Chapter

Challenges to Airway Management in Space

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Abstract

Human interest in space exploration is boundless. We are driven to investigate the unknown and push the limits of our understanding of our universe. Given that space flights are for extended periods of time—in the hazardous environments of space and the growth of the space tourism industry is credibly anticipated; the incidence of medical and surgical events is bound to increase during space travel. Airway management becomes an essential skill in such situations. Microgravity, shortage of medical personnel, inability of the crew to return to earth expeditiously or access real time assistance from earth are some of the reasons that warrant training and preparation of the crew, towards this end. The purpose of this chapter would be to explore the challenges and the various recourses available for airway management during space travel.

Keywords: space travel, airway management, space medicine, space flight, anaesthesia

1. Introduction

There is expanded access to space. Government agencies and private companies alike have planned manned missions to the moon and to Mars, for the coming years. Currently, we are also witnessing a meaningful growth in the space tourism sector.

It is now more important than ever to increase our understanding of human physiology and pathology in space. Furthermore, it is of prime importance that astronauts can manage medical and surgical emergencies, that may arise especially given that a space tourist—as against the typical astronaut—is unprepared for the rigours of space travel and therefore exposed to a higher risk of medical complications [1].

Man's tryst with space began in 1961. The International Space Station (ISS), which has been in orbit for almost 20 years now, has enabled humans to stay in space for long durations. This has provided a swifter and a more profound bioastronautics development.

The environment of space is harsh and challenging, with a prolonged exposure to multiple stressful stimuli, radiation, weightlessness, isolation, and confinement to tight enclosed spaces for long periods of time. Microgravity, which affects all organ systems, has the most profound effect on human physiology [2].

Travelling to Mars will require transitioning between three different gravitational fields: being weightless during a six month interplanetary flight, being at about one third of the Earth's gravity on Mars, and re-acclimatising to Earth's gravity upon return [3].

2. Airway management in space

With increasing flight durations, there is an increased prospect that a medical emergency will entail airway management. It is currently estimated that the probability of a medical intervention requiring general anaesthesia, over the course of a 950 day mission to Mars and with six crew members is 2.6%. This speaks to the importance of how even the unlikeliest of events could imperil the mission and lead to loss of life [1]. Airway management is an important skill that is required to manage a great many medical emergencies. Some of the possible scenarios necessitating airway management in space are listed in **Table 1** [1, 4, 5].

Seventeen medical emergencies were documented during spaceflight between the periods of 1961–1999 [1]. In one instance, in 1962, on the Mercury 7 flight, Scott Carpenter, an American astronaut, aspirated food crumbs in orbit and in 1975 several astronauts on the Apollo-Soyuz mission developed a mild form of chemical pneumonitis after accidentally inhaling propellent fluid during re-entry [4]. Incidentally, none of the seventeen cases have required intubation. Also, no one has required GA in space to date [1].

Medical evacuation is not an option, in case of an airway emergency, owing to the distance as well as the absolute need to maintain oxygenation to avoid brain death. It is therefore necessary that immediate care is provided, while on board [6]. This warrants a crew equipped with emergency care skills as well as continuous training, to prevent skill erosion [1, 6, 7]. Furthermore, communication delays prohibit real time telemedicine support. For example, the communication delay between Earth and Mars is about twenty minutes—one way [1]. Airway management skills are thus critical to the mission of exploring space safely.

In the first half of this chapter, we will deal with the physiology of airway management and the physiological adaptations of the human body in space. This would provide the essential foundation to understand the challenges associated with airway management in space.

The term 'Airway Management' refers to the maintenance of airway patency and ensuring adequate ventilation and oxygenation. Successful airway management entails that the practitioner anticipates and predicts difficult airway and at the same time devises an airway management plan. The practitioner should also be adequately skilled to execute that plan, with the available resources. In order to enable this plan, anaesthesia is typically required—to provide patient comfort, limit airway reflexes, and to moderate the hemodynamic response to airway instrumentation [8].

3. Physiology of airway management

3.1 Pre-oxygenation

Hypoxaemia can occur on induction of anaesthesia and muscle paralysis on account of hypoventilation and apnea. Pre-oxygenation or denitrogenation helps to replace the nitrogen in the lungs with oxygen. This, consequently, extends the apnea time and allows the anaesthesiologist to secure the airway and resume ventilation.

Pre-oxygenation is achieved by providing 100% oxygen via a face mask, at a flow rate of 10-12 L/min to prevent rebreathing. This can be achieved by asking the patient to breathe for 3 min using tidal volume ventilation; or by taking 8 vital capacity breaths over 60 seconds. During this process, it must be ensured that there are no leaks around the face mask [8].

1. Hypoxic cardiopulmonary arrest
2. Airway obstruction
3. Foreign body aspiration
4. Burns or smoke inhalation
5. Coma
6. General Anaesthesia (GA)

Table 1.
Indications for airway management in space.

3.2 Pulmonary aspiration of gastric contents

Patients are required to have an empty stomach to reduce the risk of regurgitation and pulmonary aspiration of acidic gastric contents. The American Society of Anaesthesiologists task force recommends 4 hours of fasting from breast milk, 6 hours of fasting from infant formula, non-human milk and solid foods; and up to 8 hours or more from fried or fatty food. Clear fluids may be allowed up to 2 hours prior to anaesthesia [9].

Prophylactic drugs may be beneficial in patients with specific risk factors for aspiration. They help in decreasing gastric volume and increasing the gastric fluid pH. The commonly used drugs (alone or in combination) are—non-particulate antacids, promotility drugs and H2-receptor antagonists. These drugs may be used alone or in combination [8].

3.3 Airway reflexes and the physiological response to intubation of the trachea

One of the main functions of the larynx is protection of the airway. Sensory receptors in the glottic and subglottic mucosa are triggered—on airway instrumentation—leading to the adduction of the vocal cords and laryngospasm. Furthermore, foreign body irritation of the lower airway can result in bronchospasm [8].

Airway instrumentation causes an intense noxious stimulus via the vagal and glossopharyngeal afferents. This results in a reflex autonomic activation, manifesting as hypertension and tachycardia. Although this response lasts only for a short duration, it may have serious consequences in patients with significant cardiac disease. Also, CNS activation can occur leading to an increase in the electroencephalographic activity, cerebral metabolic rate and blood flow, which may result in an increased intracranial pressure [8].

3.4 Anaesthesia for airway management

General anaesthesia is the most common technique employed in airway management. A rapid acting intravenous anaesthetic agent is most commonly used for induction of anaesthesia, followed by a neuromuscular blocking agent to provide muscle relaxation [8, 10].

Rapid sequence induction is used when there is an appreciable risk for gastric regurgitation and pulmonary aspiration of gastric contents. In this technique, after pre-oxygenation, cricoid pressure is applied. This is followed by an induction dose of an intravenous anaesthetic and 1–1.5 mg/kg of intravenous succinylcholine. The trachea is then intubated without any attempts at positive pressure ventilation. The cricoid pressure is applied constantly until the airway is secured.

Inhalation induction of anaesthesia with volatile anaesthetics is commonly used in paediatric patients—to provide a needle free experience—and in adults where intravenous access is difficult or when this technique is desirable [8].

Intravenous induction without neuromuscular blocking drugs is used for LMA (laryngeal mask airway) placement. Propofol is the drug of choice for this technique due to its distinct ability to suppress airway reflexes and produce apnea [11, 12].

Awake airway management is indicated, but not limited to, difficult mask ventilation and difficult intubation [13]. In such a case, the pharyngeal muscle tone and patency of the upper airway is maintained. This allows for spontaneous ventilation and acts as a safeguard against aspiration. It also provides an opportunity for a quick neurological examination, if indicated. Awake airway management is achieved by topicalisation of the airway with local anaesthetics [8].

3.5 Equipment for airway management

Equipment for basic airway management includes face masks for pre-oxygenation and delivery of inhalational anaesthetic agents, supraglottic airways are devices that are inserted blindly into the pharynx to provide a conduit for ventilation without requiring tracheal intubation, and endotracheal tubes, that provide maximum protection against the risk of aspirating gastric contents while establishing a definitive airway and at the same time, allowing positive pressure ventilation with higher airway pressures.

In patients with known or predicted difficult airway, videolaryngoscopy, rather than direct laryngoscopy is indicated since videolaryngoscopy inherently provides better glottic visualisation as well as effortlessly employed by non-experts [8].

3.6 Laryngoscopy and endotracheal intubation

Endotracheal intubation is established as the gold standard for airway management. It is typically achieved by direct laryngoscopy with patients placed in the sniffing position. A line of sight must be established from the mouth to the larynx. Direct laryngoscopy displaces the hyoid, tongue and epiglottis anterior to a line running from the upper teeth to the glottis.

In this technique, the mouth is opened, the laryngoscope blade is inserted and the tip is positioned to apply a lifting force exposing the glottis. The endotracheal tube is then inserted through the vocal cords into the trachea [8, 14].

4. The human body in space

The Earth's constant gravitational force is an important factor in the evolution of life on this planet. It has determined the development of all forms of life. All biological adaptations on land and water have been influenced by its interactions with gravity forming complex systems for stability, fluid regulation, gravity sensing, and locomotion.

The human body responds to microgravity in the same manner that it responds to senescence (ageing): Both ageing and microgravity produce a decline of biological function [15]. Also, like ageing, microgravity causes a negative calcium balance leading to a loss of bone density, muscle atrophy, cardiovascular and haematic changes, and metabolic, endocrine, and sleep disturbances. In microgravity, astronauts undergo rapid senescence. However, they subside over time on returning to Earth, departing from the typical path of the ageing process. This correspondence of symptoms combined with a prolonged stationing in space requires that we are alive to the issue of accelerated ageing in space [15].

4.1 Cardiovascular system

Changes in the cardiovascular system because of microgravity are paramount from the standpoint of the anaesthesiologist. Gravity influences the equilibrium of the various functional fluid compartments of the vascular system and in particular that of the venous capacitance vessels [16]. In the upright posture, there is higher arterial pressure in the feet (200 mmHg) and lower pressure in the head (70 mmHg) relative to the heart (100 mmHg). In space, this gradient is absent, leading to redistribution of body fluids toward the head [2, 15, 17]. This phenomenon is referred to as "fluid shift". As a result of this, astronauts develop facial puffiness coupled with reduced volume in the lower limbs [2, 16].

Also, due to this 'fluid shift', there is engorgement of the central circulation. Mechanoreceptors sense this blood redistribution activating autonomic offloading and volume regulating reflexes leading to vasodilation and pooling of blood in the viscera and tissues, and initial renal fluid and salt loss. Most of these adaptations occur within 6–10 hours of spaceflight. After one week in space, the plasma volume reduces and the intracellular volume increases [15, 16]. In the same period, the RBC mass drops by about 10%. This "space anaemia" can again be attributed to the fluid shift toward the upper body, which is associated with an increase in kidney tissue oxygen partial pressure leading to the inhibition of erythropoiesis. A second hypothesis explains this as being due to haemolysis of recently formed RBCs [2, 16, 18].

Despite the headward fluid shift, paradoxically the central venous pressure is not increased. Further, a reduction in the intrathoracic pressure and the loss of gravitational force on the cardiac muscle may even reduce it [15, 16].

Microgravity affects the heart rate and blood pressure minimally [16, 19]. The initial headward fluid shift increases the stroke volume and cardiac output. Subsequently, after a few days of adaptation, the resulting hypovolemia and cardiac atrophy, increase the ejection fraction and decrease the stroke volume. The left ventricle mass reduces by 8% due to reduced myocardial load in microgravity [16, 20–22]. The left ventricular systolic function is minimally affected even though diastolic dysfunction has been identified in astronauts [16].

The nitric oxide release as a result of endothelial cell adaptation to microgravity and the loss of tone due to smooth muscle cell deconditioning causes vasodilation. Systemic vascular resistance reduces after 1 week of weightlessness due to this vasodilation [15, 16].

The baroreflex response is weakened by 50% after just 24 hours of being in space. It is constrained after long-duration spaceflight and these changes linger on for up to 2 weeks after returning to Earth. There are changes in adrenergic-receptor sensitivity in microgravity: beta-adrenergic receptors sensitivity is increased and alpha-adrenergic receptors sensitivity is decreased. There is also an increased risk of arrhythmias in space due to catecholamine discharge [16].

In space, aerobic capacity may be either maintained or increased. On return to Earth, there is an orthostatic challenge due to readaptation to gravity. As a result of this, astronauts experience reduced stroke volume and cardiac output which leads to landing-day orthostatic stress [2].

4.2 Endothelial changes

Microgravity and reduced motor activity produces endothelial changes by altering the regional blood flow and vascular transmural pressure, which in turn, produces an adaptation of vasomotor tone and long term vascular remodelling mainly in the endothelium and smooth muscular cells [16].

This microvascular endothelial dysfunction in astronauts, plays a material role in osteoporosis, muscle atrophy and cardiovascular deconditioning considering that the endothelial cells of the microvasculature cover a surface area that is fifty times larger than that of all the large vessels put together [15].

4.3 Space motion sickness

Space motion sickness is a result of neurovestibular disturbance that happens to about two-thirds of astronauts. It occurs within a few minutes of being in space and gradually resolves over a period of 48–72 hours. Nevertheless, it can last up to a few days and can reappear after landing. Some causes that are suggested as a possible hypothesis include: an increase in cerebrospinal fluid and intracranial pressure due to the headward fluid shift, a lowered threshold for vestibular stimulation due to central volume expansion and the absence of gravity triggering an abnormal vestibular activity leading to a parasympathetic overstimulation [15, 23].

Space motion sickness is characterised by an imbalance in spatial orientation, balance, gaze control and autonomous vestibular function. Symptoms include facial pallor, cold sweating, stomach awareness, anorexia, vomiting, nausea, headache and malaise [2, 15, 16].

4.4 Eye

On Earth, venous return from the head, neck and upper trunk is supported by gravity. Unlike the lower half of the body, the veins draining this region do not have valves and lack muscular contraction. In space, there is reduced arterial blood supply and venous flow from the eye. This increases the venous pressure and filtration at the capillaries causing an increase in both intracranial pressure and IOP [15].

4.5 Effects on the musculoskeletal system

Extended exposure to microgravity leads to a loss of bone and muscle mass due to its reduced use and perfusion changes. Inadequate nutrition and stress are additional reasons that lead to muscle atrophy [2]. Weight bearing bones: lumbar spine, pelvis, femoral neck and trochanter, and calcaneus and postural muscles: back, abdominal wall, lower limbs are most commonly affected [2, 24].

In addition to absence of gravitational loading, decreased Vitamin D production—partly due to low levels of sunlight—leads to decreased calcium fixation in bones and reabsorption in kidneys. Higher ambient levels of carbon dioxide, leading to respiratory acidosis also contribute to bone loss [2, 15] Increase in urinary calcium coupled with a reduction in diuresis and decreased fluid intake increases the risk of kidney stones [25–27].

4.6 Effects on the respiratory system

Microgravity induced changes in the lungs have been the subject of much interest for decades. The ventilation to perfusion ratio attains equilibrium in the absence of gravity [15, 16]. There is an increase in the total alveolocapillary surface which in turn improves the lung diffusing capacity [16]. Gas exchange in space does not undergo a substantial change but there is reduced oxygen consumption and carbon dioxide production. This is attributed to a reduced physical activity in space and change in the ventilation to perfusion ratios between the upper and lower lung regions. These factors lead to an overall reduction in the metabolic rate [15].

Changes in the thoracoabdominal compliance is advantageous to the pulmonary function [16].

Microgravity can cause weakening of the respiratory muscles leading to a reduced rib cage expansion. Thus, there is an increased contribution of the abdomen to tidal volume [28]. Intra-abdominal pathology and subsequent intra-abdominal hypertension is important to providing life support and mechanical ventilation. However, it has been demonstrated that intra-abdominal gas insufflation during laparoscopic surgery in space and the subsequent intra-abdominal hypertension is made better by the absence of gravity [15, 16].

It has been suggested that changes in the respiratory system are similar to those that occur to individuals on prolonged bed rest and are anatomical in nature [15]. These typically occur over several weeks. There is a significant reduction in tidal volume [15, 16] and residual volume [29]. Vital capacity and forced vital capacity reduce initially followed by subsequent recovery. Functional residual capacity (FRC) reduces by 500 ml and remains at that level for the remainder of the period in space [29, 30]. Peak inspiratory and expiratory flows are also not significantly altered. However maximum inspiratory pressure significantly reduces, while the maximum expiratory pressure (MEP) at total lung volume initially reduces at month 2 and month 4, but recovers by month 6 of being in microgravity. The MEP at FRC however is not affected [15].

4.7 Immune system

Immune system dysregulation occurs in space. High levels of physical and psychological stress—immediately before and after space flight— physiological stress, isolation, confinement, disrupted circadian rhythms are some of the contributing factors to immune system dysregulation [2]. Additionally, increase in levels of glucocorticoids and catecholamines, may also contribute to change in the immune system [3, 31]. Various studies have demonstrated that lack of gravity impairs the signalling pathways that are necessary for early T-cell activation. This leads to changes in the organisation of the cytoskeleton and microtubule organising centres [2].

Immune system dysregulation can lead to an increased incidence of hypersensitivities, autoimmunity, allergies, infectious diseases, latent viral reactivation and even malignancies [3].

Microbes undergo several changes in their characteristics in space. Notably, bacteria cultured on board have increased pathogenicity [32]. The microorganisms present in the human body, are transmitted easily between persons, in such confined habitats [3].

4.8 Gastrointestinal motility

Gastrointestinal motility is reduced in space especially in the first 72 hours. It has also been observed that the gastric content pH decreases [16].

4.9 Weight loss

Astronauts experience a weight loss of up to 5% after a 6 month stay on the International Space Station (ISS). This is explained by a mismatch between caloric intake and caloric expenditure [16, 33, 34].

4.10 Psychological effects

Confinement and isolation in constrained spaces, for extended periods of time, affects one's psychological health. Even with screening, training, and support; behavioural issues, cognitive conditions, and psychiatric disorders among crew members, is to be expected. Decline in mood, cognition and morale can occur. Sleep disorders due to changes in their circadian rhythms is also quite common [2, 3].

Extended exposure to stress, isolation and changes in circadian rhythm can have a psychological impact on astronauts. Cognitive impairment, sleep disorders, psychosomatic symptoms, anxiety and even depression can occur [7].

Personnel skills like team coordination, communication, logistics, etc. and technical skills like troubleshooting equipment, use of safety equipment, orientation, etc. contribute to the health and safety of astronauts. Selection of suitable crew, training and maintenance of skills during the mission, is important. Therefore, medical and psychological benchmarks for crew-member selection ought to be very high [7].

4.11 Exposure to radiation

Space travel presents the additional risk of exposure to harmful radiation. On Earth, we are shielded from cosmic radiation by the Earth's magnetic field and its atmosphere. However, on a space station astronauts are exposed to up to ten times the radiation they are exposed to while on Earth. Radiation in space can cause radiation sickness and degenerative tissue disease, among many other serious issues [3].

5. Challenges to anaesthesia delivery and airway management in space

Anaesthesia is important for airway management. Blunting airway reflexes and hemodynamic response to airway instrumentation is a chief consideration. This can be achieved by anaesthesia.

Delivery of anaesthesia in space is highly demanding and complicated, and the reasons can be grouped into three main categories: physiological, technical and human as shown in **Table 2** [16, 17, 35].

5.1 Physiological considerations

5.1.1 Challenges related to cardiovascular changes in space

In weightlessness, a new physiological equilibrium is established, adapted to the reduced loading conditions. However, this equilibrium is delicate as is the tolerance to any additional event or even an interventional procedure. Reaction of the human body to blood loss, anaphylaxis or any event that reduces cardiac function, may be further compromised. General anaesthesia and mechanical ventilation may also adversely affect this physiological equilibrium [16].

On landing in gravity environments different from Earth, cardiovascular changes and hypovolemia causes orthostatic intolerance. The aerobic capacity is also impaired as a result of hypovolemia, anaemia and orthostatic intolerance [16, 36]. These factors combined with space motion sickness, limits the crew's ability to perform tasks effectively.

Preloading with intravenous (IV) fluids before the induction of general anaesthesia is important to prevent cardiovascular collapse [37]. Any significant

1. Physiological
   - Cardiovascular changes
   - Fluid shift
   - Gastrointestinal System
   - Pharmacology in Space environment
   - Choice of anaesthetic technique
2. Technical
   - Fluid generation and handling
   - Vascular access
   - Closed cabin pressures
   - Medical equipment
   - Use of restraints
   - Telemedicine and information technology
3. Human
   - Crew Skills
   - Psychological effects on crew

Table 2.
Factors complicating delivery of medical care in space.

hypovolemia should be treated concomitantly with IV fluids and vasopressors. Alpha agonists such as phenylephrine, metaraminol, midodrine, norepinephrine should be at hand; higher doses than usual may be required. Beta-agonists and beta-antagonists should be used with care [16]. For induction of anaesthesia, drugs that preserve cardiovascular stability, such as ketamine, are preferred [37].

5.1.2 Fluid shift

Although not documented, headward fluid shift and facial oedema can complicate the intubating conditions [16]. Drug distribution during spinal anaesthesia may also be altered due to the cephalad fluid shift and is therefore not recommended, in microgravity [38].

5.1.3 Gastrointestinal system

Space motion sickness accompanies gastroesophageal reflux in astronauts, sometimes lasting the entire mission. It may even persist after their return to Earth. The gastroesophageal reflux along with decreased gastrointestinal motility puts the crew at a risk for pulmonary aspiration, both during and after flight [16, 17].

5.1.4 Pharmacology in the space environment

Both the pharmacokinetics and pharmacodynamics of drugs are altered in weightlessness [39].

Cardiovascular changes, weight changes, changes in hormonal, electrolyte and immunoglobulin levels, decrease in the amount of microsomal P-450 as well as its dependent enzymes are some of the factors that cause changes to the pharmacokinetic and pharmacodynamic properties of drugs in space [16, 40]. As a result, the corresponding drug dosages need to be altered as well [39].

Also, long term storage of drugs may render them ineffective or even toxic [16].

A notable mention: the depolarising muscle relaxant succinylcholine is contraindicated due to disuse atrophy of muscles and changes in the neuromuscular junction, and the increased risk of hyperkalemia after prolonged exposure to microgravity [17, 39]. Instead, rocuronium is recommended to be used as an alternative [16, 41].

5.1.5 Choice of anaesthetic technique

One of the limiting aspects of the anaesthesia protocol for microgravity is that it should be carried out by a small crew of non-medical personnel, with limited training. In several low-income countries, anaesthetic procedures are regularly performed by non-medical personnel, with relatively low complications. Simplified versions of the protocols—one which can easily be followed by non-physicians—must be developed.

The worst case scenario approach should be the basis for making the choice of the anaesthetic technique. It must be borne in mind that astronauts who may require anaesthesia in space may have to be managed by nonmedical personnel with limited training, in case the crew medical officer (CMO) is incapacitated or deceased. In addition, they maybe hypovolemic, deconditioned, at a risk for rhythm disturbances and gastric aspiration, and intolerant to succinylcholine [16].

Although ultrasound guided regional anaesthesia may be used safely and successfully, it requires considerable training [16, 38, 42, 43]. Spinal anaesthesia is not feasible in microgravity, its safety and efficacy is unpredictable because the heavy local anaesthetic solutions used depend on gravity. Epidural anaesthesia may be used, but it also requires considerable training and absolute asepsis, and therefore carries significant risks [16].

General anaesthesia with endotracheal intubation is suitable for all types of surgical conditions and is the recommended choice of anaesthetic technique.

Intubation, in general, is facilitated by use of general anaesthesia and muscle relaxants [16]. Furthermore, use of video laryngoscopy also increases the intubation success rate especially among new users [44, 45].

5.2 Technical considerations

5.2.1 Fluid generation and handling

Intravenous (IV) fluids have a limited shelf life and usually remain unused during that period. Shipping and storing them is expensive due to the added weight and the wastage of valuable storage volume. It is however expedient, and necessary to be able to generate IV fluids on demand using drinking water. This process was successfully tested on the ISS (project IVGEN) [16, 46].

Fluids and gases do not separate in space, owing to their different densities, which complicates fluid handling and drug preparation. Hence most drugs and intravenous fluids exist as a foamy liquid [16, 17].

It is advisable that injectable drugs be carried in prefilled syringes. Needleless vial adapters that allow direct drug aspiration into the syringe without the need for a needle to pierce the vial septum are also preferred. Experiments have been successfully conducted by NASA Scientific and Technical Information Program for removal of air bubbles [16, 17, 47].

Another important concern is that many medical devices such as anaesthetic vaporisers and suction equipment, that depend on gravity induced separation of fluids and gases, do not function properly in microgravity [17, 37].

5.2.2 Vascular access

During a medical emergency, vascular access may be difficult to obtain. In space, securing the body of the IV administrator as well as mastering fine motor skills to perform the required task can be a challenge. Also, microgravity causes small objects to float away. Sharp objects such as IV cannulae can present a potential hazard to the crew [47].

Using ultrasound to obtain central venous access either autonomously or robotically is currently under development. An intraosseous access kit has also been included in the ISS medical gear [16].

5.2.3 Closed cabin atmospheres

A spacecraft offers a tightly sealed environment. Medical procedures requiring the use of oxygen would risk oxygen enrichment in the closed cabin atmosphere, increasing the risk of explosion and fire. Use of a closed ventilation circuit limits the dumping of oxygen in the cabin. Volatile anaesthetics cannot be used in such an environment, as a gas leak can contaminate the on-board closed loop environment and therefore general anaesthesia must be provided by the technique of total intravenous anaesthesia (TIVA) [16, 17, 38]. Xenon may find utility as an anaesthetic gas in such space operations [17].

5.2.4 Medical equipment

Advanced medical care requires equipment such as a monitor, ventilator, suction equipment, and oxygen concentrator. Equipment carried to space must comply with specific spaceflight standards. There are a number of stipulations in terms of weight, size, and power consumption. For perspective: It costs about US$ 22,000 USD to transport one kilogramme of material into low Earth orbit. Drugs that do not need refrigeration and that which have a long shelf life are preferable, in this regard [16, 17].

5.2.5 Use of restraints

Airway management is made possible during spaceflight using restraints, allowing the operator's hands to be free to hold and guide the endotracheal tube into the airway [38]. Use of restraints are absolutely necessary to hold instruments, patients and personnel in place. For surgical procedures, it has been demonstrated that it is possible to restrain instruments in microgravity using various supplies ensuring sterility, operator accessibility, safe waste disposal, while maintaining ergonomic capability [48, 49].

5.2.6 Telemedicine and information technology

Telemedicine, as a medium for healthcare delivery, has tremendously improved and finds great many applications, in the current healthcare setting. Today, availing a virtual opinion, of an expert, at a remote location, is fairly uncomplicated. This becomes very useful during spaceflight operations. However, a delay of about 20 minutes to receive one way communication is to be expected during a journey to Mars [4]. Since anaesthetic procedures and airway management require prompt and expedient responses, telemedicine—with its inherent latency issues—may not prove to be the most optimal solution. Hence, other advanced on-board information systems will need to supplement telemedicine technology in space [17].

5.3 Human factors

5.3.1 Medical skills and training

It must be borne in mind that the crew is unlikely to have a trained physician on board. Therefore anaesthetic procedures and airway management may have to be carried out by non-anaesthetists and non-physicians [35]. At present the Crew Medical Officer in each mission receives a training of about 80 hours [17]. Fading of skills during flight is an important concern and continuous training of the crew members is essential [1]. Fatigue and sleep debt during long duration space flight [2] can further affect performance of the medical officer during emergencies.

5.3.2 Incomplete knowledge about human physiology in partial gravity

At present we have very little information about human physiology in partial gravity. This knowledge is important in helping to plan the mission as well as preparing for medical contingencies. The moon has about one-sixth the Earth's gravity and Mars has about one-third. The Apollo moon missions did not include extensive physiological experiments unfortunately.

We have information about short term changes from transitioning from 1G to partial gravity levels. This has been obtained during parabolic flight, head-up tilt, lower body unweighting experiments. However, physiological impact of prolonged stay in reduced gravity is not available [16].

6. Airway management in space

An integrated space surgery research found that most procedures performed on Earth can be performed in microgravity with the right equipment and with the operator, subject and tools sufficiently restrained [38].

6.1 Training of crew

The medical team identified for the space exploration mission can be as lean as a single crew medical officer (CMO)—who is not necessarily a medical doctor [35].

On Earth, anaesthesia techniques, in high income countries, are performed only by experienced practitioners. In space, however, sophisticated medical expertise may be absent, or the CMO may have become injured, incapacitated or seriously ill, even requiring anaesthesia [35]. Since real-time telemedical support is not immediately forthcoming, the crew will have to be self-reliant. It may be imperative that lifesaving procedures may then have to be performed by personnel with limited training. Until now, neither an anaesthetic technique nor human surgery has been performed in space, except for local infiltration [50].

Simulation and ground research are important programmes in framing protocols since there is a poor knowledge base about managing medical events in space. Simulation tools and techniques are routinely used in the medical field for continuous training of doctors [51–53]. The benefits of such training on their performance has been well documented [51, 54]. Needless to say, the simulation setup must resemble the target environment as closely as possible [54, 55].

In low income countries, especially ones facing a shortage of trained medical professionals, non-physician medical professionals regularly provide anaesthesia and perform surgical procedures. Many of them have a modest medical background [7]. They are trained mostly on the job and often work alone, even lacking recommended equipment and safety levels [35, 56–60] Ketamine based anaesthesia combined with the considerable skills that the providers acquire in a limited time could explain the perioperative mortality rate in these countries—which is "only" about two to three times more— when compared to high resource ones [35]. However, a crucial difference between anaesthesia providers in these low income countries and future space exploration missions is that the former treat a high number of patients and therefore skill redundancy is not a factor [7].

Personnel with modest medical training may be able to perform invasive procedures safely which is being witnessed in austere environments in different parts of the world. Astronauts are perhaps best positioned to respond to such a challenge [35]. Apart from their multitude of skills, astronauts are also selected for their ability to tolerate extreme stress. They are unquestionably among the best candidates, besides healthcare providers, to be able to perform advanced and invasive medical procedures, in the remotest of settings [35].

Currently, the International Space Station (ISS) has an on-board crew medical officer (CMO), who is not necessarily a trained medical doctor [7]. Given the uniqueness of future long distance space missions, the ideal profile of a crew physician is a subject for discussion [61, 62].

The CMO will need to possess a broad spectrum of knowledge, be competent in basic surgical skills and in the management of the critically ill [61–63]. He/She will have to be resourceful and flexible in his/her thinking and approach, and have the ability to improvise for unanticipated medical scenarios [62]. A single physician is required to manage both surgery and anaesthesia. If the CMO herself becomes ill, injured, incapacitated or dies, it is imperative that non-physicians take over. It is therefore prudent to train several of the crew members to manage at least the most common emergencies [7].

Recently, progress has been made in the field of artificial intelligence, especially in its application in medicine. It is now possible to achieve better monitoring, improve disease detection and bring in more efficient clinical decision support systems. Safety of crew members could be improved by autonomous diagnostic systems, closed-loop automated anaesthesia or other clinical decision support systems. Furthermore, these measures could also simplify the training programme [7].

6.2 Equipment

Devices for airway management that are brought on board the space shuttles, comprise of: a face mask, a pressure-cycled ventilator, a single-bladed laryngoscope, tracheal tubes, an introducer, a capnograph, and a tracheostomy kit [64].

Care has to be taken to ensure that the airway equipment carried on board is adequately restrained and made conveniently accessible to the person performing the procedure.

Cuffed endotracheal tube is the recommended device in view of the changes in gastric motility and reflux. However several studies have shown that non-anaesthesiologists can secure the airway more easily with supraglottic airways than with endotracheal intubation [65–67]. A laryngoscope is not required to be used in order to insert these devices and hence one hand is now available to stabilise the head as well as the neck [64]. The second generation supraglottic airways provides a better seal and also allow gastric drainage making it a good fit for emergencies, in microgravity [1].

Videolaryngoscopy may also be used with increased success in these scenarios since they have better glottic visualisation and a higher success rate with less experienced clinicians [68–70].

6.3 Technique

Airway management in space, with all its challenges, is amplified for non-medical personnel. Checklists and other such simple and minimal protocols will immensely help to streamline the process [7].

A mandatory pre-anaesthetic evaluation of all space travellers, before their departure from Earth, is recommended. A thorough airway assessment and detailed clinical documentation for every space traveller would prove to be valuable in case of emergencies. Clinical documentation may include details like the size of the endotracheal tube, requirement of additional intubation equipment, etc. Checklists for airway management and anaesthesia may include details of that equipment that must be available conveniently with the corresponding drug doses calculated and made available.

Conventional laryngoscopy and intubation with the patient placed in the sniffing position, without the use of restraints, is likely to have a high failure rate in microgravity. The head and neck move out of the field of vision during direct laryngoscopy, due to the anterior force exerted. It is not possible for the hand—the one not holding the laryngoscope—to stabilise the head–neck as well as direct the endotracheal tube toward the glottic opening simultaneously [64]. Anaesthesiologists exert a force of about 40 N, lasting for about 10–20 s during direct laryngoscopy. This force is sufficient for a 70 kg human to move about 0.3 m in 1 second in microgravity. Use of a restraint (**Figure 1**) will allow the stabilisation of the head and neck, so that the hand not holding the laryngoscope is free to direct the endotracheal tube toward the glottic opening [64]. However, there are some limitations in applying them during a medical emergency. Data indicates that it takes 5 to 10 seconds for strap application [71].

Figure 1.
*Crew medical restraint system used during the space shuttle missions. Restraints hold the patient in place and allow the operator's hands to be free. Source: Photograph S81E5933 - STS-081 - RME 1327 - Crew Medical Restraint System (**CMRS**); "STS-81 pilot Brent Jett straps mission specialist John Blaha into the Crew Medical Restraint System (**CMRS**) in the Spacehab module." January 1997; File Unit: STS-81, 4/12/1981 - 7/21/2011; Series: Mission photographs taken during the space shuttle program, 4/12/1981–7/21/2011; Record Group 255: Records of the National Aeronautics and Space Administration, 1903–2006; National archives at College Park, Adelphi road College Park (MD). Accessed on 30th April, 2021.*

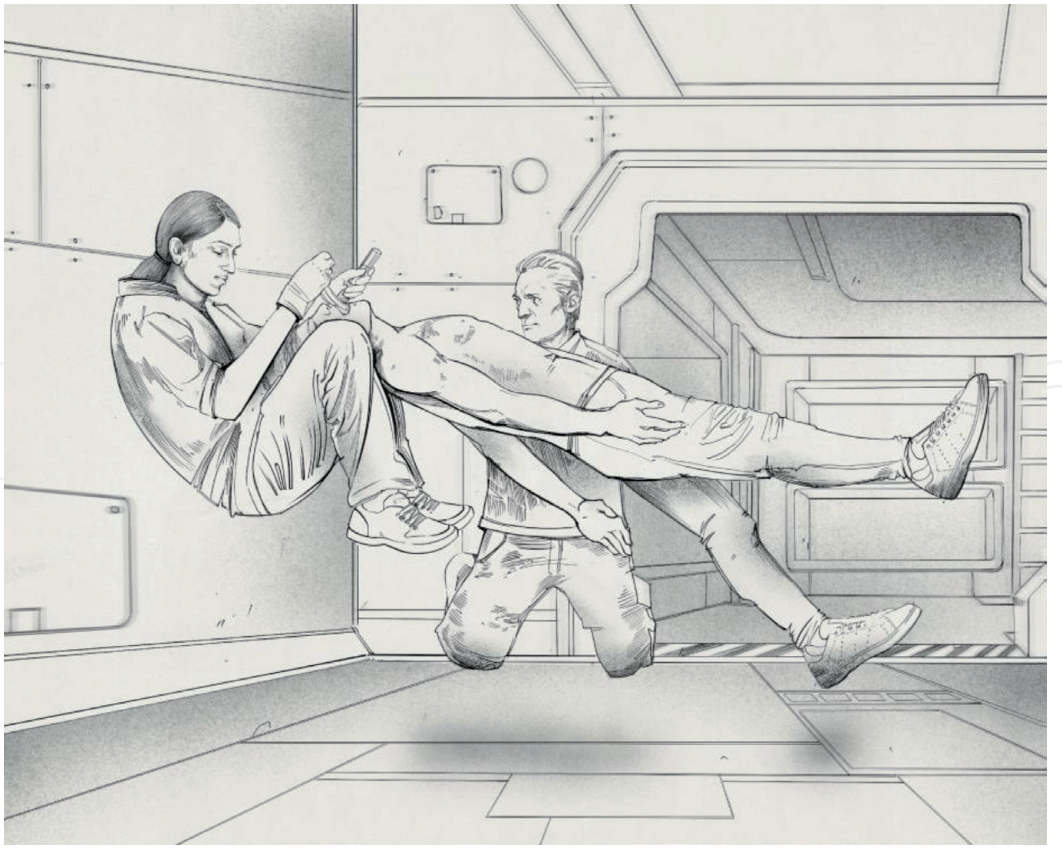

Figure 2.
An artist's representation of the sit down-lean back technique. (Image provided by the author.)

A self-retaining, bivalved laryngoscope may allow the hand that is holding the laryngoscope to be free in order to help stabilise the head and neck. The head and neck of the patient may also be stabilised between the knees of the person intubating the patient [64, 71].

During cardiopulmonary resuscitation, stabilising the head by gripping it between the knees (**Figure 2**) is recommended [71]. Even though this technique provides a distant view of the glottic inlet, it is stable and saves time. This technique may be compared to the "sit down–lean back technique" used by paramedics to stabilise the victim's head [72].

In the case of elective procedures, it is advisable to use restraints. If exercise of restraints is not feasible then extra tracheal airway devices may prove to be useful. It is not essential to position oneself at the head end of the patient for use of the extra-tracheal airway devices, in the interest of saving time [64].

Restraints are not necessary for either the patient, the equipment or the operator—on Mars—since its gravity is approximately one-third of Earth's gravity. In microgravity, however, restraining is recommended [35].

Robotic intubation may not find an application, at least in the foreseeable future, as far as space is concerned, in view of the undue up-mass they constitute and given that the chances of using this technique is remote [1].

7. Conclusion

Recent technological advances and scientific discoveries will lead mankind to realise its aspirations as a spacefaring species. If we are to support an enduring human exploration of space, we would have to rapidly update our understanding of human physiology, as well as find better ways to manage medical and surgical events in space. Persons other than professional astronauts are unprepared for the rigours of space travel and are prone to medical complications and emergencies. In this regard, it is of great importance that astronauts manage medical and surgical events in space.

With increasing flight durations, as a result of advances made in spaceflight enabling technologies that would afford deeper exploration into space, the prospect of a medical emergency entailing airway management is increased. Medical evacuation is not an option in such cases and therefore becomes imperative that immediate care is provided, while on board. Such situations call for a crew equipped with emergency care skills and training. Airway management is an important skill that is required to manage a great many medical emergencies.

This chapter briefly overviews the physiology of the airway, anaesthesia delivery and airway management, on Earth, to compare with and highlight the challenges to human physiology in space given the unique nature of the environment, so as to understand the specific challenges to anaesthesia delivery and airway management, in space.

The enabling technology for space travel, powered by Artificial Intelligence and Machine Learning algorithms, is advancing exponentially. Medical science typically tends to follow a more measured trajectory and tends to trail relative to the strides made by technology. We will also likely travel to Mars in the near future and this particular mission will come under more scrutiny than any other previous space missions. The crew will be required to travel farther and longer than any other human being in the history of our world. Techniques for airway management will need to undergo and be better defined in the coming years. As it stands, an expanding body of research that is trying to provide a better understanding of many aspects of human health in space is already underway. It is imperative for medical science to rapidly expand its body of knowledge when it comes to space travel, if it is to support human quest for space exploration.

Conflict of interest

The author declares no conflict of interest.

Notes/Thanks/Other declarations

Looking up into the night sky is looking into infinity – distance is incomprehensible and therefore meaningless.
–Douglas Adams, A Hitch-hikers Guide to the Galaxy.

Of all milestones and achievements in medicine, conquering pain must be one of the very few that has potentially affected every human being in the world.
–DH Robinson.

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