

TOOTH LOSS MAY BE AN UNAVOIDABLE RISK OF SPACE TRAVEL

William Stenberg, DDS
Commander, U.S. Public Health Service
W.W. Hastings Indian Hospital
Tahlequah, OK 74464

ABSTRACT

It has been many years since man first set foot on the moon. The next logical step in the sequence exploration is a manned mission to Mars. Although the Martian surface has been explored by unmanned spacecraft, human interplanetary travel presents some unusual difficulties, the most salient of which is the lack of gravity. In a zero-gravity situation the human body is not able to maintain bone mass resulting in a type of osteoporosis. It is estimated that a human being loses approximately 1% of bone mass for each month in space. A typical Mars mission of thirty months could therefore result in 30% bone loss, which is considered severe osteoporosis. This could result in a high-risk of fracture upon return to Earth's gravitational field. This is considered one of the major showstoppers of long duration space flight. Various protocols have been developed in an attempt to minimize the bone loss in zero-gravity. These include vigorous exercise programs, which may last several hours each day, and weightlifting using elastic cords as a substitute for weights. There is some evidence that these measures may compensate for lack of gravity and reduce the severity of the bone loss. Loss of bone mass from the long bones of the skeleton may not be the only problem. Recent research in periodontology has shown that osteoporotic periodontal bone is more susceptible to breakdown than healthy bone, and that tooth loss is more frequent in subjects with osteoporosis. The strategies which may prove useful in the long bones, exercise, etc., are not adaptable to the oral bone. The bone surrounding the teeth is very susceptible to damage from the type of overloading that this would cause. Strategies to preserve the oral bone may include dietary and pharmacologic measures, as well as artificial gravity.

INTRODUCTION

When we think of dentistry and space travel, the most common context is the toothache in space, which is indeed a special problem of its own, that does deserve special consideration. But as a periodontist, I have become convinced that we may be facing other, equally serious challenges to the oral structures that will seriously impact space travel.

Since we do not yet have a lot of long-term data on the fate of the oral structures in space, we can look at the condition of the oral structures in analogous environments.

SUBMARINE EXPERIENCE

One such environment is the submarine. We know from experience that sailors on extended submarine patrols are more susceptible to scorbutic gingivitis, which is an oral form of scurvy. This has been the scourge of generations of sailors who travel farther than their supply of fresh fruit and vegetables will hold out. Research performed at the Naval Submarine Medical research Laboratory showed that blood levels of vitamin C were lowered by the unique environmental conditions aboard submarines. This occurred in many subjects, even those who were receiving dietary supplements of vitamin C (Gilman, 1980).

SPACE TRAVEL ENVIRONMENT

In space travel, we also face unique environmental conditions that result in the depletion of nutrients from the body, but it seems that in space flight the main problem is not vitamin depletion, but calcium homeostasis.

Periodontitis is a gum infection that results in the majority of tooth loss in adults. Its etiology is a combination of factors, such as the presence of anaerobic bacteria and a susceptible host. Such things as smoking and poor oral hygiene can make the condition worse. This is not exactly the problem that we need to be concerned with astronauts. What we are concerned with is a combination of factors caused by life in a zero-gravity environment that results in the weakening of the alveolar, or jaw bones, which can lead to destruction of the alveolus and loss of teeth. We call this condition space osteoporosis. Although some recovery of bone may be possible following return to earth, we are most concerned about the tooth loss aspects of space osteoporosis because of the irreversible nature of tooth loss.

Bone is a living tissue that is in a constant state of change. Under normal conditions, there is an equilibrium between the cells which erode the bone away, which are called osteoclasts, and the cells which follow behind and fill the holes back in which are known as osteoblasts. If we consider the bone mass of a human throughout his lifetime, we see that there is a rapid increase of mass from the time of birth until about the age of twenty-one. At this time the body reaches its peak bone mass. This growth slope is similar for men and for women. The one difference between the sexes is that men generally achieve a higher peak bone mass. Although it seems contrary to our daily observations, our own bones are never really in a steady state. They are either growing during the first twenty-one years of life, or deteriorating from the peak achieved at that age. The best we can hope for in our adult lives is a slow controlled descent.

Most people are familiar with age-related bone loss related to osteoporosis. This is related to impaired differentiation and function of the osteoblast cells. Space osteoporosis appears to be similar, and this establishes a relative hyperactivity of the

osteoclasts with the net result of quicker bone resorption than bone replacement. While it may take several decades for osteoporosis to manifest itself with clinical symptoms, space osteoporosis is much more rapid. Age related osteoporosis will result in weakened bones that fracture with use. It is presumed that space osteoporosis will result in equal or worse morbidity if long space flights are planned. We diagnose osteoporosis when bone density falls at least two standard deviations below the mean. This level of bone loss is possible in humans subjected to a space mission of long duration, such as a Mars mission.

When we examine photomicrographs of bone we see that the destruction of osseous structure as a result of osteoporosis does not cause a reduction in the size of the bones, but a decrease in the density. The spaces in the cancellous, or inner portions, of the bones become larger as the osseous matrix resorbs. Extreme structural weakness of the bone follows. In Earthbound subjects, the normal forces of gravity can result in fractures, most often in the hip, spine, and wrist.

When an astronaut moves into a zero-gravity environment there are various changes in the bone metabolism. These all culminate in a loss of skeletal bone. The rate of bone loss has been estimated at about 1% per month, which is about ten times faster than in age-related bone loss. As of this time, no one has stayed in space long enough to develop a case of osteoporosis, as the Mir missions have been up to 18 months in duration and the Skylab missions average up to 3 months. As of yet, astronauts and cosmonauts are not coming back to Earth with hip fractures, so for short term space flight this level of bone depletion may be tolerable. It is interesting to note that from data developed from these flights, there is a great amount of individual variation, with some of the cosmonauts on the longest flight actually experiencing very little bone loss. With length of mission planned for the Mars expeditions, however, the estimated amount of bone loss during a three year mission due to zero gravity would equal about thirty years of earthly bone loss due to aging.

Zero gravity has various effects on the cellular function of the bone, most important of these is the inhibition of osteoblast function due to an interruption of gene expression. There is also an effect of parathyroid function which causes the dumping of calcium from the body. These effects have been seen in humans and adult mammals. When embryonic life forms are sent into space, the bones that are in their growth phase do not seem to be affected by zero gravity and appear to grow (Holick 1998). It is only when the growth phase stops that they appear to deteriorate. These studies have generally been done on chick and quail embryos.

SPACE SHUTTLE EXPERIENCE

Dr. Jay Buckey of Dartmouth Medical School reported on his own experience as a crew member of the Space Shuttle as a part of the Neurolab mission. He reported his urinary calcium excretion 2.5 years before the mission at 230 mg/ day and the immediately after his mission at 349 mg/ day. This represents a 54% increase in excreted calcium. Studies on the Skylab from the 1973-74 period showed that there is a gradual

rise in calcium excretion during the first one to two weeks of the mission leading to a plateau level corresponding to 60 to 100% greater than control levels. Average calcium loss was 184 mg per day which translates into a 0.4% loss of total calcium per month.

What the calcium levels did not show was whether bone loss was occurring as a result of this calcium loss. A subsequent study by Smith et al. examined urine samples, which had been saved from the mission. In this way they could apply new technology to old samples. They used a chemical marker of bone resorption, N-telopeptide, which is used to track earthly bone diseases and are also used to track the success of osteoporosis treatments. What they found was that there was a 100% increase in N-telopeptide levels from the preflight baseline. The levels increased and remained elevated throughout the flight, indicating constant bone resorption.

MIR EXPERIENCE

More recent studies from the Euromir 95 Mission, have confirmed these findings (Caillot-Augusseau 1998). On a 180 day mission, the levels of C-telopeptide were elevated 78%. They also examined markers of bone formation, and observed a marked decrease. So there are really three effects of weightlessness on the bone: loss of calcium, decrease in bone formation, and increase in bone resorption. This bone depletion of 0.4% per month do not occur equally throughout the skeleton. Critical load-bearing areas such as the spine were affected to a much greater degree, often as much as 1% per month which far exceeds the bone loss of postmenopausal osteoporotic women who can lose up to 2-4% of bone mass per year.

In a French study by Vico, Collet & Guignandon, et al (2000), 15 Russian cosmonauts from the MIR space station were examined before and after space excursions of 1, 2, and 6 month duration. The bone mineral density (BMD) of the tibia and the distal radius were evaluated by DXA. Then after recovery periods equal to the duration of the space missions, the BMDs were again evaluated. The results of this study showed that there was actually very little bone loss on the non-weight bearing bone of the radius. The main areas of bone loss appeared to be at the weight bearing sites, specifically the tibia. Even after the first month, bone loss was evident in the cancellous portions of this bone, and there was continued deterioration throughout the duration of the space mission. The cortical areas of the bone were more resistant to deterioration, probably because of their greater initial density, but again, loss of bone density was evident after the 2-month space flight. In the six-month group, bone deterioration was quite pronounced in some subjects, with the cancellous areas again showing more deterioration than the cortical areas. The recovery periods, which were equal in duration to the space flights, were not adequate to allow complete remineralization of the osseous structures. A striking feature of this study was the amount of individual variation in the response to zero-gravity, some subjects showing great deterioration and others showing almost no loss of bone mineral density.

Fielder, Morey, and Roberts (1986) showed that weightlessness specifically affects cells in the periodontal ligament. The periodontal (PDL) is a connective tissue

interface between the tooth and the bone. It is composed mainly of fibroblasts, but other cell types are present. Osteoblasts within the PDL serve to maintain the bone housing around the tooth, which is known as the alveolus. This study in rats showed that the differentiation of osteoblasts from their preosteoblastic precursors was severely diminished by weightlessness. It was found that this effect was equal in the non-weight bearing structures of the PDL to the weight bearing areas of the tibia. This indicates a systemic component to the gravity related mechanism of osteoblast histogenesis.

RELATED STUDIES

In the 1970's there was a controversial paper published by a veterinarian at Cornell University. Using the beagle dog model, he studied the effects of a calcium depleted diet on the skeleton. The purpose of his studies was to determine the order in which bone is depleted from the skeleton. As in space osteoporosis, the weight bearing bones were the first to resorb. The long bones started demineralizing from the shaft portion first followed by the epiphyseal structures. An interesting outcome of the study was that the dogs teeth became loose and exfoliated prior to the appearance of symptoms in the other bones. The author of this study proposed that this process, calcium depletion, was the mechanism responsible for periodontitis, gum disease. To those working in the field of periodontology, these findings were interesting, but did not represent the experience of the other research groups, and were therefore dismissed. Henrikson (1968) published several papers on this subject, and made detailed references to calcium depletion in human gum disease, but these studies were eclipsed by several reports by periodontologists during the same period, which showed a purely bacterial etiology to periodontal bone loss. For the next 20 years the role of calcium depletion was relatively ignored, but during the past 2-3 years, as a result of new, advanced epidemiologic techniques, it has re-emerged as a significant factor in tooth loss.

The NHANES III study was conducted from 1988 to 1994 on a nationwide sample of non-institutionalized, non-military adults. The sample size was 39,695 people age 1 to 90. Dietary, demographic, clinical, biochemical, and dental exams were performed. Dietary calcium levels were determined over a 24 hour period and the data was stratified into three groups. Periodontitis was determined by clinical measurement of attachment loss with a diagnosis of attachment loss being made if the loss was greater than 1.5 mm. Laboratory analysis of venous blood for total serum calcium was also conducted.

After correcting for tobacco use, age, gingival bleeding scores, there was still a definite correlation between low dietary calcium levels and loss of periodontal attachment, and between low serum calcium levels and periodontitis in young females (Nishida, 2000).

What happens when we superimpose infectious periodontitis over osteoporotic bone? According to a recent study (Klemetti, 1994) there is a very strong correlation between the two. By using radiographs and clinical measurements, they found that those

patients with a high mineral status of the skeleton were able to keep their teeth longer despite deep, infected periodontal pockets.

MARS EXPEDITION PLANNING

Current plans from NASA for Mars exploration include a five to six month transit to and from Mars. The plans also include a stay on the Martian surface of around six-hundred days. The in a 0.38 G environment. So while in transit, they would be experiencing zero gravity, and on the Martian surface they would experience roughly one-third of the Earth's normal gravity. It is not known whether the Martian gravity is sufficient to prevent that rapid depletion of bone mineral, but it is generally thought that it will at the very least be preferable to a zero-gravity environment.

Some plans have suggested having a crewmember remain in orbit while the landing party is on the surface. The orbiting astronaut would be exposed to zero gravity for a prolonged period of time and serious amounts of bone deterioration could be expected.

Obviously, astronauts contemplating prolonged space flight should start with a maximum bone density. This can be accomplished with a diet rich in calcium and an aggressive exercise program. Astronauts can be chosen who have naturally occurring heavy bone structure. Bone depleting substances like caffeine, tobacco and alcohol would need to be limited or curtailed during the conditioning period. Female astronauts would need to have estrogen levels monitored, and possibly supplementation if levels are inadequate.

In the Mir97 mission (Heer 99), calcium supplementation and vitamin D supplementation increased calcium levels, but bone resorption markers were still present in high levels. In contrast to earthbound subjects, it did not prevent factors leading to osteoporosis. It appears that calcium and vitamin D supplementation is mandatory, but it is not sufficient to control deterioration.

We might think that stimulation of the periodontal bone by heavy forces would help condition the bone, in a manner similar to exercising on the weight bearing bones. What about clenching the teeth together with force? Unfortunately, when the teeth are in contact with excessive muscular forces, as in clenching, the lower jaw acts as a lever, concentrating forces on the area of contact between the mandible and the temporal bone. These bones are normally separated by a cartilagenous disc. When excessive forces are applied, deformation, destruction, and perforation can ensue. Exercising to maintain condition is just not practical. Likewise, jiggling forces applied to the tooth do not result in bone strengthening but bone deterioration. It appears that the best solution to the problem is to provide artificial gravity. Most studies have compared zero gravity to 1-G forces, but fractional levels of gravity have not been extensively investigated. It is possible that lower levels of gravity may preserve bone, and would be easier to engineer.

CONCLUSION

Tooth loss will occur with unabated osteoporosis, so something has to be done when travelling through zero G environments. It appears that there will be no simple answers, but prevention will require a combination approach, similar to prevention of other chronic conditions. Space osteoporosis need not be a showstopper if we manage it with care, and continue to develop research as we proceed. Any developments in this field will likely result in collateral developments in the treatment and prevention of terrestrial osteoporosis. If we can provide artificial gravity, it appear that problems will be limited.

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