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Chapter

Airway Management in Aviation, Space, and Microgravity

Mohamed Abdelwahab Elarref,
Mogahed Ismail Hassan Hussein, Muhammad Jaffar Khan
and Noran Mohamed Elarif

Abstract

Although medical services in aviation have evolved over years based on our understanding of physiology, advancement in monitoring technology but airway management was only recently studied with a focus on space environment. The barometric pressure of ambient air declines as altitude increases, while the volume of air in a confined space will increase according to Boyle law, and therefore oxygen concentration remains at a constant 21%. Altitude sensitive equipment includes endotracheal and tracheostomy cuffs, pneumatic anti shock garments, air splints, colostomy bags, Foley catheters, orogastric and nasogastric tubes, ventilators, invasive monitors, and intra-aortic balloon pumps. The microgravity reduces the body compensation capacity for hemorrhage, while the redistribution of the blood can affect intubation by causing facial edema. Another change is the decreased gastric emptying during aviation. Acute respiratory failure, hypoxemia or inadequate ventilation and protection of the airway in a patient with impaired consciousness are common indications for advanced airway management in aviation. Airway management requires adequate training to maintain excellent medical care during aviation. Tracheal intubation using laryngoscopy would be difficult in microgravity, since the force exerted by the laryngoscope causes the head and neck move out of the field of vision by lever effect exerted on the head and generated through the laryngoscope blade by hand generating a lack of stability, resulting in the difficulty to insert the tracheal tube. While on the ground with the help of gravity, an adequate positioning of the patient is facilitated to achieve alignment of the laryngeal, pharyngeal and oral axes, which is known as sniffing position that allows visualization of the vocal cords and supraglottic structures allowing the introduction of an endotracheal tube.

Keywords: medical aviation, microgravity, weightless environment, stratosphere, high altitude, near space, space medicine

1. Introduction

Space exploration is rapidly advancing and requiring a parallel advancement of medical services that can be provided in aviation for any kind of medical issues that may arise during the space flight. The physiology of human body is definitely affected by the change in gravity during space flights, this why the extent of physiological changes, the required monitoring and intervention should be carefully tailored based on the physiological response to the space environment and the underlying medical conditions. Although medical services in aviation has evolved over years based on our understanding of physiology, advancement in monitoring technology but airway management was only recently studied with a focus on space environment. Airway management and other hemodynamic goals parameters, especially during medical air transport and aviation put the patient and medical team under unfamiliar and extreme physiological conditions, with detrimental clinical sequalae. In this chapter will cover the airway management in aviation with high emphasis on physiological changes and he preferred airway management techniques during air transport and aviation conditions.

2. Physiological changes in microgravity

The changes occur to human body during aviation can affect the anesthesia delivery if surgery is needed. Almost all the body organs will be affected, but what is more relevant to anesthesia administration is: cardiac systolic and diastolic changes, gastric motility, reduction in blood volume as well as neuromuscular junction changes.

2.1 Pressure related effects

At sea level, barometric pressure is 760 mmHg with a partial pressure of oxygen of 160 mmHg. The barometric pressure of ambient air declines as altitude increases, while the volume of air in a confined space will increase according to Boyle law, and this is why oxygen concentration remains at a constant 21% [1]. The intracranial air volume could be increased by 30% at the usual maximum cabin altitude of 8000 feet. These volume and pressure effects are sometimes associated with hemodynamic compromise (tension pneumothorax), barotrauma (sinuses), equipment malfunction (blood pressure cuffs), and possible injury or compromised monitoring as inflated gas bubble in the arterial line. Certain conditions such as pneumopericardium, subcutaneous emphysema, gas gangrene, systemic air emboli, decompression sickness, and gastric distension may be worsened at altitude. [2] Altitude sensitive equipment includes endotracheal and tracheostomy cuffs, pneumatic antishock garments (eg, medical antishock trousers), air splints, colostomy bags, foley catheters, orogastric and nasogastric tubes, ventilators, invasive monitors, and intra-aortic balloon pumps. Most aircraft cabins are usually pressurized to a pressure equivalent to 5000 to 8000 feet, giving an atmospheric partial pressure of oxygen of 118 mm Hg [3]. Thus, the oxygen requirement (Fio_2) of a patient on mechanical ventilation may increase at altitude. ARDS in animal models were more responsive to increased PEEP, yet resistant to increases of (Fio_2) [4].

Hypoxemia, even at low altitudes (3281–9843 feet), which is the usual flight range for the medical helicopter transport, could lead to global hypoxic pulmonary vasoconstriction and pulmonary edema. Hypoxemia is detrimental to patients with coronary ischemia, pulmonary compromise acute respiratory distress syndrome [ARDS], or neurologic injury. Besides, the hypoxia associated-tachycardia and hypertension increases the cardiac mechanical load and myocardial oxygen consumption.

Flying at low altitude is commonly known as "Altitude restrictions" which mainly for pressure sensitive conditions as in eye trauma, pneumothorax, intracerebral air, and sinusitis [5]. Those low altitude flying restrictions come with the cost of more turbulence and longer transport times, another risk factor for more vibration injury, anxiety and prolonged access to healthcare.

2.2 Cardiovascular changes

The loss of gravity effect of the distribution of blood volume in different body compartments is notable in a microgravity environment. In normal environment at the earth surface there is a pressure gradient created by the gravity and the loss of this gradient during aviation result in more diuresis and by so reduction in blood volume [6–8]. The blood volume is one of the determinants of cardiac output, the reduction in the blood volume in microgravity will result in a 20% reduction in COP [6]. The reduction in these parameters will definitely reduce the body compensation capacity for hemorrhage, while the redistribution of the blood can affect intubation by causing facial edema [6, 9–11].

2.3 Musculoskeletal changes

Two main issues regarding musculoskeletal system changes in microgravity are the reduced bone mass [12] and the muscle atrophy which may lead to increase expression of extra junctional acetylcholine receptors [13, 14]. The abnormally expressed receptors can explain the risk of severe hyperkalemia after succinylcholine in space men [6, 10, 11].

Along with muscle atrophy changes in fat distribution affect the pharmacokinetics of anesthetic medications.

2.4 Gastrointestinal changes

Some studies suggest that there is a decrease gastric emptying during aviation in the first three days [6, 15, 16]. Some studies used paracetamol absorption as an indicator of gastric emptying [17, 18]. In anesthesia, gastric emptying time is very important factor in the assessment of aspiration risk following anesthesia induction.

3. Special consideration in anesthesia and airway management in space and microgravity conditions

The first vehicles carrier used to carry humans to the stratosphere atmosphere, was the Balloons in 1783, the first round across the Earth had been achieved by the hybrid balloon. The increasing advancement of advanced life support programs and control systems progress had allowed to transport humans higher for more plans and the preparation to colonize the Moon and the trip to Mars [19].

Now recently aerospace companies are aiming to give scientists the chance to develop their clinical experience by arranging near space trips [20]. A great progress in Human spaceflight has expanded over the last 40 years leading to a larger, more sophisticated, and more distant journeys. As a result of this continuous advancement, space flight crews might require medical procedures, that mandates anesthesia, so the medical personnel on board should be well experienced to perform surgery and anesthesia during flights in deep space. So anesthesia strategies and techniques have to be adjusted to deal with specific problems and dangers that may rise while patients are under the effects of microgravity [10].

Airway management requires adequate training to maintain excellent medical care during aviation, our knowledge about airway management in microgravity is progressing and numbers of trials that examine the difference between different airway management methods is increasing. This justifies the importance of reviewing this topic to so that a better understanding of all the challenges in microgravity environment is achieved.

The most common indications for advanced airway management in aviation are acute respiratory failure, hypoxemia or inadequate ventilation and protection of the airway in a patient with impaired alertness.

4. Challenges in airway management during space exploration missions

Challenges during space mission are very numerous, it can be classified into: patient related, environmental, and caregivers related. Medical emergency during aviation will more likely to have high risk of morbidity or mortality.

The patient factors are discussed in the physiological changes in microgravity.

The environment during aviation is characterized by the loss of gravity which may make very important simple adjuncts as fluids unavailable, it also affects the actual force that the body control, this render the caregiver with a totally new circumstances while doing intubation. Any practicing Anesthesiologist will be able to appreciate the importance of the ability to create the same effect while holding the laryngoscope with the usual power that the operator tends to use in normal conditions. The weightlessness also creates a big difference in patient positioning, the patient will be in free floating position and precision will be difficult without adequate training as tracheal intubation will be a single-handed technique.

Multiple factors in space are expected to create a challenging environment for airway management and by so affecting patient safety. Stress and cognitive factors, environmental hazards, deficiency in equipment, lack of intubation skills and suboptimal working conditions are not all but most of the challenging factors.

Loss of gravity alter the coordinated effort between the eye and the brain, which will impair eye - hand coordination [10].

Caregivers related factors are mainly related to the lack of expertise in this field, the crew will not likely be accompanied by a trained Anesthetist, and this is why most of the fine anesthesia techniques will be done by non-anesthesiologist during these missions. Facing these challenges, some scientists conducted clinical trials in a simulated environment, they compared the use of video-laryngoscopy in microgravity between the naïve and expertise in airway management. Results suggested that video- laryngoscopy help health care-givers to overcome these factors and it also decreases the difference in intubation efficacy between naive and expertise [21].

4.1 Anesthesia and airway management in microgravity

The approach to provide anesthesia on space flights missions would be necessary to the success of the mission. Physiological accommodation to microgravity may hinder any planning of anesthesia. A previously published assumption for anesthesia airway management reported monitoring, preoxygenation, induction then bag – mask ventilation then they used Rocuronium as a muscle relaxant, followed by endotracheal tube insertion using video laryngoscopy, the tube size was smaller than the proper size to avoid edema [21].

The adaptations of the muscle performance in microgravity particularly the functional changes in acetylcholine receptor variations can have an effect on the administration of depolarizing and non-depolarizing neuromuscular blockers in patients exposed to microgravity promoting their cautiously use. [10]

Advance airway management requires adequate skills, knowledge and training to perform in the microgravity setting that add a new difficulty to the existing ones which necessities a proper training and knowledge. [22] Microgravity environments is a significant challenge for the person who is performing airway procedure since it is difficult to position the patient as the body is unsubstantiated, without the gravity of Earth's. [23]

Caregiver loaded on the International Space Station (ISS). May be affected with situations that necessitate management of Airway to establish a patent airway for a patient suffering respiratory distress.

4.2 The NASA flight surgeon and NASA space person companions

Airway management procedures had been investigated in a previous study which described using them in inadequate conditions pertaining to space flight. Actually, the optimal way for patient care aboard on space station require that caregiver and patient to be restrained. The Medical Operation Support Team (MOST), 2007 and others previously assessed how to secure airways in microgravity experiments using different techniques for establishing airways in substandard positions by caregiving non-physician – they had accomplished direct laryngoscopy and inserted a cuffed endotracheal tube. [24] As researches are advancing in this field, NASA doctors and companions would be able to provide proper airway management during space trips.

There have been several important studies on airway management in microgravity, with the assumption that a laryngeal airway mask (LMA) had been used. Intubating Laryngeal Mask Airway effectively used which is a supraglottic airway device. Either approach is adequate to perform in substandard situations within a microgravity situation. [23, 25] The challenge to the advanced airway management during space journey is the presence of expertise to be one of the medical onboard team, occasionally the crew physician may had been diseased or incapacitated.

4.3 NASA studies on airway management in microgravity

In studies investigating the efficacy of airway management during air transport. Air medical transport teams are periodically confronted with the responsibility of conducting airways in unexpected and difficult circumstances, meanwhile they should be essentially trained to do the task in a limited field with less resources during their duty in the aircraft.

Unexpected abrupt patient deterioration prominently considered as the prevailing reason for Airway management during aviation. Intubation process achievement was not related to the category of aircraft. The total intubation successfulness rate for advanced airway handling procedures, was 96%. The successful Airway management procedures during flights was conducted with a high achievement percentage in a variety of venues and for a variety of patient status and conditions. Air medical transport teams achievement rates were proportionate to other emergency medical staff. [26] Anatomically the epiglottis lies at the base of tongue and provides an essential reference point for direct laryngoscopy. The epiglottis fulfills the function of gate that covers the glottis, the vallecula is the concavity between the base of the tongue and the epiglottis, shown as reference point where a curved laryngoscope blade is placed. The pressure exerted by the blade tip against the vallecula elevates the epiglottis and this elevation is affected by gravity. In 1978, LeJeune hypothesized that tracheal intubation using laryngoscopy would be difficult in microgravity, since the force exerted by the laryngoscope causes the head and neck move out of the field of vision by lever effect exerted on the head and generated through the laryngoscope blade by hand generating a lack of stability, resulting in the difficulty to insert the tracheal tube. [27]

In 2000, a group tried using a deep pool to simulate microgravity and found that the success rate for anesthesiologists in the free-floating condition was 15%, increasing to 92% if the mannequin was tied to a surface. [22]

On the ground with the help of gravity, an adequate positioning of the patient is facilitated to achieve alignment of the laryngeal, pharyngeal and oral axes, which is known as sniffing position. This sniffing position allows visualization of the vocal cords and supraglottic structures that allows the introduction of a endotracheal tube (as shown in **Figure 1**).

The need to intubate personnel in the space can arise from traumatic injuries or some other medical condition leading to deterioration of consciousness or respiratory failure and this possibility increases with longer stays in the space that arises with further incursions, and for this it is necessary to evaluate and try to determine probable complications which involves Airway management in non-terrestrial conditions with microgravity or zero gravity, with the complication extra conferred by not having a doctor trained in advanced Airway management and unavailability of an ideal area with the enough space to maneuver comfortably. [23]

Intubation and suction techniques used for Airway management in terrestrial conditions are inefficient and of little use in the environment of a space station; so, it is necessary to have special equipment that facilitates endotracheal intubation. In an environment of minimal gravity or zero gravity the main problem will be the proper positioning of the patient to achieve proper alignment and approach of the airway, since without the help of terrestrial gravity the patient's body and personnel attempting Airway management lack adequate support, hence the need for creating a fixation device is paramount. The need to make these attachments has made are tested in simulators that create environments with minimal gravity or zero gravity. [24]

Assessment of respiratory failure or the need for airway management can be evaluated by assessment that includes observation of the ventilatory pattern, pulse oximetry and vital signs; after which and if required, the patient must being moved

Figure 1.
Simulation of microgravity environment and intubation in restrained mannequin with a demonstration of sniffing position.

to a special area for medical or surgical procedure that indicate airway management, which could be affected in microgravity environments. [28] So it is necessary to provide a mean of fixation of the patient and the person who will secure the airway so that positioning would be easier also decreasing the possibility of complications that might happens during laryngoscopy using a restraint system. [24]

A study published in 2005, which simulated a least gravity environment within a deep pool, in which the ability to manage the airway by expert staff and non-expert staff with and without devices holding and optimizing the alignment position; it was found that the success rate for the airway approach was equally rare for inexperienced staff and expert personnel in the free floating condition with the head of the mannequin caught between the knees, and in the fixation condition using a stability device while the dummy tied to a surface, this opens the discussion about using devices to restrain the patient either mandatory or using simple techniques is quite sufficient. [25]

So the use of other alternative methods is required to overcome this difficulty like the practice for tracheal intubation as a single hand in free floating attitude or using a device that facilitate intubation indirectly, such as laryngeal masks would be alternatively possibly useful. [22]

Studying all the difficulties which is possible to happen in space flights is challenging due to the difficulty of creating a simulated environment, and the research in this field have great limitations. This research field needs an interest to develop the necessary devices, and train flight personnel under these circumstances and manufacture airway approach instruments that makes their approach easier. [23]

Moreover, the accessibility of telecare, use of telecommunication and information technologies in order to provide clinical health care assistance at a distance will be unavailable. Managing critical conditions may necessitate some measures, that needs the help of anesthesia provider, but the flight staff might be deficient or unskilled. So, proper training and skills of airway management are essential to perform this procedure during microgravity or aviation circumstances whilst they are in outer space journey.

5. Future consideration

5.1 End of life guidelines

A very important point to raise regarding medical care during aviation is the supportive care and medical resuscitation. A structured protocol needs to be in place to guide medical practice during management of emergency situation in space missions, the development of such protocols must take into account the limited availability restorative care, pain control and psychological adjuncts.

5.2 Health care providers

It is expected that, the increasing demand for a trained personal in space missions will affect the training structure of medical schools and hospitals, and space companies will support this kind of training. In aviation at least one crew member needs to be trained to deal with medical emergencies and the physicians should be skilled and competent in all basic lifesaving procedures. A focus on psychomotor skills and telemedicine is expected as telemedicine in the shape of the future and psychomotor skills is affected by microgravity. The special skills actually required for performance of surgery can be acquired, augmented, or practiced by using simulators and a hybrid technology that has been termed “cybersurgery” Training and retraining in clinical decision-making skills, clinical problem solving, and decision making for multiple casualties or illnesses are also necessary.

5.2.1 Equipment

Coming days and young minds might be able to provide us with a special tool that can be used in the setting of microgravity to safely manage airway. Human mind always get more creative when faced by struggles, so new laryngoscopy with a physical principle that may cancel the effect of microgravity and increase the efficacy of doing the intubation might emerge.

6. Conclusion

The recommended procedure and monitoring during Aviation are aiming to maintain the maximum safety with regards to the requirement of medical services during space flights. However, specific standards for monitoring and airway management are not yet developed.

As planning for future missions targeting distant planets is continuous, all space programs are aiming to include airway management protocols within their plans. Positioning of the patient in microgravity environments is the main problem for proper alignment and Airway management that focus on restraints use in microgravity environment being important for successful endotracheal intubation.

In summary the continuity of the research and Knowledge about accommodation to the space environment would help the crew and other non-anesthesiologist to do some anesthetic procedures that would be lifesaving.

The airway management in the space environment, by non-anesthetist can be improved by using video- laryngoscopes that had been gaining more popularity. A tight balance between: the patient condition, the nature of the medical condition and the safety of the environment, including the monitoring, equipment and back up interventions for unexpected deleterious effects during the trip is needed for a better outcome.

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Author details

Mohamed Abdelwahab Elarref[1,2,3]*, Mogahed Ismail Hassan Hussein[4], Muhammad Jaffar Khan[4] and Noran Mohamed Elarif[5]

1 Department of Anesthesiology, ICU and Periop. Medicine, HMC, Qatar

2 Faculty of Medicine, T.U., Egypt

3 Clinical Anesthesiology Weill Cornell Medical College, Qatar

4 HMC, Qatar

5 Heart Institute, Egypt

*Address all correspondence to: melarref@gmail.com

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