8/ Physiological effects of Space Flight

Problems that have to face in space flight are hazards due to X-ray and gamma radiations, linear acceleration, weightlessness, survival in a sealed cabin and lastly the temperature in space. In space flight the subject does not have angular acceleration as the spacecraft cannot make rapid turns. But he has to withstand the *take-off* acceleration and landing deceleration. During *take-off* in 'three-stage spaceship', he has to face linear acceleration as high as 9G at first stage booster and as high as 8G at second stage booster. As the subject stays within the spacecraft in a semi-reclining position, transverse to the axis of acceleration, the subject can withstand the G effect easily. When the spacecraft re-enters the atmosphere, problems arise due to deceleration.

Artificial climate in the spacecraft. In the outer space there is no atmosphere and for this reason artificial atmospheric climatic condition is to develop within the spacecraft. In such spacecraft sufficient O_2 is provided to the astronaut and suitable arrangement is made for absorption of CO_2. Besides this, food and water are provided according to the need. The gas mixture that is provided to the spacecraft is one of almost pure O_2 at 200 to 240 mm of Hg.

Radiation hazards. Cosmic particles in a large quantity are bombarding the earth. Some cosmic particles are coming from the sun and some are coming from the outer space. Magnetic field of the earth traps many of these cosmic particles at two major belts —inner and outer—around the earth—the Van Allen radiation belts (see Volume I) The *inner belt* ranges from about 480 to 4800 km (300 to 3000 miles) from the earth and the outer belt from about 9650 to 32000 km (6000 to 20,000 miles) from the earth. Possibilities of the radiation hazards at two belts are high-energy electrons in the outer belt, and electrons and protons in the inner belt.

Weightlessness in the space. Weightlessness is an acute problem in the space

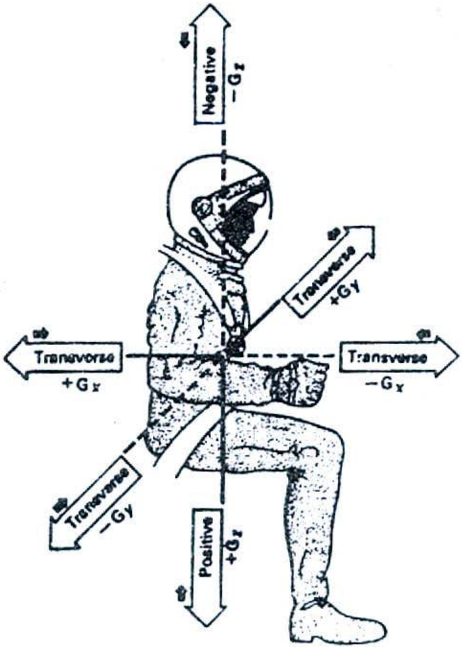

FIG. 8.1. It shows the various notations of acceleration as followed by Wunder (1966). Compare terminology as described in the table in page 1537. *Solid arrows* depicting acceleration forces; *open arrows* denoting resulting inertial forces, always opposite in direction.

due to *negative* G. Posture has got little effect on blood pressure and the subject may have a condition of *red-out*.

Temperature in the space. In the ionosphere of several miles from the earth, the kinetic energy of atmospheric molecules, atoms and ions is very extreme. For this reason, the temperature of atmosphere is about 3000°C. at an altitude of about 350 miles. But the spacecraft does not experience such temperature because of the *sparsity* of these particles.

Acceleration exposure. During space flight the space vehicle and crew must attain a velocity of 8000 m/sec. to enter the earth orbit and attain an escape velocity of 11,600 m/sec. to leave the earth's gravitational field.

The Advisory Group for Aerospace Research and Development Space Medical Panel has used certain terminology and symbols for different acceleration forces. On the basis of such terminology, Wunder (1966) has put forward certain terminology in order to express the different acceleration forces and it has been presented in Fig. 8.1). Acceleration forces and resulting inertial forces are always opposite in direction. The distance through the body from front to back is designated by subscript x, the distance across the body from side to side is denoted by subscript y, and the length of the body is expressed by subscript z. G vector notations and descriptions* have been classified below:

Vector	*Linear motion*	*Direction relative to body*	*Eyeballs of the pilot*	*Classic physiological description*
$+G_x$	forward	chest-to-back: *toward spine*	*in*	supine G
$-G_x$	backward	back-to-chest: *toward sternum*	*out*	prone G
$+G_y$	to right	lateral: *toward left*	*left*	lateral G
$-G_y$	to left	lateral: *toward right*	*right*	lateral G
$+G_z$	upward	head-to-feet: *toward feet*	*down*	positive G
$-G_z$	downward	foot-to-head: *toward head*	*up*	negative G

Physiological changes (*Bullard*, 1972) in bodily processes are presented as follows:

1. **Cardiovascular system.** The main factors that play during space flight are due to positive G ($+G_z$) for linear acceleration and due to negative G ($-G_z$) for absence of effect of gravity at space.

Hydrostatic factors the ρgh mainly govern the pressure and flow in the vascular system. ρ is the density of fluid (gm/ml), g is the acceleration of gravity (980 cm/sec./sec.) and h is the depth (cm). When a subject remains in horizontal position the blood pressure will be same all throughout the body (Fig. 8.2.), but when the subject will be in erect position the blood pressure will be different (Fig. 8 2). Pressure at head level will be lower than those of the heart and foot levels. This is due to the effect of ρgh. Furthermore if the G force is increased several times as in case of acceleration then the pressure in the head will be so decreased that a condition *black-out* may be developed in the subject under such acceleration forces (Fig. 8 1). Besides this, if the acceleration forces go opposite the force

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of gravity then the pressure will be altered. Under such state, G effect will be nil and the subject feel weightlessness. Postural effect on blood pressure will not be observed and all throughout the body there will be uniform blood pressure. Thus this opposite acceleration force exceeding the G force will raise the blood pressure in the brain above normal causing a condition known as *red-out*. Within the physiological limits, the body homeostasis can withstand against these effects of G. Human limit of

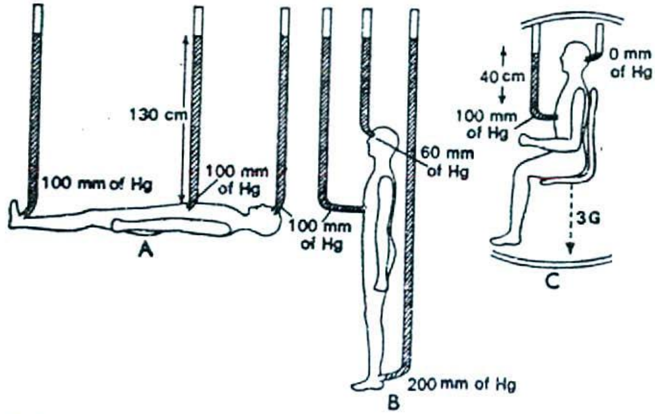

FIG. 8.2. It demonstrates the role of hydrostatic factor ρgh on systemic blood pressure. A=Subject in supine position shows uniform pressure all throughout the body. B=Subject in standing posture shows unequal pressure in head, chest (heart level) and in feet. C=Subject in sitting posture is under acceleration of 3G directed towards the feet. It shows the fall of pressure in the head level due to effect of increased g. Cannulae inserted into aorta and arteries of brain and foot would support columns of blood to heights shown.

tolerance against G is about 3G. Different vascular reflexes play an important role in maintaining the flow and pressure in the brain at such acceleration forces. Subjects having less active vascular reflexes cannot withstand such acceleration forces and become unfit for aviation or space flight.

Cardiovascular effects that have been studied during acceleration forces are an increased incidence of cardiac arrhythmias, alterations in the electrocardiograph, cardiac output, blood flow, blood pressure, etc. Incidence of arrhythmias is very common under $+G_z$ and $+G_x$ accelerations. High incidence of premature ventricular contractions has been reported by many under $+G_x$ acceleration. Flattening of T-waves in standard II and III leads, aVF and V_4–V_6 were observed by many under $+G_z$ and $+G_x$ acceleration forces. Increase of heart rate with acceleration is also a common factor. But excessive G forces may decrease heart rate. Squirrel monkeys kept under $400+G_x$ show bradycardia (Prince, 1963).

Haemodynamic changes with increased gravitational force vary greatly with the direction, magnitude and duration of the applied forces.

In experimental animals under $+G_x$ acceleration has been observed to decrease cardiac output. Stroke volume is decreased greatly under acceleration forces from 5, 10 and $15+G_x$. Marked increase in arterial pressure has been observed by Sandler (1966). He has observed increase of pressure from 130 to 220 mm of Hg at $15+G_z$. Intraventricular pressure is increased under acceleration forces. Venous pressure and atrial pressure are also increased. These above pressures are increased greatly under transverse acceleration.

Regional blood flow is greatly decreased under $+G_z$ acceleration. Tissue fluid flows are decreased in renal cortex, adrenal gland and in small intestine. Blood in left coronary artery (circumflex) and common carotid artery has been measured. Blood flows through both the vessels are increased under $15+G_z$. Very recently it has been reported that prolonged space flight may alter the size of the heart. Heart weight is reduced after space flight.

2. **Respiration.** Extreme failure of respiration during space flight and also in space is the great problem. Respiratory structures are greatly affected due to displacement and distortion of the circulatory system. Major respiratory distresses are atelectasis, airway closure, increased transudation of fluids from capillaries and marked variations in ventilation-perfusion ratios. Marked distortion of pulmonary structures causes increased effect upon ventilation. Up to $4\text{–}6+G_z$, the musculature can lift the increased weight of the thoracic cage and the abdominal viscera. There is an increased rate of respiration of about 30/min. Tidal volume is decreased. Hyperventilation as well as apnoea are also encountered.

3. **Blood volume.** Blood volume is decreased by 7–15% in 4–8 day missions. In this brief period, loss of red cell volume appears to be very great.

4. **Kidney function and body fluid regulation.** Increased gravitational forces affect the kidney function and the regulatory mechanisms of body fluid vary greatly. At $6+G_z$ renal blood flow is decreased along with diminution of arterial pressure and oliguria starts. This reduction in renal blood flow is attributed to intrarenal vasoconstriction mediated by α-receptors.

When human beings are centrifuged in $+G_z$ axis then changes in haematocrit ratio and plasma-protein concentration occur. Free water clearance decreases with an increase in G load to $3+G_z$. Ability to excrete water is markedly lowered. It is claimed to be mediated through the action of antidiuretic hormone (ADH). Rogge *et al* (1967) have observed a mean rise in ADH of 2·97 μU/ml of blood in subjects under 30 minute exposure of $2+G_z$ acceleration. Besides this, aldosterone secretion as well as renin secretion are also enhanced due to acceleration forces.

5. **Weightlessness.** Weightlessness is the great problem in space. Many sorts of hazards that have to face are the nausea, anorexia, disorientation, sleeplessness, fatigue, restlessness, euphoria, hallucination, gastro-intestinal disturbances, diuresis, urinary retention, muscular atrophy, bone demineralisation, red-out. Prolonged weightlessness resulted in subjective feelings of heaviness of head, limbs, and body reported on the 18-day flight of Soyuz 9.

6. **Bone and electrolyte metabolism.** Demineralisation is the problem of space flight. This effect has been predicted to be of prolonged weightlessness. This part has been neglected however the Gemini programme included the measurement of bone density. Decrease of bone density in Gemini flight was observed.

Electrolyte metabolism is greatly altered. During entire flight potassium excretion is reduced and this effect is unrelated with aldosterone. Aldosterone excretion in the urine is not detectable in the early four days of flight, but later on it is increased above the *pre*flight level. For each forty-eight hours of flight, urine sample indicates retention of sodium paralleled by a similar decrease in chloride secretion. Calcium excretion is increased.

7. **Work capacity.** Work capacity is altered during space flight. Marked decrement in exercise capacity following a prolonged space flight is encountered when *pre*flight and *post*flight exercise tolerance is compared. Muscle tone of the legs is decreased. Walk and posture are not normal until ten days after flight.

8 **Metabolic problems.** Energy metabolism under absence of G has not been studied so clearly. The basal requirements for an average man of about 1·85 m² body surface have been estimated to be about 1700 kcal/day. The energy cost of movement will probably be somewhat reduced in absence of G. But attempt of movement in free space or within the capsule will certainly alter the energy expenditure. It is suggested that the energy expenditure in space will probably be less than that of in the earth. However, other factors like psychic problems, changes in hormonal level, adverse temperature, etc., may have some influence on energy metabolism.