Objectives

1. Describe the Occupational Medicine approach to controlling medical Hazards for Spaceflight
2. Provide a critical appraisal of the current Cardiovascular Hazard Controls used for long duration missions.
3. Describe the operational research needed to validate the current cardiovascular hazard controls for exploration class missions.
Agenda

• Occupational Medicine
• Bioastronautics Roadmap
• NRC review of NASA's Biomedical Research Program
• Treatment of Uncontrolled CV Hazards
  – Hazard - Orthostatic Intolerance
  – Hazard - Cardiac Atrophy
  – Hazard – Significant arrhythmias
• Discussion/questions

Hazard Controls - Prevention

• Tertiary prevention “the care of established disease, with attempts made to restore to highest function, minimize the negative effects of disease, and prevent disease-related complications."
• Secondary Prevention – "those measures that "identify and treat persons who have already developed risk factors or preclinical disease but in whom the condition is not clinically apparent."
• Primary prevention - “those measures provided to individuals to prevent the onset of a targeted condition."

Focused Risk Mitigation Strategy

Bioastronautics Critical Path Roadmap SD/CB Input
Review of NASA’s Biomedical Research Program

- Committee on Space Biology and Medicine Space Studies Board
- Commission on Physical Sciences, Mathematics, and Applications
- National Research Council
  – http://www.nap.edu/catalog/9950.html

FY 1999 funding of NASA supported programs in biomedical research and countermeasures.

CRITICAL HAZARD

Any condition which may cause a non-disabling personnel injury, severe occupational illness
CATASTROPHIC HAZARD

Any condition which may cause a disabling or fatal personnel injury, or loss of one of the following: Orbiter or ISS.

Cardiovascular Hazards

• Cardiac hazards are considered to be controlled for long and short duration missions since no outstanding waivers in this area of medicine exists.

• Regardless, cardiac anomalies have been seen in astronauts within temporal proximity of space missions.

• To date, the root cause of these cardiac anomalies has not been proven to be associated with spaceflight.
FY 1999 Review of NASA’s Biomedical Research Program recommendations for a cardiac summit

1. Determine if cardiac arrhythmias are a significant concern and if monitoring is warranted;
2. Determine if cardiac atrophy is a significant concern and should be monitored;
3. Determine if there are pre- and in-flight predictors of orthostatic intolerance;
4. Determine which ground-based human and animal models best reproduce the effects of spaceflight;
5. Review the data and rationale for current countermeasures and suggest new countermeasures on the basis of the existing physiological data;
6. Determine what level of aerobic fitness should be maintained in space; and
7. Determine if countermeasures have been effective when used as recommended.

These are clearly Hazards

The “mission design” will determine if they are critical or catastrophic.

Their “incidence” and “severity” will determine if they are controlled.
4. Determine which ground-based human and animal models best reproduce the effects of spaceflight;

5. Review the data and rationale for current countermeasures and suggest new countermeasures on the basis of the existing physiological data;

6. Determine what level of aerobic fitness should be maintained in space; and

7. Determine if countermeasures have been effective when used as recommended.

These are clearly *hazard controls*, or the means to derive them.

Where are we today?

- Before we can determine if further research is CV necessary…..

  …..we need to determine if the absolute risk *(incidence + severity)* of a particular cardiovascular hazard is reduced to acceptable levels.

- If the CV risk is acceptable for the mission *certification of flight readiness*, then the suite of hazard controls which accomplished this must be a *requirement*. 
When are we OK?

If the CV hazard risk is **acceptable** for flight……

…. then it should be considered as the **standard** for controlling that hazard.
Circa 2007 – What is our risk?

Soooo……

What is our **absolute risk** for catastrophic and critical cardiovascular hazards for exploration missions?

Do we try to reduce **incidence** and/or **severity**?

Let’s look at “severity”!!!
10.

**Event Sequence Diagram**

Of AMI, Sudden Cardiac Arrest and 30 day mortality in non-Sudden Cardiac Arrest patients in robust urban environments.

**Assumptions:**
- Sex-adjusted hard cardiac event rate of 3 per 100,000 person-yrs.
- Age stratum, 40-65 yrs, 50% of AMI present as OOH SCA;
- n = 1,641 OOH SCA for outcomes
- n = 6,450 for hard event rate.
Survival of AMI, SCA and 30 day mortality in non-SCA patients in robust urban environments.

Gillis and Hamilton et al 2007

Presenting Rhythm

<table>
<thead>
<tr>
<th>SCA</th>
<th>Non-SCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asystole</td>
<td>EMS Witnessed VF/VT</td>
</tr>
<tr>
<td>PEA</td>
<td>Unwitnessed VT</td>
</tr>
<tr>
<td>VF/VT</td>
<td>Hosp.</td>
</tr>
<tr>
<td>VT &amp; VF</td>
<td>Hosp.</td>
</tr>
<tr>
<td>No VT or VF</td>
<td>Hosp.</td>
</tr>
</tbody>
</table>

% of all events

- SURVIVED
- FATAL

FY 1999 Review of NASA’s Biomedical Research Program recommendations for a cardiac summit

1. Determine if cardiac arrhythmias are a significant concern and if monitoring is warranted;
2. Determine if cardiac atrophy is a significant concern and should be monitored;
3. Determine if there are pre- and in-flight predictors of orthostatic intolerance;

These are clearly Hazards

The "mission design" will determine if they are critical or catastrophic.

Their “incidence” and “severity” will determine if they are controlled.

http://www.nap.edu/catalog/9950.html
Task 3: Determine if there are pre- and in-flight predictors of orthostatic intolerance

- Current exercise and fluid loading countermeasures are an adequate hazard control.
- Not possible to validate post flight tilt-table results to emergency vehicle egress success.
- Med Ops not convinced orthostasis will be a problem for lunar surface operations
- Forward work for Mars needs to be performed. Only a critical hazard?
- Levine et al has shown initial results of subjects finishing 5 weeks of bedrest with an INCREASE in orthostatic tolerance from rowing/strength training program + a volume load.
2. Determine if cardiac atrophy is a significant concern and should be monitored.

Task 2: Determine if cardiac atrophy is a significant concern and should be monitored

- Need echo data with cardiovascular interventions to better understand the physiology and space normal clinical findings
- In the past astronauts have not been able to “get the shot” for retrospective analysis.
- Pre/Post flight data is high fidelity because experience echo technicians are collecting the data.
• Bed rest deconditioning leads to physiologic cardiac atrophy compromises left ventricular filling during orthostatic stress by reducing diastolic untwisting and suction.

• Dorfman and Levine used MRI with myocardial tagging to confirm that diastolic untwisting is impaired by head-down tilt bed rest but preserved by exercise training while confined to strict bed rest.

T. Dorfman et al “Diastolic Suction is Impaired by Bed Rest: MRI Tagging Studies of Diastolic Untwisting” Submitted for print

• Dorfman et al performed myocardial tagged MRI and calculated maximal untwisting rates by Harmonic Phase Analysis (HARP) before and after -6° head-down tilt for 18 days with (N=14) and without exercise (N=10) on previously sedentary subjects (34.8 ± 9yr.).

• They also measured left ventricular mass and left ventricular end-diastolic volume using cine MRI.

• The exercise group cycled on a supine ergometer in a horizontal position for 30 minutes, 3 times a day at 75% of their maximal heart rate measured in an upright position.

T. Dorfman et al “Diastolic Suction is Impaired by Bed Rest: MRI Tagging Studies of Diastolic Untwisting” Submitted for print
MRI tagging images using SPAMM

Before Bed Rest
Mid-cavity level and short axis image.
This individual's max midwall untwisting rate prior to bed rest was -31.8 degrees/sec and it decreased to -25.5 degrees/sec following bed rest.

Spatial Modulation of Magnetization (SPAMM) UTMB

Untwisting rates versus frame interval before bed rest and after bed rest.

- This individual's max untwisting rate prior to bed rest was -67.1 degrees/sec. Untwisting rates are positive during systole and negative during diastole, and a more negative untwisting rate is indicative of an enhanced diastolic function.
- This individual's max untwisting rate decreased to -42.8 degrees/sec following bed rest.

T. Dorfman et al “Diastolic Suction is Impaired by Bed Rest: MRI Tagging Studies of Diastolic Untwisting” Submitted for print
Conclusions Dorfman et al

- Diastolic untwisting is impaired following sedentary short term HDT bed rest.
- Exercise training during bed rest can prevent the atrophy associated with bed rest and preserve or even enhance diastolic suction.
- Exercise appears prevent deleterious cardiac remodeling during unloading conditions such as bed rest or perhaps space flight.

T. Dorfman et al “Diastolic Suction is Impaired by Bed Rest: MRI Tagging Studies of Diastolic Untwisting” Submitted for print

Next Steps …. Integrated Cardiac
Benjamin D. Levine, M.D. & Michael W. Bungo, M.D.

- In-flight resting echocardiograms with ECG recording followed by 24 to 48 hour Holter/Blood Pressure/Activity Monitoring at FD15 and 30, and every one to two months thereafter with a final session required 15 days before landing.
- A post-exercise echo as part of the FD90 session.
- Pre- and postflight BDC Cardiac MRIs as well as Exercise Echo/ECG and Resting Echo/ECG sessions followed by 24 to 48 hour Holter/BP/Activity monitoring.
- Holter/BP/Activity monitoring is also performed on R+0.
- A graded tilt test with echocardiograph, ECG, and BP measurement is also required pre- and postflight.
- Magnetic Resonance Spectroscopy (MRS) to ground MRI sessions
- Strain rate imaging for pre/postflight tests
1. Determine if cardiac arrhythmias are a significant concern and if monitoring is warranted.

Sources of Cardiac Data

- Detailed Supplemental Objectives (DSOs)
- Extended Duration Orbiter Medical Project (EDOMP) program
- NASA Research Announcements (NRA)
- National Space Biological Research Institute (NSBRI)
- Flight Medicine Clinic (FMC)
- Shuttle mission medical records
- ISS mission medical Records
- Skylab, Apollo-Soyuz, Apollo, Gemini console logs
- Biomedical Engineer (BME) Console logs
- Online Data Reduction Center (ODRC)
- Bld 8 Space Medicine Archives
- Life Sciences Data Archive (LSDA)
- Longitudinal Study of Astronaut Health (LSAH)
- Literature review
- NASA internal Technical Reports
- Astronaut interviews
- Flight Surgeon interviews
Cardiac Monitoring Occurrences

- Selection
- Annual physical/FMC visits
- Parabolic flight
- Preflight
  - MRIDs
  - NBL
  - Chamber
- Inflight
  - PFE
  - EVA
  - Contingency Ops
  - Payload activities
- Postflight
  - MRIDs

Incidence of Ectopy in Aviation

24-hour Holter recordings from 303 patients with normal cardiac catheterization found that only 11.9% of these patients had no ectopy.

- Of significance was the presence of isolated atrial and ventricular ectopy, pairs, and nonsustained SVT
- Results indicate that ectopy in this asymptomatic cohort with no evidence of cardiac disease is very common.

Incidence of Cardiac Events In Spaceflight Crews

- **Apollo 15** was the first U.S. spaceflight in which cardiac arrhythmias other than the occasional PVC were observed.
  - Lunar module pilot experienced 5 **unifocal PVCs within a 30-second interval**
  - 1 hour later, the lunar module pilot experienced a **22-beat run of nodal bigeminy**.
  - LM pilot recalled experiencing **profound fatigue at the time of this bigeminal rhythm**.
- Twenty-one months after the mission he experienced an **myocardial infarction**.
- Angiogram revealed diffuse disease
  - Mission Medical Archive

- Skylab Space Project also revealed significant arrhythmias in several of crewmembers, including
  - **3-beat ventricular tachycardia (VT) complex (triplet)** occurring with exercise
  - **Atrial-ventricular block during LBNP recovery**
  - **Atrio-Ventricular Junctional rhythm at rest after LBNP**
  - **Multifocal PVCs after an EVA**.
- **Is this bad?**

Incidence of Cardiac Events In Spaceflight Crews

- A Holter recording taken during the second month on orbit revealed an asymptomatic, non-sustained, 14-beat run of VT.

- We now know that this subject experienced a myocardial infarction 2 years after his flight.


Circa 2003 EVA Monitoring system
Incidence of EVA related Cardiac Events on STS and ISS

New EVA ECG Monitoring System
How reliable was our EVA ECG data?

Strip Chart Recorder
Red Tag and Critical Anomaly Report
GMT = XXX:15:47:07.000

Triplet, Aberrancy or Artifact?
Let’s now playback a mission backup tape – Run #2

- Legacy “hard copy” ECG data is corrupt – Space Medicine advised not to use for mission decisions
- EVA telemetry, from April 1983 (STS-6) until present, was reanalyzed.
- Software developed by Advanced Projects to convert the digital archives into telemetry streams for Holter analysis.
AEMS Admin Display

> 20,000 ‘lines of code’ verified for STS 114 “return to flight”

Data Taken From 160 EVA’s STS-006 Thru STS-116

<p>| | |</p>
<table>
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<tr>
<td>Total STS</td>
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<td>Total ISS</td>
<td>4</td>
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<tr>
<td>Total Joint</td>
<td>52</td>
</tr>
<tr>
<td>Total EVA’s Analyzed</td>
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<tr>
<td>Total STS</td>
<td>32</td>
</tr>
<tr>
<td>Total ISS</td>
<td>4</td>
</tr>
<tr>
<td>Total Joint</td>
<td>14</td>
</tr>
<tr>
<td>Total EVA’s Not Analyzed</td>
<td>50</td>
</tr>
<tr>
<td>Total EVA’s</td>
<td>210</td>
</tr>
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</table>
Average Percent Monitored = 72.89%
Total QRS Complexes = 3,828,826
Total Ectopic Beats = 11869

<table>
<thead>
<tr>
<th>PVC</th>
<th>PVC Sigan</th>
<th>V C Coup</th>
<th>SVE Sigan</th>
<th>SVE Coup</th>
<th>Junctional</th>
</tr>
</thead>
<tbody>
<tr>
<td>6787</td>
<td>852</td>
<td>13</td>
<td>3323</td>
<td>1022</td>
<td>25</td>
</tr>
</tbody>
</table>

Total EVA’s with Sinus Arrhythmia = 77 of 160 (48%) Prelim data
Total Sinus Arrhythmia preflight = 9 of 160 (5.6%) Prelim data
Total Time of 160 Analyzed EVA’s
= 60688 minutes
= 42 Days, 16 Hours and 54 Minutes
Average EVA length = 300.5 ± 43.1 SD minutes
Average Heart rate = 86.2 BPM
Average age at EVA = 45.04 ± 17.63 SD
The majority of EVA’s had ectopy, which can be explained by examining pre and post flight medical data (resting ECG, Treadmill Stress Test, Electronic Medical Record etc.)

1 EVA had ectopy with no terrestrial medical data to correlate (129 junctional beats over 6 ½ hour EVA) . Query “Afrin” effect

62 had occasional (< 30) PVC’s per EVA

62 had no ectopy

All EVA’s who had “serious” ectopy was diagnosed with some degree of “Cardiac Disease” within temporal proximity to the mission.

Preflight, In-flight and Post flight Data

QTc vs Time After Launch

ISS = 15, MIR = 3, SkyLab = 9

- ISS Mission Archives
- Skylab Mission Archives

In-flight Data

QTc vs Time After Launch

ISS = 15, MIR = 3, SkyLab = 3

- ISS Mission Archives
- Skylab Mission Archives
On Orbit Periodic Fitness Exam

- ECG and blood pressure data from 26 on orbit fitness tests were analyzed.
- All exercise protocols were written to prevent the crewmember from exceeding 80% of their prelaunch VO2 max.
- Pre launch exercise stress tests were used as baselines for comparison.
- ECG's were acquired using the Dower EASI 5 to 10 electrode lead conversion system.

ISS Mission Archives
On Orbit Periodic Fitness Exam

Actual HR

Heart Rate (BPM)

% of Exercise Portion of PFE

On Orbit Periodic Fitness Exam

Target Heart Rate

% of Max Heart Rate Target

% of Exercise Portion of PFE
On Orbit Periodic Fitness Exam

• 26 exercise PFE’s lasting approximately 20 minutes each were compared to pre launch exercise stress tests.
  • No clinically significant ectopy was observed on orbit.
    • Resting: Heart rate (mean 68 ±5.7 SD)
    • PR interval (155 msec ±24 SD)
    • QRS duration (95 msec ±4.2 SD)
    • QT interval (389 msec ±1.4 SD)
    • QTc interval (419 msec ±10.6 SD).
  • One clinically significant ST change was observed on orbit.
  • One incident of “false positive” ST elevation was observed when the crew member was pedaling on the cycle ergometer at the same rate as their heart.
  • Will update database to include 54 PFE’s to date

Summary of Incidence Data
Does Spaceflight Cause Arrhythmias?

• The evidence strongly suggests that preflight cardiac disease is the main cause of “serious” in-flight cardiac arrhythmia and anomalies.
• NO space related risk factors have been validated to date.
• Until we stop launching cardiac disease……
  …..a prospective study looking at spaceflight induced arrhythmia (flight surgeon insomnia) will be impossible.
Sooooo…..

…if we think that **serious** on orbit arrhythmias are due to cardiac disease …. 

How much ‘disease’ do we fly?

---

**Incidence Of Cardiac Disease in Aviation**

Age-specific rates of severe coronary disease among pilots who were involved in a fatal aviation accident.

- A 3 year study of 710 pilot autopsies from airline accidents, 69% had some degree of heart disease and 2.5% had severe heart disease. (Booze C.F., Staggs C.M., Aviat. Space Environ. Med 1987;58:297-300.)
- These studies give us an idea of the incidence of heart disease which is present in apparently healthy pilots flying aircraft today.
Incidence Of Cardiac Disease in Aviation

• A study of 288 military, commercial, and private pilots killed in aviation mishaps and of 132 healthy males aged 18 to 62 who died accidentally revealed no significant difference in the prevalence of coronary artery disease between the aviators and the control group.

• A study of apparently healthy U.S. Air Force aviators
  – reported myocardial infarction, angina, and sudden cardiac death of 0.02% per year from 1988 to 1992 (20 per 100,000 years)
  – the mean age of aviators having a cardiac event was 44 years.
  – 61% were myocardial infarction and 21% were sudden cardiac death.
  – Angina only represented 18% of the cardiac events. Does this suggests that denial or underreporting may be a significant concern in this population?


Bayesian Theory

Adapted from Kruyer 2004
The sensitivity, specificity, positive predictive value, and negative predictive values for treadmill, thallium, and CAF for the presence of SCAD as determined by coronary angiography.


Cardiac event rates of aviators (%/year/person) for 2, 5, 10, and 15 years for minimal coronary artery disease and significant coronary artery disease.

Natural History of CAD

44 military aviators who were diagnosed with asymptomatic MCAD by angiography were followed

– Progression of MCAD to SCAD occurred in 25% of these 11 aviators (63.6%) had a negative noninvasive test at the time of their re-catheterization.

– The group that progressed to SCAD had higher total and LDL cholesterol and a lower HDL cholesterol


• Gee MR, Kruyer WB. Progression of Minimal Coronary Artery Disease in USAF Aviators Followed With Serial Cardiac Catheterizations. Aerospace Medicine Association Meetings: Houston.

Longitudinal Study of Treadmill Tests of Active and Inactive NASA Astronauts

A review of 2,069 exercise treadmill tests (TMT’s) using a Bruce protocol conducted on Active and Inactive astronauts was conducted from February 1977 until July 2000.

– Age distribution

– Incidence of Positive Tests

– Follow-up of Positive Test

– Incidence of Cardiac Events

FMC and LSAH 133 Inactive Astronauts at 2001
Mean Age of Inactive Astronauts by Year

Mean Age of Active Astronauts by Year
Longitudinal Study of Treadmill Tests of Active and Inactive NASA Astronauts

- **Number of Astronauts = 295**
- **Follow up time 1 - 23 years**
- **Total Person Years = 2,240**
- **1941 negative TMT’s**
  - 2 cardiac events within 4 years of a negative TMT
  - 2 cardiac deaths within 2 years of a negative TMT
- **51 Positive TMT’s**
  - 1 Death within the year of the TMT
Longitudinal Study of Treadmill Tests of Active and Inactive NASA Astronauts

- Gross incidence of whole population = 0.22%/per person/ year
- 1/51 +TMT lost to follow up
- 2/69 Borderline TMT lost follow up
- Will complete study to include 709 new studies to 12/31/2006
- Will compare to ~5000 LSAH control population TMT’s

So….. Current circa 2004 selection methods do not adequately filter out asymptomatic “Cardiac Disease”…..

What do we do now?
Can we improve the risk factor profile?

• Approximately 25% of patients with CAD do not have any of the classically recognized risk factors.

• Presently over 200 new risk factors and markers (such as C-reactive protein, homocysteine, fibrinogen, Lp(a), ApoB, ApoA1, urine microalbumin, and some infectious agents) have been correlated with CAD.


Are there other markers which indicate the presence of cardiovascular disease?

Elevated highly selective C-reactive protein is a reliable risk factor for helping predict future cardiac events that should warrant primary prevention but not necessarily medical disqualification.

- Hamilton DR, Murray JD, Ball CG. Cardiac health for astronauts: coronary calcification scores and CRP as criteria for selection and retention. Aviat Space Environ Med 2006; 77:377-387.

Cardiovascular Screening Tests – Stress Thallium, CAF

- CAF was found to have a PPV of 68% for any measurable CAD in 613 aviators.
- CAF had a PPV of 81% for all CAD and 34% for SCAD (mean age of 42.3 years) in 220 male aviators.
- 52% of calcific lesions detected on EBCT could be seen by fluoroscopy.

Coronary Artery Calcium Score

- Approved by MMOP for Long Duration Astronauts
- Astronauts with CACS < 100 and/or other significant risk factors should receive secondary prevention.
- Astronauts with a CACS > 100 are disqualified from long duration spaceflight.

Hamilton DR, Murray JD, Ball CG. Cardiac health for astronauts: coronary calcification scores and CRP as criteria for selection and retention. Aviat Space Environ Med 2006; 77:377-387.

New selection methods will start with Increment 16 and should filter out most asymptomatic “Cardiac Disease”…. What is our risk Circa 2007?
LaMonte et al reported CACS and an age stratum of 40-65 years, representing approximately 60% of a 10,746 total population with hard event rates (fatal or non-fatal AMI) during a 3.5 year follow-up.

### Event rates per 100,000 person-years

<table>
<thead>
<tr>
<th>CACS</th>
<th>Rate</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0 - 100</td>
<td>20</td>
</tr>
<tr>
<td>100 - 400</td>
<td>670</td>
</tr>
<tr>
<td>&gt;400</td>
<td>1060</td>
</tr>
</tbody>
</table>


The very low incidence in the Church CACS = 0 subgroup may represent a risk nadir resulting from exhaustion of the primary CV pathology in younger individuals and the nascent risk of CAD in the 4th decade of life for persons with low CAC scores and minimal conventional cardiac risk factors.
Is Space Flight a “root cause” for significant arrhythmias?

- Given that the incidence of all cause sudden cardiac death or myocardial infarction in the CACS = 0 astronaut cohort on Earth…
- What is the evidence that space flight is responsible other root causes of hard cardiac events?
- How will we find this out?
Yep….Integrated Cardiac…. Again!
Benjamin D. Levine, M.D. & Michael W. Bungo, M.D.

• In-flight resting echocardiograms with ECG recording followed by 24 to 48 hour Holter/Blood Pressure/Activity Monitoring at FD15 and 30, and every one to two months thereafter with a final session required 15 days before landing.
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• A graded tilt test with echocardiograph, ECG, and BP measurement is also required pre- and postflight.
• Magnetic Resonance Spectroscopy (MRS) to ground MRI sessions
• Strain rate imaging for pre/postflight tests

Thank You
So now you know what keeps the flight surgeons up at night.
The Team
Ashot Sargsyan
Shannon Melton
Scott Dulchavsky
Kat Garcia
Dave Martin
Jack Butler
Steve Platts
Ben Levine
Jan Meck
Mike Bungo
Jennifer Fogerty
Mark Scheutte
Peggy Winston
ISS Crew
John Charles
Mike Barratt
Kelly McFarlin
David Gillis
Kieran Smart
Phyllis McCulley
Karen Mathis
Melisa Rosse
Chuck Lloyd
Jim Locke
JD Polk
Mike Duncan
Ashkan Moghaddam
Terry Guess
Rick Pettys
Sonny Belinkie
John Tyberg
Cathy Modica
HRF team
Byron Smith
Ben Voigt
Victor Hurst
Hal Doerr
George Beck
Jack Rasbury
Don Hagen
Tom Goodwin
Jon Clark
Jeff Sutton
Gary Gray
Bill Kruyer
Steve Nissan
Mary Wear
Jocelyn Murray
Chad Ball
Andy Kirkpatrick

Please excuse me if I missed you.

AEROSPACE MEDICINE GRAND ROUNDS

Questions?

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Flight Surgeon / Electrical Engineer - Wyle Life Sciences