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Anesthetic Concerns of Spaceflight

THE missions of crewed spacecraft will evolve from brief forays close to the home planet into years-long voyages to Mars and, eventually, colonies independent of Earth. A need for surgical interventions and critical care is inevitable in these operations. Anesthesiologists are acutely aware of the fact that, although a given surgical procedure may be relatively simple, the required anesthetic care is, in certain cases, extremely complex. This principle becomes particularly evident as one considers strategies for the delivery of anesthetic and critical care in space. In this issue of ANESTHESIOLOGY, Keller *et al.*¹ confront some of these problems through their evaluation of airway management techniques in simulated microgravity.

These investigators used water immersion as a model of microgravity, a reasonable choice because immersion facilities are readily available. Limitations of this method include the possibility of “cheating” on the simulation of microgravity through swimming movements, the presence of sensory cues for spatial orientation, and damping of reactive motions (*e.g.*, a diver who pushes off a pool wall will come to a halt in a few feet rather than gliding the length of the pool). Spaceflight conditions are more perfectly reproduced by parabolic flight in aircraft, but this method yields periods of microgravity that last only 25 s. The best approach to these studies is through

formal investigations during spaceflight. A limited number of such studies have been performed, but none has emphasized airway management. The future may hold more opportunities for these “real world” studies.

Keller *et al.*¹ found that direct laryngoscopy of an unrestrained patient is difficult. Their conclusions are valid for the specific techniques that were investigated. At least one other approach to laryngoscopy in microgravity is possible: My colleagues and I have evaluated laryngoscopic techniques during parabolic flight, and we found that grasping the head of an unrestrained patient with one’s knees affords a quick, stable, albeit somewhat distant, view of the glottic opening (fig. 1). Further innovations, evaluated with rigorous methods similar to those developed by Keller *et al.*,¹ will optimize procedures for in-flight medical care.

As a further prelude to the article by Keller *et al.*,¹ I would like to outline other challenges to be overcome before surgical, anesthetic, and critical care can be delivered beyond our planet.

Physiologic Considerations

Anesthetic complications that arose during the recent Bion 11 mission indicate that a cautious approach should be taken to in-flight and post-flight anesthetic care. This project, conducted jointly by Russia and the United States in 1997, flew two primates for 14 days in a dedicated “biosatellite.” An anesthetic was delivered to the animals on the first post-flight day to perform minor surgical procedures such as muscle biopsies. Despite competent care by a team of veterinarians from both countries, one animal died during anesthesia and the other experienced serious complications. In previous Bion flights, no animal received an anesthetic before the seventh post-flight day, and no anesthetic complications occurred. Clearly, our knowledge of the risks of anesthesia associated with spaceflight is imperfect.

Patterns of Disease

The goal of crew medical selection and health-maintenance programs is to fly fit people. Consequently, the type of disease observed in space is likely to arise as a

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physiologic reaction of a normal person to an abnormal environment. For example, microgravity induces disorders of calcium metabolism that increase the risk of nephrolithiasis.² Therefore, a need for the capability to perform urologic procedures should be anticipated. In addition, trauma is inevitable. Guidance regarding likely patterns of disease can be obtained from analysis of operations in analog environments such as ballistic missile submarine cruises³ and from longitudinal studies of astronaut health. A wide spectrum of diseases is encountered in these settings, indicating that versatile medical capabilities will be needed during extended space missions.

Autonomic Dysfunction

Cardiovascular deconditioning, disruptions of central modulation of baroreceptor reflexes, nonresponsiveness of autonomic function to cardiovascular stresses, and decreases of intravascular volume have been frequently observed during and immediately after spaceflight.⁴ The implications of these observations on the conduct of anesthetic care are profound. For example, because spinal anesthesia seems to carry a risk of cardiovascular

collapse due to autonomic dysfunction,⁵ an astronaut might be at increased risk for this complication.

Neuromuscular Physiology

Succinylcholine can produce hyperkalemic cardiovascular collapse in bed-ridden individuals.^{6,7} Extended exposure to microgravity conditions seems to carry at least a theoretical risk of eliciting changes in the neuromuscular junction similar to those induced by bed rest. Until more is known about the effects of spaceflight on the neuromuscular junction, depolarizing neuromuscular blockers should be avoided during and immediately after flight.

Gastroesophageal Reflux

The majority of crew experiences "space motion sickness" during the first few days of flight. An unlucky few are never free of symptoms throughout multiweek flights. Some suffer a relapse on return to Earth. In-flight investigations have revealed marked decreases in gastric motility early in the course of space motion sickness.⁸ In addition, crew members frequently report symptoms of



Fig. 1. A technique for direct laryngoscopy that requires restraint of neither the patient nor the operator. Photograph taken during the "zero-g" phase of parabolic flight aboard NASA's KC-135 aircraft.

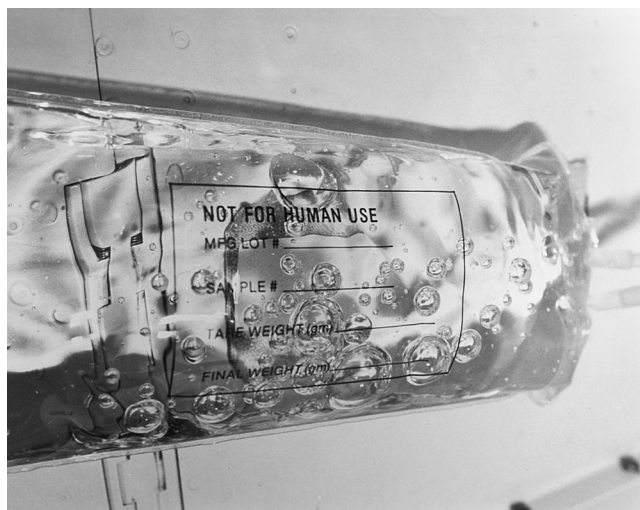


Fig. 2. A 1-l bag of normal saline in orbital flight. Gas and liquid do not separate in microgravity, a factor that greatly complicates routine fluid handling tasks.

gastroesophageal reflux during flight. These observations suggest an increased risk of aspiration, both in-flight and post-flight.

In-flight Technical Considerations

Fluid Handling

In microgravity, fluids, and gases do not separate on the basis of differing densities. Consequently, a vial of a drug or a bag of intravenous fluid contains something akin to foam (fig. 2). This seemingly trivial methodologic detail is a significant obstacle to the delivery of health care in microgravity. Each fluid transfer involves a procedure that, if not performed properly, produces a useless mix of gas and fluid. Furthermore, many devices that depend on gravity-induced separation of gases and fluids (e.g., anesthetic vaporizers) malfunction in microgravity.

Closed Environments

Spacecraft contain tightly sealed environments. Drugs used in flight should not be capable of unintentionally reaching crew through the cabin atmosphere or water reclamation systems. Dumping of oxygen from respiratory support equipment into the cabin atmosphere must be avoided to control fire hazards. The safe use of gaseous anesthetics in spacecraft will be difficult. Minimal-flow systems that have been developed for xenon anesthesia⁹ may prove useful.

Logistics

The bill associated with placing 1 kg of material (e.g., 1 l of crystalloid solution) into Earth orbit is currently \$22,000 USD. Furthermore, stowage space aboard spacecraft is extremely limited. Clearly, the inventory of medical supplies that is flown must minimize mass and volume. In addition, chosen pharmaceuticals should have long shelf-lives at room temperature.

Crew Skills

Currently, the crew complement of each mission includes a Crew Medical Officer (CMO). The CMO may have no biomedical background whatsoever before entering the Astronaut Corps, and the formal training a CMO receives totals approximately 80 h. CMO background requirements and training will need to be modified before advanced medical care in space is possible.

Information Technology

Telemedicine technology has obvious applicability to space operations. However, during a journey to Mars, the speed of propagation of electromagnetic transmissions is such that as much as 40 min may be required to receive an answer to a question. Given the fast pace of events during anesthetic procedures, telemedicine technology will need to be supplemented with advanced on-board information systems.

Approaches to In-flight Care

Expertly performed local and regional anesthesia may avoid many of the problems associated with conducting a general anesthetic in space. However, the on-board anesthetist is unlikely to be an expert, regional blocks sometimes fail, and anesthetic complications do occur. Consequently, although local and regional anesthesia may be preferred approaches, they cannot be the only options.

Many techniques are available to perform total intravenous anesthesia. Adaptation of these methods to microgravity conditions seems entirely feasible. Total intravenous anesthesia is a promising means of providing general anesthetics in space.

Post-flight Care

Because the number of potential landing sites is large, the medical infrastructure necessary to support missions is widely dispersed. Surgical procedures may need to be

performed immediately after landing. Advances in post-flight anesthetic care should be thoroughly communicated to any practitioner who might participate in such a drama.

Significant difficulties must be overcome before anesthetic and critical care can be delivered safely in-flight and post-flight. The same can be said of virtually any other aspect of medical care. Meeting these challenges is the task of the nascent field of space medicine. Anesthesiologists have much to contribute to these efforts.

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