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| **Fiscal Year:** | FY 2014 | **Task Last Updated:** | FY 03/13/2018 |
| **PI Name:** | Qin, Yi-Xian Ph.D. | | |
| **Project Title:** | Portable Quantitative Ultrasound with DXA/QCT and FEA Integration for Human Longitudinal Critical Bone Quality Assessment | | |
| **Division Name:** | Human Research | | |
| **Program/Discipline:** | NSBRI | | |
| **Program/Discipline--Element/Subdiscipline:** | NSBRI--Smart Medical Systems and Technology Team | | |
| **Joint Agency Name:** | | **TechPort:** | Yes |
| **Human Research Program Elements:** | (1) **ExMC**:Exploration Medical Capabilities | | |
| **Human Research Program Risks:** | (1) **Medical Conditions**:Risk of Adverse Health Outcomes and Decrements in Performance Due to Medical Conditions that occur in Mission, as well as Long Term Health Outcomes Due to Mission Exposures<br>(2) **Renal Stone**:Risk of Renal Stone Formation | | |
| **Space Biology Element:** | None | | |
| **Space Biology Cross-Element Discipline:** | None | | |
| **Space Biology Special Category:** | None | | |
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| **Zip Code:** | 11794-5281 | **Congressional District:** | 1 |
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| **No. of PhD Candidates:** | 3 | **No. of Master' Degrees:** | 1 |
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| **No. of Bachelor's Candidates:** | 5 | **Monitoring Center:** | NSBRI |
| **Contact Monitor:** | | **Contact Phone:** | |
| **Contact Email:** | | | |
| **Flight Program:** | | | |
| **Flight Assignment:** | | | |
| **Key Personnel Changes/Previous PI:** | | | |
| **COI Name (Institution):** | Gelato, Marie M.D. ( University of Kentucky )<br>Lin, Wei Ph.D. ( SUNY- The State University of New York ) | | |
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**Task Description:**

Project Overview
Skeletal complications, i.e., osteoporosis, induced by microgravity during extended space missions represent a key astronaut health problem. Lack of on-board diagnosis has increased significant risk in astronauts' bone loss during long term space flight. Early diagnosis of such disorders can lead to prompt and optimized treatment that will dramatically reduce the risk of fracture and longitudinal monitoring microgravity and countermeasure effects. Advents in quantitative ultrasound (QUS) techniques provide a method for characterizing the material properties of bone in a manner for predicting both bone mineral density (BMD) and mechanical strength. We have developed a scanning confocal acoustic navigation (SCAN) system capable of generating noninvasive ultrasound images at the site of interest. Both animal and human tests indicated strong correlations between SCAN determined data and microCT determined BMD, and bone strength, as well as monitoring fracture healing with guided ultrasound. The objectives of this study are to develop a portable broadband SCAN for critical skeletal quality assessment, to longitudinally monitoring bone alteration in disuse osteopenia, and to integrate ultrasound with DXA, QCT (quantitative computed tomography), and finite element analysis (FEA) for human subject. In vivo human tests will be evaluated at Stony Brook Osteoporosis Center. Human cadaver and animal samples will be used for testing feasibility of identifying bone loss, microstructural and mechanical strength properties. Development of a noninvasive diagnostic and treatment technology using noninvasive ultrasound with new crystal transducer technology will have a great potential to perform longitudinal measurement of bone alteration and prevent the risk of fracture.

Technical Summary: Non-invasive assessment of trabecular bone strength and density is extremely important in predicting the risk of fracture in space and ground operation. Quantitative ultrasound (QUS) has emerged with the potential to directly detect trabecular bone strength. To overcome the current hurdles such as soft tissue and cortical shell interference, improving the quality of QUS and applying the technology for future clinical applications, this phase of the development of image based SCAN system will concentrate on several main areas: (1) increasing the resolution, sensitivity, and accuracy in diagnosing osteoporosis through confocal acoustics to improve signal/noise ratio, and through extracting surface topology to accurately calculate ultrasound speed of sound; (2) minimizing the scanning time while maintaining reasonable resolution via micro-processor controlled and phased array electronic confocal scanning, e.g., in deep bone tissue scan; (3) developing broadband ultrasound system to measure deep bone tissue density and structural parameters in the critical regions; (4) improvement of functionality of SCAN system from a translational research perspective; (5) development of a micro-gravity capable method of QUS assessment through the removal of open-water coupling; (6) assessment of the capability of the SCAN system of imaging the proximal and distal tibia, elbow, humerus, and femur. The proposed work will develop a portable rapid SCAN system combined with imaging capability, and test its efficacy in human, which will ultimately provide a portable, noninvasive device for bone loss assessment in space.

Earth Applications: Skeletal decay complications are major health problems on Earth, i.e., osteoporosis, and delayed healing of fractures. Development of a low mass, compact, noninvasive diagnostic and treatment technology, i.e., using ultrasound, will have a great potential to prevent and treat bone fracture. Our principal goal is to develop a portable quantitative ultrasound system with therapeutic capability, not only for determination of bone's physical properties, but also for predicting subtle changes of bone during extended flights and diseased condition, which will impact both diagnosis and noninvasive treatment for musculoskeletal disorders. Use of a desktop based non-ionizing bone assessment device has great clinical applications as an in-office quantitative assessment of fracture risk in the general and at-risk populations.

Key findings and milestones: In this study, the teams are able to continue development of a scanning confocal acoustic diagnostic (SCAN) combined with therapeutic system capable of generating acoustic images at the regions of interest for identifying the strength of trabecular bone with high-resolution ultrasound (QUS) attenuation and velocity maps, and thus determining the relationship between ultrasonic parameters and bone mineral density (BMD), and bone's physical properties, as well as providing treatment for fracture healing. Ultrasound has been used in an OVX and femur fracture animal model to mitigate bone loss and acceleration of fracture healing. Phase array transducer and system are built and successfully demonstrated at the National Space Biomedical Research Institute (NSBRI) Capitol Hill Demo in March 2014.

Summary of key findings

• Redesign of portable SCAN mechanical array hardware

• Utilization of a non-water coupling method for region of interest bone imaging implementing polyurethane molded standoffs

• Translation of SCAN device from calcaneus scanning to wrist imaging

• Development of a hand-held SCAN device for assessment of bone quality in the forearm, upper arm, and proximal tibia

• Assessment of frequency specific ultrasound attenuation information in higher frequency (1-7 MHz) signals

• Validation of repeat measure consistency of SCAN device

Summary of deliverables (these deliverables are primarily completed)

• Development of second generation portable SCAN desktop device

• Development of hand-held portable SCAN device

• Skeletal imaging and bone quality assessment of the wrist and hand using an integrated mechanical and electronic SCAN device

• Skeletal imaging of the hand, tibia, and humerus using a hand-held SCAN device

**Rationale for HRP Directed Research:**

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| **Research Impact/Earth Benefits:** | Musculoskeletal decay due to a microgravity environment has greatly impacted the nation's civil space missions and ground operations. Such musculoskeletal complications are also major health problems on Earth, i.e., osteoporosis, and the delayed healing of fractures. About 13 to 18 percent of women aged 50 years and older and 3 to 6 percent of men aged 50 years and older have osteoporosis in the US alone. One-third of women over 65 will have vertebral fractures and 90% of women aged 75 and older have radiographic evidence of osteoporosis. Thus, approximately a total of 24 million people suffer from osteoporosis in the United States, with an estimated annual direct cost of over $20 billion to national health programs. Hence, an early diagnosis that can predict fracture risk and result in prompt treatment is extremely important. Ultrasound has also demonstrated its therapeutic potentials to accelerate fracture healing. The objectives of this study are focused on developing a combined diagnostic and treatment ultrasound technology for early prediction of bone disorder and guided acceleration of fracture healing, using SCAN imaging and low-intensity pulse ultrasound. Development of a low mass, compact, noninvasive diagnostic and treatment modality will have great impacts as early diagnostic to prevent bone loss and accelerate fracture healing. This research will address critical questions in the Bioastronauts Roadmap related to non-invasive assessment of the acceleration of age-related osteoporosis and the monitoring of fractures and impaired fracture healing. The results have demonstrated the feasibility and efficacy of SCAN for assessing bone's quality in bone. We have been able to demonstrate that the bone quality is predictable via non-invasive scanning ultrasound imaging in the ROI (reactive oxygen species), and to demonstrate the strong correlation between SCAN determined data and microCT identified BMD, structural index, and mechanical modulus. These data have provided a foundation for further development of the technology and the clinical application in this research. |
| **Task Progress:** | Musculoskeletal complications induced by age-related diseases like osteoporosis, and in long-term disuse osteopenia such as a lack of microgravity during extended space missions and long-term bed rest, represent a key health problem. Such a skeletal disorder changes both the structural and strength properties of bone, and the latter plays a critic role in ultimately leading to fracture. Early diagnosis of progressive bone loss or poor bone quality would allow prompt treatment and thus will dramatically reduce the risk of bone fracture. While most of the osteoporotic fractures occur in cancellous bone, non-invasive assessment of trabecular strength and stiffness is extremely important in evaluating bone quality. Ultrasound has also been shown therapeutic potentials to accelerate fracture healing. We are able to develop a SCAN system combined with therapeutic ultrasound capable of generating acoustic images at the regions of interest for identifying the strength of trabecular bone, in which the system is capable of generating non-invasive, high-resolution ultrasound (US) attenuation and velocity maps of bone, and thus determining the relationship between ultrasonic specific parameters and bone mineral density (BMD), and bone strength and bone's physical properties (i.e., stiffness and modulus). The ultrasound resolution and sensitivity are significantly improved by its configuration, compared to the existing technology. The new generation of SCAN devices greatly improve the practically use of ultrasound imaging. The issue of free water in microgravity has been solved by the development of a self-contained transducer tank, which would also allow for the replacement of water with a more ideal liquid such as mineral oil. Additionally, the development of a hand-held scanner requiring only a thin coating of ultrasound gel on the skin greatly improves the mobility of the device as well as allowing for the QUS (quantitative ultrasound) assessment of additional regions of interest. |
| **Bibliography Type:** | Description: (Last Updated: 02/17/2021) |
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