Development of a Mechanical Strain Device to Prevent Microgravity-Induced Bone Loss

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ABSTRACT

Microgravity-induced bone loss bears similarities to musculoskeletal pathologies such as disuse osteoporosis. The development of mechanical strain devices for astronauts may provide similar benefits as have been demonstrated for postmenopausal women with low bone mass. This communication proposes a hypothetical design and optimization for a strain device, based on the Fourier method, that could potentially used to limit bone loss on mid- to long-term manned space flight missions

(Keywords: bone mass, mechanical strain device, microgravity, space flight biology, osteoporosis)

INTRODUCTION

Understanding that microgravity-induced bone loss for astronauts on space missions is akin to musculoskeletal pathologies such as disuse osteoporosis in the elderly, there may be some common solutions for them. The literature suggests low magnitude, high frequency mechanical loading as a potentially effective countermeasure to bone loss [1]. For example, brief bouts of Optimass model 1000 Mechanical Strain Device of 0.2-g stimulus at 30 Hz, 2 × 10 min/day, for 12 months to postmenopausal Caucasian women with low bone mass showed a ~2% increase in bone mass density [2].

If we can replicate a similar mechanical strain device for astronauts, we may be able to improve bone adaptability to load-bearing in 0-g..

NOVEL DESIGN

Here, we propose to develop a similar mechanical strain device that can be incorporated into microgravity conditions for astronauts on space missions. We aim to:
a) describe a model that can be used for the vibrational settings, which can be adjusted based on gravitational fields and delivered in bouts so as to foster bone adaptation in a consistent, pre-emptive manner prior to landing;

b) design a mechanical strain device that can be easily embedded into conventional spacecraft infrastructure; and

c) determine the bones and anatomical landmarks that should be targeted to best see effect. In doing so, we improve health outcomes, maintain peak performance during the mission, partially reduce the cost burden for rehabilitation post-flight.

OPTIMIZATION

Optimal prescription can be calculated using the Fourier method, an equation that describes bone adaptation as a function of strain magnitude. However, the proportionality constant k is unique to the gravitational field and other biological factors. This calculation can enable us to determine the optimal frequency of vibration and degree of force for the mechanical strain device.

The device itself will be designed as a six-degrees of freedom platform with soft robotic appendages that offer the required levels of frequency and strain, while providing additional massage-induced comfort. Additionally, keeping in mind that physical exertion tasks such as running can produce peak strain magnitudes of 2000–3500 microstrains and standing impose strains in the optimal spectral range of 10–50 Hz, it represents an instrument that can permit astronauts to take part in exercise activities. As such, more robust extraterrestrial exercise programming can be developed around this device.

Noting that bone loss tends to be critical around long bones [3], the landmarks with joints such as the shoulder, hip, and ankle, to apply compressional and tensional forces along and around the plane of the bone shaft (diaphysis). Provided the context of irreparable terrestrial climate change and the growing interest for colonizing outer space, these types of technology implementation represent a forward-thinking approach to the long-term survival of humanity.

LIMITATIONS

While this technology may be theoretically sound, there is no experimental proof-of-concept to demonstrate its feasibility in microgravity conditions. Perhaps, more significantly, this may compromise physiological adaptations of bone and muscle to as opposed to foster acclimatization.

CONCLUSION

While mechanical strain devices have conventionally been used for more clinical applications, here we suggest the innovative utilization of this same piece of equipment for acclimatizing astronauts to long-term manned spaceflights such as upcoming planned Mars missions. Use of such devices in space facility simulation spaces can help us tap into the potential for exploring uncharted terrains. Furthermore, we propose a simple, but innovative, design incorporating biomechanical loading principles to improve astronaut health.

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