Validation of the NASA Integrated Medical Model: A Space Flight Medical Risk Prediction Tool

J. Myers¹, Y. Garcia², J. Arellano³, L. Boley², D. A. Goodenow¹, E. Kerstman⁴, M. Koslovsky², D. Reyes⁴, L. Saile², W. Taiym², Millennia Young⁵

¹NASA - Glenn Research Center
²KBRwyle
³MEI Technologies
⁴University of Texas Medical Branch
⁵NASA – Johnson Space Center
Quantifying Spaceflight Medical Risk

Human Spaceflight Involves Both Engineering and Medical/Health Risks

Mission and Vehicle Engineering and Design

Balance Medical and Vehicle Resource Limitations with Quantitative Medical Risk Information

Spaceflight Medical Community

Quantitative Tools to Assess Medical Risk and Optimize Mission Medical Resources
Integrated Medical Model : IMM

Stochastic simulation model that predicts in-flight medical events, the resources required to treat, and approximate impacts to the spaceflight mission.

- Mission medical risk
- Medical resource trade studies
Inputs
Mission Specific
- Crew Member Attributes
- Crew Composition
- Mission Duration and Profile
- ISS Medical System Resources

Monte Carlo Simulations

Quantified Outputs
- Type and Quantity of all Medical Events
- Risk of Evacuation
- Risk of Loss of Crew
- Medical Resources Used
- Quality Time Lost

Optimization
- Optimized Resource Choices Balanced with Vehicle and Mission Constraints

Integrated Medical Model

Medical Knowledge Base
- Diagnosis and Treatment of Medical Conditions
- Medical Condition Incidence Data
- Risks due to EVAs
- IMM Medical Database

13,500+ data elements
IMM Methodology

Best-Case Scenario

- Best-Case resources available?
  - Yes: Treated Case: Decrement medical resources
  - No: Untreated Case

Worst-Case Scenario

- Worst-Case resources available?
  - No: Untreated Worst-Case
  - Yes: Treated Case: Decrement medical resources

Medical Event

Calculate End States:
- EVAC
- LOCL
- QTL
- Resource utilization (how many bandages?)
- Type and number of medical events

Weighted for partial treatment
# The IMM Medical Conditions

## SKIN
- Burns secondary to Fire
- Skin Abrasion
- Skin Laceration

## EYES
- Acute Angle-Closure Glaucoma
- Eye Corneal Ulcer
- Eye Infection
- Retinal Detachment
- Eye Abrasion
- Eye Chemical Burn
- Eye Penetration

## EARS, NOSE, THROAT
- Barotrauma (Ear/Sinus Block)
- Nasal Congestion (SA)
- Nose Bleed (space adaptation)
- 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 (space adaptation)
- Abdominal Injury
- Acute Cholecystitis/Biliary Colic Acute Diverticulitis
- Acute Pancreatitis
- Appendicitis
- Diarrhea
- Gastroenteritis
- Hemorrhoids
- Indigestion
- Small Bowel Obstruction

## LUNG
- Choking/Obstructed Airway
- Respiratory Infection
- Toxic Exposure: Ammonia
- Smoke Inhalation
- Chest Injury

## IMMUNE
- Allergic Reaction (mild to moderate)
- Anaphylaxis
- Skin Rash
- Medication Overdose/Adverse Reaction

## NEUROLOGIC
- Space Motion Sickness (Space Adaptation)
- Head Injury
- Seizures
- Headache (Late)
- Stroke (cerebrovascular accident)
- Paresthesia Secondary to Extravehicular Activity
- Headache (Space Adaptation) Neurogenic Shock
- VIIP (Space Adaptation)

## MUSKULOSKELETAL
- Back Pain (Space Adaptation)
- Abdominal Wall Hernia
- Acute Arthritis
- Back Sprain/Strain
- Ankle Sprain/Strain
- Elbow Dislocation
- Elbow Sprain/Strain
- Finger Dislocation
- Fingernail Delamination Secondary to Extravehicular Activity
- Hip Sprain/Strain
- Hip/Proximal Femur Fracture
- Knee Sprain/Strain
- Lower Extremity (LE) Stress fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Shoulder Sprain/Strain
- Acute Compartment Syndrome
- Neck Sprain/Strain
- Wrist Sprain/Strain
- Wrist Fracture

## PSYCHIATRIC
- Insomnia (Space Adaptation)
- Sleep Disorder
- Anxiety
- Behavioral Emergency
- Depression

## GENITOURINARY
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (space adaptation)
- Urinary Retention (space adaptation)
- Vaginal Yeast Infection

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

## ENVIRONMENT
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness Secondary to Extravehicular Activity
- Headache (CO2)
Spaceflight Medical Knowledge Database: iMED*

- Categorize astronaut symptomatology into conditions, flight medicine concerns, and resources
- Lifetime Surveillance of Astronaut Health (LSAH)
  - ISS Expeditions 1 thru 13 (2006)**
  - STS-01 thru STS-114 (2005)
  - Apollo, Skylab, Mir (U.S. crew only)
- Analog & terrestrial data
  - Bayesian and Independent models analyses
- Flight surgeon Delphi study
  - *Russian medical data not used*

* Integrated Medical Database, iMED
** More current data used for Spaceflight Associated Neuro-ocular Syndrome, SANS
Validation

Compare IMM predictions to relevant referent:
Real spaceflight observed medical events during real missions

- **Real Environment**
  - **Similar Environment**
    - **Similar System**: Carefully consider analogues system
    - **Best**: Data from previous flight of system in same space environment
  - **Better**: System and Environment fidelity must be carefully considered
  - **Better**: Carefully consider analogues Environment
What Data is Used for Comparison?

- **Real World System (RWS):** 31 ISS and 21 STS missions not previously incorporated into the primary IMM data repository

STS 115 through STS 135 and STS 107

ISS Expedition (Exp) 14 through 39/40 and ISS Exp 9

*Image Credits: NASA*
IMM Simulations of the RWS Missions

Equivalent simulations performed for each RWS mission profile using IMM v 4.0

• Length of mission
• Mission schedule (EVA)
• Crew complement (sex, limited medical history)
• ISS simulation assumed resupply of medical supplies
• 100 Medical condition set
Observed and Predicted Outcomes

- Total medical events (TME)
- Medical consumable utilization
- Loss of crew life (LOCL) and potential need for evacuation (EVAC)*

* RWS had zero LOCL and EVAC events
(Cumulative) Total Medical Events

Predicted (P)
Observed (O)
Observed: IMM medical conditions list only (mc)
20% of the STS and 15% of the ISS medical events within expected uncertainty.

14% for STS and 24% for ISS medical events outside of the expected uncertainty.

The remainder of the events had an indeterminate comparison.
Out of Range ISS Conditions

Over predicted the number of events for all but 6 conditions.
Out of Range STS Conditions

Under predicted the number of events for all but two conditions.
## Medical Consumables

<table>
<thead>
<tr>
<th>Medical Resource Category</th>
<th>STS</th>
<th>ISS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Predicted</td>
</tr>
<tr>
<td>Antacids</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Antibiotics</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Antidiarrheals</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Antiemetics</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Antifungals</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Antihistamines</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Antivirals</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Decongestants</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Hypnotics</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Laxatives</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Non-opioid Analgesics</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Ophthalmic Lubricants</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Opioid Analgesics</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Steroids</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Positive correlation between the IMM predictions with the observed RWS
STS: Kendall Tau-b = 0.76 and ISS: Kendall Tau-b = 0.57
### LOCL and EVAC Comparison

#### STS

<table>
<thead>
<tr>
<th></th>
<th>Predicted Number</th>
<th>90% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVAC RWS = 0</td>
<td>0</td>
<td>0, 1</td>
</tr>
<tr>
<td>LOCL RWS = 0</td>
<td>0</td>
<td>0, 0</td>
</tr>
</tbody>
</table>

#### ISS

<table>
<thead>
<tr>
<th></th>
<th>Predicted Number</th>
<th>90% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVAC RWS = 0</td>
<td>0</td>
<td>0, 1</td>
</tr>
<tr>
<td>LOCL RWS = 0</td>
<td>0</td>
<td>0, 0</td>
</tr>
</tbody>
</table>

- Predicted counts are estimated using the median of the simulated distribution.

- A confidence limit of (0, 0) indicates that more than 95% of the generated LOCL counts was 0 as these confidence limits are estimated by the 5th and 95th percentiles of the simulation distribution.
Potential Implications on Decision Making

• Variation exists in IMM predictive power for STS and ISS missions

• Decision should account for information limits
  – Longer mission profile - IMM tends to over predict incidences
  – Shorter mission profiles - IMM tends to under predict incidence.

• Difference in predictions
  – Different ISS and STS reporting conditions.
  – Combining all “mission type” data
  – Constant occurrence rate or fixed proportion.
Future Work (Some Already Done!)

- Incorporation RWS data into the iMED
- Review of Treatment Pathway Data
Acknowledgments

GRC
• Kelly Gilkey
• DeVon Griffin

KBRwyle
• Marlei Walton
Questions?