Space Medicine
• The presenter has no financial affiliations to disclose.
• The presenter does not discuss off label use or investigational use in the presentation.
Overview

• Human physiology in microgravity
• Medical and laboratory support
• Astronaut training
• Need for new medical sensors and biomarker technologies
• One year ISS mission
At the conclusion of this lecture, the audience might:

• Understand a little of microgravity’s effect in the space flight environment
• Recognize the redistribution of body fluids on human physiology in space flight
• Identify effects of long-duration space flight on the human body
• Healthy individuals in extreme environments
• Monitor and maintain the health of astronauts throughout their careers
• Support crews with the stressors of space flight
Physiological Changes of Spaceflight
Rapid Effects--Fluid Shift

Acute physiological changes due to redistribution of body fluids towards the head

- On Earth, gravity exerts a downward force to keep fluids flowing to the lower body (A).
- In space, fluids redistribute toward the chest and upper body (B).
- The body undergoes rapid volume contraction. The body functions with a smaller plasma volume (C).
- Upon return to Earth, gravity again pulls the fluids downward, but there are insufficient fluids to function normally on Earth (D).
**Fluid Shift**

- Fluids make headward shift
  - Head fullness
  - Decreased thirst and oral fluid intake
  - Nasal congestion
- Volume contraction by 1-2 L
  - Intracellular fluid shift
  - No diuresis
- Appearance: Puffy face - Bird legs
Physiological Changes in Space--Hematology

Hematologic effects--normal adaptation to microgravity:

• **After Launch**
  • Cephalad fluid shift
  • Volume contraction
  • Erythropoietin and RBC production decline
  • Red cell mass reduced 10%, with return to normal Hct
  • Plateau after first weeks of space flight

• **Upon Landing**
  • Normal plasma volume within 24-48 hours
  • Dilutional “Space Flight Anemia” short term
  • Increased RBC production returning both Hct and red cell mass to normal over several weeks
Space Adaptation Syndrome

Primarily problematic for the first 2-3 days and upon earth return for 48-72 hours

• Incidence - All crewmembers affected to some degree
• Symptoms
  • Headache and lethargy
  • Sensitivity to motion
  • Diminished appetite and stomach awareness
  • Nausea and vomiting
Neurovestibular Effects

Initial adaptation to microgravity: Lack of gravitational cues
- Mismatch between eyes and other sense organs
- Visual and perceptual illusions
- Rapid adaptation to permit fine motor control

Post-landing: clinically significant neurologic impairments
- Neurosensory control of motor activities disrupted
  - Postural instability and loss of coordination
  - Clumsiness in movement
  - Difficulty walking a straight line
- Vertigo
- Perceptual illusions: illusory self-motion

Functional assessment tasks
- Balance control, ambulation, and eye-head coordination tasks
- Aid in decision to return to terrestrial activities
Calcium Metabolism

- Kidney Stone Risk Factors
  - Microgravity
  - Dehydration
  - Altered bone metabolism
  - Increased urine and fecal calcium excretion

- Kidney stones reported following short- and long-duration space flight

“Wait a minute here, Mr. Crumbley . . . Maybe it isn’t kidney stones after all.”
Bone Loss during Spaceflight

Bone Loss – typically 1-2% per month

- Major areas: femoral neck, greater trochanter, spine
- Recovery process lengthy
- Risk of fragility fracture long-term concern
- DXA scans for changes in bone mineral density
- Bisphosphonates an effective countermeasure to maintain bone density
- Better hardware for resistive exercise and treadmill decreasing bone loss on ISS
Effects of Spaceflight on Muscle

Normal adaptation to microgravity:

- Absence of gravitational loading on bones and muscles
- Decrease in mass and strength
- Atrophy of the postural muscles that maintain our bodies upright in a gravitational environment (thigh, calf, lumbar muscles)
- Straightening of natural spinal curve
- Back pain
Exercise as Countermeasure
• Quarantine program pre-launch
• Depression of lymphocyte T-cell function affecting at least 50% of space crew members
  • Mostly subclinical
  • Lack of normal activation of T cells
  • Humoral responses not affected
• Adaptive immunosuppression during flight may be due to:
  • Physiological stress
  • Circadian misalignment
  • Isolation and confinement
  • Space radiation
• Gradual improvement in immunity over days to weeks post-flight
Vision Impairment Intracranial Pressure (VIIP)

- **Visual Changes**
  - Changes in visual acuity
  - Optic disc edema
  - Papilledema
- **Headache**
- **Elevated CSF pressure**
- **Potential causes:** fluid shift, microgravity, ppCO$_2$
- **Mitigation strategies**
  - Maintain ppCO$_2$ on ISS < 3.0
  - MRI 3.0 Tesla pre- and post-flight with eye coils
  - In-flight monitoring
- **Changes not always reversible**
• Microorganisms inevitable travelers with humans into space
  • Estimated 10-times more microbial cells than human cells in our bodies (several pounds)
  • Enhanced bacterial cell growth during spaceflight: Salmonella enterica, Escherichia coli, and Bacillus subtilis
  • Increased bacterial virulence

• Latent virus reactivation
  • More frequent reactivation of Herpes viruses in astronauts (EBV, CMV, VZV, HSV)
  • Thought to be due, in part, to the uniquely stressful environment of spaceflight

• Microbiome research ongoing
ISS Environmental Monitoring

- **Pre-flight**
  - Microbial analyses of consumables (water and foods)
  - MRSA and H Pylori screening of crewmembers
- **In-flight**
  - Air and potable water quality
  - Cleanliness of surfaces
  - Radiation hardware
  - Space weather
  - Acoustics (Noise levels)

Biosafety Review Board of all scientific payloads containing biohazardous materials for appropriate levels of bio-containment
Space Flight Environment

Hazards to the human unique and not well understood:

- Microgravity
- Closed-loop Environment with a Man-made Atmosphere
  - Long-term exposure to elevated CO₂
  - Iodine as microbial disinfectant in spacecraft water system
- Isolation and confinement
- Space Radiation--charged particles, electromagnetic radiation, galactic cosmic rays
- Toxicological Risks in Spacecraft
  - Ammonia and ethylene glycol
  - Offgassed products (formaldehyde)
  - Batteries (electrolytes and fire hazards)
- Vibration and Noise
Medical and Laboratory Support for Human Space Missions
Space Medicine Responsibilities

• Provide comprehensive medical and behavioral health care for active astronauts
• Conduct astronaut selection screening
• Provide routine pre-, in-, post-flight care
• Review and monitor research participation
• Oversee astronaut training
  • Medical procedures
  • Space physiology
  • Teamwork, leadership, cross-cultural training
• Conduct astronaut occupational surveillance for astronaut retirees
Clinical Laboratory Support

- Provide comprehensive laboratory testing for astronaut selection and recertification
- Participate in expert panel reviews of laboratory test profiles and other ancillary testing
- Identify diseases or predilection for diseases, which might compromise individual health or mission safety
Shuttle Astronaut Selection Laboratory Testing

- **Blood work-up**
  - **Hematology** - Complete blood count, PT, PTT
  - **Biochemical screen** – Urea, creatinine, uric acid, AST, ALT, GGT, ALP, bilirubin, TSH, total cholesterol, HDL, LDL, triglycerides, HS-CRP, electrolytes (Na, K, Cl,), calcium, magnesium, inorganic phosphate, fasting blood glucose, HgA-1-C, prostate specific antigen (males, over age 40)
- **Immunology**
- **Serology**
- **Endocrinology**
- **Pregnancy test**

- **Urinalysis**
  - 24-h urine chemistry
  - Renal-stone profile
  - Endocrinology

- **Stool analysis**
  - Occult blood
  - Ova and parasites

- **Infectious Disease Screen**
  - Syphilis screen – VDRL or RPR or equivalent
  - HIV screen
  - Hepatitis screen for A, B, C exposure and immunity
  - Tuberculin test (PPD)

- **Drug screening**

Pre-flight and In-flight Care for Long-Duration ISS Crew

• **Pre-flight Medical Screening**
  • Resolves any medical conditions that could interfere with a successful mission
  • NASA Aerospace Medicine Board review of astronaut record to ensure medical requirements are met
  • All crews approved for flight by an international medical board composed of space medicine specialists from agencies participating in the ISS

• **In-flight Medical Care**
  • Dedicated flight surgeons and behavioral health teams for each mission
  • Medical capabilities and in-flight diagnosis constrained due to challenges associated with deploying clinical instrumentation to space
Post-flight Medical Care

- Post-flight medical care
  - Address acute medical issues
  - Implement rehabilitation plan
  - Long term monitoring and follow-up
- Recovery may be longer than the mission itself
- Blood volume limits
  - Landing day: 120 ml
  - R+1 to R+45 days = 300 ml
  - 6 month in-flight blood volume = 450 ml
“Okay, men, we’re going to start you off easy.”
Desert Survival Training
Reduced Gravity Aircraft
“Vomit Comet”
Medical Instrumentation Onboard ISS

Current diagnostic capabilities limited:
• Blood collection supplies
• Urinalysis strips
• Working fixed-angle centrifuge
• -80 degree C freezer
• Portable ultrasound
• Vision instrumentation
• Glove box
MELFI - Minus Eighty-degree Laboratory Freezer for ISS
• Planned for future human space flight related research
• Repository to be opened to solicitation from investigators following the end of the ISS in 2024
• All participating agencies will be represented on the Advisory Committee and will review the protocols and specify the conditions under which data and specimens may be released and shared (JSC, ESA, JAXA and CSA).
**Bringing Samples Home**

**Space Shuttle**
- Clinical Lab supported all landings in Florida and California
- 2011 retirement eliminated ISS sample return

**SpaceX**
- Began 2012
- 6 successful launches
- Provides sample return from ISS to Earth for analyses
NASA’s Deep Space Missions—Desired Analyzer

- On-orbit sample analysis
- **Single compact device** for multiple sample types and multiple analytes
- Mobile device technology
  - Medical add-ons for smart phones
  - Cameras and video recorders
  - **Sensor technologies**—measure vital signs, such as temperature, heart and respiration rates
- Non-invasive specimens (breath and saliva)
- Intuitive Interfaces to accommodate the skill and medical training of crew
New Laboratory Hardware Specifications

Minimize:

- Size
- Power requirements
- Moving parts
- Use of liquid reagents
- Liquid biohazardous waste
- Time required for sample pre-processing
- Start-up time
- Refrigerated storage
- Hardware certification for spaceflight

Maximize:

- Ease of operation—minimal training
- Intuitive user interface
- Rapid analysis
- Room temp shelf-life stability of reagents and supplies for prolonged periods of time (goal 3-5 years)
- Expansion of analyzer’s capability over time (through software, reagents)
- Ruggedness and vibration tolerance
- Achievement of FDA approval or equivalent

Overcome limitations of current portable POC devices – all ill-suited for space travelers on extended missions
Breath Analysis

NASA Ames Smart-phone integrated Carbon Nanotube Array Sensor
$10M Qualcomm Tricorder XPRIZE
- Single portable device weighing no more than 5# (2.3 kg)
- Ability to diagnose more than a dozen medical conditions
- 7 finalists, with winner to be announced in early 2016

$2.25M Nokia Sensing XCHALLENGE
- Address resource scarcity in third world economies
- Miniaturized hardware sensors and software sensors
- Improved test methods and new alternatives to blood testing, heart monitoring, and imaging
- 2 competitions thus far: 2 grand-prize winners and 10 distinguished awards

FDA offering regulatory input to the competing teams
One-Year Mission
One-Year Missions

- Need to know much more about human reaction to long-term spaceflight before any deeper exploratory missions can be planned.
- Remarkable similarities between how the body changes in microgravity and how it changes as a result of ordinary aging.
- By learning more about one, we hope to apply that same knowledge toward arresting both conditions.