Space Medicine in the Human System Integration Process

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Acknowledgements

- David Baumann, ExMC project lead
- Kate Kubicek and Debbie Berdich
- Jeff Jones, MD
- Jenn Fogarty, PhD
- JD Polk, DO
- Pete Bauer, Serena Aunon, David Alexander, Kjell Lindgren, Duane Chin, Tom Hatfield, David Gillis, Doug Hamilton, Dov Adelstein, Brian Daniel, John Bolte, Brent Buetter, Marsha Ivins, Evan Brown, Phil Root, and a lot of other folks
- Michelle C. Scheuring
The HSI Knowledge Broadcast is intended to educate personnel about the importance of considering the human (health, performance and limitations) in the early stages of a project's lifecycle, thus reducing costs, increasing safety and improving overall system performance.
Historical Precedence

Lunar Surface Operations

- Metabolic expenditure: deconditioning or poor pre-flight preparation?
Historical Precedence

♦ Lunar Surface Operations

- Recommendations
  - The hatch and ingress corridor should be sized appropriately for an inflated 1/6 g pressure suit

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Overview

- Evidence Base
- Medical Condition List
- Medical Technology Development

Research
- How can we do better?

Operations
- Lessons learned!

Requirements Development
- Space Flight Human System Stnd
  - Levels Of Care
- HSIR Medical Requirements

Requirements Integration
- Flight Surgeons assigned to Projects
  - Orion, LSS, EVA

Verification
- Were requirements met?

Design
- Hands-on architectural involvement

Operations
- Shuttle
- ISS
- Apollo

Human in the Loop testing
Analog Testing of Medical Hardware
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Operations
Lessons learned!

- In-flight sleep disturbances
- Post-flight herniated discs (HNP)
- Lunar dust
- Thrust oscillations
- Risk factors for lunar surface injuries
- In-flight hypothermia
- Apollo EVA suit issues
- Landing/Recovery
- Waste management systems
Injury Prevention

Lunar Surface Operations

- Risk factors for injuries identified
  - Limit navigation into craters to < 20-26° slope
  - Rover activities
    - CDR
    - LMP
  - Falling from a height
    - Ladder
    - Rim of a crater

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Crew experience with egress training

- Elevated heart rates (>120s) due to heat stress
- 2-4 Kg weight loss from sweating
- Elevated core body temperature (38.6-40.0°C)

Video courtesy of Serena Aunon, MD
**Research**

How can we do better?

**Space Medical Issues - Back to the Future**

- **Expected illnesses and problems**\(^2,3,4\)
  - Orthopedic and musculoskeletal problems
  - Infectious, hematological, and immune-related diseases
  - Dermatological, ophthalmologic, and ENT problems
- **Acute medical emergencies**
  - Wounds, lacerations, and burns
  - Toxic exposure and acute anaphylaxis
  - Acute radiation illness
  - Dental, ophthalmologic, and psychiatric conditions
- **Chronic diseases**
  - Radiation-induced problems
  - Responses to dust exposure
  - Presentation or acute manifestation of nascent illness

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- What conditions do we expect to see for long lunar stays?
  - Outpost Medical Condition List\(^4\)
    - [Lunar Outpost Conditions.xls](#)

Health Monitoring on the Lunar Surface\textsuperscript{5,6}

\begin{itemize}
  \item \textbf{Lab analysis}
    \begin{itemize}
      \item Blood
        \begin{itemize}
          \item CBC w/differential
          \item Chemistries
          \item Oxidative stress markers
        \end{itemize}
      \item Urine
        \begin{itemize}
          \item Solutes
          \item Dipstick
            \begin{itemize}
              \item Spec G, Cells, LE, etc.
            \end{itemize}
        \end{itemize}
      \item Saliva
        \begin{itemize}
          \item Immune parameters, shed virus, etc.
        \end{itemize}
    \end{itemize}
  \item \textbf{Pulmonary function tests (PFT’s)}
  \item \textbf{Ultrasound}
  \item \textbf{ECG monitoring (IVA)}
  \item \textbf{HR monitoring (EVA)}
\end{itemize}

\textsuperscript{5}Grigoriav AI, Popatov LN, Jones JA, Sullivan TA, Scheuring RA. Medical Support for Interplanetary Space Flights, in Space Biology and Medicine, Volume V \\


In-vivo Real Time Imaging Cervical Spine

Ultrasound (USN)

MRI

Courtesy of Dan Buckland, 2009.
Exploration Vehicles Atmospheres

Pre-launch Transition

Shuttle/Mir/ISS

Ascent Transition

Shuttle EVA Preparation

Lunar Sortie CEV

LER/Outpost

Early Apollo Design

Normoxic Equivalent

Hypoxic Boundary

Historical Designs

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♦ Medical Technology Development

- High Intensity Focused Ultrasound (HIFU)
- Non-invasive blood analyzers
- Non-contact electrodes
- Lightweight trauma module
- Oxygen concentrators
- Real-time radiation dosimetry
- Ultrasound stethoscope
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Requirements Development

NASA HQ Standard

Constellation Req’ts

Vehicle Requirements and Specifications

Levels of Care
Performance Stnds

Space Med Req’ts
Crew Function Req’ts

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 Levels of Care

<table>
<thead>
<tr>
<th>Level of Care</th>
<th>Mission</th>
<th>Example Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>LEO &lt; 8 days</td>
<td>SMS, BLS, First Aid</td>
</tr>
<tr>
<td>II</td>
<td>LEO &lt;30 day; e.g. STS EDOMP</td>
<td>Level I + Clinical Diagnostics, Ambulatory Care, Private Audio, (+/- Video) Telemedicine</td>
</tr>
<tr>
<td>III</td>
<td>LEO &gt; 30 day (ISS or Lunar Sortie)</td>
<td>Level II+ Limited Advanced Life Support, Trauma Care, Telemedicine, Minor Surgical and Dental Care</td>
</tr>
<tr>
<td>IV</td>
<td>Lunar &gt; 30 day (Outpost)</td>
<td>Level III+ Imaging, Sustainable ALS</td>
</tr>
<tr>
<td>V</td>
<td>Mars Expedition</td>
<td>Level IV+ Autonomous ALS, Basic Surgical Care</td>
</tr>
</tbody>
</table>

Table-1: Levels of Care is matched to mission duration and destination  

LEO= Low Earth Orbit; STS= Shuttle Transport System; EDOMP= Extended Duration Orbiter Medical Project; SMS= Space Motion Sickness; BLS= Basic Life Support; ALS= Advanced Life Support.

HSIR Medical Req’ts

- 3.2.1.4.4 Lunar Dust Contamination

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Flight Surgeons integrated with Projects during development stages

Requirements Integration

Negotiating project
Design

Hands-on architectural involvement

• Thrust Oscillations
ESR2 Config 1 suit testing
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Instrumentation of the PMHS

Accelerometers
Results:
Post 4
Vehicle development

- Orion
- Altair
- Lunar Electric Vehicle (LEV)
- Lunar Outpost
Lunar Lander (Altair) and Ascent Stage
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Lunar Electric Rover

- Exploration range of up to 1000km (vs. 240km w/ large pressurized rover)
- Shirt-sleeve environment with visibility as good as suited EVAs
- Single-person EVA capability
- **Dust control through use of suitport**
- SPE protection within 20mins
- Pressurized safe-haven within 20mins
- DCS treatment within 20mins
- Expedited on-site treatment and/or medication of injured crewmember
- Reduces suit induced trauma
- Better options for nutrition, hydration, waste management
- Provides resistive and cardiovascular exercise (75% VO2 peak) during otherwise unproductive translation time
- Better background radiation shielding vs. EVA suit
Rear-Entry Suit Port (Shoulder Study)

- Examine rear-entry suit port in overhead and “dip” position to determine force loads on the shoulder.
Verification

Were requirements met?

- Analog testing of medical hardware, procedures, and concepts
## Analog Function Characteristics Mapped to Sites

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Haughton-Mars 1</th>
<th>H Remote Sci 2</th>
<th>Desert RATS 3</th>
<th>Mars Desert R 4</th>
<th>Flashline Arctic 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical space for infrastructure setup</td>
<td>HI</td>
<td>Lo</td>
<td>HI</td>
<td>HI</td>
<td>HI</td>
</tr>
<tr>
<td>Physical space for an Outpost configuration (at least 0.5 sq km)</td>
<td>HI</td>
<td>Lo</td>
<td>HI</td>
<td>HI</td>
<td>HI</td>
</tr>
<tr>
<td>Extended physical space for long distance testing (able to traverse up to 100 km)</td>
<td>Med</td>
<td>Lo</td>
<td>HI</td>
<td>HI</td>
<td>Med</td>
</tr>
<tr>
<td>Regolith Handling</td>
<td>HI</td>
<td>Lo</td>
<td>HI</td>
<td>HI</td>
<td>HI</td>
</tr>
<tr>
<td>Power source (electricity via generators or grid connection)</td>
<td>Med</td>
<td>HI</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td>Full Internet access to remote locations</td>
<td>Med</td>
<td>HI</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td>Good vista (not too many man made objects or vegetation insight, looks like the Moon or Mars)</td>
<td>HI</td>
<td>Lo</td>
<td>Med</td>
<td>Med</td>
<td>HI</td>
</tr>
<tr>
<td>High Temperature extremes (&lt; 100 degrees F)</td>
<td>Lo</td>
<td>Lo</td>
<td>Med</td>
<td>HI</td>
<td>Lo</td>
</tr>
<tr>
<td>Low Temperature extremes (&lt; 32 degrees F)</td>
<td>HI</td>
<td>Lo</td>
<td>Med</td>
<td>Lo</td>
<td>HI</td>
</tr>
<tr>
<td>Zero-G capability</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Partial-G</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Site Diversity</td>
<td>Med</td>
<td>Lo</td>
<td>HI</td>
<td>Lo</td>
<td>HI</td>
</tr>
<tr>
<td>Access for large equipment</td>
<td>Lo</td>
<td>Hi</td>
<td>Med</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Access for People</td>
<td>Lo</td>
<td>Hi</td>
<td>Med</td>
<td>Lo</td>
<td>Lo</td>
</tr>
<tr>
<td>Cost of working there</td>
<td>$$$</td>
<td>$</td>
<td>$$$</td>
<td>$$$</td>
<td>$$$</td>
</tr>
<tr>
<td>Partnerships/Shared Costs</td>
<td>HI</td>
<td>Med</td>
<td>Lo</td>
<td>Med</td>
<td>HI</td>
</tr>
</tbody>
</table>

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Verification

Were requirements met?

- Analog testing/training for Lunar Surface Operations
  - To ensure operational success and optimize performance of the crews
  - Allow adequate time to practice mission activities in a variety of environments including good analogs that allows preparation for off-nominal events
Analog Exploration Environments

- **Backyard/Nearby**
  - Rockpile
  - Desert RATS

- **Remote/Extreme Environments**
  - Devon Island, Haughton Crater- HMP
  - NEEMO
  - Antarctica- Coastal and Polar Stations

- **Flight**
  - Zero- and partial-g Aircraft
  - ISS

Docs are operational oriented and focused on developing experienced-based confidence in medical support system.

Many are ex- or current military and/or have experience in expeditionary support.
Apollo Medical Operations Recommendations

- **Analog environments**
  - Remote location, not easily accessible
  - Operationally focused - multiple “Experiments” for days/week

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3rd Party Assisted Rescue on Sloped Terrain (haul from top)\(^9\)

Procedure

Photos courtesy of HMP 2000/J. Jones
Analogue Exploration Environments

Benefits of the Analogue Environment

- Mission Constraints
- Timeline
- Crew dynamics
- Limited resources
- Coordination w/ teams
- Collaboration w/ centers
- Simulated planetary environments
- Lack of one perfect analogue
- Psychological factors
- Training
- Similar dimensions to space vehicles (NEEMO)
- Testbed for hardware and systems
- Recommendation from Apollo crewmembers
- Subsystem testing vs. system integration testing\(^{10}\)

Research

How can we do better?

Requirements Development

Operations

Lessons learned!

Verification

Were requirements met?

Requirements Integration

Negotiating project buy-in

Design

Hands-on architectural involvement

Questions?