Special Article

Cardiology in Space

Philip J. Lees

Hellenic Journal of Cardiology Editorial Staff

Key words:
Spaceflight, space medicine, orthostatic hypotension, microgravity.

Manuscript received:
August 25, 2005;
Accepted:
September 9, 2005.

Address:
Philip J. Lees

P.O. Box 686,
Kokkini Hani,
71500 Heraklion
Crete, Greece
e-mail:
pjlees@her.forthnet.gr

How do you carry out an exercise test on the Moon? Are cardiac arrhythmias more or less common in low-gravity conditions? What is "normal" systolic blood pressure on Mars?

The North American Space Agency (NASA) has recently announced plans for a return to the Moon, with the intention of building a permanent base there (Table 1: a). The European Space Agency (ESA) has been considering a similar project (Table 1: b). The NASA base will eventually be used to launch a manned mission to Mars, which is likely to last around three years. Surely they will want to take a physician along. Although sceptics may question whether NASA's Mars mission will indeed take place within the next two decades, the question is likely to be one of "when", rather than "if". If the Americans or Europeans don't get there first, the Chinese probably will (after all, Mars has long been known as the "red planet").

Then there is the prospect of space tourism. For a mere $20,000 (10% of the total ticket price), you can secure yourself a flight reservation with Virgin Galactic (Table 1: c) and look forward to travelling into space on the VSS Enterprise during 2008. Can an orbital hotel be far behind (Table 1: d, e)? In any case, the questions at the start of this article, and other, similar ones, are likely to become of practical interest to the world cardiological community within the career lifetime of most readers.

In fact, we already have representatives on Mars. The robot rovers Spirit and Opportunity have been crawling over the red planet's surface for well over a year now, examining rock and soil samples and sending back gigabytes of scientific data, as well as stunning photographs of the Martian landscape (Table 1: f). Elsewhere in our solar system, in a joint NASA/ESA project, the Cassini orbiter is exploring the rings and moons of Saturn and last Christmas it successfully dropped the Huygens probe to the surface of Saturn's enigmatic moon, Titan (Table 1: g). Another probe, Deep Impact, went one-on-one with comet Tempel earlier this year so that the comet's composition could be investigated (Table 1: h).

But human beings are curious creatures, and adventurous ones. Analysing data sent back to Earth by robots will not satisfy us indefinitely. Sooner or later we will have to go and see for ourselves, and when we go, our health care needs will go with us. This article aims to provide a brief overview of what those needs are likely to be, at least as far as the cardiologist is concerned.

Weight matters

The human body has evolved to function under a constant vertical attraction of one Earth gravity, one g, equivalent to an acceleration of just under 10 $m.s^{-2}$. Our muscles compensate for this force whenever we move; our heart pumps blood against it. Change the gravitational force, or take it away altogether, and one might expect serious consequences for the human organism.

Table 1. Web sites with information about space exploration and research.

a.	http://www.nasa.gov/missions/solarsystem/cev.html
b.	http://www.esa.int/esaCP/Pr_9_1998_p_EN.html
c.	http://www.virgingalactic.com/
d.	http://news.bbc.co.uk/1/hi/sci/tech/293366.stm
e.	http://www.bigelowaerospace.com/news.html
f.	http://marsrovers.jpl.nasa.gov/home/
g.	http://saturn.jpl.nasa.gov/home/index.cfm
h.	http://www.nasa.gov/mission_pages/deepimpact/main/
i.	http://www.spaceelevator.com/

For the cardiovascular system, weight, or the lack thereof, is by far the most important factor that must be considered. In fact, the potential hazards can be imagined as lying within a two-dimensional graph, where one axis is weight and the other is time. We know that the seated human body can tolerate a weight increase of three to five times for short periods, measured in seconds or minutes, without permanent harm. We have also learned some of the effects of near weightless conditions experienced for periods of days or months. And of course, we are familiar with the consequences of a body weight within normal limits over the course of a human lifetime.

Increased gravitational force, and thus a sensation of greater weight, is experienced by spaceship crews (and passengers) during takeoff and landing. Lifting a space vessel out of Earth's gravity requires several g's of acceleration for several minutes, at least with our current technology. Short exposure to even higher g forces can be tolerated with the aid of special equipment.

High g has been associated with a variety of cardiac arrhythmias during centrifuge training.[1-3] Although these were acute, spontaneously reversible responses, it must be remembered that the subjects of the studies were young, extremely fit individuals. The impact of high acceleration on the cardiovascular function of an average healthy human being is still unknown and may be a cause for concern.

However, it is the opposite end of the spectrum that is likely to pose more serious problems. In the not too distant future human space travellers will probably have to undergo low-gravity conditions on a chronic basis.

A space shuttle or space station in orbit is said to be in "free fall", that is, not subject to gravitational attraction. The gravitational force is still there, of course, but it is all used to keep the vehicle in orbit, rather than flying off into space. A person within such a space vehicle is not aware of any gravitational pull.

For technical reasons, the gravitational force is never quite zero, so it is usual to talk about the effects of "microgravity" in such a situation. However, from the point of view of the person experiencing it, "weightlessness" is an adequate description.

Expeditions to the Moon or Mars may ameliorate the weight loss, but entail a prolongation of the time of exposure. The Moon's gravity is 16% that of Earth, Mars' is 38%. Inhabitants of a permanent Moon base may have to live with one sixth their Earth weight for months or years at a time. Maybe some of them will come to like it.

Microgravity and haemodynamics

Although microgravity itself does not appear to present a chronic stress to the cardiovascular system,[4] adaptive changes are known to occur. One primary problem that has been identified in many astronauts who have undergone even relatively short exposure to microgravity is that of orthostatic hypotension. After returning from a short-duration spaceflight, about 20% of astronauts experience episodes of syncope or presyncope for several days. This orthostatic intolerance could be partially due to alterations in body fluid volume,[5,6] but microgravity also appears to induce a change in the autonomic balance, in the form of a shift away from the parasympathetic towards sympathetic predominance.[7-10] More recent evidence[11] suggests that this is not the consequence of a failure of autonomic function, but rather a response to the redistribution of fluid, with a deficit in the lower body and an increased cardiac preload.

Attempts to mitigate these changes through mechanical means have met with only partial success.[12] Recovery is rapid, but whether the same will hold true after long periods in a low-gravity environment is as yet unknown. Using tilt testing to simulate weight changes can provide useful information, but cannot faithfully mimic the changes that occur during a real space flight.[13]

Microgravity and cardiac arrhythmias

A number of minor rhythm disorders have been recorded during spaceflight.[14] The shift in autonomic balance may also lead to alterations in heart rate and rhythm.[15] This is again a physiological adaptation, rather than a response to psychological stress. For example, the incidence of dysrhythmias has been found to be no greater during extravehicular activity than under normal flight conditions,[16] while heart rate perturbations have also been measured during sleep.[17]

During spaceflight, heart rate decreases early in microgravity and then gradually returns to normal.[18] After return to normal gravity heart rate increases and remains elevated for around two weeks. Spectral analysis of heart rate variability found no significant changes during spaceflight, but after return to Earth the ratio of low to high frequency components of the short-term HRV increased, suggesting a decrease in vagal tone.[18]

Recent evidence suggests that microgravity simulation may have a measurable effect on cardiac electrical repolarisation,[19] but whether or not the space environment actually increases the risk of cardiac arrhythmias is still unknown. However, there is concern that more serious rhythm disturbances may have an impact on long-duration spaceflight.[20]

Microgravity and cardiac remodelling

It would be surprising if exposure to microgravity did not have some effect on myocardial electromechanical function, at least in the long term. Indeed, echocardiographic studies have found significant changes in heart volume, affecting left ventricular function, following shuttle craft missions.[21]

However, the extent and the mechanism of ventricular remodelling during spaceflight are still the subject of some controversy. A decrease in left ventricular mass of the order of 10% has been observed after exposure to real or simulated microgravity and attributed to a physiological adaptation to reduced myocardial load and work.[22] Conversely, others maintain that such a reduction is simply the result of physiological fluid exchanges.[23]

In any case, these are short-term reactions. Limited evidence from longer stays in space suggests that there may be a reduction in left ventricular ejection fraction that is related to mission duration and could be due to a decrease in cardiac function, rather than altered blood volume.[24] Clearly, further study is needed in order to elucidate these points.

Diagnosis

Apart from the new spectrum of microgravity-related disorders, the cardiologist in space will have to contend with new challenges to standard diagnostic methods. The standard physical examination will need to be modified for these different conditions.[25] Although many modalities, such as electrocardiography or cardiac ultrasound, are not gravity-dependent, storage and weight limitations on the spacecraft itself will necessitate the development of smaller and lighter equipment that can also withstand the stresses of launch and orbital reentry.[26] (As in other areas of space research, this technological progress is likely to bring benefits to the folks back on Earth, too.) Other common diagnostic tests may have to be completely redesigned. Conventional exercise testing, for example, may need to be replaced by other means of stressing the heart.

Non-invasive examinations, in any case, will be at a premium. The release of even small amounts of blood or other fluids in a microgravity environment is something to be avoided if at all possible.

To make matters worse, the on-board physician examining a patient on a long-distance space flight is likely to encounter physiological alterations that have never been seen before. Hormonal changes have been reported after periods in microgravity,[27] as have alterations in blood composition[28] and lipid metabolism.[29] How these changes might progress and interact with one another during a long space voyage is quite unknown. If some kind of artificial or simulated gravity could be provided during a long space voyage, for example the Mars expedition, it might eliminate many potential problems. However, such a solution raises technical difficulties that still remain to be overcome.[30]

The role of the cardiologist in space exploration

Realistically, the physician on a mission to Mars will be a general practitioner, perhaps with extra specialisation in certain specific fields, including cardiology (as well as, for example, nutrition, radiation medicine, psychiatry). It is likely to be a challenging position.

The cardiologist's role, at least for the time being, will be confined to preliminary research, perhaps involving extended stays in Earth orbit or on a Moon base. One interesting speculation that may shift additional emphasis to the speciality of cardiology is the possibility that the crew of a Mars mission could be older than typical space personnel. There are a number of reasons for this, including the potential consequences of exposure to cosmic radiation during the voyage and the intriguing observation that an elderly individual may be better equipped to handle cardiovascular adaptations to a microgravity environment.[31]

Taking speculation a little further into the future, orbital hotels may wish to have a cardiologist on their staff, either in residence or on-call down on Earth. Although currently in the realm of science fiction, the concept of an orbital hospital, with low-weight or microgravity wards tailored for patients who suffer from certain debilitating conditions, is perhaps not entirely ridiculous. Temporary release from the burden of body weight might improve the prognosis in such cases, although a means of travelling to and from orbit without the violent accelerations that are necessary at present would need to be found (for example, the space elevator – Table 1: i).

Even leaving aside those more outlandish possibilities, space exploration over the next few decades[32] is likely to pose sufficient challenges to any cardiologist who yearns to explore the "final frontier".

References

1. Whinnery JE: The electrocardiographic response to high +Gz centrifuge training. Aviat Space Environ Med 1990; 61: 716-721.
2. McKenzie I, Gillingham KK: Incidence of cardiac dysrhythmias occurring during centrifuge training. Aviat Space Environ Med 1993; 64: 687-691.
3. Tachibana S, Akamatsu T, Nakamura A, Yagura S: Serious arrhythmias coinciding with alteration of consciousness in aircrew during +Gz stress. Aviat Space Environ Med 1994; 65: 60-66.
4. Fritsch-Yelle JM, Charles JB, Jones MM, Wood ML: Microgravity decreases heart rate and arterial pressure in humans. J Appl Physiol 1996; 80: 910-914.
5. Leach CS, Inners LD, Charles JB: Changes in total body water during spaceflight. J Clin Pharmacol 1991; 31: 1001-1006.
6. Bungo MW, Charles JB, Johnson PC Jr: Cardiovascular deconditioning during space flight and the use of saline as a countermeasure to orthostatic intolerance. Aviat Space Environ Med 1985; 56: 985-990.
7. Fritsch JM, Charles JB, Bennett BS, Jones MM, Eckberg DL: Short-duration spaceflight impairs human carotid baroreceptor-cardiac reflex responses. J Appl Physiol 1992; 73: 664-671.
8. Fritsch-Yelle JM, Charles JB, Jones MM, Beightol LA, Eckberg DL: Spaceflight alters autonomic regulation of arterial pressure in humans. J Appl Physiol 1994; 77: 1776-1783.
9. Whitson PA, Charles JB, Williams WJ, Cintron NM. Changes in sympathoadrenal response to standing in humans after spaceflight. J Appl Physiol 1995; 79: 428-433.
10. Gisolf J, Immink RV, van Lieshout JJ, Stok WJ, Karemaker JM: Orthostatic blood pressure control before and after spaceflight, determined by time-domain baroreflex method. J Appl Physiol 2005; 98: 1682-1690.
11. Baisch F, Beck L, Blomqvist G, et al: Cardiovascular response to lower body negative pressure stimulation before, during, and after space flight. Eur J Clin Invest 2000; 30: 1055-1065.
12. Herault S, Fomina G, Alferova I, Kotovskaya A, Poliakov V, Arbeille P: Cardiac, arterial and venous adaptation to weightlessness during 6-month MIR spaceflights with and without thigh cuffs (bracelets). Eur J Appl Physiol 2000; 81: 384-390.
13. Lathers CM, Charles JB: Comparison of cardiovascular function during the early hours of bed rest and space flight. J Clin Pharmacol 1994; 34: 489-499.
14. Leguay G, Seigneuric A: Cardiac arrhythmias in space. Role of vagotonia. Acta Astronaut 1981; 8: 795-801.
15. Baevsky RM, Bennett BS, Bungo MW, Charles JB, Goldberger AL, Nikulina GA: Adaptive responses of the cardiovascular system to prolonged spaceflight conditions: assessment with Holter monitoring. J Cardiovasc Diagn Proced 1977; 14: 53-57.
16. Rossum AC, Wood ML, Bishop SL, Deblock H, Charles JB: Evaluation of cardiac rhythm disturbances during extravehicular activity. Am J Cardiol 1997; 79: 1153-1155.
17. Gundel A, Drescher J, Spatenko YA, Polyakov VV: Heart period and heart period variability during sleep on the MIR space station. J Sleep Res 1999; 8: 37-43.
18. Migeotte PF, Prisk GK, Paiva M: Microgravity alters respiratory sinus arrhythmia and short-term heart rate variability in humans. Am J Physiol Heart Circ Physiol 2003;284:H1995-2006.
19. Grenon SM, Xiao X, Hurwitz S, et al: Simulated microgravity induces microvolt T wave alternans. Ann Noninvasive Electrocardiol 2005; 10: 363-370.
20. Fritsch-Yelle JM, Leuenberger UA, D'Aunno DS, et al: An episode of ventricular tachycardia during long-duration spaceflight. Am J Cardiol 1998; 81: 1391-1392.
21. Bungo MW, Goldwater DJ, Popp RL, Sandler H: Echocardiographic evaluation of space shuttle crewmembers. J Appl Physiol 1987; 62: 278-283.
22. Perhonen MA, Franco F, Lane LD, et al: Cardiac atrophy after bed rest and spaceflight. J Appl Physiol 2001; 91: 645-653.
23. Summers RL, Martin DS, Meck JV, Coleman TG: Mechanism of spaceflight-induced changes in left ventricular mass. Am J Cardiol 2005; 95: 1128-1130.
24. Martin DS, South DA, Wood ML, Bungo MW, Meck JV: Comparison of echocardiographic changes after short- and long-duration spaceflight. Aviat Space Environ Med 2002; 73: 532-536.
25. Harris BA Jr, Billica RD, Bishop SL, et al: Physical examination during space flight. Mayo Clin Proc 1997; 72: 301-308.
26. Martin DS, South DA, Garcia KM, Arbeille P: Ultrasound in space. Ultrasound Med Biol 2003; 29: 1-12.
27. Hinghofer-Szalkay HG, Noskov VB, Rossler A, Grigoriev AI, Kvetnansky R, Polyakow VV: Endocrine status and LBNP- induced hormone changes during a 438-day spaceflight: a case study. Aviat Space Environ Med. 1999; 70: 1-5.
28. Lane HW, Alfrey CP, Driscoll TB, Smith SM, Nyquist LE: Control of red blood cell mass during spaceflight. J Gravit Physiol 1996; 3: 87-88.
29. Leach CS, Johnson PC Jr, Kraubs JM, Cintrom NM: Cholesterol in serum lipoprotein fractions after spaceflight. Aviat Space Environ Med 1988; 59: 1034-1037.
30. Young LR: Artificial gravity considerations for a Mars exploration mission. Ann N Y Acad Sci 1999; 871: 367-378.
31. Rossum AC, Ziegler MG, Meck JV: Effect of spaceflight on cardiovascular responses to upright posture in a 77-year-old astronaut. Am J Cardiol 2001; 88: 1335-1337.
32. Nicogossian A, Pober D: The future of space medicine. Acta Astronaut 2001; 49: 529-535.