Estimating the Risk of Renal Stone Events during Long-Duration Spaceflight

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Disclosures

No financial relationships

Off-label use and/or investigational use of drugs or other treatments will not be discussed
Potential Renal Stone Outcomes

- Infection
- Obstruction
- Incapacitation
- Mission failure
- Evacuation
- Long-term disability
- Death
Space Flight Risk Factors

- Fluid shifts in microgravity
- Bone demineralization
- Decreased thirst and fluid intake
- Concentrated urine
- Calcium excretion

Renal stone is a disqualifying medical condition for long duration space flight

- Presence or history of urinary calculus
- Requires a medical waiver
History of Renal Stones in Space Flight

- U.S. Space Program
  - 14 renal stone events among 12 astronauts as of 2008
  - 4 events prior to space flight (no association)
  - 10 events within 2 years postflight
- Russian Space Program
  - 3 renal stone events postflight
  - 1 renal stone event inflight
Inflight Renal Stone Event

- Acute abdominal pain in a cosmonaut on 11/11/82 on Salyut 7 (6 months into a 7 month mission)
- Initially diagnosed as appendicitis
- Caused severe pain and significantly impacted the inflight timeline
- Resolved on-orbit with apparent passing of the stone spontaneously over a period of days
- No medical evacuation
- Mission was completed
Renal Stone Epidemiology

- Lifetime prevalence 10% male, 5% female
- 3.7% to 4.6% of commercial aviation pilots between 2000 – 2007*
- Similar to astronaut prevalence

## Asymptomatic Stones

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Stone Free</th>
<th>Progression</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5</td>
<td>28%</td>
<td>40.4%</td>
<td>5.3%</td>
</tr>
<tr>
<td>5 - 10</td>
<td>4.8%</td>
<td>52.4%</td>
<td>9.5%</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>0%</td>
<td>71.4%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

Size vs. Spontaneous Passage

Days to Pass vs. Size


**Fig. 1.** Average (avg.) days to stone passage
## Medical Risk Matrix – Long-Duration Missions (ISS)

### MDC-1

<table>
<thead>
<tr>
<th>Medical Risk Matrix – Long-Duration Missions (ISS)</th>
<th>Class 1 Medical Event</th>
<th>Class 2 Medical Event</th>
<th>Class 3 Medical Event</th>
<th>Class 4 Medical Event</th>
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<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>
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</tr>
<tr>
<td>May cause a moderate reduction in performance</td>
<td>Significant reduction in performance</td>
<td>Major degredation in performance</td>
<td>Loss of critical function</td>
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<tr>
<td>Can handle with onboard capabilities</td>
<td>Requires extensive medical resource utilization</td>
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<td>Can handle within designated timeline</td>
<td>May cause failure to meet mission objectives</td>
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### Renal Stone Risk

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely ≥2%&lt;5%</td>
<td>![Color]</td>
<td>![Color]</td>
<td>![Color]</td>
<td>![Color]</td>
</tr>
<tr>
<td>Possible ≥1%&lt;2%</td>
<td>![Color]</td>
<td>![Color]</td>
<td>![Color]</td>
<td>![Color]</td>
</tr>
<tr>
<td>Unlikely &lt;1%≥0.5%</td>
<td>![Color]</td>
<td>![Color]</td>
<td>![Color]</td>
<td>![Color]</td>
</tr>
<tr>
<td>Highly unlikely &lt;0.5%</td>
<td>![Color]</td>
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<td>![Color]</td>
</tr>
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</table>

### MSMB Risk-based Decision Analysis

- **Low risk** – acceptable for MDC 1 disposition (long duration)
- **Moderate risk** – Further consideration required for an MDC 1 disposition
- **High risk** – unsuitable for MDC 1 disposition
Integrated Medical Model (IMM)

- IMM Background
  - Software model used to simulate human space flight missions
  - Simulates medical events during space flight missions
  - Estimates the impact of these medical events on crew health and mission success
  - Outputs include estimates of crew health, probability of medical evacuation, and probability of medical loss of crew life
  - Optimization routines can be used to design medical systems which maximize crew health and probability of mission success
IMM Conceptual Model

**Inputs**
- Medical Conditions & Incidence Data
- Crew Profile
- Mission Profile & Constraints
- Potential Crew Impairments
- Potential Mission End States
- In-flight Medical Resources

**Outputs**
- Medical Condition Occurrences
- Crew Impairments
- Clinical End States
- Mission End States
- Resource Utilization
- Optimized Medical System

Integrated Medical Model
### Medical Risk Matrix – Long-Duration Missions (ISS)

**MDC-1**

#### Astronaut with no history of stones

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**MSMB Risk-based Decision Analysis**

- **Likely ≥2%<5%**
- **Possible ≥1%<2%**
- **Unlikely <1%≥0.5%**
- **Highly unlikely <0.5%**

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

- **Renal Stone (<5mm)**
- **Renal Stone (>5mm)**
IMM Analysis

Six month ISS mission with 6 crew
- with all crew meeting current med standards

• Evacuation
  1. Visual Impairment
  2. Dental Abscess
  3. **Kidney Stone**
  4. Sepsis
  5. Smoke Inhalation
Three Scenarios

1. No history of stone
2. History of stone
3. Current stone
**Hypothetical Case #1**

- 38 year old female Astronaut
- No stone history
- No findings on imaging
- Will launch in 2 months to the ISS
- For a 6 month mission

**Risk of developing first stone?**
Hypothetical Case #2

• 45 year old male Cosmonaut
• History of symptomatic 5 mm stone
• Treated with lithotripsy, resolved
• Will launch in 2 months to the ISS
• For a 6 month mission

Risk of developing a new stone?
Hypothetical Case #3

• 42 year old male Astronaut
• 2 mm calcification in renal parenchyma
• Asymptomatic
• Will launch in 2 months to the ISS for a 6 month mission

Risk of becoming symptomatic?
Risk Quantification

• IMM can provide renal stone risk estimates that can be used to assist
  • Crew medical certification decisions
  • Medical resource allocation
  • Crew medical training
Renal Stone Issues

Renal stones are a low likelihood but high consequence event

• What are acceptable waiver criteria?
• Can renal stone events be prevented?
• How do we monitor for stone formation pre-flight and in-flight?
• How do we manage in-flight stones?
**Future Work**

- Improved risk assessment
- Prevention
- Close monitoring and early detection
- Improved treatments
- Creation of a NASA Renal Stone Clinical Practice Guideline