2014 Bone and Muscle Risks Standing Review Panel

Research Plan Reviews for:

The Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance and
The Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity

Status Reviews for:
The Risk of Bone Fracture,
The Risk Of Early Onset Osteoporosis Due To Spaceflight,
The Risk of Intervertebral Disc Damage, and
The Risk of Renal Stone Formation

Final Report

I. Executive Summary and Overall Evaluation

The 2014 Bone and Muscle Risks Standing Review Panel (from here on referred to as the SRP) met for a site visit in Houston, TX on December 17 - 18, 2014. The SRP reviewed the updated research plans for the Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance (Muscle Risk) and the Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Aerobic Risk). The SRP also received a status update on the Risk of Bone Fracture (Bone Risk), the Risk of Early Onset Osteoporosis Due To Spaceflight (Osteo Risk), the Risk of Intervertebral Disc Damage (IVD Risk), and the Risk of Renal Stone Formation (Renal Risk).

The SRP would like to commend Dr. Ploutz-Snyder and Dr. Sibonga for their presentations. Dr. Ploutz-Snyder did a great job presenting a very large volume of material on the muscle and aerobic gaps. The SRP appreciates Dr. Sibonga's overview of the complex, cumulative activities regarding research in osteoporosis and fracture and the Human Health Countermeasures (HHC) Element's approaches to mitigate fracture risk.

There were several areas of concern that were discussed by the SRP. These include the following:

- A major concern was raised related to exercise hardware, specifically, its basic function, validity, and reliability onboard the International Space Station (ISS). Adequate exercise protocols are critical in maintaining performance and astronaut health during prolonged exposure to microgravity and a great deal of time has been devoted to the development of three major pieces of exercise equipment over the past few decades. A great deal of evidence gathered over the past few decades has supported the need for regular exercise during prolonged spaceflight. However, despite this evidence it appears the actual hardware designed to maintain physical performance levels on board the ISS is substandard. This concern emerged during the presentation by Dr. Ploutz-Snyder and again during the *"integration discussion"*. The Advanced Resistive Exercise Device (ARED), Cycle Ergometer with Vibration Isolation and Stabilization System (CEVIS) and T2 treadmill are not performing up to the standards required to assess whether the astronauts are able to achieve the high exercise intensities necessary to complete task-specific workload demands.

- An additional concern related to exercise protocols during a mission to Mars was raised. The SRP was led to believe there were no plans in place; given there has been extensive discussion of this matter, for the development of equipment and/or exercise protocols for the flight to Mars. The SRP did learn however, during the *"integration discussion"* that some plans for equipment have been developed. The SRP thinks its' input should be considered in those discussions and that better interface/integration between the SRP and the appropriate engineering groups should be developed.

- Issues related to the different rates of variability in exercise responses across the broad range of astronauts were also discussed. There was a suggestion to obtain additional information on the astronauts as they are screened into the program that might permit "grouping" them according to previously identified markers. This might then permit interpretation of response into a "group" response to better deal with the high variability in current data. It was also suggested that a more direct integration and documentation of their exercise progression with the strength and conditioning coaches be part of an ongoing analysis to better understand the starting point when going in-flight. The efficacy of the in-flight exercise programs should include and maintain ground-based training program designs. Equipment functionality is therefore essential for this aspect of physiological maintenance during a mission. The SRP would also like to receive reports on which strength and conditioning programs are currently being implemented to make sure they provide an adequate stimulus for improvement and maintenance of the various physiological systems essential for long-term spaceflight.

- Finally, the SRP requests that they receive reports from all other workshops, summits, etc., on a regular basis as a first step toward better integration of much needed information regarding the human response to long-term spaceflight. The SRP also requests reprints of important 2015 research publications supported by NASA.

II. Critique of Gaps and Tasks for the Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance

1. *Have the proper Gaps been identified to address the Risk?*
   A. *Are all the Gaps relevant?*
   B. *Are any Gaps missing?*
2. *Have the appropriate targets for closure for the Gaps been identified?*
   A. *Is the research strategy appropriate to close the Gaps?*
3. *Have the proper Tasks been identified to fill the Gaps?*
   A. *Are the Tasks relevant?*
   B. *Are there any additional research areas or approaches that should be considered?*
   C. *If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap*
4. *If a Gap has been closed, does the Rationale for Gap closure provide the appropriate evidence to support the closure?*

Gaps and Tasks:

- Overall, the SRP thinks all of the gaps are relevant and appropriate.
- The SRP agreed with the changes and edits made to the Muscle and Aerobic gaps.
- The SRP thinks there is a need to identify task demands, i.e., those demands required of the crewmembers for all tasks performed on the ISS. To date, it is not clear what specific exercises are required to train the crewmembers to appropriately perform the many different tasks needed each day. Hence, the study and identification of *"task-specific"* demands is needed. It is acknowledged and supported that there are general *"core"* exercises for large muscle groups (e.g., squat, seated row, deadlifts) that are basic to any resistance exercise training program, but task specificity for other demands need to be determined for optimizing a program.
- The SRP recommends a universal change to all the gap titles that have *"muscle fitness"* in the title to change it to *"muscle function."*
- The SRP changed the gaps to show the need for information, when possible, pre-, in- and post-flight. The SRP realizes there are time constraints, some related to scheduling and some related to cooperative efforts and crew access but, when feasible, the SRP thinks a complete set of data should be obtained.

M1: What is the current state of knowledge regarding exercise performance?

- This Gap is closed and the SRP thinks that is appropriate.

No Current Tasks

M2: Characterize in-flight and post-flight muscle performance.

- The SRP thinks this gap is relevant and appropriate.
- The SRP thinks this is a high priority gap.
- The SRP recommends clarifying the "Initial State" for this gap. Specifically why is power mentioned in the first sentence ("Loss of muscle performance metrics such as strength, power and endurance following spaceflight is well documented")? There should be a measurement capability for strength, power, and endurance.

Tasks:

- Integrated Resistance and Aerobic Training Study – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Biomechanical Analyses of Resistance Exercise Using the Advanced Resistive Exercise Device – PI: Giancarlo Ferrigno, Ph.D. – Politecnico di Milano
- Retrospective analysis of inflight exercise loading and health outcomes – PI: John DeWitt, Ph.D. – NASA Johnson Space Center
- In-flight Demonstration of Portable Load Monitoring Devices-Phase I: XSENS ForceShoe – PI: Andrea M. Hanson, Ph.D. – NASA Johnson Space Center
- Reliability of the Power Cycle: A Comparsion to Current NASA Exercise Laboratory Muscle Performance Tests – Completed Task

M4: Establish muscle fitness standards for successful completion of mission tasks.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends changing the gap title to: "*Establish **muscle function** standards*

for successful completion of mission tasks."

- The SRP thinks that more than four mission tasks should be identified and investigated.
- The SRP thinks the "Interim Stages" for this gap are out of context and should be re-evaluated.
- How is strength being measured on the ISS? Strength was measured during the Integrated Resistance and Aerobic Training (iRAT) ground-based studies, but does not appear to be measured on the ISS. Appropriate measurement technology is needed to accurately and reliably assess muscle strength, power, and endurance.

Tasks:

- Standardized "Pre-flight" Exercise Tests to Predict Performance during Extravehicular Activities in a Lunar Environment – PI: Thomas Barstow, Ph.D. – Kansas State University
- Identification of skeletal muscle performance thresholds for extended duration functional task performance – PI: Jeff Ryder, Ph.D. – NASA Johnson Space Center
- Critical Task Evaluations –Workshop – Planned Task
- Critical Task Evaluations – Planned Task
- Flight Mission Task Assessments – Planned Task
- Development of a Submaximal Cycling Protocol to Identify the Ventilatory Threshold in Astronauts: Application to Monitor Changes in Endurance Capacity in Response to Long-Duration Spaceflight Missions – Completed Task
- Space Suit Simulator (S3) for Partial Gravity EVA Experimentation and Testing – PI: Jessica Duda, Ph.D. – Aurora Flight Sciences Corporation

M6: Develop pre-flight and in-flight evaluations to determine if muscle fitness standards are met.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends rewording the gap title to include post-flight and changing muscle fitness to muscle function: *Develop pre-flight, in-flight, and **post-flight** evaluations to determine if **muscle function** standards are met.*
- The SRP recommends adding a task that includes vertical jumps where you can preload one time the body weight. Any resistance system used during this task in microgravity will need to maintain 1g preload throughout the jump as in Earth-based models. Along with other ground-based fitness tests for muscular strength, power, and endurance, it is vital that a ground based measurement system also include tests that can be used during a mission for ongoing monitoring of fitness capabilities assisting in training program progression.

Tasks:

- Hardware and Protocol Test Development to Assess Flight Mission Task Readiness – Unfunded Task/Not within Current Budget
- Reliability of the Power Cycle: A Comparsion to Current NASA Exercise Laboratory Muscle Performance Tests – Completed Task

M7: Develop the most efficient exercise program for maintenance of muscle fitness.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends changing the gap title to: *Develop the most **effective** exercise program for maintenance of **muscle function**.*
    - By changing efficient to effective it is no longer entirely in the engineer's domain.
    - It is important to fully characterize any test population outside of the astronaut corps in order to understand the generalizations that can be made for translation to them.

Tasks:

- Integrated Resistance and Aerobic Training Study – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Exercise Autonomy Technologies Development – Planned Task
- Exercise in Isolation – Planned Task
- Biomechanical Analyses of Resistance Exercise Using the Advanced Resistive Exercise Device – PI: Giancarlo Ferrigno, Ph.D. – Politecnico di Milano
- Biomechanical Analysis of Treadmill Locomotion on the International Space Station – PI: John DeWitt, Ph.D. – NASA Johnson Space Center
- Ground-based Biomechanical Analyses of Resistance Exercise Using the Advanced Resistive Exercise Device – Completed Task
- Integrated Endurance and Resistance Exercise Countermeasures Using a Gravity Independent Training Device – PI: Gregory Adams, Ph.D. – University of California, Irvine
- Integrated Resistance and Aerobic Exercise Training with Small Compact Exercise Equipment – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Exploring the Relationship between In-Flight Training Load Data and Musculoskeletal Health Outcomes – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- A New Harness For Use with Exercise Countermeasures-Validation of Improved Comfort and Loading with the Center for Space Medicine (CSM) Harness – Completed Task
- Testosterone Supplementation as a Countermeasure against Musculoskeletal Losses during Space Exploration – PI: Randall Urban, M.D. – University of Texas Medical Branch at Galveston
- ESPIRIT: Exercise Sensing and Pose Recovery Inference Tool – PI: Mun Lee, Ph.D. – Intelligent Automation, Inc.
- Enhancing the Efficacy of Musculoskeletal Countermeasures Using Computer Simulation – Completed Task
- Retrospective analysis of inflight exercise loading and health outcomes – PI: John DeWitt, Ph.D. – NASA Johnson Space Center

M9: Identify and validate exploration hardware for maintenance of muscle fitness.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends changing the gap title to: *Identify and validate exploration **countermeasure** hardware for maintenance of **muscle function**.*
- The SRP thinks the "exploration hardware" needs to be better defined. The phrase as stated is vague.

Tasks:

- Integrated Endurance and Resistance Exercise Countermeasures Using a Gravity Independent Training Device – PI: Gregory Adams, Ph.D. – University of California, Irvine
- Integrated Resistance and Aerobic Exercise Training with Small Compact Exercise Equipment – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Evaluation of Advanced Exercise Concepts Devices for Down-Select Decision – PI: Gail Perusek, Ph.D. – NASA Glenn Research Center
- Advanced Exercise Concepts Demonstration, Human-In-Loop Testing, and Ground Training Study 1 – Planned Task
- Advanced Exercise Concepts Analog (Best Rest) Evaluation 1 – Unfunded Task/Not within Current Budget
- Advanced Exercise Concepts Device Flight Demonstration 1 – Planned Task
- Advanced Exercise Concepts Demonstration, Human-In-Loop Testing, and Ground Training Study 2 – Planned Task
- Advanced Exercise Concepts Analog (Best Rest) Evaluation 2 – Unfunded Task/Not within Current Budget
- Advanced Exercise Concepts Device Flight Demonstration 2 – Planned Task
- Advanced Exercise Concepts Demonstration, Human-In-Loop Testing, and Ground Training Study 3 – Planned Task
- Advanced Exercise Concepts Analog (Best Rest) Evaluation 3 – Unfunded Task/Not within Current Budget
- Advanced Exercise Concepts Device Flight Demonstration 3 with Integrated Countermeasures Suite – Planned Task
- A New Harness For Use with Exercise Countermeasures-Validation of Improved Comfort and Loading with the Center for Space Medicine (CSM) Harness – Completed Task
- The Constant Force Resistive Exercise Unit (CFREU) for Multi-Functional Exercise – Completed Task
- Compact, Controlled Force Crew Exercise System – Completed Task
- Controlled Resistance Exercise Device – PI: Alton Reich, Ph.D. – Streamline Automation, LLC
- Computer-Controlled Force Generator – PI: John Wright, Ph.D. – TDA Research, Inc.

M14: Identify adjuncts to exercise countermeasures that can be used to better mitigate muscle loss.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends changing the gap title to: *Identify adjuncts to exercise countermeasures that can be used to better mitigate muscle* ***atrophy****.*
- The SRP recommends changing the word hardware to exercise countermeasure in the note under the description for this gap: *Adjuncts may include nutritional supplements, pharmaceuticals, novel* ***exercise countermeasure*** *technologies, etc.*

Tasks:

- Testosterone Supplementation as a Countermeasure against Musculoskeletal Losses during Space Exploration – PI: Randall Urban, M.D. – University of Texas Medical Branch at Galveston
- Adjunct to Exercise Countermeasures for the Protection Against Muscle Atrophy (Study 2) – Planned Task
- Adjunct to Exercise Countermeasures for the Protection Against Muscle Atrophy (Study 3) – Planned Task

M23: Determine if factors other than unloading contribute to muscle atrophy during spaceflight.

- The SRP thinks this gap is relevant and appropriate.

Tasks:

- Loading-Independent Factors that Contribute to Spaceflight-Induced Muscle Loss – Planned Task
- Loading-Independent Factors that Contribute to Spaceflight-Induced Muscle Loss (Study 2) – Planned Task
- Loading-Independent Factors that Contribute to Spaceflight-Induced Muscle Loss (Study 3) – Planned Task
- Redox Modulation of Skeletal Muscle Function in Microgravity – Completed Task

M24: Characterize the time course of changes in muscle protein turnover, muscle mass, and function during long duration spaceflight.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends changing the gap title to: *Characterize the time course of changes in muscle protein **accretion**, muscle mass, and function during long duration spaceflight.*
- The SRP also recommends changing the "Target for Closure" to: *Establishment of a timeline for changes in muscle protein synthesis, breakdown, net muscle protein **accretion**, and muscle mass/volume during long-duration spaceflight.*

Tasks:

- Modulation of Muscle Function by Lower Limb Loading during SpaceFlight – Flight – Planned Task
- Development of Novel Technologies for the Assessment of Muscle Protein Turnover During Long Duration Spaceflight. Solicitation 1 – Planned Task
- Development of Novel Technologies for the Assessment of Muscle Protein Turnover During Long Duration Spaceflight. Solicitation 2– Planned Task
- Determination of Muscle Protein Turnover During Long Duration SpaceFlight – Planned Task

SM7.1: Determine if there are decrements in performance on functional tasks after long-duration spaceflight. Determine how changes in physiological function, exercise activity, and/or clinical data account for these decrements.

- The SRP thinks this gap is relevant, appropriate, and very well established.
- The SRP is very supportive of the integrative efforts of Dr. Ploutz-Snyder with Dr.

Rachael Seidler at the University of Michigan, in the broad scientific domain of muscle function.

Tasks:

- Physiological Factors Contributing to Postflight Changes in Functional Performance (FTT-Bloomberg, Active) – PI: Jacob Bloomberg, Ph.D. – NASA Johnson Space Center
- Recovery of Functional Performance Following Long Duration Spaceflight (Field Test-Reschke, Active) – PI: Millard Reschke, Ph.D. – NASA Johnson Space Center
- Bed Rest as a Spaceflight Analog to Study Neurocognitive Changes: Extent, Longevity, and Neural Bases (NeuroMapping-Bedrest-Seidler, Active) – PI: Rachael Seidler, Ph.D. – University of Michigan
- Spaceflight Effects on Neurocognitive Performance: Extent, Longevity, and Neural Bases (NeuroMapping-Flight-Seidler, Active) – PI: Rachael Seidler, Ph.D. – University of Michigan
- Recovery Data Mining: Relationship Between In-Flight Exercise and Postflight Sensorimotor Performance. (Recovery Data Mining-Reschke, Completed) – Completed Task
- Data mining activities for Sensorimotor Discipline (Sensory DM-Reschke, Completed) – Completed Task
- Performance Data Mining: Correlation Between Previous Performance Data with Clinical Observations – Completed Task

III. Critique of Gaps and Tasks for the Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity

1. *Have the proper Gaps been identified to address the Risk?*
   A. *Are all the Gaps relevant?*
   B. *Are any Gaps missing?*
2. *Have the appropriate targets for closure for the Gaps been identified?*
   A. *Is the research strategy appropriate to close the Gaps?*
3. *Have the proper Tasks been identified to fill the Gaps?*
   A. *Are the Tasks relevant?*
   B. *Are there any additional research areas or approaches that should be considered?*
   C. *If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap*
4. *If a Gap has been closed, does the Rationale for Gap closure provide the appropriate evidence to support the closure?*

Gaps and Tasks:

CV2: What is VO2max in-flight and immediately post-flight?

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends rewording the gap title to: *What is VO_{2max}* ***pre-flight****, in-flight and immediately post-flight?*
- The SRP thinks the tasks will help close the gap.

Tasks:

- Maximal Oxygen Uptake (VO2max) and Submaximal Estimates of VO2max Before, During and After Long Duration International Space Station Missions – PI: Alan Moore, Ph.D. – NASA Johnson Space Center
- Hypovolemia as A Model Of Spaceflight: Cardiovascular Exercise Effects and Countermeasures – Completed Task

A4: Establish aerobic fitness standards for successful completion of mission tasks.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends rewording the gap title to: *Establish **VO_2 standards (ml/kg)** for successful completion of mission tasks.*

Tasks:

- Standardized "Pre-flight" Exercise Tests to Predict Performance during Extravehicular Activities in a Lunar Environment – PI: Thomas Barstow, Ph.D. – Kansas State University
- Identification of skeletal muscle performance thresholds for extended duration functional task performance – PI: Jeff Ryder, Ph.D. – NASA Johnson Space Center
- Critical Task Evaluations –Workshop – Planned Task
- Critical Task Evaluations – Planned Task
- Flight Mission Task Assessments – Planned Task

A6: Develop pre-flight and in-flight evaluations to determine if aerobic standards are met.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends rewording the gap title to: *Develop pre-flight, in-flight, **and post-flight** evaluations to determine if **VO_2 standards (ml/kg)** are met.*

Tasks:

- Integrated Resistance and Aerobic Training Study – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Maximal Oxygen Uptake (VO2max) and Submaximal Estimates of VO2max Before, During and After Long Duration International Space Station Missions – PI: Alan Moore, Ph.D. – NASA Johnson Space Center
- New aerobic measures/functional correlates – Unfunded Task/Not within Current Budget

A7: Develop the most efficient exercise program for the maintenance of aerobic fitness.

- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends rewording the gap title to: *Develop the most **effective** exercise program for the maintenance of **VO_2 standards (ml/kg)**.*

Tasks:

- Integrated Resistance and Aerobic Training Study – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Cyber Partners: Harnessing Group Dynamics to Boost Motivation for More Efficient

Exercise – PI: Deborah Feltz, Ph.D. – Michigan State University
- Exercise Autonomy Technologies Development – Planned Task
- Exercise in Isolation – Planned Task

A9: Identify and validate exploration hardware for maintenance of aerobic fitness.
- The SRP thinks this gap is relevant and appropriate.
- The SRP recommends rewording the gap title to: *Identify and validate exploration hardware for maintenance of* ***VO_2 standards (ml/kg)***.

Tasks:
- Integrated Endurance and Resistance Exercise Countermeasures Using a Gravity Independent Training Device – PI: Gregory Adams, Ph.D. – University of California, Irvine
- Integrated Resistance and Aerobic Exercise Training with Small Compact Exercise Equipment – PI: Lori Ploutz-Snyder, Ph.D. – NASA Johnson Space Center
- Evaluation of Advanced Exercise Concepts Devices for Down-Select Decision – PI: Gail Perusek, Ph.D. – NASA Glenn Research Center
- Advanced Exercise Concepts Demonstration, Human-In-Loop Testing, and Ground Training Study 1 – Planned Task
- Advanced Exercise Concepts Analog (Best Rest) Evaluation 1 – Unfunded Task/Not within Current Budget
- Advanced Exercise Concepts Device Flight Demonstration 1 – Planned Task
- Advanced Exercise Concepts Demonstration, Human-In-Loop Testing, and Ground Training Study 2 – Planned Task
- Advanced Exercise Concepts Analog (Best Rest) Evaluation 2 – Unfunded Task/Not within Current Budget
- Advanced Exercise Concepts Device Flight Demonstration 2 – Planned Task
- Advanced Exercise Concepts Demonstration, Human-In-Loop Testing, and Ground Training Study 3 – Planned Task
- Advanced Exercise Concepts Analog (Best Rest) Evaluation 3 – Unfunded Task/Not within Current Budget
- Advanced Exercise Concepts Device Flight Demonstration 3 with Integrated Countermeasures Suite – Planned Task

IV. Discussion on the strengths and weaknesses of the IRP and identify remedies for the weaknesses, including answering these questions:

A. Are the Risks addressed in a comprehensive manner?
   - The SRP thinks the Risks are addressed in a comprehensive manner.

B. Are there obvious areas of potential integration across disciplines that are not addressed?
   - The SRP thinks the bone and muscle discipline integration is integrative by design, e.g., both are endocrine organs, and the additional integration with the sensorimotor discipline (muscle is a major sense organ), the cardiovascular discipline (muscles are a major fluid pump) and the existing integration with

studies related to changes in aerobic capacity are all natural interfaces with the major purpose of maintaining astronaut health. The SRP believes that while the science is by definition, integrated, the integration of personnel involved in these studies and their way of thinking, development of more integrated hypotheses, will be influenced as integrated projects are designed. The current focus on integration of SRP goals is a very positive step supported by the Bone and Muscle SRP that has been an integrated SRP for some time.

V. Evaluation of the progress on the Muscle and Aerobic Risks Research Plans since the 2013 SRP meeting

- The SRP is pleased with the progress made in the IRP since the 2013 SRP meeting, but very disappointed with the status of the exercise hardware onboard the ISS.

- The SRP would also like to have a better understanding of the strength and conditioning programs and astronaut progression in ground-based programs.

VI. Additional Comments regarding the Risk of Bone Fracture (Bone) and the Risk of Early Onset Osteoporosis Due To Spaceflight (Osteo) Status Review

- The SRP commends Dr. Sibonga for the presentation on "Path to Risk Reduction" and the useful concept to distinguish "essential research vs. good-to-know". This shows the bone discipline's approach to prioritizing gaps. Also of critical value is the prioritization approach used to describe Risk, Likelihood, and Consequence Rating.

- The SRP also commends Dr. Sibonga's outreach activities, such as the session she co-organized at the 2014 annual meeting of the American Society for Bone and Mineral Research. The session concerned NASA internship opportunities for students and experiences of scientists who collaborated with NASA scientists or had research projects funded by NASA.

- The SRP thinks the interaction with academic investigators during the two Bone Summits (2010, 2013) is a positive.

- The SRP is enthusiastic about initiatives to increase international data standardization, collections, and analyses to not miss opportunities to increase understanding of skeletal effects of spaceflight.

- The SRP wants to be thorough about its charge to assess the work/progress on addressing the risks and gaps, but is concerned that it is unable to fully and effectively address its charge because of missing information. There are two important issues that need to be improved for the SRP to accomplish their charge:
  1. As recommended in previous Bone Status Reviews, the SRP asks that annual progress be presented in a tabular form, such as Dr. Sibonga's "Deliverables" table, but to include an explicit statement explaining how the task filled the

intended gap. This recommendation does not intend to cover all work done, but only to those matters that address current specific gaps. It is acceptable to also include a bibliography of all projects in a list, but the tabular format is needed to assess progress towards mitigating current specific risks. This table would be a beneficial tool not only for the SRP, but also for management to see how the tasks are moving towards addressing a knowledge gap.

2. There is a concern about missing information. The SRP had made regular recommendations about the need for astronaut data to better understand the bone risks. The SRP was not presented with data that appeared in a publication published in June 2013 (J Bone Mineral Res 2013; 28:1243-55), reporting to the public the proceedings of the 2010 Bone Summit Panel. The publication included important analyses of data from long-duration flights. That publication was not presented to the SRP by NASA nor included in their lists of progress; it was found independently and after the fact. More recently, according to the Bone Summit II summary, which was not shared with the SRP until requested at the December 2014 meeting, an update of the astronaut data was reviewed at that November 2013 summit. Those analyses were not presented at either subsequent SRP meeting, Dec, 2013 and Dec, 2014. There was ample opportunity to inform the SRP at the meeting, especially when comments were reiterated about astronaut data. Those data and references to fracture data (also not presented) are critical to understanding bone and fracture risks. The SRP thinks it would be appropriate to have that information as those analyses are done. The SRP seeks clarification on why the findings of the two summits were not shared in a timely manner.

- The SRP acknowledges the problem of longer duration missions and the unknown course of bone loss. It is not known whether bone loss would plateau or accelerate or stay constant. Comprehensive data from 12-month missions will add to this knowledge base, even with small numbers of subjects.

- Efficacy of the ARED was shown to be good. The SRP supports emphasis on exercise countermeasures for near-Earth missions and would like to highlight the importance of continuing work on development and evaluation of a similarly effective, more compact exercise device designed for practical use on space exploration missions.

- More information is needed about the efficacy of different exercise regimens on the skeletal system, especially with heavy resistance exercise. For this, age-matched controls are needed, possibly with college students and team athletes.

- In order to prevent and optimize bone health it is important that structural exercises with proper stress vectors and loading are used in ground based strength and conditioning programs as well as during missions. This necessitates properly functioning equipment and appropriate exercise training programs both in ground-based and space exploration mission based scenarios.

- The SRP supports monitoring astronauts and age-matched controls by quantitative computed tomography (qCT) and looks forward to evidence testing whether or not qCT provides better assessment of fracture risk than does dual-energy x-ray absorptiometry (DXA) with the fracture risk assessment tool (FRAX) or similar tools.

- The SRP supports tasks addressing the efficacy of Reclast infusion to mitigate the rate of bone loss in the microgravity environment and in well validated ground-based analogue models of unloading.

- The SRP supports the need for biomarkers of bone loss, stress, inflammation, etc., that should be tested in-flight, for example, with saliva and emerging point-of-care technologies.

- The SRP recommends continuing active monitoring of advances in osteoporosis therapeutic approaches.

- NASA should not lose sight of basic and translational advances in relevant areas because they may have importance for spaceflight, such as exercise mimetics, anti-apoptotic agents, influence of the microbiome on the musculoskeletal system, bone as an endocrine organ, and others.

- Some members of the SRP had questions about the relevance of spinal cord injury and short-term bed rest studies to research countermeasures for bone loss.

- The SRP requests to see an organized summary of the high priority (vis-a-vis "likelihood and consequence" criteria) deliverables, unfinished, and planned studies that most closely address the "essential vs. good-to-know" parts of the current Bone Research Portfolio for fracture, osteoporosis, intervertebral disc damage, and renal stone risks. (The recommendation above to add to the "Deliverables" table may work to show how tasks are filling gaps),

VII. 2014 Bone and Muscle Risks SRP Research Plan Reviews: Statement of Task for the Risk Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance and the Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity

The 2014 Bone and Muscle Risks Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Chief Scientist. The purpose of the SRP is to review the Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance (Muscle) and the Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity (Aerobic) sections of the current version of the HRP's Integrated Research Plan (IRP) which is located on the Human Research Roadmap (HRR) website (http://humanresearchroadmap.nasa.gov/). Your report, addressing each of the questions in the charge below and any addendum questions, will be provided to the HRP Chief Scientist and will also be made available on the HRR website.

The 2014 Bone and Muscle Risks SRP is charged (to the fullest extent practicable) to:

1. Based on the information provided in the current version of the HRP's IRP, evaluate the ability of the IRP to satisfactorily address the Risk by answering the following questions:

    A. Have the proper Gaps been identified to address the Risk?
        i) Are all the Gaps relevant?
        ii) Are any Gaps missing?

    B. Have the appropriate targets for closure for the Gaps been identified?
        i) Is the research strategy appropriate to close the Gaps?

    C. Have the proper Tasks been identified to fill the Gaps?
        i) Are the Tasks relevant?
        ii) Are there any additional research areas or approaches that should be considered?
        iii) If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap.

    D. If a Gap has been closed, does the rationale for Gap closure provide the appropriate evidence to support the closure?

2. Identify the strengths and weaknesses of the IRP, *and* identify remedies for the weaknesses, including, but not limited to, answering these questions:
    A. Is the Risk addressed in a comprehensive manner?
    B. Are there areas of integration across HRP disciplines that are not addressed that would better address the Risk?
    C. Other

3. Based on the updates provided by the Element, please evaluate the progress in the research plan since the last SRP meeting.

4. Please comment on any important issues that are not covered in #1, #2, or #3 above, that the

SRP would like to bring to the attention of the HRP Chief Scientist and/or the Element.

Additional Information Regarding This Review:

1. Expect to receive review materials at least four weeks prior to the meeting.

2. Attend the 2014 Bone and Muscle Risks SRP meeting in Houston, TX on December 17 - 18, 2014.
   A. Attend Element or Project presentations, question and answer session, and briefing.
   B. Prepare a draft report that addresses each of the evaluation criteria listed in the panel charge. Debrief the HRP Chief Scientist and a representative from the Human Health Countermeasures (HHC) Element on the salient points that will be included in the report and specifically the items in the panel charge.

3. Prepare a draft final report (approximately one month after the meeting) that contains a detailed evaluation of the current IRP specifically addressing items #1, #2, #3, and #4 of the SRP charge. The draft final report will be sent to the HRP Chief Scientist and he will forward it to the appropriate Element for their review. The HHC Element and the HRP Chief Scientist will review the draft final report and identify any misunderstandings or errors of fact and then provide official feedback to the SRP within two weeks of receipt of the draft report. If any misunderstandings or errors of fact are identified, the SRP will be requested to address them and finalize the 2014 SRP Final Report as quickly as possible. The 2014 SRP Final Report will be submitted to the HRP Chief Scientist and copies will be provided to the HHC Element that sponsors the muscle and aerobic disciplines and also made available to the other HRP Elements. The 2014 SRP Final Report will be made available on the HRR website (http://humanresearchroadmap.nasa.gov/).

VIII. 2014 Bone and Muscle Risks SRP Status Review (WebEx/Telecon): Statement of Task for the Risk of Bone Fracture, the Risk of Early Onset Osteoporosis Due To Spaceflight, the Risk of Intervertebral Disc Damage, and the Risk of Renal Stone Formation

The 2014 Bone and Muscle Risks Standing Review Panel (SRP) will participate in a Status Review that will occur via a site visit with the Human Research Program (HRP) Chief Scientist, Deputy Chief Scientist and members of the Human Health Countermeasures (HHC) Element. The purpose of this review is for the SRP to:

1. Receive an update by the HRP Chief Scientist or Deputy Chief Scientist on the status of NASA's current and future exploration plans and the impact these will have on the HRP.

2. Receive an update on any changes within the HRP since the 2013 SRP meeting.

3. Receive an update by the Element or Project Scientist(s) on progress since the 2013 SRP meeting.

4. Participate in a discussion with the HRP Chief Scientist, Deputy Chief Scientist, and the Element regarding possible topics to be addressed at the next SRP meeting

The 2014 Bone and Muscle Risks SRP will produce a report/comments from this status review within 30 days of the 2014 update. These comments will be submitted to the HRP Chief Scientist and copies will be provided to the HHC Element that sponsors the bone discipline and also made available to the other HRP Elements. The 2014 SRP Final Report will be made available on the Human Research Roadmap public website (http://humanresearchroadmap.nasa.gov/).

IX. 2014 Bone and Muscle Risks Standing Review Panel Roster

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