Flight Surgeon Perspective: Gaps in Human Health, Performance, and Safety

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Where do you start?

- Look at where you have been (**Historical Gaps**).
- Look at where you are now (**Current Gaps**).
- Define the future Concept of Operations (**Future Gaps**).
- Define the Levels of Care
- Remember the Six Tenets:
  - **MASS, POWER, VOLUME, TIME, MONEY, RISK**
Levels of Care

• What level of care will you provide?
• What level of “Risk” will you accept?
• What is the Mission Con Ops?
• Where is the threshold of reasonable uncertainty?
Levels of Care

• Sure you can do major surgery. It is feasible. But should you?
• Will there be prophylactic surgery on long duration Moon and Mars explorers (ie: appendectomy)?
• Will your consumables limit your ability to provide critical care?
The SIX Tenets

• MASS
• POWER
• VOLUME
• TIME
• MONEY
• RISK
Unique Aspects of Moon and Mars Missions

- Distance
- In-situ production of consumables
- Relative Autonomy
- Communication
- Power production
- **Reversal of Life, Limb, Mission paradigm**
Autonomous

- 20 minutes one-way communication
- Can’t abort to definitive care
- Must have the proper training to take care of majority of medical issues that arise
- Consultant available, but not for emergent care
Exploration will eventually force us to answer the following questions:

- Will genetic screening be apart of selection or guide interventions?
- Will “prophylactic” procedures be performed (ex-appendectomy) for exploration astronauts?
- At what line will we allow “informed consent” to increase the risk to the individual?
- Triage and the eventuality of death or debilitating illness on orbit or planetary surface.
Gaps in Health

- Despite our rigorous selection, we still have many medical maladies that occur.
- Medication on orbit may be an “off-label use” in some circumstances.
- We are just now seeing and beginning to understand medical issues unique to long duration spaceflight.
# Medical Risk Matrix – Long-Duration Missions

<table>
<thead>
<tr>
<th>Class 1 Medical Event</th>
<th>Class 2 Medical Event</th>
<th>Class 3 Medical Event</th>
<th>Class 4 Medical Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical problem with potential long-term health risk to individual but minimal symptoms or signs during mission</td>
<td>Significant medical event, illness, or injury</td>
<td>Major medical illness or injury requiring full medical resource intervention</td>
<td>Acute medical crisis beyond ISS medical resource capabilities</td>
</tr>
<tr>
<td>May cause a moderate reduction in performance</td>
<td>Significant reduction in performance</td>
<td>Major degradation in performance</td>
<td>Loss of critical function</td>
</tr>
<tr>
<td>Can handle with onboard capabilities</td>
<td>Requires extensive medical resource utilization</td>
<td>Full utilization of all available medical resources</td>
<td>Beyond capability of ISS medical resources</td>
</tr>
<tr>
<td>Can handle within designated timeline</td>
<td>May cause failure to meet mission objectives</td>
<td>Planned decrewing (medical evacuation)</td>
<td>Emergency evacuation</td>
</tr>
</tbody>
</table>

**Likely ≥2%<5%**
- Prostate Cancer

**Possible ≥1%<2%**
- Pituitary Tumor

**Unlikely <1%≥0.5%**
- Atrial Fibrillation

**Highly unlikely <0.5%**
- S/P Correction of Dx

### MSMB Risk-based Decision Analysis

- **Green**: Low risk – acceptable for MDC 1 disposition (long duration)
- **Yellow**: Moderate risk – Further consideration required for an MDC 1 disposition
- **Red**: High risk – unsuitable for MDC 1 disposition

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UNCLASSIFIED
Space radiation is generally more biologically damaging than typical radiation on Earth.

Large uncertainties of how much more damaging limit ability to assess risks and countermeasures.

Solar Proton Events (SPEs) require new operational and shielding approaches and new biological data on risks.

Four space radiation categories below uniquely contribute to the uncertainties in the risk:

- **Carcinogenesis (Cancer)**
- Acute Radiation Syndromes
- Degenerative Tissue Effects
- Central Nervous System Disease
NASA standard: 3% Risk of Exposure Induced Death (REID) from cancer

- Requirement for 95% Confidence Interval (C.I.) for cancer risk protects against uncertainties in risk projection models

Knowledge Gaps cause large Cancer Risk Model Uncertainties

- Based on current uncertainties in risk models:
  - Mars may not fit within the current 3% constraints depending on duration.
  - Lunar and Mars surface stay-times could be constrained, depending on countermeasures, NASA policy, or risk to the individual.

If knowledge gaps are not reduced, a review of 3% REID will be required
• Brief, reliable tools for assessing effects of fatigue, radiation, medications, head trauma on cognition
• Better technologies for shifting sleep and circadian rhythms for crews and ground personnel
• How to best manage effects of Mars mission duration, communications time-lag, and desynchronized Martian day-night cycle on:
  ➢ Psychiatric monitoring and interventions,
  ➢ Crewmember and family psychological support & connectivity,
  ➢ Individual psychological adaptation & team performance?
Behavioral

- What are the relative risk levels for psychiatric symptoms and cognitive decrements?
- What are the best tools and methods for selecting individual Mars crewmembers?
- What are the best methods for assembling and training crews for compatibility and team performance?
- How can ISS, Lunar and earth analogues (e.g., polar bases) best be used as test beds for Mars flights?
- What personal items, software & hardware will make best use of the limited onboard mass & volume for psychological support?
- What Leadership/Personality Skills for required for Autonomous crew.
• KNOWLEDGE GAP: At what time point during space flight does irreversible perforation of trabecular struts occur?
• Demonstrated Impact on Trabecular thickness suggestive of suboptimal bone formation.
• Demonstrated Impact on Trabecular Number “aggressive osteoclast activity”.
Microgravity Related Bone Loss
Secondary Effect

• Architectural changes
  – Trabecular bone compartment changes-rapid
    • Leads to reduced trabecular connectivity, increased number and depth of resorption sites (stress risers), increase in under-mineralized bone matrix
    • Consequence: likely loss in strength in addition to that cause by loss in mass
  – Cortical bone
    • Evidence of periosteal expansion of femur neck
    • Consequence: ?

Data from Joyce Keyak-UCSF
Therapies for Bone Loss

- Bisphosphonates
- Denosumab
- Resistive Exercise
- Vibration
- Electrical stim

Will a fracture heal in a microgravity environment?
Changes in Vision

• Eye changes noted on several long duration missions, but not on short duration missions.
• May be secondary to fluid shift, protein deposition over time, and anatomic differences in the astronaut’s cup size.
• Gaps remain in explaining exactly what causes this phenomenon.
• Telemedicine and imaging gaps have been bridged in “innovative ways”.

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Musculoskeletal

- Skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy, structural and metabolic alterations during space flight. These alterations, if unabated, may affect performance of mission tasks.
- Exercise countermeasures have to-date not fully protected muscle integrity but have retarded the loss.
- Will they be able to perform the tasks required immediately after landing?
1. Determine if cardiac arrhythmias are a significant concern and if other prevention strategies are necessary.
2. Determine if cardiac atrophy is a significant concern and if other prevention strategies are necessary.
3. Is it spaceflight, or is it unrecognized coronary disease?
Neurovestibular

• Gaps remain on deterrents for space motion sickness after each G transition.

• Gaps remain as to neurovestibular impacts on hand-eye coordination required for complex tasks after prolonged spaceflight (e.g., piloting/landing a spacecraft after long duration flight).
Additional Gaps

- Gaps remain regarding the impact of spaceflight on immune function.
- Gaps remain on the impact of nutrition and nutrition countermeasures on multiple organ systems in spaceflight.
- Gaps remain in pharmacology and drug stability when exposed radiation.
- Gaps remain in performance of tasks after long duration spaceflight.
Gap in Occupational Medicine and Surveillance

- What are the long-term impacts of space exposure?
  - Cataracts?
  - Osteoporosis?
  - Exposures?
  - Cancer risk?
  - Cell lines?

- Institute of Medicine Recommendations for Occupational Health Surveillance

- Achieving statistical power for comparison
Patient Safety

- Electronic Medical Record
- Lean Six Sigma
- Clinical Practice Guidelines
- Quality Metrics
There is a remote possibility that vehicle charging could represent a shock hazard during the EVAs scheduled for the mission.

- A crewmember touching a positively charged surface was thought to be protected if galvanically isolated from the vehicle ground – analogous to a ‘bird on a high voltage power wire’. However, the plasma acts as a ubiquitous ground surrounding the astronaut.

- Plasma charge is something we will have to consider for exploration class missions when designing suits, hardware, and tasks.
Environmental

• Gaps remain in understanding the impact of toxins in a closed environment.

• Bacteria and viruses mutate or are altered by microgravity and radiation. The impact of these on the human system remains a gap.

• Crewmembers have a lower tolerance to CO2 in long duration spaceflight, but we don’t know why.

• Exploration missions will have exposure to silica-type dust, but we have gaps in potential lung impacts to this dust.
Gaps in Human Factors

• Micrometeoroid impact during EVA could cause catastrophic loss of pressure.

• Cuts in the EVA glove could result in catastrophic loss of pressure.
Future Safety Gaps
Summary

• There are many gaps in knowledge in human spaceflight, but the amount of knowledge gained in long duration spaceflight has been tremendous.

• The human system undergoes many changes in spaceflight, but the human system is extremely resilient.

• Many gaps remain that need research and attention in order to assure exploration mission success.
Questions?