Bioastronautics@Hopkins Mini-Symposia Series: Systems Medicine for Spaceflight (11/15/2021)

Audience/Chat Questions

1. **Dylan H:** In the larger system of systems that makes up an entire mission, what sort of emergent behavior arises when medical needs are factored in? What tools and formal methods besides tradespace analysis are used to analyze interactions and networks formed by the different components of a mission?
   Antonsen: For the different components of a mission, the primary approach is systems engineering which is documented in NPR 7120 and can be found on the NODIS website. The Systems Engineering Handbook can be publicly searched on as well. The specific approaches that wrap around the systems engineering process called Human Systems Integration takes into account areas like human factors, training, operations, and more. A new handbook for Human Systems Integration was released in November 2021 by NASA and can be found publicly online at https://procurement.ksc.nasa.gov/-/media/COMET/BiddersLibrary/Agency%20Documents/NASA_SP-20210010952-NASA_HSI_Handbook-May_2021.ashx. For medical needs prioritization there is an Accepted Medical Conditions list approach which can be found on NTRS at: https://ntrs.nasa.gov/citations/20190027540.

2. **Sarah H:** Are there existing, standardized frameworks/tools that are used for simulating missions (in order to conduct tradespace analysis)? Or do the methods vary by organization?
   Lehnhardt: Mission simulations of medical risk are done with probabilistic risk assessments using Monte Carlo simulations: http://www.iapsam.org/psam14/proceedings/paper/paper_174_1.pdf

3. **Peter B:** It seems there is also a lack of sensors capable of capturing long term bio-telemetry. Does this technology readily exist at these scales?
   Lehnhardt: I believe that the technology exists to capture this type of long-duration bio-telemetry data. The difficulty is understanding what to do with the data - what action does access to that data drive? How do we perform advanced analytics on that mountain of data to get meaningful information?
   Fogarty: I agree that the technology does exist. There are difficulties implementing in spaceflight and especially into the field setting of ISS. Sometimes EMI can limit the capability and sometimes the technology is obtrusive and impacts function (even if it's a comfort issue). When data acquisition is possible, the complexity becomes download quality and eventually the plan for analysis. There have been issues with consenting when there is no identified goal. These 'fishing expeditions' have not fared well. That being said, approaches for large long term biomedical data acquisition paired with functional data and outcomes data are forthcoming (ala Mike Schneider and Lee Hood type approaches). I think the large long term biomedical data acquisition will need to be as unobtrusive as possible and part of a larger vision for holistic data analysis across disciplines.

4. **Gary R:** Do the tradespace analyses enable you to update plans for human health and performance upmass (increase or decrease) as the "rocket scientists" change their programmatic assumptions and constraints about what can be allocated to human health and performance?
   Lehnhardt: Absolutely. Tradespace analysis can be used to "fit in the box" of vehicle constraints with an optimized system design or it can be used to argue for a bigger box or increased vehicle integration.

5. **Gary R:** Do your tradespace analyses allow you to maintain a few alternatives for a particular human health and performance capability so that you can re-plan for a backup alternative, if a better alternative is precluded by changing assumptions or constraints of the "rocket scientists"?
   Lehnhardt: Yes, the tradespace analysis looks at capabilities, not specific design solutions. Therefore, if a capability is high-yield but has multiple potential design solutions, they can be interchanged in the system design.

6. **Francis M:** How would something like precision brain medicine work? Is that possible?
   Fogarty: I think precision medicine of any kind can work if it has the maturity to inform actions. That would mean the evidence base supports the interpretation of the signal. For example, there might be

emerging CNS biomarkers via MRI or EEG that indicate how an individual might respond to extreme stress and is robustly linked ($R>0.8$) to an outcome such as mission relevant cognitive impairment. To be useful there needs to be an appropriate action to address it such as prevention in the form of pre-flight familiarization and training, or mitigation with in-flight cognitive testing and action with tools to reduce stress and restore function.

7. **Richard B:** From what I've heard, a cosmonaut had a kidney stone and took all the morphine onboard and the crew were within hours of of abandoning the MIR station to return the fellow back to Earth. But he passed the stone. Is this the "one" case among all the crew from the different space agencies?
   Antonsen: Yes, this is the 'one' case that may have occurred in mission that was likely to be a kidney stone. I'm not sure about the total pharmaceutical usage in that case. The concern has always hypothetically been there because bone unloading in microgravity conditions puts calcium back into the blood stream. But there is a big difference between hypothetical concerns and actual clinical outcomes.

8. **DM G:** Systems-thinking is usually misplaced by systems over-engineering. How can AI and data mining inform those risks that are not that risky? Kidney stones are a great example.
   Lehnhardt: Using advanced computing tools to improve NASA's understanding of risks (including likelihood and consequence) is hopefully our future state. With so few spaceflight subjects, many medical conditions become increasingly rare, so any strategies that can help NASA to better understand the true risk of a rare event will be helpful for optimizing system design.

9. **Kimia S:** Are you suggesting that crew selection should also also take into account their medical knowledge and engineering training?
   Lehnhardt: Yes, crew selection for long-duration deep space missions should absolutely include the knowledge, skills, and abilities of the astronauts in the decision-making process.
   Fogarty: just as the crews of today receive training outside their discipline and primary function, crew of the future will have to be cross-trained in many domains and rely on real-time decision support and in-mission training/refresher training to meet the needs,

10. **DM G:** What about end-of-life protocols and therapeutic efforts protocols?
    Lehnhardt: All medical scenarios need to be considered in identifying capabilities in the Mars system design including cessation of treatment, palliation, and procedures for death of a crew member. If treatment is futile or risks the lives of the rest of the crew (as well as the mission), it must be humanely stopped.
    Fogarty: Those discussions occur with the medical and flight crew community 'regularly' and require an ethical framework to guide the discussion. Coming from an organization where the astronauts are occupationally familiar with the potential for death throughout the spaceflight mission, it is hard to know to what extent and depth these discussions occur with commercial passengers.

11. **Dean D:** Of medical conditions observed in space to date, how many are one-offs, and how many of those conditions were anticipated prior to their occurrence? Do we have a good record of predicting medical conditions in space thus far?
    Lehnhardt: Using probabilistic risk assessment tools, we have been able to demonstrate that our prediction capabilities can accurately identify conditions that are most likely to occur. However, every few years, a condition will arise in spaceflight that was unanticipated, so we have to acknowledge that our PRA tools get us close to the right answer but it will never be a complete answer.
    Fogarty: One of the confounding factors has been how the spaceflight environment in concert with an individual's predisposition (asymptomatic/undetectable at the time of screening) results in the manifestation of a medical condition. Bottom line is we have been unable to quantify the effect of spaceflight as a physiological stressor on the manifestation or acceleration of a pathological process. The epidemiological approach which feeds the PRA is relatively inaccurate due to the low number of subjects and High degree of interindividual variability as well.