There are risks with long-term space missions associated with bone demineralization. The author reviews these problems together with useful monitoring techniques and possible countermeasures. In the absence of a complete answer being forthcoming, he sees a case for selecting marathon runners as Mars astronauts.

INTRODUCTION

NASA’s recently released 33-page booklet, *Human Mars Exploration* briefly outlines the currently planned mission scenario. According to Donna Shirley of the Jet Propulsion Laboratory, the ‘flags and footprints’ trip has now been abandoned in favor of a three year round trip that will see astronauts spending thirty months involved in on-surface operations. The authors of the booklet, Michael Duke and David Weaver, both accept that some of the main problems will be concerned with the mental and physical health of the crew.

HEALTH HAZARDS FOR MARS ASTRONAUTS

Whilst even a short-duration (up to two weeks) has profound effects upon the various physiological systems of the body, in certain systems these effects become progressively more severe as the mission length increases. Perhaps one of the major hazards to the Mars’ astronauts health is the continuous and progressive loss of calcium that results in the demineralization of bone and ultimately leads to the condition of osteoporosis (brittle bones).

BONE DEMINERALIZATION

The reasons for the astronauts skeletal deterioration are fairly complex. Under normal Earth-bound conditions a state of equilibrium exists between the calcium of the blood and that of the bones, but in microgravity this balance is seriously altered. Whereas after a few months most of the body’s systems have adapted to microgravity by settling down to a new equilibrium, the problem for some systems - such as those governing the regulation of calcium to bones - is that this equilibrium is not the same as experienced on Earth.

One of the first physiological changes noticed by the astronauts is the microgravity-induced headward fluid shift, normally in the order of about two liters. The astronauts brain, thinking that all the extra blood is pooling in the head because there is too much fluid in his body, informs the kidneys to release more urine. In order to prevent dehydration, the astronauts now have to consume at least two liters of fluid a day and whilst this may be an inconvenience, the real problem lies with the minerals (principally calcium and phosphorus) leached out in the extra urine. Should adequate countermeasures fail to be undertaken, the bones of Mars
astronauts would become excessively demineralized and therefore weakened with so much extra calcium being lost.

This continuous and progressive loss of calcium is one of the most striking biomedical findings of manned spaceflight and the consequences at the end of a typical trip to Mars could be potentially disastrous. For bone-weakened astronauts landing on the surface of Mars, the stress of walking may result in an abnormal concentration of forces being applied to the weakened bones and the very real possibility exists of the astronauts suffering stress fractures as a result of osteoporosis; an injury for which the recommended treatment is between 6 and 12 weeks of rest!

SECONDARY HAZARDS

Unfortunately for Mars astronauts and those planning long-term missions there are other risks associated with the demineralization process all of which constitute serious hazards to the health of crew members.

The first of these is the damage to soft tissues such as the kidneys as a result of the increased release of calcium and phosphorus. Secondly, there is the real possibility that with such a long mission the bone loss may be irreversible.

Finally, a price has to be paid for a long mission by way of a lengthy recovery period necessary for bone mass to return to normal levels (if in fact they do!).

COUNTERMEASURES

The increased urinary calcium excretion that occurs during microgravity is due to the absence of longitudinal pressure on the long bones. Clearly then, for normalization of bone growth, the Mars astronauts need to engage in some form or forms of countermeasures that involve the application of gravitational stress on the long bones. As impact forces are greatest when running (as opposed to rowing or cycle ergometry) and the magnitude of these forces play a significant role in maintaining bone density it is hardly surprising that the exercise equipment of choice for Mars-bound astronauts will be the in-flight treadmill!

Although exercise countermeasures such as running may not halt bone demineralization completely, the continued longitudinal pressure applied to the long bones whilst running aids in the maintenance of normal mineral metabolism in addition to stimulating appositional bone growth and slowing the decline in the thickness of the bone and the density of the shaft.

COUNTERMEASURE PROTOCOLS AND MISSION PLANNING

Currently, the amount of time spent exercising by astronauts is generally dictated by the length of the mission. Basically, the longer the mission, the greater is the requirement for
countermeasures. The situation for astronauts bound for Mars will be little different.

Although the treadmill will not be the only item of exercise equipment onboard, for reason already outlined, it is likely to get the most use. Mission planners’ tasks will need to include the scheduling of each crew-member’s operational exercise training regime that will involve a warm-up/down period and a time-efficient protocol.

Additionally, the countermeasures mission profile will involve extensive health monitoring as part of the requirements of the Crew Health Care System (CHeCS). For example, maximal oxygen uptake tests will monitor the efficacy of each crew members’ current training regime and any adjustments needed to the exercise prescription.

Other considerations for mission planners will be concerned with the astronauts diets. With crew members expending a significant amount of energy exercising, it may be necessary to increase the overall carbohydrate intake of astronauts so that it accounts for as much as 70% of their diet and perhaps supplement their diet with high-carbohydrate drinks which will not only supplement the diet but also offset the extra fluid lost whilst exercising.

**IN-FLIGHT MONITORING**

One of the instruments that may be used by the astronauts to monitor changes in bone density could include the Bone Stiffness Measurement Device (BSMD), a simple non-invasive device that can access the mechanical properties of the tibia using the phase velocity of flexural waves (produced by a mechanical impact to the head of the tibia) passing through it.

This equipment was flight-ratified and tested on the Euromir ‘95 mission (during which two hours per day were dedicated to exercise training) where it was used by cosmonauts Sergei Avdeev and Yuri Gidzenko, and proved itself as a useful diagnostic device able to determine critical changes in the astronauts skeletal characteristics; an essential requirement for any Mars mission.

**SPINOFFS**

Whilst all this exercise may seem rather boring and monotonous to the astronauts, the benefits, in addition to countering the effects of demineralization, are many. Not only does the performance of exercise ameliorate psychological stress, it also has a positive remedial effect for counteracting the mood and sleep impairment commonly experienced during long-term missions. Additionally, it serves as an effective countermeasure against both cardiovascular deconditioning and the deterioration of muscular skeletal function also observed during such missions.

**ALTERNATIVES**

Centrifugation is one alternative option to having marathon-running astronauts en route to
Mars. The implementation of artificial gravity routines have been demonstrated to prevent changes in the calcium and phosphorus content of long bones (in rats) and to prevent osteoporosis.

One of the problems with this method (apart from the obvious cost) is the current lack of knowledge concerning gravity gradients across an organism in a hyperdynamic environment over a long period of time. Another consideration concerns the rotational effects of the centrifuge that may interfere with research objectives.

Another possibility lies in the combined fields of pharmacology and nutrition. However, whilst drugs such as clodronate sodium and dietary manipulations involving the supplementation of calcium and phosphorous have shown some positive results, these have not been sufficiently successful to negate the need for exercise as the primary countermeasure.

**CURRENT RESEARCH: THE METABOLIC WARD IN SPACE**

With a decrease in bone mineral content having such an important medical impact upon long-term space flights, the efforts being made to solve this problem are extensive. One of the main research projects currently underway is the Metabolic Ward in Space; a study investigating calcium and bone metabolism as part of the Russo- German Mir ‘97 mission. It is led by an international team of scientists who come from various ESA-member states, Russia, USA and Germany. In addition to performing comprehensive food and chemical analysis of all available food items, the project also aims to evaluate intestinal calcium absorption by means of an oral strontium load test. Backing up these investigations will be data from the BSMD and Dual Energy X-Ray Absorptiometry equipment to determine bone architecture, substance and quality.

Other related experiments during the Mir ‘97 mission included the study of Vitamin D supplementation and documentation of food intake by the crew members. Much of the postflight data has now been collected and is being collated at the Deutsche Forschungsanstalt für Luft und Raumfahrt e.V. (Research Institute for Space Medicine).

**MARATHON RUNNERS TO MARS**

The results of such studies as described above will allow those working in the field of space biomedicine to better understand the calcium and bone metabolism in microgravity and as a result therapeutic countermeasures may be developed that will reduce the demineralization process.

At present, little is known concerning the calcium homeostatic mechanisms in space and the problems of bone remodeling and these will need to be solved before long interplanetary flights are possible. Until then, the possibility always exists for sending marathon runners as, by virtue of their greater bone density and the increased cross-sectional area of their long bones,
these candidates can afford to lose more bone mass and should therefore arrive in better (skeletal at least!) shape than their non-athletic counterparts. Selecting these subjects as Mars astronauts would of course mean that the mission planners would not need to concern themselves with the question of whether the crew members were spending sufficient time exercising!

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