbate SANS and sequelae such as visual decrements
- Obstructive pulmonary conditions – decrease in aerobic capacity in-mission may lead to worsening of the crewmember's condition or limit operational effectiveness
- Chronic diseases that may be difficult to treat in the confines of a vehicle with limited supplies
- Behavioral/Psycho-Social conditions – increase strain of being in a confined environment with limited interactions may amplify existing conditions or manifest new conditions

NASA performs examinations during selection, as well as annually, to ensure astronaut health and treat any medical conditions found. Broadly, in-depth evaluations and assessments are performed for the following areas before a crewmember enters the astronaut corps or is certified to fly: full physical examination; ophthalmology/optometry; otolaryngology/ ears, nose and throat (ENT); cardiopulmonary; psychiatry/ psychology; gastroenterology; neurology; dental; radiation history; gynecology; imaging; and laboratory tests.

Medical Program Design Guidance

In-mission medical care is influenced by the following:

1. Expected conditions due to spaceflight adaptation (e.g., neurovestibular adaptation, back pain, muscle loss, etc.)
2. Pre-mission Health Stabilization Programs (e.g., communicable diseases prevention (influenza, cold), vaccinations)
3. Mission architecture (EVAs, decompression protocols, environmental conditions of vehicle, etc.)
4. Crew selection criteria (e.g., cardiovascular conditions, behavioral conditions)
5. Mission duration
6. Distance from Earth, time to definitive medical care, and required autonomy
7. Destination / gravitational environment

Some conditions present due to the microgravity environment or are treated differently compared to terrestrial practices. These conditions include, but are not limited to:

- **Sleep Loss and Alertness**: circadian shifts and abnormal sleeping orientations lead to loss of sleep in crewmembers and subsequent alertness deficits
  - Treatment may be as simple as sleep aids (~71% use in crew; 10x higher than use in adult ambulatory medicine) and alertness aids (~21% use in crew)
  - Sleep aids are the leading reason for acute medication use in-mission
- **Headaches**: present at increased incidence during spaceflight, with contributory factors including elevated CO_2 levels, fluid shifts, pressure changes, and other non-spacecraft-associated factors
- **Joint and Muscle Pain**: increased incidence due to extravehicular activity (EVA) and exercise equipment used during the missions

Most conditions can be treated as they are on Earth, though mass, volume, consumables, and capability restrictions may limit the scope of in-mission medical treatment. Since full terrestrial care and treatment may not be possible, medical kits should be optimized to provide the best available care. Pertinent considerations include minimizing long-term health impacts and future mission success. In addition, prioritization should be given to medications that can serve multiple purposes and minimize adverse or unwanted side effects.

Extensive consideration should be given to all medications administered in-mission due to the closed-loop environment. For example, a medication that increases urinary calcium output is not only putting the crewmember at a greater risk of developing kidney stones but may also cause further stress on a vehicle's water reclamation system. Another consideration is the pharmaceutical treatment pathway. Sprays, for example, may not be as desirable as solid medications due to lack of gravity and vehicle air flow patterns.

Side effects of all medications should also be considered due to the bevy of spaceflight-induced physiological changes. For example, cardiovascular deconditioning and fluid redistribution is seen in all crewmembers. Thus, medications that produce effects such as cardiac depression or vasodilation should be avoided.

In-Mission Preventive Health Care & In-Mission Medical Care

All programs shall provide training, in-mission capabilities, and resources to monitor and treat physiological and psychosocial well-being and enable delivery of in-mission preventive health care, **based on epidemiological evidence-based probabilistic risk assessment (PRA)** that takes into account the needs and limitations of each specific design reference mission (DRM), and parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more.

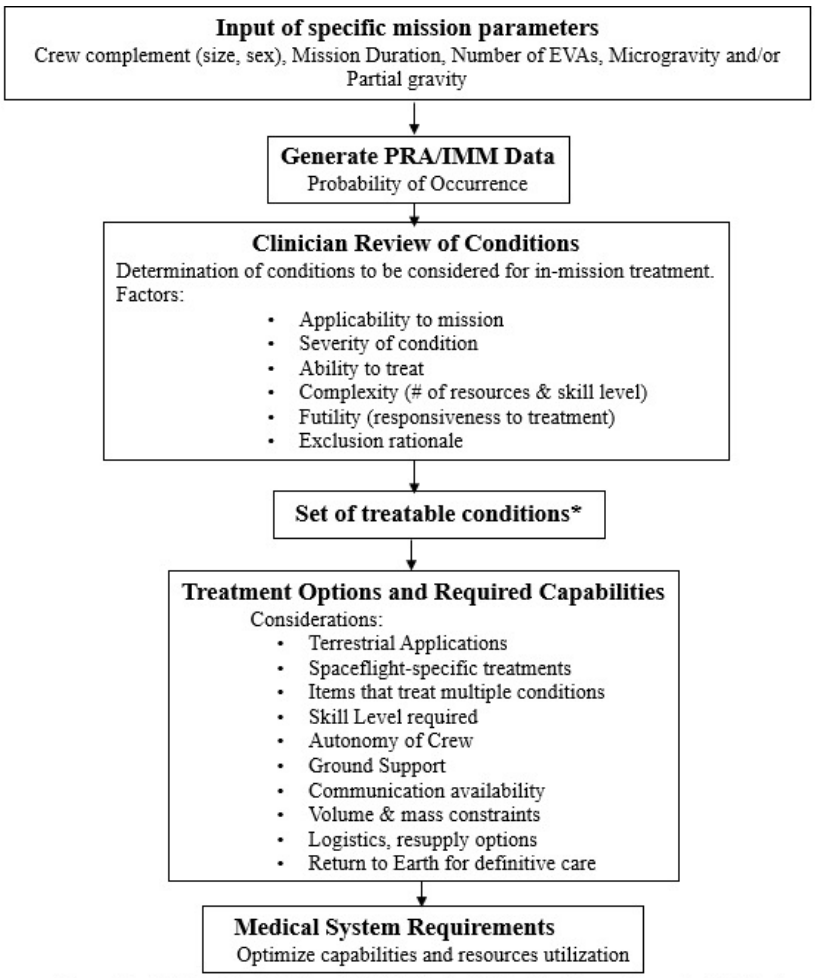


Figure 3—Outline for the Use of PRA Data to Aid in the Generation of a Medical Conditions List

*Refer to Table 11 for a medical conditions list.

From NASA-STD-3001 Volume 1, Rev B

Epidemiological evidence-based probabilistic risk assessment (PRA) approach utilizing ISS experience and terrestrial data.

Table 7—Sample IMM Output

	Medical Condition	Likelihood
1	Late Insomnia	13.85 per mission
2	Skin Abrasion	9.86 per mission
3	Skin Rash	9.83 per mission
4	Eye Abrasion	7.42 per mission
5	Late Headache	5.25 per mission
6	Space Motion Sickness (SAS)	4.37 per mission
7	Diarrhea	3.53 per mission
8	Nasal Congestion	3.51 per mission
9	Respiratory Infection	3.46 per mission
10	Back Injury	3.41 per mission
11	Barotrauma (Ear/Sinus Block)	3.28 per mission
12	Back Pain (SAS)	3.15 per mission
13	Insomnia (SAS)	2.70 per mission
14	Shoulder Sprain/Strain	2.43 per mission
15	CO_2 Headache	2.15 per mission
16	Headache (SAS)	2.11 per mission
17	Spaceflight Associated Neuro-ocular Syndrome (SAS)	2.08 per mission
18	Urinary Tract Infection	1.44 per mission
19	Skin Infection	1.38 per mission
20	Elbow Sprain/Strain	1.32 per mission
21	Ankle Sprain/Strain	1.22 per mission
22	Allergic Reaction	1.18 per mission
23	Pharyngitis	1.17 per mission
24	Constipation	1.02 per mission
25	Neck Injury	0.99 per mission
26	Mouth Ulcer	0.96 per mission
27	Dental Caries	0.88 per mission
28	Knee Sprain/Strain	0.78 per mission
29	Paresthesia [Extravehicular Activity (EVA)]	0.65 per mission
30	Indigestion	0.64 per mission
31	Eye Chemical Burn	0.64 per mission
32	Sinusitis	0.64 per mission
33	Hearing Loss	0.57 per mission
34	Wrist Sprain/Strain	0.55 per mission
35	Eye Infection	0.53 per mission
36	Hip Sprain/Strain	0.45 per mission
37	Gastroenteritis	0.42 per mission
38	Fingernail Delamination [Extravehicular Activity (EVA)]	0.40 per mission
39	Otitis Externa	0.32 per mission
40	Otitis Media	0.30 per mission
41	Hemorrhoids	0.22 per mission
42	Lower Extremity Stress Fracture	0.13 per mission
43	Urinary Retention	0.11 per mission
44	Skin Laceration	0.11 per mission

Integrated Medical Model probability risk assessment output which includes a list of potential conditions is utilized by flight physicians to generate an inflight medical system.

Table 8—Medical Conditions Considered of High Likelihood or High Consequence for Space Flight Missions

Conditions noted with an asterisk (*) should be addressed on every mission regardless of the DRM parameters.

Category	Specific Condition
Environmental or space flight-induced medical conditions	Acute radiation syndrome **Allergic reaction** * Altitude sickness **Anaphylaxis** * **Back pain (space-adaptation related)** * Barotrauma (ear/sinus block) Burn (thermal) Burns secondary to fire Celestial dust exposure Choking/obstructed airway Cold injury (chilblains frostbite) **Constipation (space-adaptation related)** * Decompression sickness Embolism Electrical injury Epistaxis (nose bleed, space adaptation related) EVA-related dehydration **Headache (CO_2 related)** * **Headache (space-adaptation related)** * Hearing loss (noise related) Heat illness Hypothermia Medication adverse reaction **Nasal congestion (space-adaptation related)** * Nutritional deficiency **Space motion sickness (space-adaptation related)** * Smoke/combustion product inhalation Toxic inhalation injury **Urinary incontinence (space-adaptation related)** * **Urinary retention (space-adaptation related)** *
Ophthalmic conditions	Acute glaucoma **Chemical eye injury** * **Corneal abrasion** * Corneal ulcer **Eye foreign body** * Eye infection Eyelid/anterior eye infection
	Loss of vision Penetrating eye injury Retinal detachment/injury SANS
Ear, nose, and throat conditions	Acute sinusitis Cerumen impaction Epistaxis (nose bleed) Hearing loss Otitis externa Otitis media Pharyn Respir
Dental/oral conditions	Caries Crown Dental Filling Fractu Oral u Tooth
Cardiovascular conditions	Acute Angin Cardia Cardio Gravi Hyper Sudde Traum Venou
Pulmonary and other chest conditions	Chest Chest Reacti Respir Respir
Gastrointestinal and other abdominal conditions	Abdon Abdon Abdon Acute Acute Acute Appen Const Diarrh Gastro Hemor Indige Reflux Small
Genitourinary conditions	Abnor Acute Acute Bacter Nephr Urina Unpro
	Vaginal yeast infection *
Musculoskeletal conditions	Acute arthritis Acute compartment syndrome Back injury (sprain/strain) Dislocation (finger, elbow, shoulder) Fingernail delamination (EVA related) Fracture (finger, hand, wrist/arm, distal leg, hip/proximal femur, thoracolumbar spine, cervical spine) Hand injury (EVA related) Joint sprain/strain (shoulder, elbow, wrist, hip, knee, ankle) Lower extremity stress fracture Muscular sprain/strain Neck injury (sprain/strain) Overuse injury – Upper or lower extremity Paresthesia Subungual hematoma Suit contact injury (EVA related) Vertebral disc injury
Dermatological conditions	Burn – Chemical, skin **Cellulitis – Bacterial skin infection** * Herpes zoster (Shingles) **Skin abrasion** * **Skin laceration** * **Skin rash** * Toxic dermal exposure Viral/fungal skin infection
Neurologic conditions	Benzodiazepine/Opiate overdose Cerebrovascular accident **Gravity transition neurovestibular disturbance** * **Headache** * Head trauma (major) Head trauma (minor) Neurogenic shock Neuropathy (Central – impingement) Paresthesia Seizure
Psychological, cognitive, or behavioral conditions	**Acute stress** * **Adjustment reaction** * **Anxiety/panic** * Apathy/low motivation **Cognitive disturbance** * Delirium Depression Grief reaction **Insomnia/sleep disturbances/circadian dysregulation** * **Interpersonal conflict (i.e., team, ground, family)** * Lack of meaningful work and/or monotony **Mood disturbance (e.g., irritability)** * Neurocognitive disorders (adjustment, mood, anxiety, trauma-related, or stress-related) Psychosis Relationship problems (family, crew, mission support personnel) Work overload/burnout/exhaustion

From NASA-STD-3001 Volume 1, Rev B

Required In-Mission Capabilities

The following are examples of in-mission capabilities (i.e., procedures, protocols, vehicle accommodations, etc.) that might be required for a spaceflight mission.[1]

- Administer and manage medications
- Assess and store vital signs
  - e.g., blood pressure, oxygen saturation, heart rate, respiratory rate, etc.
- Perform physical exam and conduct screening exams/tests
- Perform procedures
  - e.g., inserting a catheter, suturing, blood draw, etc.
- Delivery of basic behavioral health and performance countermeasures
  - e.g., recreational time, books, movies, music, crew care packages, access to fresh produce, Earth viewing opportunities
- Assess and monitor physical, behavioral and cognitive health with neurobehavioral measurements
  - e.g., private medical/psychological conferences, computer-based programming, cognitive and psychological assessments, etc.
- Monitor, manage, and control sleep/fatigue
- Dietary control and nutrition monitoring
- Evacuation

Procedures & Protocols

- Configure environment for care
- Physical or pharmaceutical restraints for physiological and psychological use
  - e.g., restraint systems, various medications
- Medical support system (i.e., inventory monitoring/maintenance, etc.)
- Private two-way audio and video communication with ground
  - with ground medical and psychological support, family, and crew support system
- Knowledge augmentation
  - e.g., in-mission computer-based therapy, smart medical devices, just-in-time training, etc.

Vehicle Accommodations

[1]Capabilities can be tailored (i.e., added in or taken out) according to the mission profile and spacecraft design

Additional In-Mission Conditions for Program Consideration

Based on the required overall mission architecture assessment (activities, duration, vehicle design, etc.), the following conditions may need to be treated in-mission. **While some of the conditions can be treated as they are on Earth, mass, size, consumables, and capability restrictions may limit the scope of in-mission medical treatment.** Since full terrestrial care and treatment may not be possible, medical kits should be optimized to provide the best available care.

The below conditions are dependent on mission length, mission architecture, spacecraft design, launch/landing loads, the program's Health Stabilization Program (HSP), and mission activities. Thus, this subset of conditions may not apply to every spaceflight mission. Conditions from this list that are required to be treated in-mission should be tailored to each program. Such conditions may include:

- *Musculoskeletal conditions* – muscular sprain/strain; joint sprain/strain (shoulder, elbow, wrist, hip, knee, ankle); dislocation (finger, elbow, shoulder); fracture (wrist, hip/proximal femur, lumbar spine); lower extremity stress fracture
- *Ophthalmic conditions* – eye penetration (foreign body) / chemical burn / corneal ulcer / infection; SANS and potential vision changes; retinal detachment; acute glaucoma
- *Dental conditions* – caries; exposed pulp; dental abscess / filling loss / avulsion / crown loss
- *Abdominal conditions* – abdominal wall hernia; nephrolithiasis; acute pancreatitis; acute cholecystitis / biliary colic; small bowel obstruction; appendicitis; acute diverticulitis; acute prostatitis; hemorrhoids abnormal uterine bleeding
- *Psychological, Cognitive, or Behavioral Conditions* – work overload / burnout / exhaustion; lack of meaningful work and/or monotony; apathy / low motivation; grief reaction; depression; delirium; relationship problems (family, crew, mission support personnel); adjustment, mood, anxiety, trauma-related, stress-related, and neurocognitive disorders; psychosis
- *Infectious/Immune diseases* – pharyngitis; influenza; gastroenteritis; respiratory infection; herpes zoster reactivation
- *Other traumatic injuries* – back, neck, head, chest, abdominal injury; traumatic hypovolemic shock; neurogenic shock; barotrauma
- Hearing loss
- Paresthesia
- Decompression Sickness, secondary to EVA
- Fingernail delamination
- Burns, secondary to fire
- Smoke inhalation
- Choking / obstructed airway
- Altitude sickness
- Toxic exposure (e.g. ammonia, hydrazine, methane, formaldehyde, Freon, etc.)
- Sepsis
- Acute Compartment Syndrome

Rigorous crew selection should prevent major conditions from occurring. At NASA, individuals with any substantial risk of significant medical illness or decompensation from conditions are not certified for flight. If NASA-level crew selection criteria is not used, additional conditions may need to be considered for treatment in-mission, such as:

- Major cardiovascular events, e.g., myocardial infarctions and atrial fibrillation
- Major neurologic events, e.g., seizures and strokes (cerebrovascular accident (CVA))

Additional In-Mission Capabilities for Program Consideration

The following list of additional in-mission capabilities (i.e., procedures, protocols, vehicle accommodations, etc.) may be required based on mission length, mission architecture, spacecraft design, launch/landing loads, the program's HSP, and mission activities. Capabilities should be tailored to each program based on applicability and mass/volume constraints.

Asterisked (*) conditions are capabilities that may be needed for medically autonomous missions (i.e., no real-time ground communications).

Procedures & Protocols

- Delivery of physical health countermeasures
  - countermeasures intended to counteract cardiovascular, musculoskeletal, and neurovestibular deconditioning; e.g., exercise
- Monitor and trend vital signs
- Perform imaging
- Perform cardiac waveform monitoring
- Perform laboratory analyses
- Monitor and alter work/rest schedule and balance
- Individualized behavioral health and performance countermeasures suite*
  - e.g., each crewmember has access to their own personal device with entertainment, photos, audio, personal video clips, virtual reality, store and forward communications with family and friends
- Evidence-based asynchronous behavioral health treatment protocols available on electronic devices*
- Medical devices for treating neurobehavioral disorders
- Sensory deprivation countermeasures*
  - e.g., novelty, virtual reality, greenhouse
- Social isolation countermeasures*
  - e.g., games, observance of important holidays/events

Vehicle Accommodations

- Monitor and assess environment
- Access to private personal spaces and sleep accommodations with visual and auditory privacy

Example Medical Kit

Individual missions must have a detailed analysis to determine specific needs for Medical Kits. Physician screening and input will be required for every mission. Below is an example of two Medical Kit categories and related medications/equipment and medical conditions treated.

Pharmaceuticals	Examples	Examples of Associated Conditions[1]
Ophthalmic Medications	Cyclopentolate, eye lubricant (carboxymethylcellulose; dextran and hypromellose; mineral oil and white petrolatum), Fluorescein, Tropicamide	Eye irritation, eye chemical burn, eye abrasion
Other	Acetazolamide, Glycopyrrolate, Carbamide peroxide, iodine, silver nitrate	Altitude sickness, skin laceration, skin infection, sudden cardiac arrest, traumatic injuries
Overdose Medications	Flumazenil, Naloxone	Benzodiazepine or opioid overdoses
Pulmonary Meds	Albuterol, Benzonatate, Dextromethorphan, Fluticasone, Salmeterol	Smoke inhalation
Stimulants	Caffeine, Modafinil	Insomnia / sleep disorder

Note: the pharmaceuticals list does not include crewmember personal medications (e.g., antihypertensives, statins, etc.)

Medical Equipment & Technology	Related Parts/Equipment	Examples of Associated Conditions[1]
AMBU bag and mask	--	Respiratory distress, cardiac event
Antiseptics	BZK wipes, iodine swabstick	Skin laceration, abrasion
Bandages	Band-Aids (1”x3”, 2”x3”, knuckle, dot); burn, and clear bandages; gauze; medical tape	Skin laceration, burn, traumatic injury
Biohazard trash bags	--	Bleeding, vomiting
Blood oximeter	--	Altitude sickness, choking /obstructed airway, smoke inhalation
Blood pressure monitor	Cuffs (varying sizes); manual BP cuff	Hypertension, atrial fibrillation/flutter, cardiac injury/event
Camera	Photo camera, camcorder	Traumatic injury, skin infection
Countermeasure Restraint System	Treatment restraint in microgravity	Activities that require accurate administration of treatment by one crew member to another
Compressive bandages	Ace Bandage (2", 3", 4")	Sprain, strain, dislocation
Cotton goods	Balls, nasal packing, and swabs	Skin laceration, abrasion, epistaxis, traumatic injury
Dental equipment	Adhesive, adhesive tip, crown remover, elevator, explorer/probe, file, forceps, mirror, temp tooth filling	Dental abscess, exposed pulp, dental crown loss
Ear curette	--	Otitis externa/media
Ear irrigation tip	--	Foreign bodies

[1]The listed conditions and capabilities in this table are not exhaustive

Post-Landing Considerations and Crewmember Treatment

Pre-landing Preparations

- Crewmembers can take measures before reentry to mitigate symptoms post-landing. These measures may include prophylactic medication use, fluid loading, and orthostatic intolerance compression garments.

Neurovestibular

- Cause / Background: neurovestibular system is still adapted to the spaceflight environment (i.e., microgravity)
- Symptoms: vertigo; unstable gait; nausea; vomiting
- Medical Recommendations & Treatment: medications (e.g., meclizine, promethazine); avoid rapid head movements; slow, progressive increase in activity; rest

Cardiovascular

- Cause / Background: fluid redistribution, third-spacing of total body water, relative intravascular depletion
- Symptoms: orthostatic intolerance; decreased blood pressure; increased heart rate; nystagmus and/or blurry vision; nausea; weakness/malaise; syncope
- Medical Recommendations & Treatment: compression garment (often donned prior to reentry); oral fluids (as tolerated); normal saline bolus; medications to treat symptoms; rest
- Due to relative intravascular depletion, IVs can be challenging to start. Thus, ground crew personnel need to be prepared appropriately.

Musculoskeletal

- Cause / Background: weightlessness causes bone and muscular atrophy; may be mitigated by in-mission countermeasures, such as exercise
- Symptoms: weakness; fatigue; poor coordination; impaired physical abilities; feeling of heaviness; slow & deliberate movements; muscle pain due to gravitational forces (esp. back aches from spinal recompression)
- Medical Recommendations & Treatment: assistance with ambulation; rest; long-term rehab and physical therapy may be needed

Egress is often difficult for crewmembers upon landing. Assisted egress will most likely be needed for missions >2 weeks.

Vehicle-Induced Trauma and Toxic Exposures

- Spaceflight re-entries and landings may result in traumatic injuries to the crew (e.g., fractures, neck injuries, etc.) or exposures to toxic chemicals (e.g., hypergolic substances). Upon landing, ground medical personnel must be able to accommodate and care for a crewmember who incurs injury or exposure due to the vehicle operations.

Major Changes Between Revisions

Rev A → Rev B

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Original → Rev A

- Added 'fluid shifts and altered vascular motility' to spaceflight changes
- Added a crew selection page
- Changed the medical care philosophy
  - Removed '14 day' time break from the Levels of Care and created a two-step process for selecting applicable conditions
  - The two steps include: 1. conditions required for every mission; 2. conditions tailored to each program based on mission architecture assessments
  - Further sorted conditions and capabilities
  - Deleted the Levels of Care pyramid
- Updated the total medical conditions list
- Reformed the example medical kit, including removal of the short- vs. long-duration denotations
- Updated the example medical kit contents to become closely aligned with current medical kits

Referenced Standards

NASA-STD-3001 Volume 1 Revision B

[V1 3003] In-Mission Preventive Health Care
[V1 3004] In-Mission Medical Care
[V1 3005] Medical Training for In-Mission Medical Care Providers
[V1 3006] Crew Medical Officers
[V1 3007] Medical Evacuation
[V1 3008] In-Mission to Definitive Medical Care Facilities
[V1 3009] Palliative Comfort Care
[V1 3010] Termination of Care
[V1 3011] Capability to Handle Deceased Crewmembers
[V1 3012] Terrestrial Launch/Landing Medical Support
[V1 3013] DMCF Medical Care
[V1 3014] DMCF Transport
[V1 3015] Certification of Training Plans for Launch/Landing Medical Team
[V1 3016] Post-Mission Health Care
[V1 3017] Post-Mission Reconditioning
[V1 3018] Post-Mission Long –Term Monitoring
[V1 4001] Microgravity EVAs Aerobic Capacity Standard
[V1 4002] Celestial Surface EVA Aerobic Capacity
[V1 4003 In-Mission Aerobic Capacity
[V1 4004] Post Mission Aerobic Capacity
[V1 4005] Pre-Mission Sensorimotor
[V1 4006] In Mission Fitness for Duty Sensorimotor
[V1 4007] In Mission Fitness for Duty Sensorimotor Metrics
[V1 4008] Sensorimotor Performance Limits
[V1 4009] Sensorimotor Countermeasures
[V1 4010] Post Mission Sensorimotor Reconditioning
[V1 4011] Mission Cognitive State
[V1 4012] End of Mission Cognitive Assessment and Treatment
[V1 4013] End of Mission Psychosocial Assessment
[V1 4014] Completion of Critical Tasks
[V1 4015] Pre-Mission Hematological/Immunological Function
[V1 4016] In-Mission Hematological/Immunological Countermeasures
[V1 4017] Hematology and Immunology Countermeasures and Monitoring
[V1 4018] Post-Mission Hematological/Immunological
[V1 4019] Pre-Mission Nutritional Status
[V1 4020] In-Mission Nutrient Intake
[V1 4021] In-Mission Nutritional Status
[V1 4022] Post-Mission Nutritional Assessment and Treatment
[V1 4023] Post-Mission Muscle Strength and Function
[V1 4024] In-Mission Skeletal Muscle Strength
[V1 4025] Post-Mission Reconditioning
[V1 4026] Pre-Mission Bone Mineral Density
[V1 4027] Pre-mission Bone Countermeasures
[V1 4028] Post-Mission Bone Reconditioning
[V1 4029] As Low as Reasonably Achievable (ALARA) Principle
[V1 4030] Career Space Permissible Exposure Limit for Space Flight Radiation
[V1 4031] Short Term Radiation Limits Solar Particle Events
[V1 4032] Crew Radiation Limits for Nuclear Technologies
[V1 5001] Medical Training
[V1 5002 Astronaut Training
[V1 5003] Crew Medical Officer Medical Training
[V1 5004] Medical Training Verification
[V1 5005] Crew Surgeon Training
[V1 5006] Medical Operations Flight Controller Training
[V1 5007] Support Personnel Training
[V1 5008] Psychological Mission Training
[V1 5009] Physiological Exposure Mission Training
[V1 6001] Circadian Shifting Operations and Fatigue Management
[V1 6002] Private Medical Communication {PMC} Schedule
[V1 6003] Private Medical Communications information Delivery
[V1 6004] Behavioral Health and Performance Provisions
[V1 6005] Behavioral Health for Key Ground Personnel
[V1 6006] Extravehicular Activities (EVAs0
[V1 6007] Medical and Survival Kits
[V1 6008] Crew Health Operations Concept Document
[V1 6009] Medical and Crew Health Requirements Document
[V1 7001] Crew Health Results
[V1 7002] Crew Records Communication
[V1 7003] Crew Records Storing

NASA-STD-3001 Volume 2 Revision C

[V2 3001] Selection and Recertification
[V2 3002] Pre-Mission Preventive Health Care

Reference List

1. Human System Risk Board Risk Packages – including Orthostatic Intolerance; Radiation; Back Pain; Sensorimotor Alterations; Reduced Muscle Mass, Strength; Reduced Aerobic Capacity; Renal Stone Formation; and, Vision Alterations
2. Space Operations Medical Support Training Course: Space Physiology and the Deconditioned Astronaut. NASA JSC, Space Medicine Operations Division
3. HSP Technical Brief, Longitudinal Health Surveillance Technical Brief, Orthostatic Intolerance Technical Brief
4. Wotring, V. E. Medication use by U.S. crewmembers on the International Space Station. *FASEB J*. 29, 4417–4423 (2015).
5. Marshall-Goebel K, Laurie SS, Alferova IV, et al. Assessment of Jugular Venous Blood Flow Stasis and Thrombosis During Spaceflight [published correction appears in JAMA Netw Open. 2020 Jan 3;3(1):e1920195]. *JAMA Netw Open*. 2019;2(11):e1915011. Published 2019 Nov 1.