Medical Risks and Capabilities for Human Exploration Spaceflight

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Risk of Human Spaceflight

O’Campo RP, Klaus DM. Applying regression analysis to model the risk of space flight and terrestrial activities. Journal of Space Safety Engineering. Sep-Dec 2018;5(3-4): 135-139.
Outline

• History and Current Ops
• Why Exploration Spaceflight is different
• How ExMC approaches the medical risk
  – Probabilistic Risk Assessment
  – Crew Health and Performance System
    • Trade Space Analysis
    • Medical Data Architecture
  – Specific Issues
Do we need medical care in spaceflight?

<table>
<thead>
<tr>
<th>Medical Condition</th>
<th>Events</th>
<th>Medical Condition</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergic reaction (mild to moderate)</td>
<td>11</td>
<td>Mouth ulcer</td>
<td>9</td>
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<tr>
<td>Ankle sprain/strain</td>
<td>11</td>
<td>Nasal congestion (space adaptation)</td>
<td>389</td>
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<tr>
<td>Back injury</td>
<td>31</td>
<td>Neck injury</td>
<td>9</td>
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<tr>
<td>Back pain (space adaptation)</td>
<td>382</td>
<td>Nerve blood (space adaptation)</td>
<td>6</td>
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<tr>
<td>Barotrauma (ear/sinus block)</td>
<td>31</td>
<td>Otitis externa</td>
<td>3</td>
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<td>Choking/obstructed airway</td>
<td>3</td>
<td>Otitis media</td>
<td>3</td>
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<tr>
<td>Constipation (space adaptation)</td>
<td>113</td>
<td>Paresthesias</td>
<td>26</td>
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<tr>
<td>Diarrhea</td>
<td>33</td>
<td>Pharyngitis</td>
<td>11</td>
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<td>Elbow sprain/strain</td>
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<td>Respiratory infection</td>
<td>33</td>
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<td>Eye abrasion (foreign body)</td>
<td>70</td>
<td>Shoulder sprain/strain</td>
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<td>Eye chemical burn</td>
<td>6</td>
<td>Sinusitis</td>
<td>6</td>
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<tr>
<td>Eye infection</td>
<td>5</td>
<td>Skin abrasion</td>
<td>94</td>
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<tr>
<td>Finger dislocation</td>
<td>1</td>
<td>Skin infection</td>
<td>13</td>
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<tr>
<td>Fingernail delamination (EVA)</td>
<td>16</td>
<td>Skin laceration</td>
<td>1</td>
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<tr>
<td>Gastroenteritis</td>
<td>4</td>
<td>Skin rash</td>
<td>94</td>
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<tr>
<td>Headache (CO2 induced)</td>
<td>20</td>
<td>Smoke inhalation</td>
<td>3</td>
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<tr>
<td>Headache (late)</td>
<td>49</td>
<td>Space motion sickness (space adaptation)</td>
<td>325</td>
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<tr>
<td>Headache (space adaptation)</td>
<td>233</td>
<td>Urinary incontinence (space adaptation)</td>
<td>5</td>
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<tr>
<td>Hemorrhoids</td>
<td>2</td>
<td>Urinary retention (space adaptation) – female</td>
<td>5</td>
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<tr>
<td>Herpes Zoster reactivation (shingles)</td>
<td>1</td>
<td>Urinary retention (space adaptation) – male</td>
<td>4</td>
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<tr>
<td>Indigestion</td>
<td>6</td>
<td>Urinary tract infection – female</td>
<td>5</td>
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<tr>
<td>Influenza</td>
<td>1</td>
<td>Urinary tract infection – male</td>
<td>4</td>
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<td>Insomnia (space adaptation)</td>
<td>299</td>
<td>Visual impairment/increased intracranial pressure (space adaptation)</td>
<td>15</td>
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<tr>
<td>Insomnia (late)</td>
<td>133</td>
<td>Wrist sprain/strain</td>
<td>5</td>
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<tr>
<td>Knee sprain/strain</td>
<td>7</td>
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</tr>
</tbody>
</table>
Project Mercury

**Figure 4.1.** Mercury medical kits containing items such as antibiotics, decongestants, stimulants, electrode paste, and medications to treat nausea and diarrhea. (Photo courtesy of NASA)

**Figure 4.2.** Mercury medical kit containing items such as saline solution, bandages, stimulants, and decongestants (Photo courtesy of NASA)

Principles of Clinical Medicine for Spaceflight
Eds. Barratt, Pool, 2008
### Table 4.1. Contents of the Gemini VII medical kit [10].

<table>
<thead>
<tr>
<th>Medication</th>
<th>Indication</th>
<th>Dose</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Amphetamine sulfate</td>
<td>Stimulant</td>
<td>5-mg tablets</td>
<td>8</td>
</tr>
<tr>
<td>Aspirin-phenacetin</td>
<td>Pain</td>
<td>Tablets</td>
<td>16</td>
</tr>
<tr>
<td>Caffeine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclizine HCI</td>
<td>Motion sickness</td>
<td>50-mg tablets</td>
<td>8</td>
</tr>
<tr>
<td>Diphenoxylate HCI</td>
<td>Diarrhea</td>
<td>2.5-mg tablets</td>
<td>16</td>
</tr>
<tr>
<td>Meperidine HCI</td>
<td>Pain</td>
<td>100-mg tablets</td>
<td>4</td>
</tr>
<tr>
<td>Methyl cellulose solution</td>
<td>Eye lubricant</td>
<td>15-ml bottle</td>
<td>1</td>
</tr>
<tr>
<td>Parenteral cyclizine</td>
<td>Motion sickness</td>
<td>45 mg (0.5-ml injectors)</td>
<td>2</td>
</tr>
<tr>
<td>Parenteral meperidine HCI</td>
<td>Pain</td>
<td>90 mg (0.5-ml injectors)</td>
<td>2</td>
</tr>
<tr>
<td>Phenacethidine HCI</td>
<td>Decongestant</td>
<td>60-mg tablets</td>
<td>16</td>
</tr>
<tr>
<td>Tetracycline HCI</td>
<td>Antibiotic</td>
<td>250-mg coated tablets</td>
<td>16</td>
</tr>
<tr>
<td>Triprolidine HCI</td>
<td>Decongestant</td>
<td>2.5-mg tablets</td>
<td>16</td>
</tr>
</tbody>
</table>

**Figure 4.3.** Apollo medical kit containing items such as skin cream, antibiotic ointment, nasal spray, band-aids, and stimulants (Photo courtesy of NASA)

**Figure 4.4.** Apollo Command Module medical kit (Photo courtesy of NASA)

**Figure 4.5.** Apollo clinical physiological monitoring kit and emergency medical kit (Photo courtesy of NASA)

**Figure 4.6.** Apollo emergency medical kit (Photo courtesy of NASA)

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Principles of Clinical Medicine for Spaceflight
Eds. Barratt, Pool, 2008
Space Shuttle

Figure 4.7. Shuttle Orbiter Medical System. Following redesign in 2000, components include Saline Supply Bag, EENT Subpack, IV Administration Subpack, Trauma Subpack, Sharps Container, Drug Subpack, and Airway Subpack (Photo courtesy of NASA)
Health and Medical on ISS

CHeCS

CMS

EHS

HMS

**Figure 4.8.** ISS Health Maintenance System. Components include (from left) defibrillator, Advanced Life Support Pack, Respiratory Support Pack, and Crew Medical Restraint System (Photo courtesy of NASA).
How is medical care provided in mission?

• Live remote guidance

• Live monitoring

• Store and forward
EXPLORATION SPACEFLIGHT
NASA Human Spaceflight Missions

- Soyuz Launch and Landings
- International Space Station
- Commercial Crew Program
- Multi-Purpose Crew Vehicle
- Gateway Habitat
- Deep Space Transport
- Mars Missions

Near Term (Current - 5 yrs)

Medium Term (within 10 yrs)

Long Term (10 – 20 yrs)
What about Mars?
1. Radiation
2. Isolation and Confinement
3. Altered Gravity Fields
4. Hostile/closed environments
5. Distance from Earth
Access to the Deep Space Network for the vehicle may be as limited as 1 hour in a 24 hour period.

Trans-Mars Cruise
About 9 months

A Mars mission cannot use the current operational medical approach because that approach is totally dependent on real-time communication with the ground.
A Mars mission cannot use the current operational medical approach because that approach requires significant, continuous ground support.
A Mars mission cannot use the current operational medical approach because that approach requires frequent resupply.
A Mars mission cannot use the current operational medical approach because that approach is dependent on evacuation for delivery of definitive care.
How do we scope a medical system to meet the needs of a planetary mission that is:

- 2-3 times as long as any prior mission
- >500 times as far as any prior mission

Vehicle is committed after trans-Martian injection?
MEDICAL PROBABILISTIC RISK ANALYSIS
Exploration Medical Conditions

SKIN
Burns secondary to Fire
Skin Abrasion
Skin Laceration

EYES
Acute Glaucoma
Eye Corneal Ulcer
Eye Infection
Retinal Detachment
Eye Abrasion
Eye Chemical Burn

EARS, NOSE, THROAT
Barotrauma (sinus block)
Nasal Congestion (SA)
Nosebleed (SA)
Acute Sinusitis
Hearing Loss
Otitis Externa
Otitis Media
Pharyngitis

DENTAL
Abscess
Caries
Exposed Pulp
Tooth Loss
Crown Loss
Filling Loss

CARDIOVASCULAR
Angina/Myocardial Infarction
Atrial Fibrillation / Atrial Flutter
Cardiogenic Shock secondary to Myocardial Infarction
Hypertension
Sudden Cardiac Arrest
Traumatic Hypovolemic Shock

GASTROINTESTINAL
Constipation (SA)
Abdominal Injury
Acute Cholecystitis
Acute Diverticulitis
Acute Pancreatitis
Appendicitis
Diarrhea
Gastroenteritis
Hemorrhoids
Indigestion
Small Bowel Obstruction

Pulmonary
Choking/Obstructed Airway
Respiratory Infection
Toxic Exposure: Ammonia
Smoke Inhalation
Chest Injury

NEUROLOGIC
Space Motion Sickness (SA)
Head Injury
Seizures
Headache
Stroke
Paresthesia
Headache (SA)
Neurogenic Shock
VIIP (SA)

MUSKULOSKELETAL
Back Pain (SA)
Abdominal Wall Hernia
Acute Arthritis
Back Injury
Ankle Sprain/Strain
Elbow Dislocation
Elbow Sprain/Strain
Finger Dislocation
Fingernail Delamination (EVA)
Hip Sprain/Strain
Hip/Proximal Femur Fracture
Knee Sprain/Strain
Lower Extremity Stress fracture
Lumbar Spine Fracture
Shoulder Dislocation
Shoulder Sprain/Strain
Acute Compartment Syndrome
Neck Injury
Wrist Sprain/Strain
Wrist Fracture

PSYCHIATRIC
Insomnia (Space Adaptation)
Late Insomnia
Anxiety
Behavioral Emergency
Depression

GENITOURINARY
Abnormal Uterine Bleeding
Acute Prostatitis
Nephrolithiasis
Urinary Incontinence (SA)
Urinary Retention (SA)
Vaginal Yeast Infection

INFECTION
Herpes Zoster (shingles)
Influenza
Mouth Ulcer
Sepsis
Skin Infection
Urinary Tract Infection

IMMUNE
Allergic Reaction
Anaphylaxis
Skin Rash
Medication Reaction

ENVIRONMENT
Acute Radiation Syndrome
Altitude Sickness
Decompression Sickness (EVA)
Headache (CO2)
Spaceflight Medical Risk

~100 Medical Conditions

Medical Conditions for which we have not planned.
How do we extrapolate human system risk?

- Lack of single source for data
- Flight data - high internal validity, small volume
- Analog data - Lower validity, higher volume
- Terrestrial experience
- Expert opinion
Probabilistic Risk Assessment

- Best-case Scenario:
  - Resources available?
  - Medical Event

- Worst-case Scenario:
  - Resources available?

Treated Case:
- Decrement medical resources

Untreated Case:
- Decrement medical resources

Calculate End States:
- Evacuation (EVAC)
- Loss of Crew Life (LOCL)
- Crew Health Index (CHI)
- Resource Utilization
- Type and Number of Medical Events

Slide courtesy of E Kerstman
Proportion of Mission Risk attributable to Medical
Some Assumptions…

1. All diagnoses are 100% accurate.
2. All events receive appropriate treatment.
3. All meds and equipment are 100% reliable and effective.
4. All events respond as they would terrestrially.
5. No mistakes in medical procedures (regardless of training)
6. Power, water, oxygen unlimited
PRA Estimates of Loss of Crew Life

21 Day Lunar  6 Month ISS  1 Year ISS  2.5 Years Mars Design Reference Mission

- Perfect
- Physician - No Detraining
- Non-Physician - No Detraining

Slide courtesy of E Kerstman
Proportion of Mission Risk attributable to Medical
“…[The] assumption has been that risk of vehicle system malfunction far outweighs the risk of human system failure…NASA buys down the risk of failure of the human system through rigorous selection of individuals designed to minimize medical issues and optimize available capability in flight.”

NASA SP-2017-0633
CREW HEALTH AND PERFORMANCE SYSTEM
Habitat System

Crew Health and Performance

- Natural and Induced Environments Protection
- Medical
- Mission Task Performance
- Health and Wellness

Structures
Command & Data Handling
Guidance, Navigation and Control
Comm & Tracking
Power
etc.

Ground System

MedOps

Vehicle/Mission Architecture Integration
Crew Health and Performance System Must...

- **Protect from environmental hazards**
  - Radiation protection
  - Noise, vibration, CO₂, etc.

- **Keep healthy crew well**
  - Exercise
  - Other physiological countermeasures
  - Food
  - Behavioral health

- **Prevent, diagnose, treat, manage long-term health care**
  - Data system
    - Medical Data Capture
    - Medical Training
  - Medical devices
  - Medical supplies

- **Support crew to accomplish mission tasks**
  - Procedures
  - Training
  - User interfaces
System Performance Threatened by Sleep Deficit
Sleep Deficit Affects Other System Aspects

- Cognition
- Sleep
- Team Cohesion
- Team Dynamics
- Training Capabilities
- Mood
- Physical Strength
- Stamina
- Exercise Equipment
- CO2 Levels
- Oxygen
- Water Quality
- Air Quality
- Radiation Monitoring
- Waste Management
- Food and Nutrition
- Pharmacy
- Medical Skills Maintenance
- Medical Equipment
- Biomonitoring
- Ground Support
- Emergency response
Translate Medicine to Engineering

- Stakeholder needs, goals
- NASA Standards
- Program requirements & architecture
- System functions & behaviors
- System requirements & architecture
- Subsystem requirements & architecture
- Characterize system
- Analyze & trade
- Design & Build

Do we have the capabilities to meet the needs? What allocations are necessary?
TRADE SPACE ANALYSIS
Medical and Non-medical Risk

Mission Risk

0

Mass/Volume of Medical System

Notional
MEDICAL DATA ARCHITECTURE
We’re not bringing an Intensive Care Unit but…

Crew Health and Performance System

These technologies exist today

Notional
Where are we today? MDA

Data Sources Layer
Structured
- Health Records
- Med Records
- Clinical Trials
- Other ....

Unstructured
- Medical devices
- Monitoring System Images
- Logs & Notes
- Exercise Machine
- Other ....

Streams
- Bio Sensors
- Env. Sensors
- Other ....

Data Storage Layer
Data Assets
- Knowledge Models
  - EHR
  - Documents
  - Sensor
  - Other
- Vitals

Integrated Data Platform
- Annotate
- Correlate
- Classify

Analytical Layer
Clinical Decision Support System
- Analytics Data Mart
- Knowledge Base

Discovery & Analytics
- Reports
  - Dashboard
- Data Mining
  - Text Classification
  - Computational Statistics
- Modeling & Analytics
  - Diagnostic Predictive
- Discovery
  - Ontological Search
- Real Time Apps
  - Alerts
- Cognitive Computing
  - Adaptive, Interactive, Contextual

User Interface
Applications & Prototypes
User Interface & Visualization

Data Virtualization
Metadata & Data Standards
Federated Access & Delivery Infrastructure (FADI)
Figure 1. Advanced RF and optical communications technologies combined with using the areostationary orbit offer 100-1000x greater data return from Mars and nearly continuous availability.

Table 1. High-Performance Mars-Earth Trunk Line Capability

<table>
<thead>
<tr>
<th>Current State-of-the-Art (MRO)</th>
<th>Frequency Band</th>
<th>Maturity</th>
<th>S/C Aperture</th>
<th>S/C Txmt Power</th>
<th>Ground Receiver</th>
<th>Data Rate (@ 2 AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-band</td>
<td>Operational</td>
<td>3 m</td>
<td>100 W</td>
<td>34 m DSN BWG antenna</td>
<td>1 Mb/s</td>
<td></td>
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<tr>
<td>Ka-band</td>
<td>TRL 6</td>
<td>3 m</td>
<td>200 W</td>
<td>34 m DSN BWG antenna</td>
<td>5 Mb/s</td>
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<tr>
<td></td>
<td>TRL 3-4</td>
<td>5 m</td>
<td>1 kW</td>
<td>34 m DSN BWG antenna</td>
<td>70 Mb/s</td>
<td></td>
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<tr>
<td>Optical (1550 nm)</td>
<td>TRL 6 (DSOC; to fly on 2023 Psyche Discovery Mission)</td>
<td>22 cm</td>
<td>4 W</td>
<td>5 m ground telescope</td>
<td>1 Mb/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TRL 3</td>
<td>50 cm</td>
<td>50 W</td>
<td>12 m ground telescope</td>
<td>100 Mb/s</td>
<td></td>
</tr>
</tbody>
</table>
Can we replace the doctor?

- Full Artificial Intelligence
- Integrative Health and Performance Prediction
- Condition Specific Guidance
- Differential Diagnosis Generation
- Automated Image/Data Analysis
- Knowledge Support/Known Algorithm Provision
- Preventive Care Strategies
**Taking a Good Image: Composition**

**Tips for good composition:**

To move the optic disc down the subject needs to look up.

To move the optic disc right the subject needs to look right.

In a good composition the optic disc is centered.

**Bad composition**

In poor composition, the optic disc is not centered or not visible.

**Bad composition**

Optic disc is too far right

Optic disc is too low

**Good composition**
Medical Technology Development

Reveal LINQ ICM + MyCareLink Patient Monitor

FUS moving stone in ER patient

SEEQ Mobile Cardiac Telemetry System: Medtronic
PHARMACY
Stability Evidence: Flown Studies

Altered Medication

Unaltered Medication

Du et al. 2011
Chuong et al. 2011
Wotring 2016

Unpublished:
Cory 2017
Wu 2016

* Drug tested only for Vit B API
** Drug would fail by today’s API standard
† drug had unidentified degradant product
Other Topics within In-Flight Medical Conditions

- Pharmacy
- Clinical Decision Support
- Autonomous Medical Operations
- Imaging
- Rehabilitation
- Lab Analysis
- Biomonitoring and Wearables
- Personalized Medicine
- Renal Stones
• From Conclusion 6:

• “The human being must be integrated into the space mission in the same way in which all other aspects of the mission are integrated.”
Questions?

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