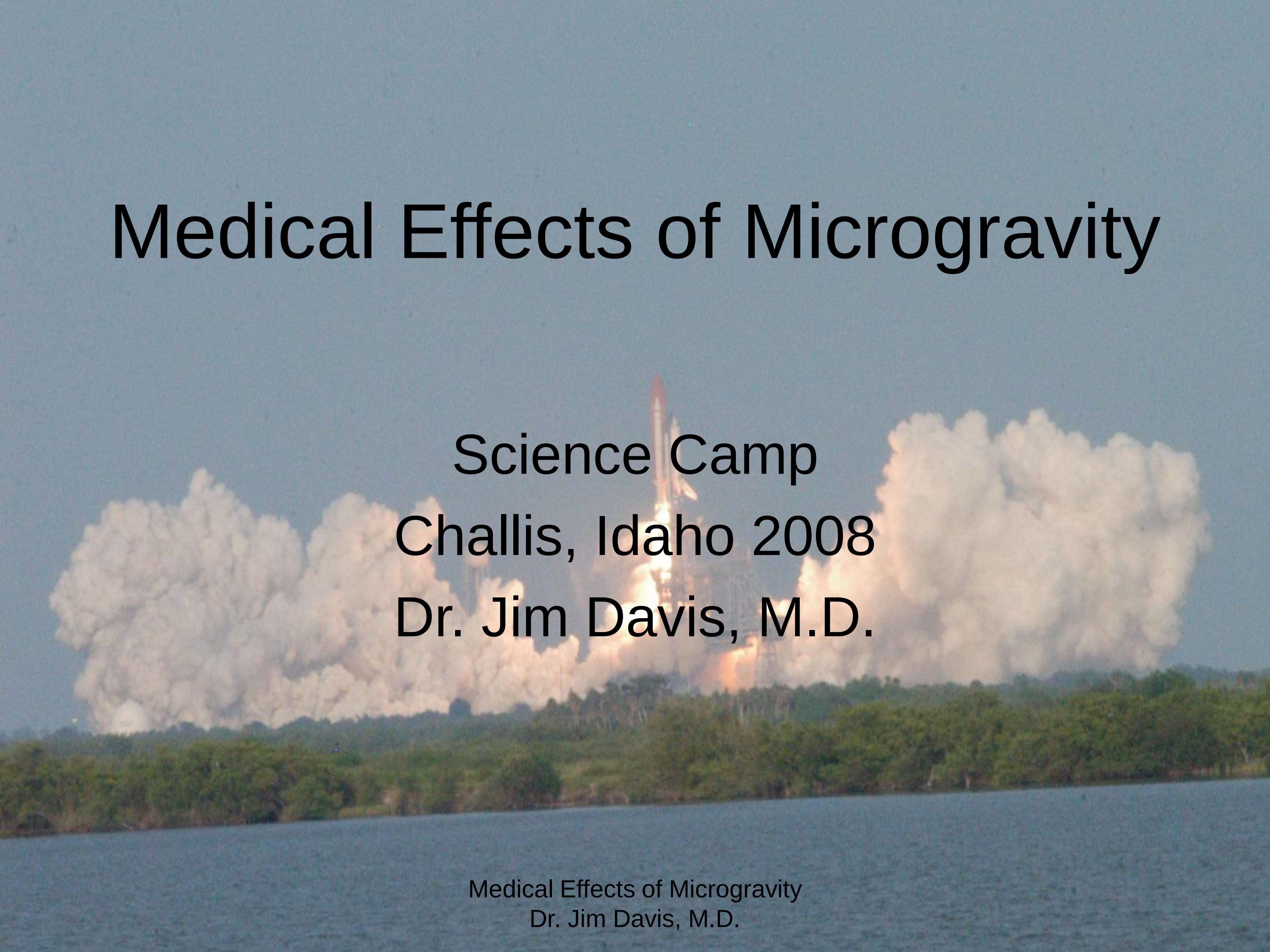


Medical Effects of Microgravity

Science Camp

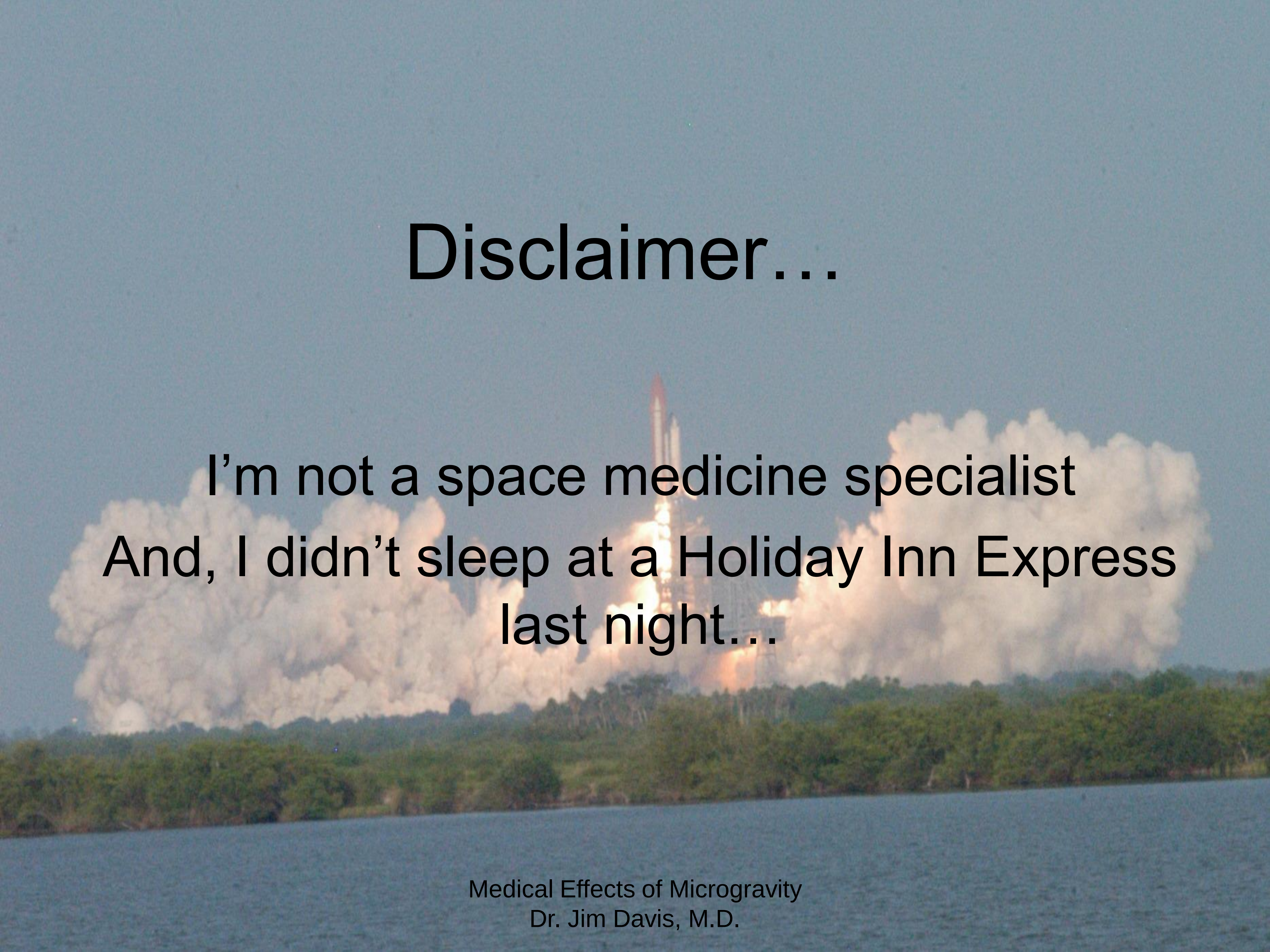
Challis, Idaho 2008

Dr. Jim Davis, M.D.

Buzz Aldrin on the Moon (July 1969)

- Space travel became a reality in 1961
- Since then, more than 200 people have been to space, and the duration of stays have increased from 2 hours to more than a year
- In the 21st Century common citizens will soon be able to travel and sight-see, or to live in space

- Before space can become a safe, habitable place we must solve many problems
- Space Medicine establishes the countermeasures to overcome the physiological effects of space



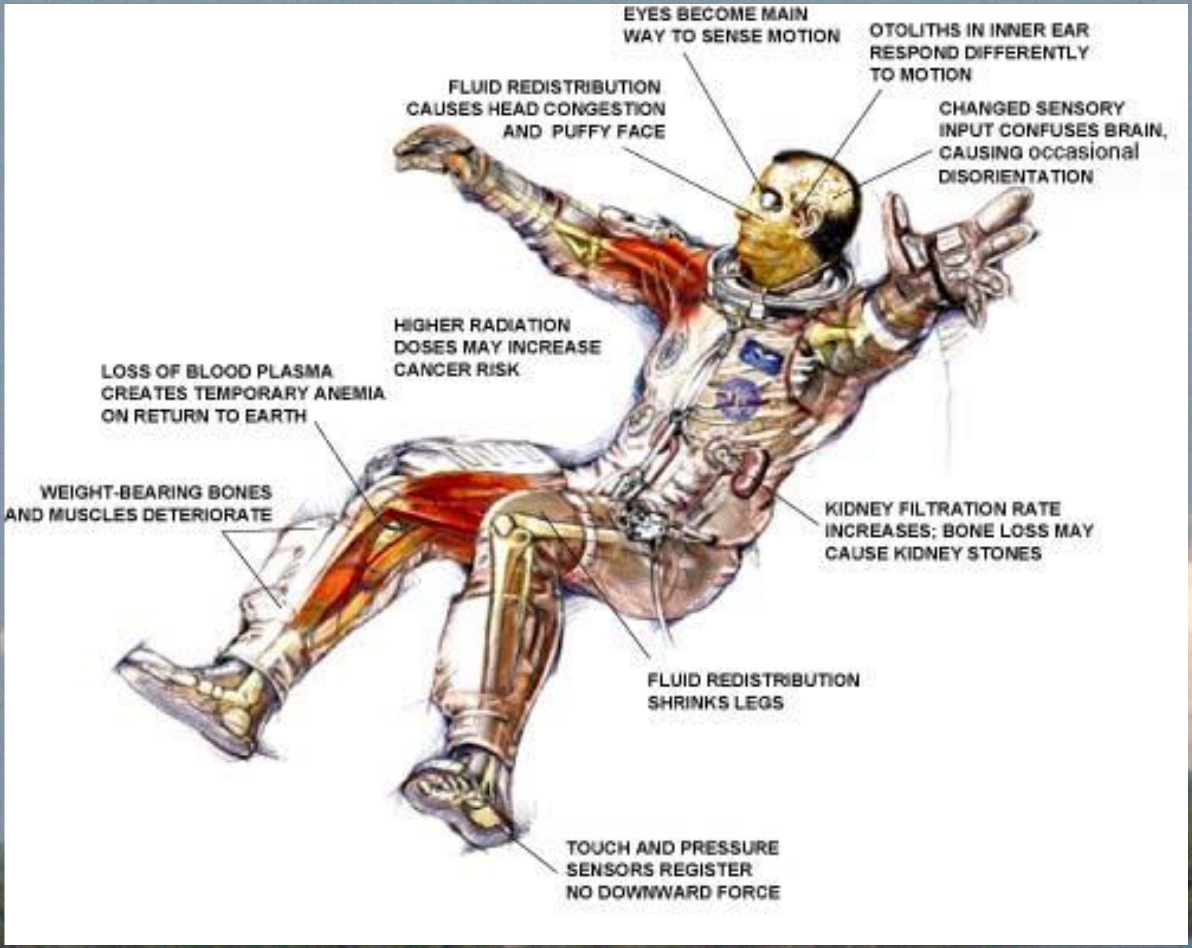
Disclaimer…

I'm not a space medicine specialist

And, I didn't sleep at a Holiday Inn Express last night…

Homeostasis

- Means, literally "self staying the same"
- Numerous "feedback" systems in body
- When something is out of balance, the body takes action to return it to original balance
- All living organisms learn to do it as a means of adapting for survival



- Strange things happen to the human body when people venture into space and the familiar pull of gravity vanishes
- Gravity is a signal that tells the body how to act

What happens to humans in space?

- **Early response (<3 weeks)**
  - **Neurovestibular disturbances Cephalad fluid shift**
  - **Cephalad fluid shift**
  - **Sleep disturbances**
  - **Bone demineralization**

- **Intermediate (3 weeks to 6 months)**
  - **Radiation exposure**
  - **Bone resorption**
  - **Muscle atrophy**
  - **Cardiovascular deconditioning**
  - **GI disturbances**
  - **Hematological changes**

- **Long Duration (6 months to 3 years)**
  - **Radiation exposure**
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  - **Hematological changes**
  - **Declining immunity**

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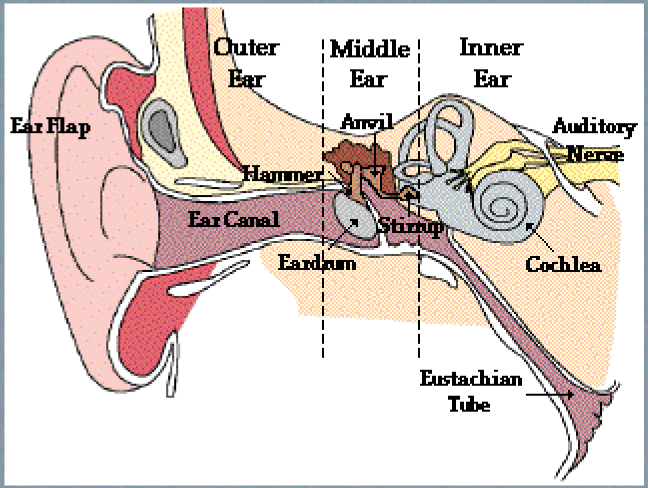
  - **Declining immunity**
  - **Renal stone risk**

Neurovestibular Disturbances (Space Sickness)



The vestibular system is a fluid filled network of canals and chambers in the ear that help us keep our balance and know which way is up

- If you close your eyes in space how do you determine which way is up?
- Three systems coordinate to give you spatial orientation information
  - Eyes
  - Ears
  - Peripheral nerves
  - 2 of 3 needed

- With your eyes closed you can't tell
- The vestibular system doesn't sense the familiar pull of gravity and the world can seem topsy-turvy
- You can become confused and disoriented in an alien world where up and down have no meaning

One astronaut lifting another with her finger
(photo courtesy of NASA)

- Space motion sickness is caused by conflicting information that your brain receives from your eyes and the vestibular organs in your inner ear
- Your eyes can see which way is up and down inside the space shuttle
- However the sensors in your vestibular system rely on the pull of gravity to tell you up versus down

Astronauts on the International Space Station posing upside-down (or is it right side up?)

- Your brain gets confused and produces nausea and disorientation which may lead to vomiting and loss of appetite
- Fortunately after a few days your brain adapts by relying solely on the visual inputs and you begin to feel better
- 60-70% of the astronauts experience these symptoms
- No adaptation, even after a year in space

An astronaut on Skylab

- In microgravity there is no natural "up" and "down" determined by our senses
- You don't know the orientation of parts of your body, especially your arms and legs, because they have no weight for you to feel in space

Skylab 2 commander Charles Conrad submits to a dental Exam by Medical Officer Joseph Kerwon

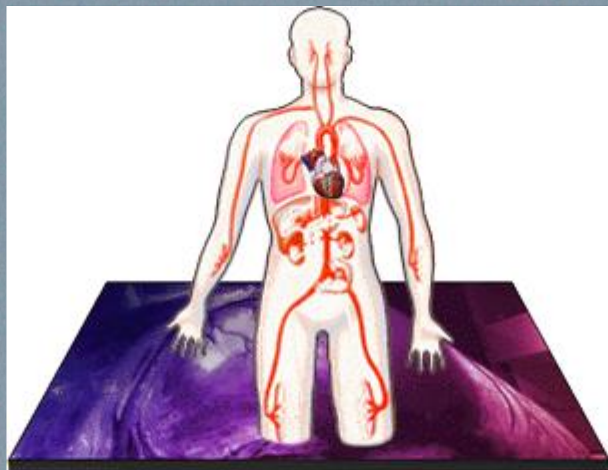
- The proprioceptive system, the nerves in the joints and muscle that tell us where our arms and legs are without having to look, can be fooled by the absence of weight
- One Gemini astronaut woke up in the dark during a mission and saw a disembodied glow-in-the-dark watch floating in front of him
- He realized moments later that the watch was around his own wrist

- Many apes have their internal organs tethered at the top and bottom so when they swing from trees or hang upside down the organs stay in place
- Human organs are tethered mainly at the top so in microgravity they tend to shift around and that can make us nauseous

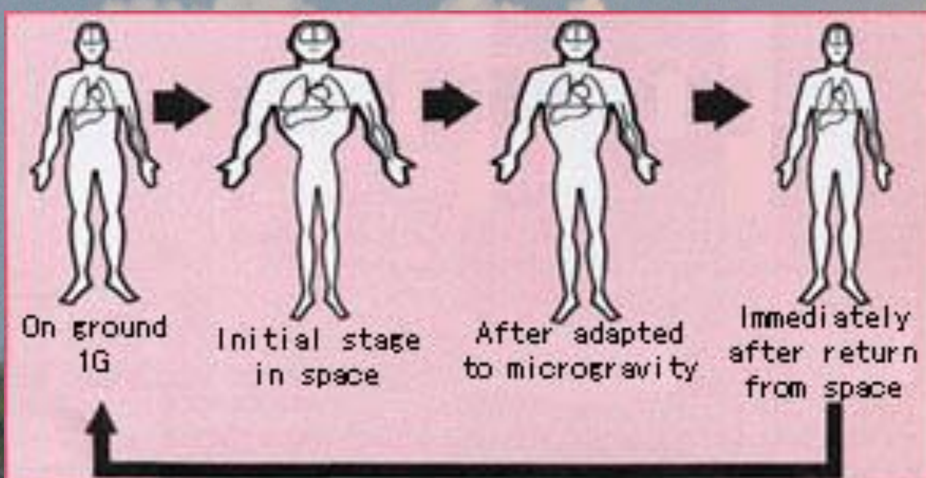
Space motion sickness

- Astronauts suffering from space motion sickness may get a headache, lose their appetite, feel there is a “knot” in their stomach and find it difficult to work efficiently
- Some astronauts get sick and vomit
- Fortunately for most astronauts these effects last for only the first few days

Circulatory System



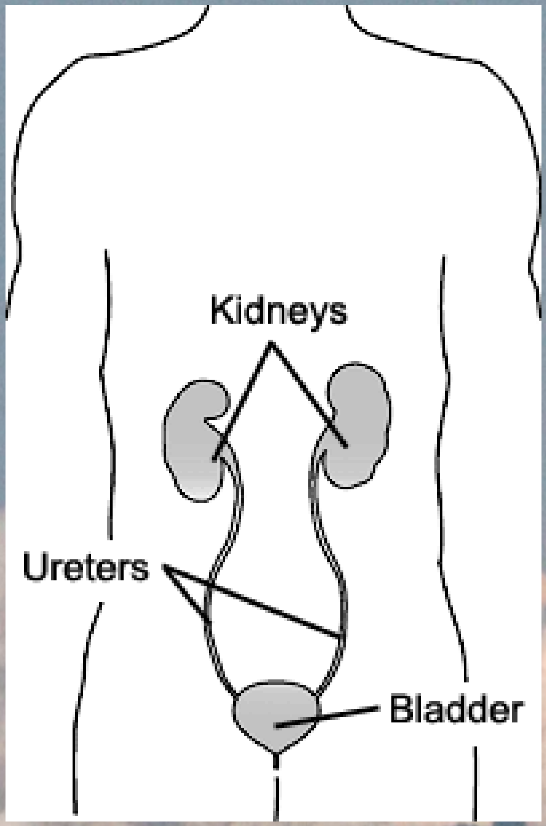
- On Earth gravity pulls on your blood causing it to pool in your legs
- 2/3 v & 1/3 a
- In microgravity the blood shifts from your legs to your chest and head causing your legs to shrink in size
- This is called a "fluid shift"



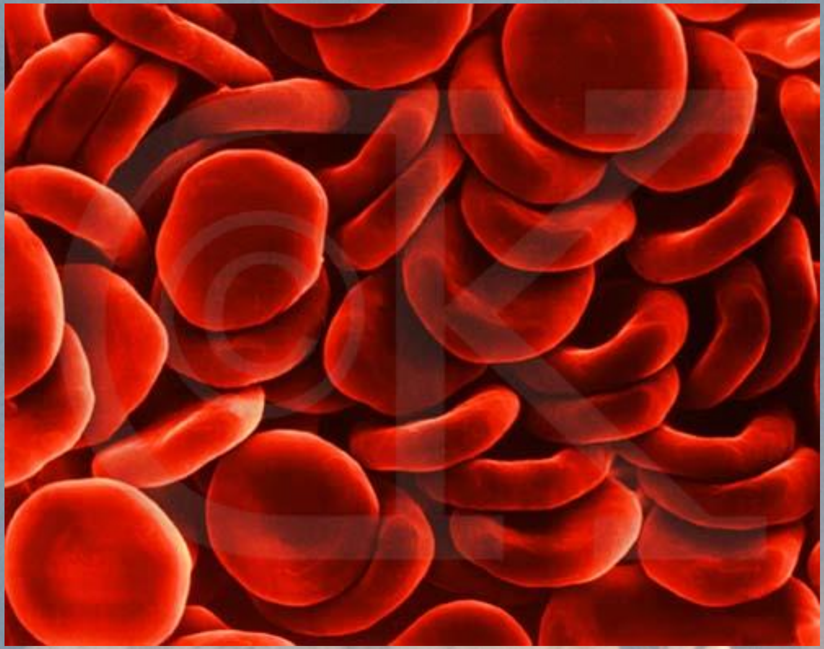
Fluid shift caused by space flight

Astronaut Susan Helms on Earth (left) and in space (right)

- In microgravity your face will feel full, your sinuses will feel congested, and you may get a headache
- You feel the same way on Earth when you bend over or stand upside down, because the blood rushes to your head
- Lisa's "Puffy Head / Bird Legs"

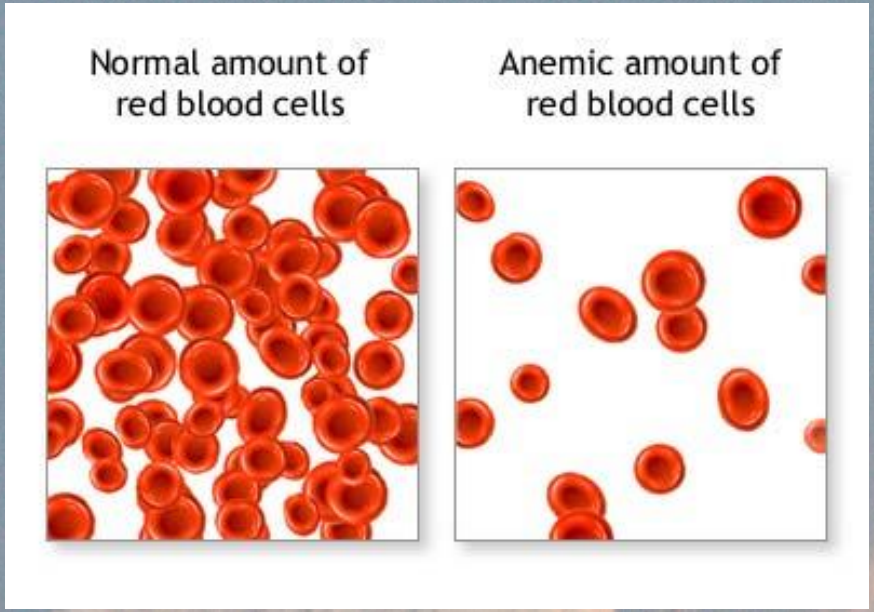


- Your body senses an overabundance of fluids in the chest and head area and sends a message to the kidneys to eliminate the excess fluid by producing more urine
- Also you do not feel thirsty and decrease your fluid intake
- The result is up to a 22% loss of blood volume



Red blood cells

- As your kidneys eliminate excess fluid, they also decrease their secretion of erythropoietin, a hormone that stimulates red blood cell production by bone marrow cells
- Otherwise, your blood would thicken dangerously
- Anemia, the decrease of red blood cells in the blood, is observed within 4 days of spaceflight

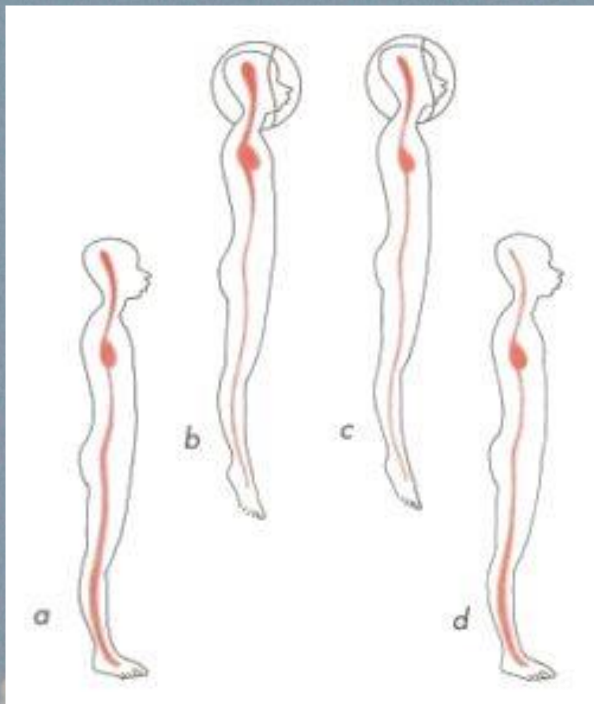


- The number of red blood cells will decrease by about 15% after a 3-month stay
- Upon returning to Earth your erythropoietin levels and red blood cell count will return to normal
- The activity of bacteria fighting lymphocytes (white blood cells) is slightly reduced but this rarely causes problems

- The change in blood volume affects your heart, too
- If you have less blood volume then your heart doesn't need to pump as hard
- It also takes less energy to move around the spacecraft
- Because it no longer has to work as hard, your heart will shrink in size

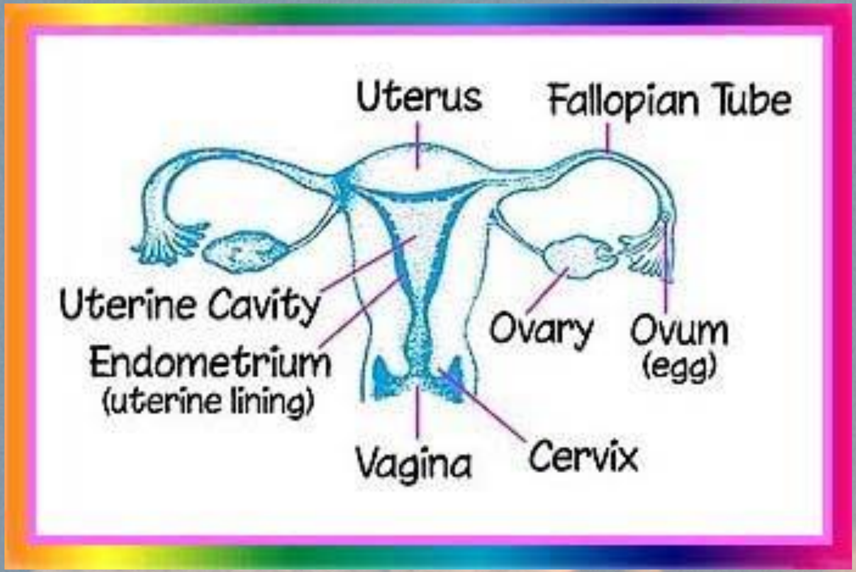
Test of the LBNP device
(photo courtesy of NASA)

- One way to deal with fluid loss in space is with a device called Lower Body Negative Pressure (LBNP)
- This device applies a vacuum-cleaner-like suction below your waist to keep fluids down in the legs
- In space you may spend 30 minutes a day in the LBNP to keep the circulatory system in near-Earth condition



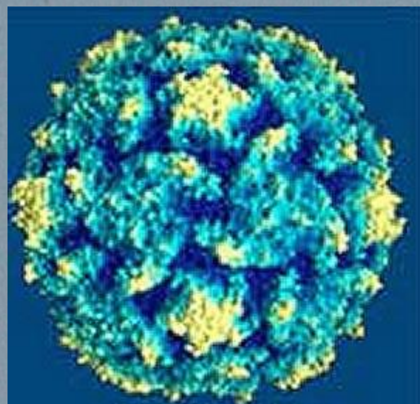
a. Fluid distribution on Earth
b. In microgravity fluids redistribute
c. Kidneys eliminate fluids
d. Returning to Earth

- Upon returning to Earth, gravity will pull those fluids back down to your legs and away from your head causing you to feel faint when you stand up
- But you will also begin to drink more and your fluid levels will return to normal in a few days

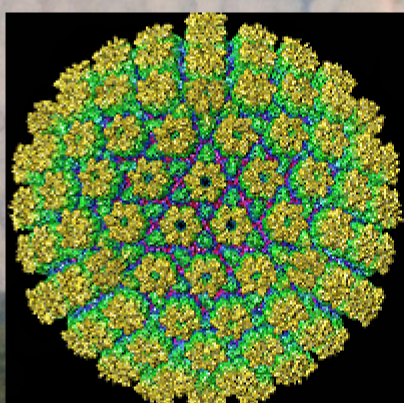


- For female astronauts gravity assists in the menstruation process by "pulling" the uterine lining blood out during her menstrual period
- In microgravity this pull is not there and in long space flights this can cause problems like clotting, toxic shock

Immune System



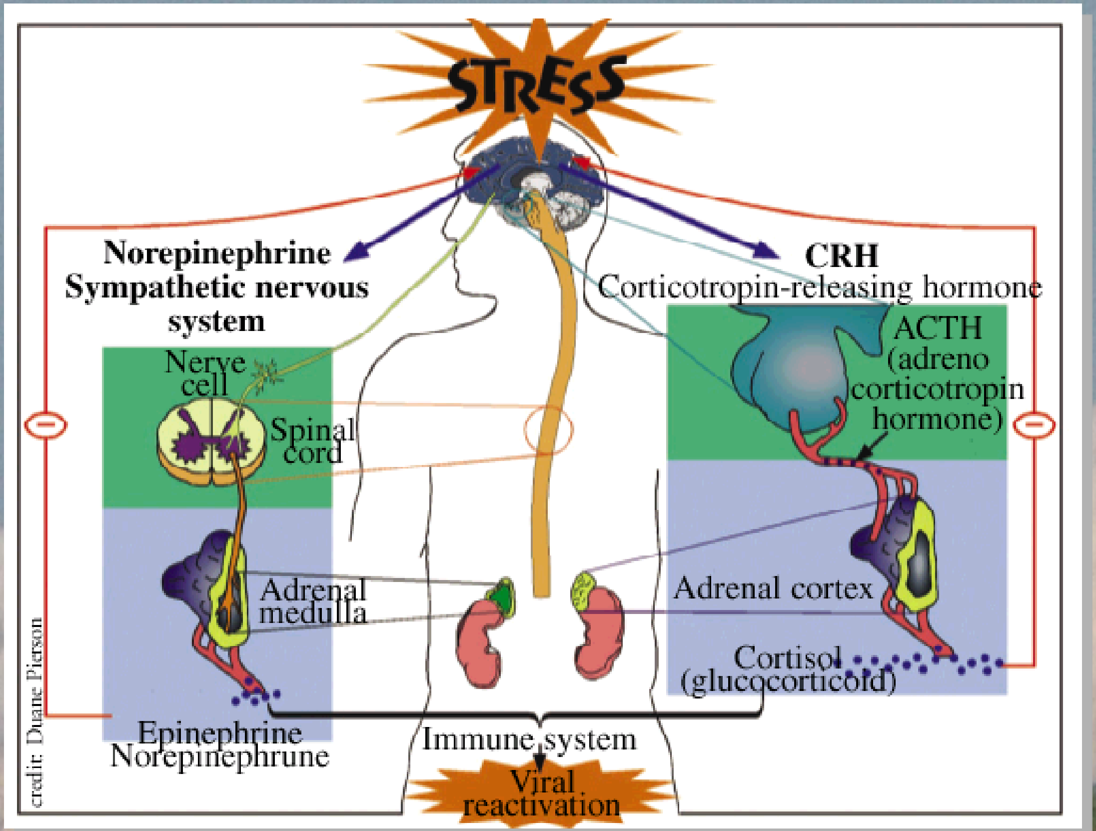
Epstein-Barr virus



Herpes Simplex virus

- Viral shedding is a huge problem in space
- Humans have many viruses in their bodies that are kept at bay by our immune system
- Space flight is very stressful and latent viruses are very often activated
- This can make astronauts susceptible to viral infections

STS-107 Experiments



Stress compromises the immune system by releasing hormones that make the body prone to infection and viral reactivation.

Body Mass Loss

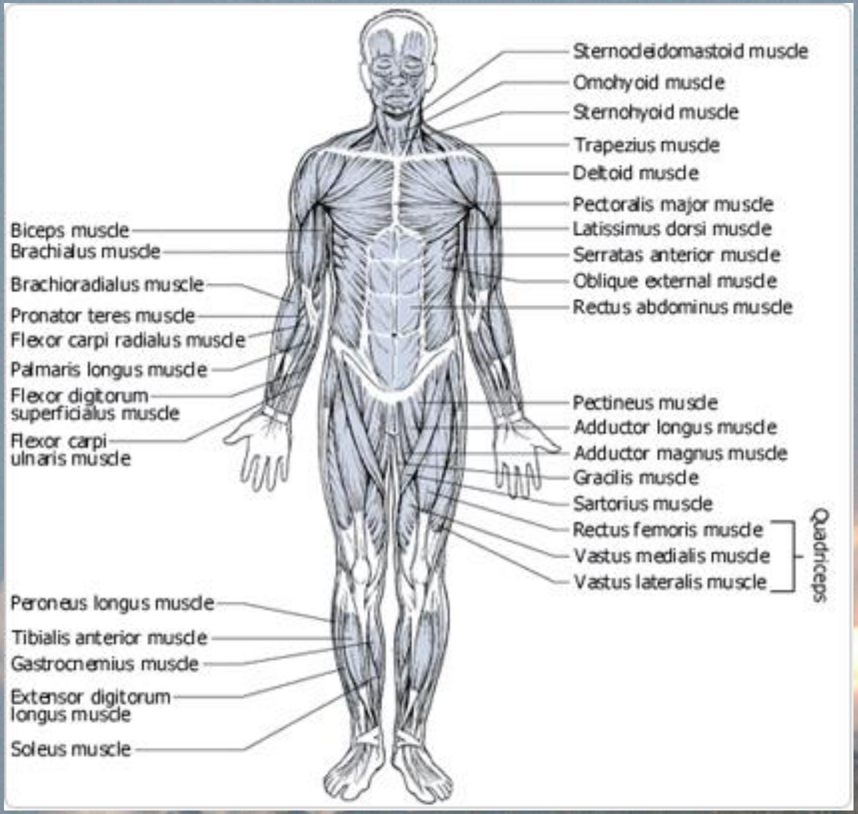
- Many of the physiological effects previously mentioned contribute to mass loss:

  - **Space Adaptation Syndrome (SAS)**
  - **Body Fluid Shift and Resultant Loss**
  - **Bone Loss**
  - **Muscular Deconditioning**
  - **Reduced Sensitivity of Taste and Olfactory Senses**

Mechanics & Components of Body Mass Loss

- Loss of both fat and lean mass; more than half the loss comes from fat-free mass such as muscle, organs, blood, and bone.
- Protein and bone catabolism increases; protein and bone mineral synthesis decreases.
- Headward fluid shift triggers baroreceptors to initiate diuresis; fluid intake decreases; thirst mechanism altered.
- In-flight energy expenditure is similar; food consumption decreases.

Muscles



- In microgravity your muscles atrophy quickly because your body perceives it does not need them
- The muscles used to fight gravity and maintain posture can vanish quickly

Exercising in space

- Muscles are adaptable tissues. If you increase the load on them by lifting weights or exercise and they grow larger and stronger
- Reduce the load by lying in bed or living in microgravity and they grow smaller and weaker

- In microgravity you do not use the muscles that help you stand and maintain posture (anti-gravity muscles)
- The muscle fiber types change from slow-twitch endurance fibers (used in standing) to fast-twitch fibers (needed as you push yourself off space station surfaces)
- During extended space flight about 20% of the slow-twitch become fast-twitch fibers which are smaller in size but use energy faster

Muscle fibers

Measurement of leg muscles in space

- The longer you stay in space, the less muscle mass you will have
- After only 11 days in space microgravity can shrink muscle fibers as much as 30%
- This loss of muscle mass makes you weaker, presenting problems for long-duration space flights and upon returning home to Earth's gravity

- Fortunately muscles recover rapidly after weeks in microgravity
- But what might happen during years-long missions, like a trip to Mars?
- Could more vigorous aerobic workouts prevent muscle wasting or are other exercises more effective?
- International Space Station research will help develop workouts to minimize or prevent muscle atrophy

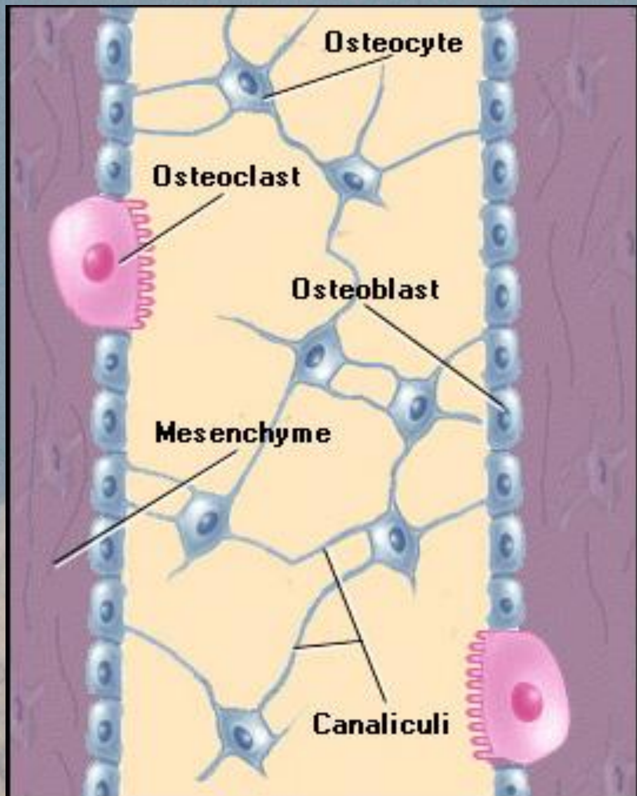
International Space Station

Bed Rest Studies

- 6º head tilt down
- Remain in bed continually for various time intervals; i.e., 60 days
- Mimics many alterations that occur in microgravity due to fluid shift to head and lack of weight bearing lower limbs; i.e., bone loss & muscle atrophy
- Often involved in countermeasure testing

ESA, WISE

Bones

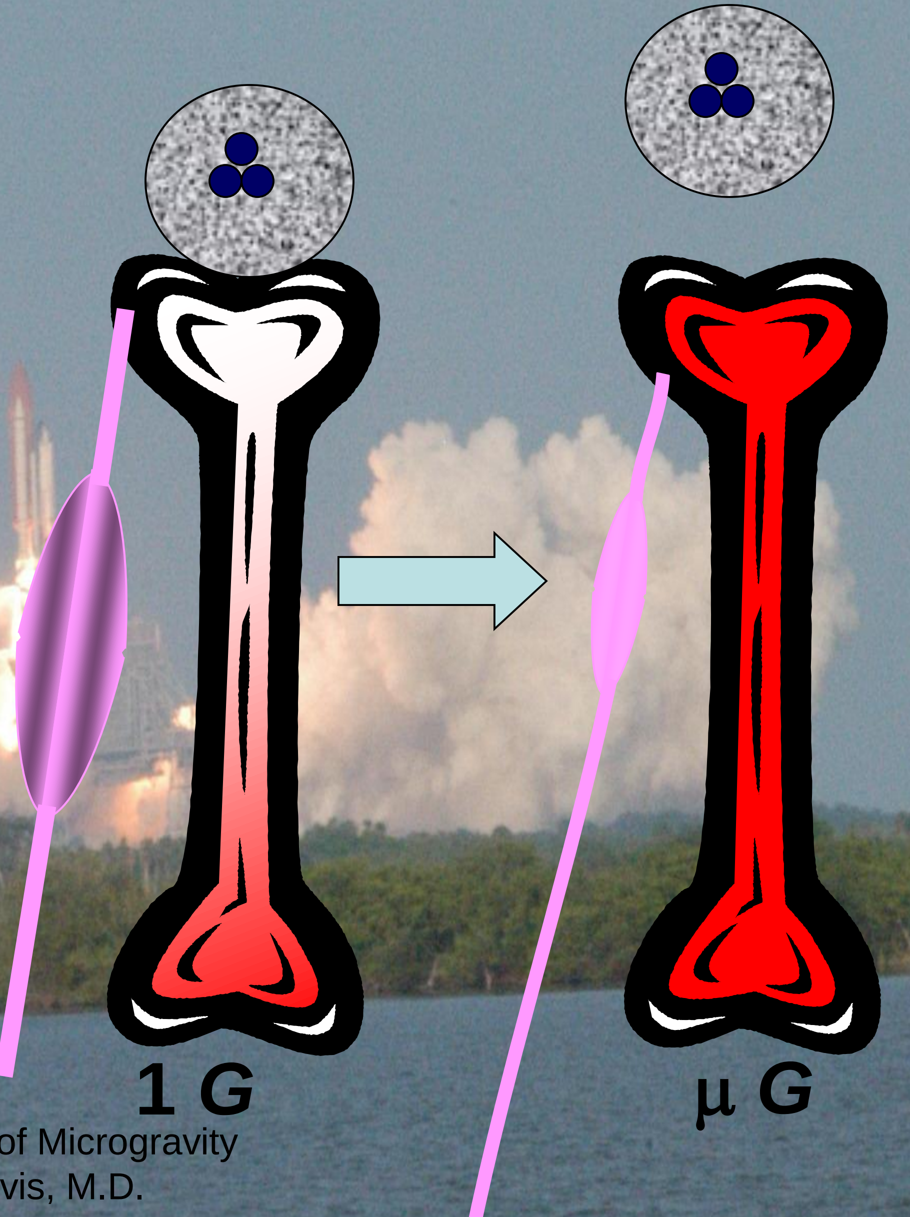


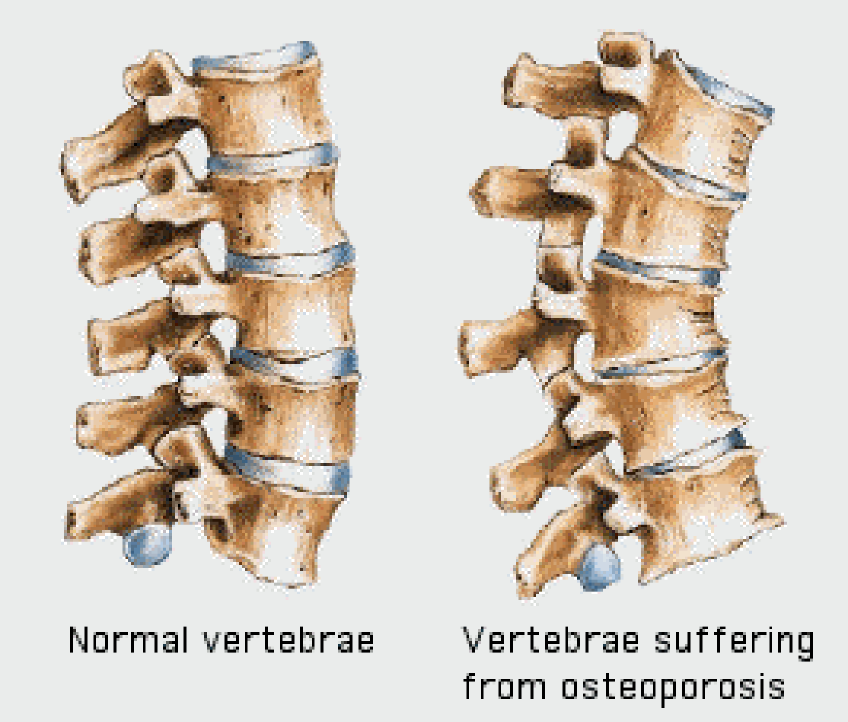
Bone formation

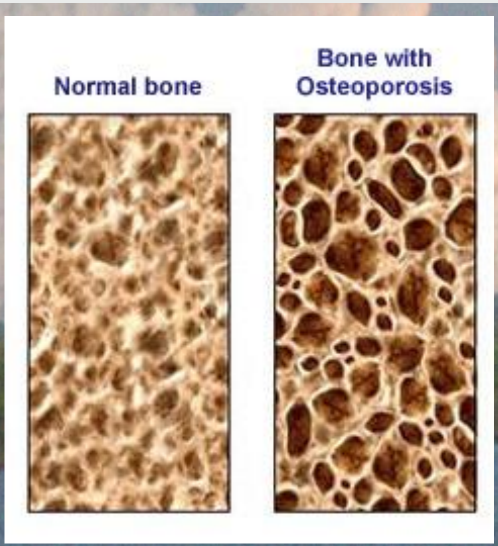
- On Earth your bones support the weight of your body
- The size and mass of your bones are balanced by the rates at which <u>osteoblast</u> cells lay down new mineral layers and <u>osteoclast</u> cells chew up those mineral layers

Causes of bone loss

- **No load because of low gravity**
- **Poor muscle performance**
- **Metabolic and hormonal changes**
- Fluid dynamic changes in the bone marrow sinusoids
  - Decreased hydrodynamic shear
  - Loss of hydrostatic pressure gradient

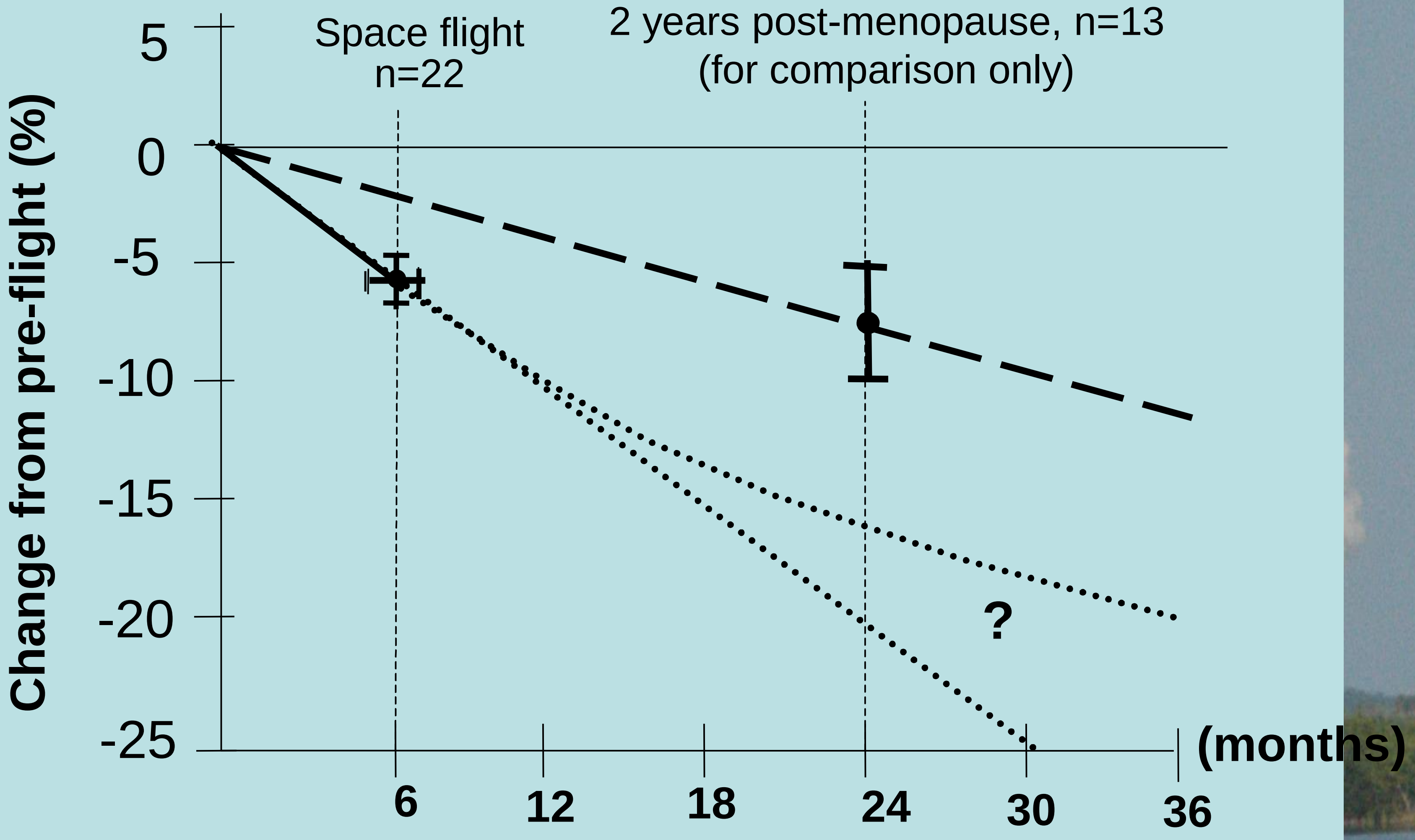






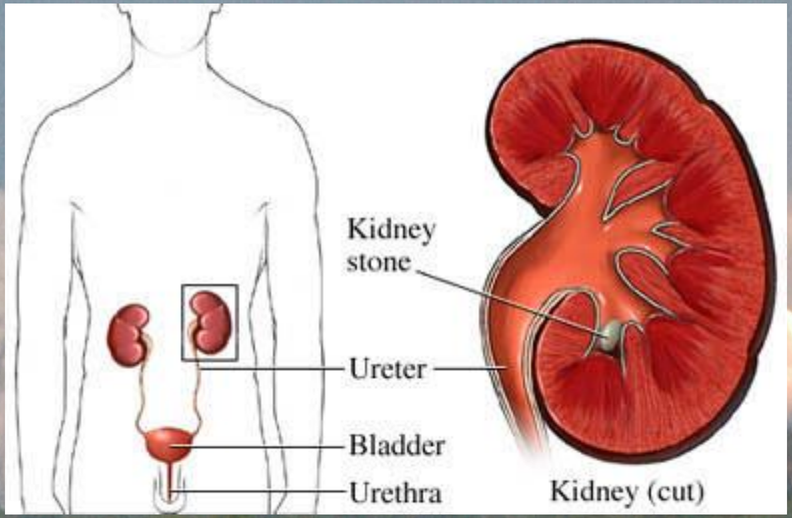
- Space travelers can lose on the average of 1-2% of bone mass each month
- The bones most commonly effected are the lumbar vertebrae and the leg bones
- Certain individuals on six-month flights have lost as much as 20% of bone mass throughout their lower extremities while maintaining upper body bone mineral density.
- There is no indication that this bone loss abates with longer flights. Furthermore, after return to Earth, bone loss continues for several months

Bone Loss in Weightlessness

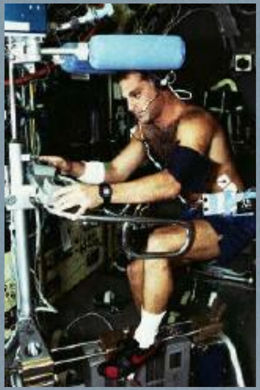


Dr. Jim Davis, M.D.

Kidney Stones

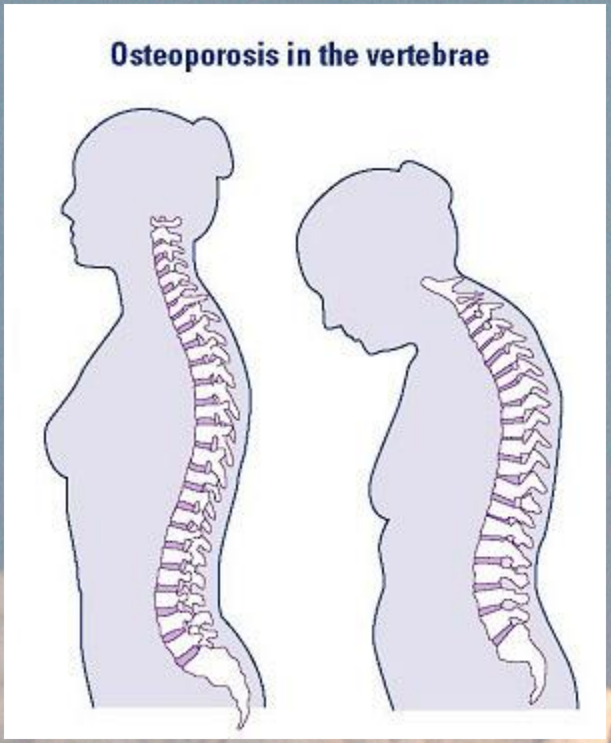


- Bone loss leads to yet another problem in space
- In addition to weak bones, your blood's calcium concentration increases as your bones get chewed up by osteoclasts
- Your kidneys must get rid of the excess calcium, which makes them susceptible to forming painful kidney stones as the calcium is excreted through the kidneys



Exercising in microgravity
(photos courtesy of NASA)

- The best way to minimize loss of muscle and bone in space is to exercise frequently, mainly with the treadmill, rowing machine, and bicycle
- This prevents muscles from deteriorating and places stress on bones to produce a sensation similar to weight

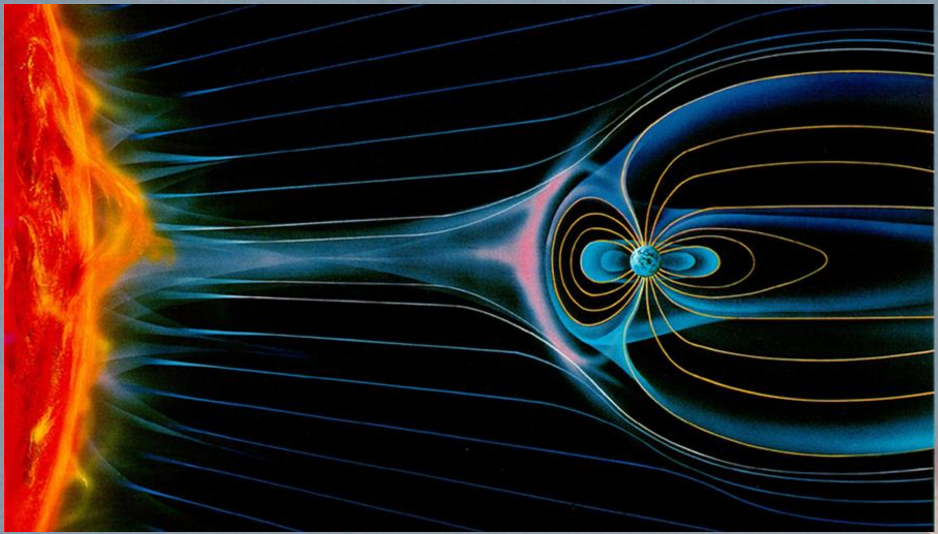


- Women and men suffer osteoporosis as they get older, Right here on Earth millions suffer from osteoporosis
- Solving the problem in space will likely bring welcome relief back home to Earth
- We still don’t know what the effect of osteoporosis and pregnancy would mean to women astronauts

Radiation

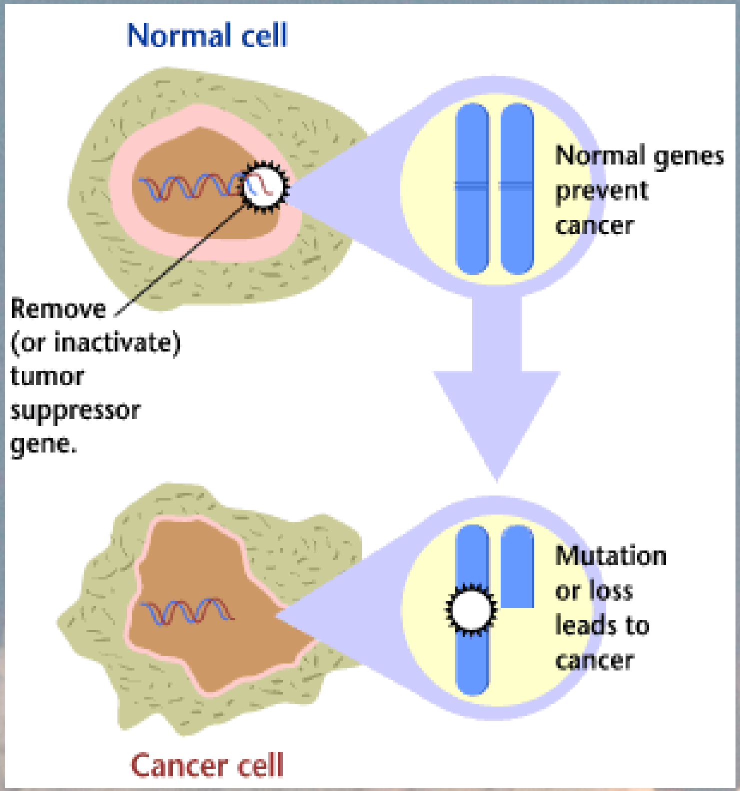
- Different from ionizing radiations on Earth
- Two types
  - Galactic cosmic radiation (GCR) dominated by neutrons
  - Solar particle events (SPE)- *sun storms* dominated by protons
- Earth is protected by the magnetosphere (van Allen Belt)

- The risk of space radiation exists in outer space
- The space vehicle must have walls of sufficient thickness, especially during solar flares
- Astronauts must also limit their extravehicular activity during high solar activity



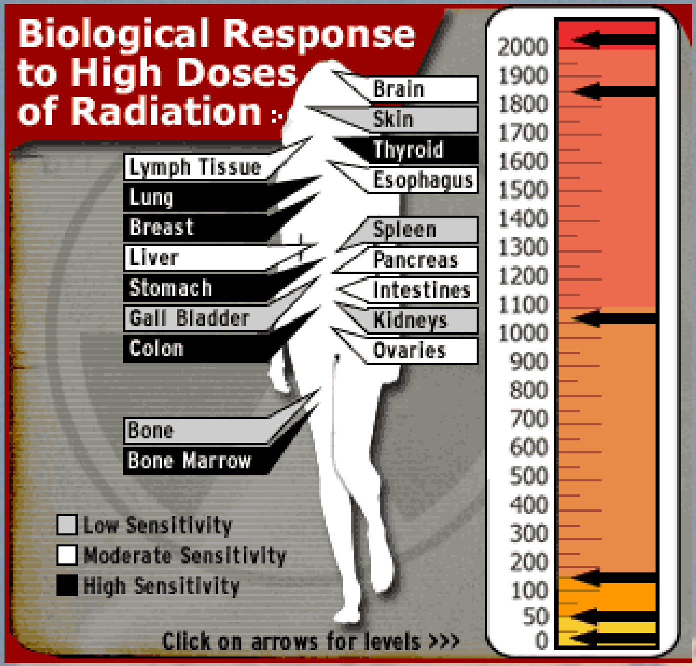
The Earth's magnetic field

- On Earth the atmosphere and magnetic field provides a shield for humans to prevent space radiation from penetrating
- The absence of this shield in space exposes astronauts to greater amounts of radiation

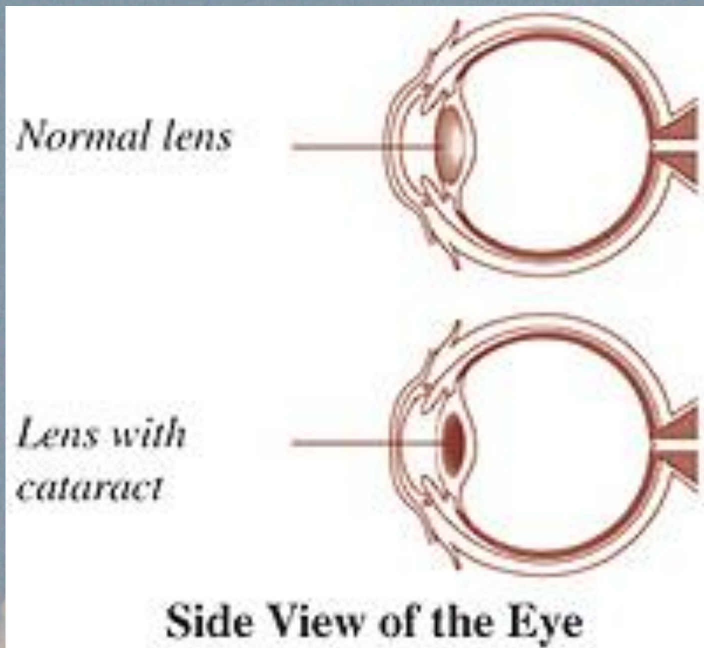


- Prolonged space radiation exposure can have wide-ranging effects on the body
- Radiation ionizes molecules in the body and can cause damage to DNA

The danger of damage to DNA



- Among the potential risks are detrimental effects to the central nervous system, tissues of the heart, eyes and digestive tract
- It can also include sterility, cataracts, neurological damage, cancer
- Astronauts are exposed to more radiation than we encounter on Earth but years or decades might pass before the appearance of a tumor



- Years after exposure to space radiation many astronauts have developed cataracts—a clouding of the lens in the eye
- At least 39 former astronauts suffer from some form of cataracts, which appeared as early as 4 years or as late as 10 years after their space travel

Exploring on the Moon

- The effects of long term cosmic radiation on the human body is not known
- Fortunately most manned space flights have occurred within the protection of the Earth’s magnetic field
- Lunar stays of 6 months and round trip duration of 3 years for Mars missions are being studied on how to prevent exceeding the radiation exposure limits

Stress and Psychology

Issues:

- Small group size
- Multi-cultural composition
- Extended duration
- Remote location
- High autonomy
- High risk (to health and mission)
- High visibility (e.g., high pressure to succeed)

Behavior and Performance

- Sleep and circadian rhythm problems
- Poor psychosocial adaptation
- Neurobehavioral dysfunction
- Human-robotic interface
- Episodic cognition problems

A dramatic sunrise captured by the crew of space shuttle mission STS-47

- Space travelers sleep poorly in space
- They sleep on an average of 2 hours less a night than they do on Earth
- In low Earth orbit the Sun rises and sets every 90 minutes which adds to their sleeplessness
- This can disrupt the circadian rhythms that ensure a good night's sleep

Post-Flight Recovery

What happens when the astronaut returns to Earth?

- The heart is smaller and weaker
- The vestibular, or balance, system has become used to a new set of signals
- Body fluids are diminished
- Muscles have atrophied
- Bones have weakened

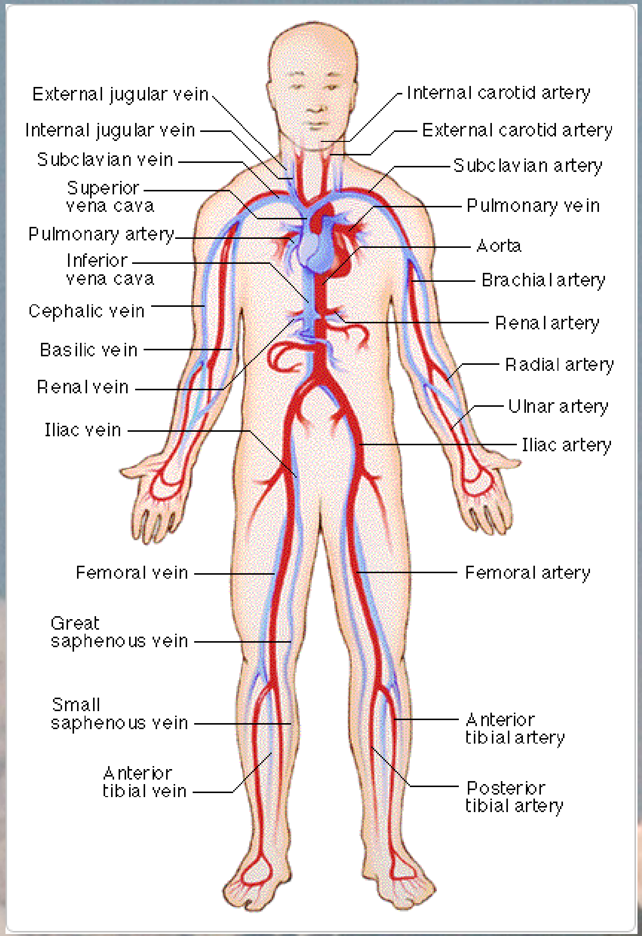
Astronauts Lisa Nowak, Michael Fossum, and Piers Sellers from STS-121 mission

Physicians testing a returning astronaut

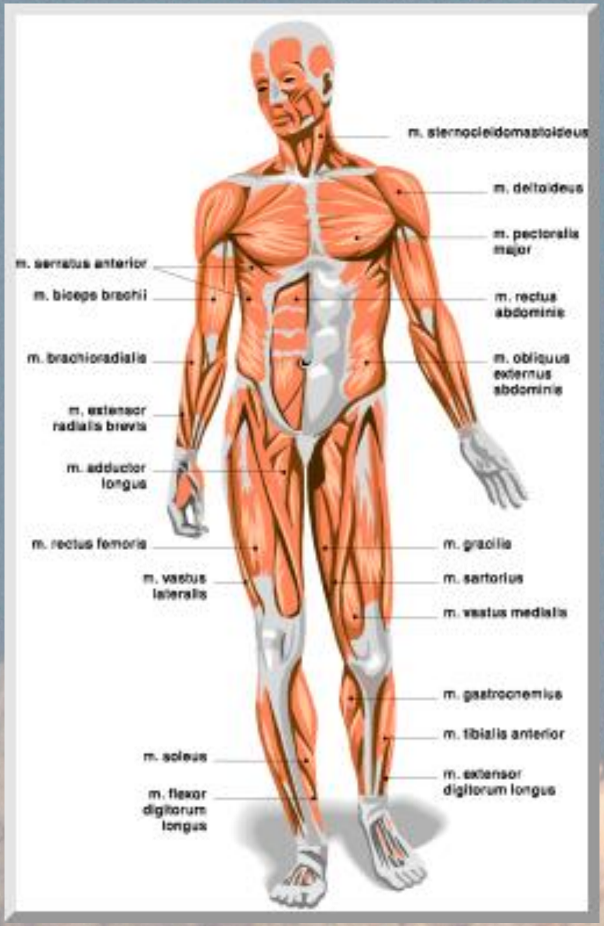
- Do all these losses matter?
- Perhaps not if you plan to stay in space forever
- But eventually astronauts return to Earth and the human body has to readjust to the relentless pull of gravity
- Most space adaptations appear to be reversible, but the rebuilding process is not necessarily an easy one

Post-Flight Recovery

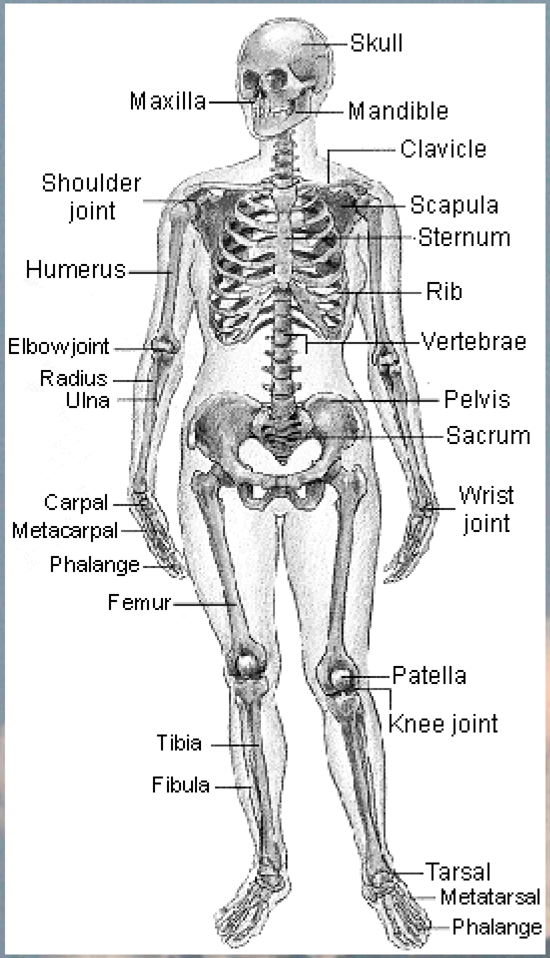
- Fainting often occurred
- Much was learned from the Russians
- US astronauts initially denied fainting



- Blood volume is typically restored in a few days
- Astronauts get thirsty when they return because their body tells them they don't have enough blood in their blood vessels and sends the signal to drink more



- Muscle loss can be recouped also
- Most muscle mass comes back within a month or two, although it may take longer to recover completely
- Usually it takes a day of recovery on Earth for each day you are in space



- Bone recovery is very problematic
- For a 3 to 6 month space flight it may require 2 to 3 years to regain lost bone
- You really have to exercise a lot both in space and after returning to Earth

- One day humans will journey to Mars
- They will spend many months in microgravity before disembarking on a planet with 38% of Earth's gravity
- Astronauts will have to have a high level of fitness

Astronaut exercising in space

- Exercise is the key
- But exercising in space differs from exercising on Earth
- On Earth the pull of gravity provides a resistive force that maintains muscles and bones
- In space even if you do the same amount of exercise you are missing that gravity component

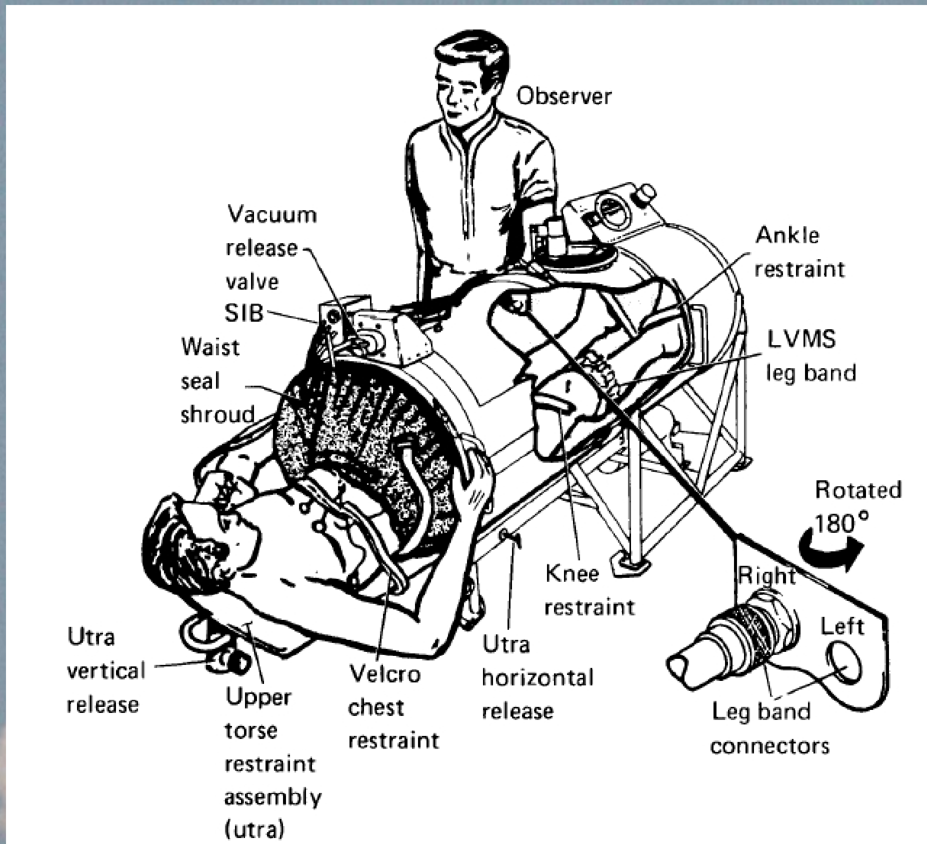
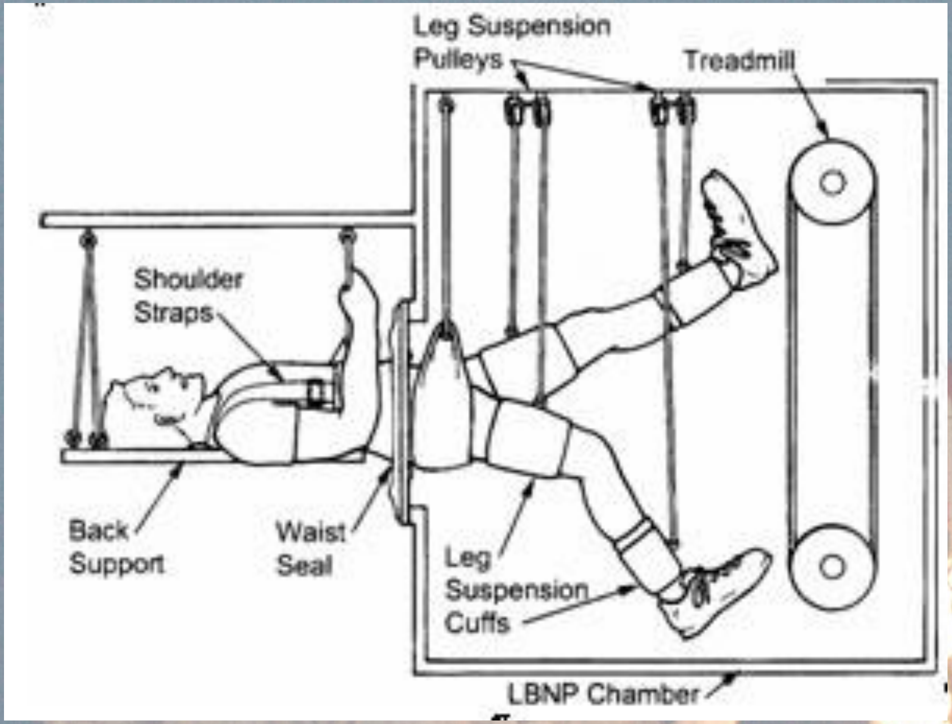


FIGURE A.I.a.–2.—Lower Body Negative Pressure Device (schematic).

- One device is promising in its attempt to mimic gravity
- The Lower Body Negative Pressure (LBNP) device relies on suction to provide negative pressure over the lower body



- The LBNP helps with cardiovascular function by increasing blood pressure to the legs
- When it includes a treadmill, it helps with muscles by allowing astronauts to exercise more efficiently
- It also seems to reduce some bone loss

- Anyone who has been on orbit for more than 30 days is required to be returned to Earth in the supine position (+Gx acceleration) to reduce the risk of orthostatic intolerance during re-entry and landing.
- The Space Shuttle is equipped with recumbent seats for returning long-duration crew members from the ISS
- There is, however, a concern that a long-duration flight crewmember could probably not egress from the recumbent seat system without some assistance.

The Neurolab crew floats on the Space Shuttle Columbia in May 1998 (photo courtesy of NASA)

- Much more research needs to be done to develop countermeasures to the body’s changes in microgravity
- This research must be conducted both on Earth and in outer space
- The results will help to improve the health of astronauts and pave the way for long-term space exploration, such as a trip to Mars

Other Clinical Problems

- Dermatological, ophthalmologic, and ENT problems
- Acute medical emergencies
  - Wounds, lacerations, and burns
  - Toxic exposure and acute anaphylaxis
  - Acute radiation illness
  - Development and treatment of decompression sickness
  - Dental, ophthalmologic, and psychiatric
- Chronic diseases
  - Radiation-induced problems
  - Responses to dust exposure
  - Presentation or acute manifestation of nascent illness

- Trauma and acute medical problems
- Illness and ambulatory health problems
- Altered pharmacodynamics and adverse drug reaction
- Meducal care systems for prevention, diagnosis or treatment

Review: Risks to Humans in Microgravity

- Exposure to ionizing radiation
- Bone density decrease
- Muscle Atrophy
- Cardiovascular Deconditioning
- Psychosocial impacts
- Fluid Shifting
- Vestibular Dysfunction
- Hematological changes
- Immune Dysfunction
- Delayed wound healing
- Gastrointestinal Distress
- Orthostatic Intolerance
- Renal stones


Medical Effects of Microgravity
Dr. Jim Davis, M.D.

- 1 Accelerated Bone Loss and Fracture Risk
- 2 Impaired Fracture Healing
- 3 Injury to Joints and Intervertebral Structures
- 4 Renal Stone Formation
- 5 Occurrence of Serious Cardiac Dysrhythmias
- 6 Diminished Cardiac and Vascular Function
- 7 Define Acceptable Limits for Contaminants in Air and Water
- 8 Immune Dysfunction, Allergies and Autoimmunity
- 9 Interaction of Space flight Factors, Infections and Malignancy
- 10 Alterations in Microbes and Host Interactions
- 11 Reduced Muscle Mass, Strength, and Endurance
- 12 Increased Susceptibility to Muscle Damage
- 13 Impaired Sensory-Motor Capability to Perform Operational Tasks During Flight, Entry, and Landing
- 14 Impaired Sensory-Motor Capability to Perform Operational Tasks After Landing and Throughout Re-Adaptation
- 15 Motion Sickness
- 16 Inadequate Nutrition
- 17 Monitoring and Prevention
- 18 Major Illness and Trauma
- 19 Pharmacology of Space Medicine
- Delivery20 Ambulatory Care21 Rehabilitation on Mars22 Medical Informatics, Technologies, and Support Systems23 Medical Skill Training and Maintenance24 Human Performance Failure Due to Poor Psychosocial Adaptation25 Human Performance Failure Due to Neurobehavioral Problems26 Mismatch between Crew Cognitive Capabilities and Task Demands27 Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems28 Carcinogenesis29 Acute and Late CNS Risks30 Chronic and Degenerative Tissue Risks
- 31 Acute Radiation Risks32 Monitor Air Quality33 Monitor External Environment34 Monitor Water Quality35 Monitor Surfaces, Food, and Soil36 Provide Integrated Autonomous Control of Life Support Systems37 Provide Space Suits and Portable Life Support Systems38 Maintain Food Quantity and Quality39 Maintain Acceptable Atmosphere40 Maintain Thermal Balance in Habitable Areas41 Manage Waste42 Provide and Maintain Bioregenerative Life Support Systems43 Provide and Recover Potable Water44 Mismatch Between Crew Physical Capabilities and Task Demands45 Poorly Integrated Ground, Crew, and Automation Functions