Technical Note

Space Osteoporosis: An Electromagnetic Hypothesis

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Loss of body calcium during spaceflight is a potential problem in long voyages. This loss does not appear to be caused by a deficiency in diet or exercise. The idea is advanced that the altered electromagnetic environment experienced in space may be at least partially responsible. We show that the electric field induced inside astronauts because of their motion in the geomagnetic field is greater than that which has produced a wide variety of biological effects in earth-bound experiments.

OSTEOPOROSIS—loss of the calcium-containing mineral of bone—occurs typically in paralyzed or unused limbs, or with advancing age. Disuse osteoporosis is generally localized in the immobilized limb, but senile osteoporosis, a systemic bone disease affecting the entire skeleton, probably arises from a hormonal imbalance (9). Metabolic studies of the astronauts have indicated that spaceflight causes a net loss of body calcium (14), and it seems reasonable to assume that it comes primarily from cancellous bone. Such a calcium loss presents a potentially serious clinical problem because it is irreversible; it results in bones having diminished mechanical strength and a corresponding increased tendency towards pathological fracture.

Because of weightlessness—and its attendant reduced demands on the musculoskeletal system—disuse osteoporosis has served as the chief model for space osteoporosis (SO). Vigorous exercise programs, however—particularly in Skylabs 3 and 4—have not ameliorated SO (12). It is worthwhile, consequently, to consider factors other than weightlessness as possible causes.

During spaceflight, in addition to the absence of gravity, an altered electromagnetic environment is also encountered. On earth, one is exposed to the earth's electrostatic and magnetostatic fields. But during earth-orbital flight, the motion of the spacecraft through the geomagnetic field results in exposure to an extremely low-frequency (ELF) magnetic field. The hypothesis advanced for consideration is that the change in the electromagnetic environment of the astronaut has a causitive role in SO.

The earth's electrostatic field varies over many orders of magnitude, and it is effectively shielded by most modern methods of construction. We tentatively dismiss, therefore, the possibility that removal of the astronaut from this field is a causitive factor in SO. The situation with regard to the magnetic field is quite different.

Consider a manned spacecraft with orbital radius $\bar{r}$, angular velocity $\bar{\omega}$, and linear velocity $\bar{v}$—all with respect to a reference frame fixed in the earth (Fig. 1). At an arbitrary point within the astronaut's body, the electric field, E, is $\bar{E} = \bar{v} \times \bar{B}$, where $\bar{B}$ is the earth's magnetic field. Utilizing for $\bar{B}$ the expression obtained from the centered dipole approximation (5), we obtain

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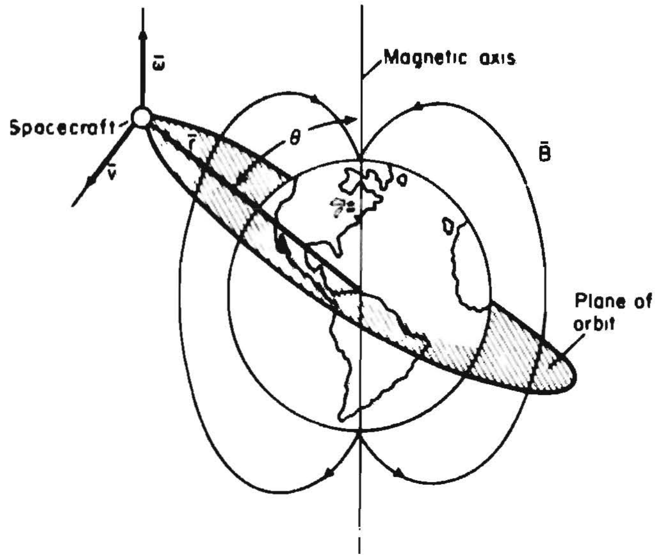

Fig. 1. Parameters describing motion of spacecraft in the geomagnetic field.

$$E = \frac{\mu_0 m \omega}{4\pi r^2} (1 + 3\cos^2\theta)^{0.5}$$

where m is the earth's dipole moment and μ_0 is the permeability of free space. The maximum electric field, E_{max}, occurs at $\theta = 0$—a circular orbit passing over the magnetic poles. In this case,

$$E_{max} = \frac{\mu_0 m \omega}{2\pi r^2}$$

For Skylab, the orbital period was about 5,400 s, and the orbital radius about 6.8×10^6 m. Since $\mu_0 m \doteq 10^{17}$ Wb·m (11), we obtain $E_{max} = 0.4$ V/m. In earth-bound experiments dealing with the biological effects of ELF fields, an electric field of such intensity may be produced within the test organism by either inductive or capacitive coupling. Depending on the frequency, for example, an ELF magnetic field of 1 gauss induces internal electric fields of the order of 0.4 V/m. And, depending on the tissue conductivity, an ELF electric field of 10,000 V/m produces a similar electric field inside the test organism. There are many reports of biological effects due to applied ELF fields of or below 1 Gs and 10,000 V/m (7). ELF magnetic fields, for example, have altered behavior (2) and serum triglycerides (1) in humans, and affected the growth rate of monkeys (3) and the orientational ability of birds (6). ELF electric fields have altered circadian rhythms (13) and reaction time (4) in humans, and have depressed the rates of growth (10) and fracture-healing (8) in rats.

Periodic motion of an astronaut through the geomagnetic field may result in biological alterations due to an induced electric field. While earth-bound experiments clearly support the hypothesis that such motion induces internal fields that are biologically active, they do not indicate that SO—or any other specific biological effect—will occur. This imprecision—which results from the infancy of the ELF bioeffects area—is no bar to exploration of the hypothesis because the latter may be directly tested by experiment.

Testing the possibility of a link between motion through the geomagnetic field and SO could begin with thorough physiological monitering of the effect on earth-bound test animals of an ELF magnetic field which best simulates the induced electric field caused by spaceflight. A more conclusive test would involve the study of the effect of such a field on test animals simultaneously undergoing weightlessness—a set of constraints which could be satisfied by test animals in synchronous orbit.

REFERENCES

1. Beischer, D. E., J. D. Grisett, and R. E. Mitchell. 1973. Exposure of man to magnetic fields alternating at extremely low frequency. NAMRL-1180. Naval Aerospace Medical Research Laboratory. Pensacola, Fl. NTIS No. Ad 770140.
2. Gibson, R. S., and W. F. Moroney. 1974. The effect of extremely low frequency magnetic fields on human performance: A preliminary study. Naval Aerospace Medical Research Laboratory. Pensacola, Fl. NTIS No. AD A005898.
3. Grissett, J. D., J. L. Kupper, M. J. Kessler, R. J. Brown, G. D. Prettyman, L. J. Cook, and T. A. Griner. 1977. Exposure of primates for one year to electric and magnetic fields associated with ELF communications systems NAMRL-1240. Naval Aerospace Medical Research Laboratory. Pensacola, Fl.
4. Hamer, J. R. 1968. Effects of low level, low frequency electric fields on human reaction time. *Commun. Behav. Biol., Part A.* 2:217-222.
5. Jackson, J. D. 1962. Classical Electrodynamics. John Wiley & Sons, Inc., New York, p. 143.
6. Larkin, R. P., and P. J. Sutherland. 1977. Migrating birds respond to Project Seafarer's electromagnetic field. *Science* 195:777-779.
7. Marino, A. A., and R. O. Becker. 1977. Biological effects of extremely low frequency electric and magnetic fields: A review. *Physiol. Chem. Phys.* 9:131-147.
8. Marino, A. A., J. M. Cullen, and R. O. Becker. 1978. Power frequency electric fields and biological stress: A cause and effect relationship. *In.* Proceedings of the 18th Annual Hanford Life Sciences Symposium: Biological Effects of Extremely-Low-Frequency Electromagnetic Fields. Battelle Memorial Institute Pacific Northwest Laboratories, Richland, Wa.
9. McLean, F. C., and M. R. Urist. Bone. Third Edition. The University of Chicago Press, Chicago, Il.
10. Noval, J. J., A. Sohler, R. B. Reisberg, H. Coyne, K. D. Straub, and H. McKinney. 1976. Extremely low frequency electric field induced changes in rate of growth and brain and liver enzymes of rats. Compilation of Navy Sponsored ELF Biomedical and Ecological Research Reports, Vol. III. Naval Medical Research and Development Command, Bethesda, Md. NTIS No. AD A035959.
11. Sugiura, M., and J. P. Heppner. 1972. Electric and magnetic fields in the earth's environment. *In:* American Institute of Physics Handbook. D. E. Gray (Ed). Third Edition. McGraw-Hill Book Co., New York, pp. 5-265.
12. Thornton, W. E., and J. Ord. 1977. Physiological mass measurements in Skylab. *In*: Biomedical Results From Skylab. R. J. Johnston and L. F. Dietlein (Eds). NASA SP-377. National Aeronautics and Space Administration, Washington, DC, p. 175.
13. Wever, R. 1974. ELF effects on human circadian rhythms. *In*: ELF and VLF Electromagnetic Field Effects. M. A. Persinger (Ed). Plenum Press, New York, p. 101.
14. Whedon, G. D., L. Lutwak, P. C. Rambaut, M. W. Wittle, M. C. Smoth, J. Reid, C. Leach, C. R. Stadler, and D. D. Stanford. 1977. Mineral and nitrogen metabolic studies, experiment M071. *In*: Biomedical Results From Skylab. R. J. Johnston and L. F. Dietlein (Eds). NASA-377, p. 164.