Fiscal Year:	FY 2013	**Task Last Updated:**	FY 04/06/2013
PI Name:	Hogan, Harry Ph.D.		
Project Title:	Contributors to Long-Term Recovery of Bone Strength following Exposure to Microgravity		
Division Name:	Human Research		
Program/Discipline:	HUMAN RESEARCH		
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Biomedical countermeasures		
Joint Agency Name:	**TechPort:**		No
Human Research Program Elements:	(1) **HHC**:Human Health Countermeasures		
Human Research Program Risks:	(1) **Bone Fracture**:Risk of Bone Fracture due to Spaceflight-induced Changes to Bone (2) **Osteo**:Risk Of Early Onset Osteoporosis Due To Spaceflight		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
PI Email:	hhogan@tamu.edu	**Fax:**	FY
PI Organization Type:	UNIVERSITY	**Phone:**	979-845-1538
Organization Name:	Texas A&M University		
PI Address 1:	Dept. of Mechanical Engineering		
PI Address 2:	TAMU 3123		
PI Web Page:			
City:	College Station	**State:**	TX
Zip Code:	77843-3123	**Congressional District:**	17
Comments:			
Project Type:	GROUND	**Solicitation / Funding Source:**	2007 Crew Health NNJ07ZSA002N
Start Date:	05/20/2008	**End Date:**	11/19/2012
No. of Post Docs:	0	**No. of PhD Degrees:**	1
No. of PhD Candidates:	1	**No. of Master' Degrees:**	5
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	7
No. of Bachelor's Candidates:	1	**Monitoring Center:**	NASA JSC
Contact Monitor:	Maher, Jacilyn	**Contact Phone:**	
Contact Email:	jacilyn.maher56@nasa.gov		
Flight Program:			
Flight Assignment:	NOTE: New end date is 11/19/2012 per NSSC information (Ed., 6/01/2012) NOTE: New end date is 5/19/2012 per NSSC information (Ed., 5/31/2011)		
Key Personnel Changes/Previous PI:	Collaborator added: Dr. Stefan Judex, Stony Brook University		
COI Name (Institution):	Bloomfield, Susan (Texas A&M University) Martinez, Daniel (University of Houston)		
Grant/Contract No.:	NNX08AQ35G		
Performance Goal No.:			
Performance Goal Text:			
Task Description:	The project used the adult male hindlimb unloaded (HU) animal model with three specific aims and associated experiments. The first aim addressed the observed "discordant recovery dynamic" reported for astronaut data (Lang et al., JBMR 21:1224, 2006) with tasks to characterize bone mass, BMD, and bone strength relationships after HU and during various periods of recovery. Additional outcome measures include bone biochemistry and gene expression. A major emphasis was to compare detailed dynamics between the animal model and astronaut data. The animal model also permits direct comparison of calculated/estimated bone strengths with measured strengths. The second aim examined multiple mission scenarios and used HU, recovery for an interim period, and then a second HU exposure with another recovery period following. The third aim also followed the two-exposure protocol but with exercise added during the recovery period. The cross-cutting area, or element, of the Bioastronautics Critical Path Roadmap (CRP) that this research project addresses is Human Health & Countermeasures (HHC). The specific health risks are the Risk of Bone Fracture and the Risk of Accelerated Osteoporosis as identified in the Bioastronautics Roadmap and the Human Research Program (HRP) Integrated Research Plan. The Gaps addressed, as defined in the HRP-IRP, are: Gap B1: a) Is there an increased lifetime risk of fragility fractures/osteoporosis in astronauts; b) is bone strength completely recovered post-flight, and does BMD reflect it; c) what are the risk factors for poor recovery of BMD/bone strength? Gap B10: How can skeletal adaptation be monitored to a) determine whether there is a plateau in bone loss, b) describe gender effects, and c) reflect changes in bone turnover/calcium kinetics? The 2007 NASA Research Announcement (NNJ07ZSA002N) to which the proposal for this project responded included the following specific solicitation wording related to Gap B1: "There are preliminary indications that overall bone quality/strength does not recover at the same rate that bone mineral density recovers after spaceflight. It is not known if there is a long term health effect related to this discordant recovery dynamic." {emphasis added} Research proposals are solicited that directly address this relationship. The specific topic solicited is: Novel research that defines the precise relationship between long term recovery of bone mineral density and bone strength/quality, including the effects of multiple spaceflights." {emphasis added}		
Rationale for HRP Directed Research:			

Research Impact/Earth Benefits:

Results from this project will provide fundamental understanding of the way bone responds to mechanical unloading and how it recovers when mechanical loads are restored. Insights gained should be applicable to the clinically relevant case of aging adults with reduced activity levels, in addition to the effects of long term exposure to microgravity for crew members. Further, many of the same basic mechanisms overlap considerably with the broader health problem of osteoporosis and increased fracture risk in aging humans. It is widely known that bone mineral density (BMD) is not an accurate predictor of fracture incidence despite its wide use as a screening tool for osteoporosis. The findings of the research being conducted in this project will help to better define the relationships between BMD and other important factors, such as bone mineral content (BMC, i.e., bone mass), bone tissue quality, and most importantly bone strength. In addition, the project will identify which anatomic sites in the rat provide the closest correspondence to bone loss and recovery characteristics in humans (astronauts in this case). These results should bolster the utility and robustness of rodent animal models and linking their findings to clinical cases. Finally, the project will generate new and unique data on the effects of resistance exercise in restoring skeletal integrity during recovery from mechanical unloading. This information should be directly applicable to corresponding efforts aimed at using exercise to combat age-related losses from osteoporosis or related pathologies.

Task Progress:

The project was originally posed in terms of three animal experiments, corresponding to the three Specific Aims. The original Specific Aims and Hypotheses are summarized below. The animal experiments for Specific Aim 1 were conducted from September 2008 to August 2009. The animal experiments for Specific Aim 2 were conducted from October 2009 to April 2010. The animal work for Specific Aim 2 took slightly longer than originally anticipated due to modifications in the experimental design as described below. The animal experiments for Specific Aim 3 started in March 2011 and ended in November 2011. Thus, the effort during year 4 (May 20, 2011 to May 19, 2012; plus extension to November 19, 2012) was devoted to completing this last set of animal protocols and conducting data analysis and post-mortem testing.
Specific Aim 1. To determine the precise relationships between bone mass, BMD, and bone strength during recovery from 28 days of HU. Recovery periods of 28, 56, and 84 days will be studied, representing 1, 2, and 3 times the period of HU.

Hypothesis 1A. Bone mass will recover completely by 28 to 56 days.

Hypothesis 1B. BMD will not recover as fast, or extensively, as bone mass.

Hypothesis 1C. Bone strength will not recover as fast, or extensively, as bone mass or BMD.

Hypothesis 1D. The strongest predictors of bone strength at the end of HU, and also after recovery from HU, will be a combination of bone mass, BMD, and bone organic matrix (collagen) parameters.

Specific Aim 2. To determine the precise relationships between bone mass, BMD, and bone strength after a second exposure to 28 days of HU, following an initial 28 days of HU plus a recovery period. Two recovery periods interposed between HU exposures will be examined, 28 and 56 days. The recovery periods may be modified, however, based upon results from the experiments for Specific Aim 1.

Hypothesis 2A. The initial HU exposure plus recovery will have minimal effect on decrements in bone mass for the second HU exposure. That is, reductions in bone mass for the second HU will be approximately the same as for the first HU exposure.

Hypothesis 2B. Incomplete recovery from the initial HU exposure for BMD and bone strength will cause compounding decrements in these parameters due to the second HU exposure. That is, values for these parameters will be lower after the second HU than at the end of the first HU.

Hypothesis 2C. The strongest predictors of bone strength after the second period of HU will be a combination of bone mass, BMD, and bone organic matrix (collagen) parameters.

Specific Aim 3. To characterize and compare the effects of resistance training and treadmill running during recovery from 28 days of HU on the relationships between bone mass, BMD, and bone strength.

Hypothesis 3A. Resistance training during recovery will cause BMD and bone strength to recover at a rate and to an extent similar to the recovery of bone mass, but treadmill running will not be as effective in improving the recovery of BMD and bone strength.

Hypothesis 3B. Resistance training during recovery (from an initial 28 days of HU) will significantly improve the status of BMD and bone strength, relative to bone mass, after a second exposure to 28 days of HU. Treadmill running will not be as effective in improving BMD and bone strength for the same scenario.

Three sets of experiments were conducted to address the three specific aims of the project. In all cases, adult male Sprague-Dawley rats (6-mos.-old) were used, and the period of initial HU was 28 days. Recovery can be characterized in three ways: (a) by comparing to age-matched, ambulatory cage control animals (no HU, but same age); (b) by comparing to values at the end of the initial 28 days of HU (day 0 of recovery); and (c) by comparing to values at baseline (day 0 before HU). The major outcome variables examined are bone mass (size, geometry, BMC), bone mineral density (total, cortical, cancellous BMD), and bone quality (strength, plus measures of tissue-level organic matrix). Tissue-level organic matrix assays quantify collagen content, cross-link maturity, and gene expression. These were being assessed for: (i) cortical bone in the mid-diaphysis (tibia and femur); (ii) mixed cortical and cancellous bone in the metaphysis (proximal tibia and distal femur); (iii) mixed cortical and cancellous bone in the femoral neck. Using these anatomic sites allowed evaluation of the response of both cortical and cancellous bone, both separately and combined (integrally).

Specific Aim 1. The basic design was to determine the time course of recovery in bone outcomes following an initial period of HU (28 days). The experiments were conducted in three cohorts of 45 animals each, constituting 5 animals in each of the 9 groups. Animals were acclimated for two weeks and singly housed in a temperature-controlled room with a 12:12 hour light/dark cycle. Body weights and total vBMD of the proximal tibia metaphysis were used to assign animals to groups with the goal of having equal mean values in all groups for these two variables. All HU animals were allowed access to food and water ad libitum. During the first week of the HU period, control animals were pair-fed to the HU animals to account for the typically observed reduced food intake during the transition to HU. All animal procedures were in compliance with the Texas A&M University Institutional Animal Care and Use Committee rules and regulations.

The in vivo animal portion of Experiment 2 was completed in April 2010. Based on results from Experiment 1, and also considering the need to accelerate the overall time schedule of the project, the detailed protocol for Experiment 2 was modified from that originally proposed. The 28d recovery groups were eliminated because results from Experiment 1 indicated that the vast majority of pQCT-based parameters did not recover at that point, and this was deemed inappropriate with respect to realistic crew member scenarios. A new group was added to allow assessment of recovery following the second HU exposure.

Research review meetings were held in Houston with JSC personnel in both November 2010 and November 2011. Several modifications were agreed upon to the scope and nature of the research plan as a result of these meetings. The major items were as follows:

(1) A new collaboration was agreed upon with Dr. Stefan Judex of Stony Brook University. Ex vivo specimens from the proximal tibia would be shipped to Dr. Judex for him to conduct microCT scans and analysis of the proximal tibia metaphysis.

(2) An internal collaboration was also established with muscle biologist Dr. James Fluckey of the Health & Kinesiology Department at Texas A&M University. As a result, Dr. Fluckey and/or one of his students participated in all subsequent necropsy sessions and harvested muscle specimens. The two main outcome variables from this collaboration are wet muscle weights and muscle protein fractional synthesis rates (FSR). These measures are being made on the whole posterior crural muscle complex, as well as the separate muscles (gastrocnemius, plantaris, soleus).

(3) Only one type of exercise would be used for Experiment 3. Several factors precipitated this decision. These included persisting scheduling issues, increased animal costs, additional time delays associated with the new collaborations, and logistical details involved with the exercise protocols and integrating these within a double-HU experimental scenario. The single exercise to be used would be the resistance training approach.

Unfunded Synergy Activity continued during Year 3. Specifically, Co-Investigator Dr. Martinez continued to participate in all tissue collection necropsy sessions, and not only did he collect tissues to be analyzed as prescribed for this project, but he also collected the following additional tissues for potential future analysis: • Knee Ligaments ~ both medial and lateral collateral ligaments ; • Tendons ~ both the patellar tendon and the Achilles tendon

Experiment 3 animal procedures started during Year 3 and were completed during Year 4. The goal of this phase was to characterize the effects of resistance exercise during the recovery period on the nature and extent of recovery following the initial HU exposure, and also on the response to the second HU exposure (both loss and recovery following HU).

Major Findings for Specific Aim 1.

In Vivo pQCT at the Proximal Tibia Metaphysis and Tibia Diaphysis

• Both vBMD and BMC (total, integral) at the proximal tibia metaphysis exhibit loss and recovery patterns better matching crewmember data than do similar parameters for the femoral neck.

• Cortical bone in the cortical shell of the proximal tibia metaphysis was lost primarily endocortically and recovered mainly periosteally.

• Calculated strength indices suggested a loss in strength at the tibia diaphysis, which was not confirmed with direct testing of mechanical properties. HU had no effect on maximum fracture force at mid-tibia diaphysis.

Femoral Neck Ex Vivo pQCT and Mechanical Testing

• Bone response to disuse and reloading is site-specific, as both mass and density at the femoral neck in the rat recover after twice the duration of unloading, whereas maximum force reaches age-matched control levels after only one recovery period.

• The femoral neck experienced a significant loss of maximum force due to unloading that fully recovered after 28 days. Estimated strength indices for the femoral

neck indicated a recovery period of 56 days in contrast to the 28-day recovery that was observed with mechanical testing.

• Strength values are not substantially different for axial loading versus lateral loading in the adult rat HU animal model.

• Losses due to HU in strength for axial loading were greater than those for lateral loading, however.

• Losses due to HU in strength were generally greater than losses in vBMD or BMC especially for axial loading.

• NCSI was a better predictor of strength then NBSI.

Major Findings for Specific Aim 2.

In Vivo pQCT at the Proximal Tibia Metaphysis for Double-HU

• Both vBMD and BMC (total, integral) exhibit milder losses for the second HU compared to the first HU or the age–matched single HU. This suggests a possible protective effect of the initial HU.

• Bone in the cortical shell was lost primarily endocortically and recovered mainly periosteally.

• Recovery was not complete following the initial unloading cycle, and losses due to the second unloading cycle were not significant and smaller in magnitude than those due to initial exposure to hindlimb unloading.

• Rates of recovery for total BMC, vBMD, and cortical area were slower in older animals exposed to single or double HU cycles compared to recovery of younger animals exposed to a single HU bout.

Ex Vivo Mechanical Properties and Micro-CT at the Proximal Tibia Metaphysis for Double-HU

• Losses in densitometric properties were most dramatic for the first HU and for the cancellous bone compartment.

• Trabecular number (Tb.N) was minimally affected, with the greatest effects being reductions in trabecular thickness (Tb.Th).

• Mechanical properties derived from reduced platen compression (RPC) mechanical testing of machined proximal tibia metaphysis samples followed trends generally similar to densitometric measures for the trabecular compartment but the magnitudes of the effects were greater for mechanical properties. Specifically, ultimate stress showed age-related declines for age-matched controls, along with a general decrease for pre-to-post HU. However, the only significant difference from age-matched controls (-36%) was noted after the 1st HU exposure at a young age (6 months old).

• Trabecular vBMD following the initial HU cycle at a young age was only 11% lower than control values, which is much less than the 36% decline in ultimate stress, and thus demonstrates how BMD is not always an accurate predictor of mechanical strength.

Overall and taken together, these findings indicate that initial exposure to mechanical unloading does not exacerbate bone loss during a subsequent unloading period and two cycles of unloading followed by recovery does not have a cumulative net negative effect on total bone mass and density at the proximal tibia metaphysis.

Ex Vivo Results at the Distal Femur Metaphysis for Double-HU

• Losses in densitometric properties were most dramatic for the first HU and for the cancellous bone compartment.

• Mechanical properties of the cancellous bone, as estimated by RPC testing, were affected quite dramatically by the initial HU exposure. However, the effects of both HU exposures at the older age were essentially indistinguishable from age–related declines and properties.

Major Findings for Specific Aim 3.

Adding exercise during recovery between HU exposures revealed impressive and powerful benefits for the vast majority of variables measured.

• For in vivo pQCT results, both total BMC and total vBMD showed significantly enhanced recovery with the exercise added. Values not only recovered completely to control levels, but the exercise also engendered an apparent "protective" effect, as the losses for the 2nd HU were milder.

• At the femoral neck, however, the results were slightly different. Specifically, exercise produced benefits for total BMC only, with no appreciable effect on total vBMD. For total BMC, however, the benefits were much more dramatic, as the exercise produced "super-recovery," which is defined to indicate that mean values actually exceeded control animal values at the end of the exercise+recovery period.

• As was true at the proximal tibia, both BMC and vBMD exhibited a protective effect for the 2nd HU at the femoral neck.

• Perhaps the most dramatic effects of exercise were reflected by the mechanical strength of the FN. Both axial and lateral loading cases yielded super-recovery, with the maximum force for axial loading 35% higher than age-matched controls, and the maximum force for lateral loading 20% higher. A protective effect was also generated for maximum force at the FN, as the 2nd HU had no significant effect (no statistically significant changes pre- to post-HU).

• Trabecular vBMD for the non-exercise (2HU) group showed losses after the second HU exposure, and there was also a very significant age-related decline in trabecular vBMD in the weightbearing control animals. With exercise, however, trabecular vBMD increased during the 2nd recovery period to be higher than both non-exercise 2HU and AC groups (n.s.) and, in fact, restored to essentially the same level as baseline (day 0).

• As revealed by the microCT results, the enhanced trabecular vBMD was mainly the result of significant increases in trabecular thickness (Tb.Th) the following the 1st HU. Tb.Th was significantly higher than both 2HU (24.5%) and AC9 (26.3%) at the end of exercise period, and remained higher after the second HU period (21.8% and 27.6%, respectively). Rats exposed to resistance training did not exhibit increased trabecular BV/TV, however, presumably because of the significant decrease in trabecular number (Tb.N), which contributed to an increase in trabecular separation (Tb.Sp).

Bibliography Type:	Description: (Last Updated: 01/11/2021)
Abstracts for Journals and Proceedings	Shirazi-Fard Y, Peoples AR, Trinward A, Judex S, Bloomfield SA, Hogan HA. "Loss and Recovery Characteristics of the Cancellous Bone Compartment of the Proximal Tibia Metaphysis after Multiple Hindlimb Unloading Exposures in the Adult Male Rat Model." Orthopaedic Research Society Annual Meeting 2013, San Antonio, TX, January 26-29, 2013. Orthopaedic Research Society Annual Meeting 2013, San Antonio, TX, January 26-29, 2013. Poster 1507. , Jan-2013
Abstracts for Journals and Proceedings	Shirazi-Fard Y, Gonzalez E, Davis JM, Boudreaux RD, Morgan DS, Shimkus KL, Bloomfield SA, Hogan HA. "Exercise during Recovery between Two Bouts of Disuse Mitigates Bone Loss on Second Exposure." 34th Annual Meeting of the American Society for Bone and Mineral Research, Minneapolis, Minnesota, October 12-15, 2012. J Bone Miner Res 2012;27(Suppl 1):S12. Presentation 1034. Available at: http://www.asbmr.org/Meetings/AnnualMeeting/AbstractDetail.aspx?aid=bacd648c-9b63-4f74-9e3e-e8e99baeb2ae ; accessed 4/9/2013. , Oct-2012
Abstracts for Journals and Proceedings	Shimkus KL, Wudeck E, Shirazi-Fard Y, Hogan HA, Fluckey J. "Deptor Expression is Altered by Mechanical Loading in Skeletal Muscle or Rats," 2012 American Physiological Society (APS) Intersociety Meeting: Integrative Biology of Exercise, Westminster, CO, October 10-13, 2012. 2012 American Physiological Society (APS) Intersociety Meeting: Integrative Biology of Exercise, Westminster, CO, October 10-13, 2012. Program and Abstracts, Abstract 8.13, p. 27. http://www.the-aps.org/mm/Conferences/APS-Conferences/2012-Conferences/Integrative-Biology-of-Exercise/Final-Version-of-IBE-Meeting-Program-10-18-12.pd ; accessed 4/8/2013. , Oct-2012
Abstracts for Journals and Proceedings	Shirazi-Fard Y, Shimkus KL, Perticone JI, Morgan DS, Davis JM, Fluckey JD, Bloomfield SA, Hogan HA. "Discordant Bone and Muscle Adaptation to Multiple Microgravity Exposure with Interposed Resistance Exercise." 34th Annual Meeting of the American Society for Bone and Mineral Research, Minneapolis, Minnesota, October 12-15, 2012. J Bone Miner Res 2012;27(Suppl 1):S398-9. Presentation MO0182. Available at: http://www.asbmr.org/Meetings/AnnualMeeting/AbstractDetail.aspx?aid=204549be-cf30-4d49-b091-0079e622695b ; accessed 4/9/2013. , Oct-2012
Abstracts for Journals and Proceedings	Shimkus KL, Shirazi-Fard Y, Hogan HA, Fluckey JD. "Impact of chronic voluntary resistance training during recovery following hindlimb unloading on rat hindlimb muscles." Experimental Biology 2012, San Diego, CA, April 21-25, 2012. FASEB Journal 2012 Apr;26(Meeting Abstract Supplement):1076.4. http://www.fasebj.org/cgi/content/meeting_abstract/26/1_MeetingAbstracts/1076.4?sid=4ec49279-f79e-436a-a207-aca7f3b83cc5 ; See also http://www.fasebj.org/content/vol26/1_MeetingAbstracts for searching. , Apr-2012
Abstracts for Journals and Proceedings	Perticone JI, Shimkus KL, Shirazi-Fard Y, Hogan HA, Fluckey JD. "Effects of Voluntary Resistance Exercise Training during Recovery from Hindlimb Unloading on Rat Gastrocnemius Muscle." Texas Chapter of the American College of Sports Medicine 2012 meeting, Austin, TX, March 1–2, 2012. International Journal of Exercise Science: Conference Abstract Submissions: 2012;2(4):Article 41. Available at: http://digitalcommons.wku.edu/ijesab/vol2/iss4/41 (3rd place, Undergraduate Posters) , Mar-2012

Abstracts for Journals and Proceedings	Jaroszewski EE, Shimkus KL, Wiggs MP, Shirazi-Fard Y, Hogan HA, Fluckey JD. "Effects of Multiple Bouts of Long-duration Hindlimb Unloading and Recovery on Rat Plantaris Muscle." Texas Chapter of the American College of Sports Medicine 2011 Meeting, Austin, TX, February 24-25, 2011. International Journal of Exercise Science: Conference Abstract Submissions: 2011;2(3):Article 7. Available at: http://digitalcommons.wku.edu/ijesab/vol2/iss3/7 , Feb-2011
Abstracts for Journals and Proceedings	Davis JD, Shirazi-Fard Y, Kupke JS, Morgan DS, McCue AM, Thompson JV, Bloomfield SA, Hogan HA. "Modeling Microgravity-Induced Alterations and Recovery in Metaphyseal and Diaphyseal Bone in Adult Hindlimb Unloaded Rats." 32nd Annual Meeting of the American Society of Bone and Mineral Research Annual Meeting, Toronto, Ontario, Canada, October 15-19, 2010. J Bone Miner Res 2010 Sep;25(Suppl 1). Poster MO0048. Available at: http://www.asbmr.org/Meetings/AnnualMeeting/AbstractDetail.aspx?aid=20a89f61-88e4-4fcf-8001-4d35f2293afb ; accessed 4/9/2013. , Sep-2010
Articles in Peer-reviewed Journals	Shirazi-Fard Y, Anthony RA, Kwaczala AT, Judex S, Bloomfield SA, Hogan HA. "Previous exposure to simulated microgravity does not exacerbate bone loss during subsequent exposure in the proximal tibia of adult rats." Bone. 2013 Oct;56(2):461-73. Epub 2013 Jul 17. http://dx.doi.org/10.1016/j.bone.2013.07.004 ; PubMed PMID: 23871849 , Oct-2013
Articles in Peer-reviewed Journals	Shirazi-Fard Y, Metzger CE, Kwaczala AT, Judex S, Bloomfield SA, Hogan HA. "Moderate intensity resistive exercise improves metaphyseal cancellous bone recovery following an initial disuse period, but does not mitigate decrements during a subsequent disuse period in adult rats." Bone. 2014 Sep;66p1:296-305. http://dx.doi.org/10.1016/j.bone.2014.06.005 ; PubMed PMID: 24929241 , Jun-2014
Articles in Peer-reviewed Journals	Shimkus KL, Shirazi-Fard Y, Wiggs MP, Ullah ST, Pohlenz C, Gatlin DM 3rd, Carroll CC, Hogan HA, Fluckey JD. "Responses of skeletal muscle size and anabolism are reproducible with multiple periods of unloading/reloading." J Appl Physiol (1985). 2018 Nov 1;125(5):1456-67. Epub 2018 Aug 9. https://doi.org/10.1152/japplphysiol.00736.2017 ; PubMed PMID: 30091665 , Nov-2018
Articles in Peer-reviewed Journals	Rosa-Caldwell ME, Brown JL, Perry RA Jr, Shimkus KL, Shirazi-Fard Y, Brown LA, Hogan HA, Fluckey JD, Washington TA, Wiggs MP, Greene NP. "Regulation of mitochondrial quality following repeated bouts of hindlimb unloading." Appl Physiol Nutr Metab. 2020 Mar;45(3):264-74. Epub 2019 Jul 24. https://doi.org/10.1139/apnm-2019-0218 ; PMID: 31340136; PMCID: PMC7370318 , Mar-2020
Articles in Peer-reviewed Journals	Shirazi-Fard Y, Kupke JS, Bloomfield SA, Hogan HA. "Discordant recovery of bone mass and mechanical properties during prolonged recovery from disuse." Bone. 2013 Jan;52(1):433-43. Epub 2012 Sep 24. http://dx.doi.org/10.1016/j.bone.2012.09.021 ; PubMed PMID: 23017660 , Jan-2013
Awards	Perticone JI, Shimkus KL, Shirazi-Fard Y, Hogan HA, Fluckey JD. "3rd place, Undergraduate Posters, for 'Effects of Voluntary Resistance Exercise Training during Recovery from Hindlimb Unloading on Rat Gastrocnemius Muscle.' Texas Chapter of the American College of Sports Medicine 2012 meeting, Austin, TX, March 1–2, 2012. International Journal of Exercise Science: Conference Abstract Submissions: 2012;2(4):Article 41. Available at: http://digitalcommons.wku.edu/ijesab/vol2/iss4/41 " Mar-2012
Dissertations and Theses	Lucas MW. (Matthew W. Lucas) "A Novel Method for the Evaluation of Mechanical Properties of Cancellous Bone in the Rat Distal Femur." M.S. Thesis, Texas A&M University, August 2009. , Aug-2009
Dissertations and Theses	Davis J. (Joshua Davis) "Characterization of the Bone Loss and Recovery Response at the Distal Femur Metaphysis of the Adult Male Hindlimb Unloaded Rat." M.S. Thesis, Texas A&M University, December 2011. , Dec-2011
Dissertations and Theses	Morgan DS. (Derrick Scott Morgan) "The Effects of Multiple Unloading Exposures on Bone Properties in the Femur of Adult Male Rats." M.S. Thesis, Texas A&M University, May 2012. , May-2012
Dissertations and Theses	Gonzalez E. (Estela Gonzalez) "Response of the Femur to Exercise During Recovery between Two Bouts of Hindlimb Unloading in Adult Male Rats." M.S. Thesis, Texas A&M University, August 2012. , Aug-2012
Dissertations and Theses	Shirazi-Fard Y. (Yasaman Shirazi-Fard) "Skeletal Response to Simulated Microgravity Exposures and Exercise in the Adult Rat Model." Ph.D. Dissertation, Texas A&M University, May 2013. , May-2013
Papers from Meeting Proceedings	Lucas MW, Swift JM, Shirazi-Fard Y, Greene ES, Schepp BD, Bloomfield SA, Hogan HA. "Characterizing Strain in the Tibia of Hindlimb Unloaded Rats During Combined Isometric and Eccentric Stimulated Muscle Contractions." 2009 ASME Summer Bioengineering Conference, Lake Tahoe, California, June 17-21, 2009. 2009 ASME Summer Bioengineering Conference, Lake Tahoe, California, June 17-21, 2009. Paper no. SBC2009-206844, p. 653-654. , Jun-2009
Papers from Meeting Proceedings	Shirazi-Fard Y, Gonzalez E, Morgan DS, Davis JM, Shimkus KL, Boudreaux RD, Bloomfield SA, Hogan HA. "Bone Response to Exercise during Recovery between Unloading Bouts in Adult Male Rats." ASME 2012 Summer Bioengineering Conference, Fajardo, Puerto Rico, June 20-23, 2012. ASME 2012 Summer Bioengineering Conference, Fajardo, Puerto Rico, June 20-23, 2012. Paper number SBC2012-80922. , Jun-2012