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Airway Management during Spaceflight

A Comparison of Four Airway Devices in Simulated Microgravity

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Background: **The authors compared airway management in normogravity and simulated microgravity with and without restraints for laryngoscope-guided tracheal intubation, the cuffed oropharyngeal airway, the standard laryngeal mask airway, and the intubating laryngeal mask airway.**

Methods: **Four trained anesthesiologist–divers participated in the study. Simulated microgravity during spaceflight was obtained using a submerged, full-scale model of the International Space Station Life Support Module and neutrally buoyant equipment and personnel. Customized, full-torso manikins were used for performing airway management. Each anesthesiologist–diver attempted airway management on 10 occasions with each device in three experimental conditions: (1) with the manikin at the poolside (poolside); (2) with the submerged manikin floating free (free-floating); and (3) with the submerged manikin fixed to the floor using a restraint (restrained). Airway management failure was defined as failed insertion after three attempts or inadequate device placement after insertion.**

Results: **For the laryngoscope-guided tracheal intubation, airway management failure occurred more frequently in the free-floating (85%) condition than the restrained (8%) and poolside (0%) conditions (both, $P < 0.001$). Airway management failure was similar among conditions for the cuffed oropharyngeal airway (poolside, 10%; free-floating, 15%; restrained, 15%), laryngeal mask airway (poolside, 0%; free-floating, 3%; restrained, 0%), and intubating laryngeal mask airway (poolside, 5%; free-floating, 5%; restrained, 10%). Airway management failure for the laryngoscope-guided tracheal intubation was usually caused by failed insertion (> 90%), and for the cuffed oropharyngeal airway, laryngeal mask airway, and intubating laryngeal mask airway, it was always a result of inadequate placement.**

Conclusion: **The emphasis placed on the use of restraints for conventional tracheal intubation in microgravity is appropriate. Extratracheal airway devices may be useful when restraints cannot be applied or intubation is difficult. (Key words: Cuffed oropharyngeal airway; laryngeal mask airway; tracheal intubation; space medicine.)**

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Reprints will not be available.

SINCE the first multiple-manned space flight in October 1964,[1,2] there has been the potential need for airway management in microgravity. During spaceflight there may be an increased risk of hypoxic cardiorespiratory arrest, aspiration of foreign bodies, and burns.[3] Animal studies have shown that general anesthesia and surgery are feasible in microgravity,[4] and it has been suggested that facilities for surgical care should be provided during prolonged spaceflight because of the difficulties of medical evacuation to Earth.[3] LeJeune[5] suggested that laryngoscopy would be difficult in microgravity without body restraints, but, to our knowledge, there has been no published data regarding airway management in microgravity. In addition, several extratracheal airway devices are available that could potentially be used in micrograv-

ity. In the current randomized, controlled study we compared airway management in simulated microgravity, with and without body restraints, using four different airway devices.

Materials and Methods

Four men (age, 32–39 yr; weight, 70–95 kg; height, 178–198 cm) with airway management (> 5 yr anesthesiology practice) and with scuba diving (> 100 open-water dives) skills participated in the study. Institutional research approval was obtained from the University of Innsbruck. Simulated microgravity was obtained using a freshwater pool and neutrally buoyant equipment and personnel.[6,7] The water temperature was 26°C. A full-scale model of the International Space Station Life Support Module (LSM) was constructed from wood and plastic and was fixed on its side at the bottom of a 4.4-m-deep pool in Innsbruck, Austria. The LSM had an internal length of 490 cm, an ID of 209 cm, and a 127-cm-wide entry hatch at the end. Fixed to the floor of the LSM was a sealed box for the randomized airway device and a customized Velcro (FASTENation Inc., Passaic, USA) strap for restraining the manikin. Four airway devices suitable for use in adult men were tested: (1) an 8-mm laryngoscope-guided tracheal intubation (ETT; Mallinckrodt Medical, Lo-Contour, Athlone, Ireland); (2) a size 11 cuffed oropharyngeal airway (COPA; Mallinckrodt Medical, Lo-Contour); (3) a size 5 standard laryngeal mask airway (LMA; Laryngeal Mask Company, Henley-on-Thames, UK); and (4) a size 5 intubating laryngeal mask airway (ILM) used only as a ventilatory device (Laryngeal Mask Company).

Each device was tested in three experimental conditions in random order: (1) with the manikin on a 1-m-high table at the poolside (poolside); (2) with the manikin floating free in the submerged LSM (free-floating); and (3) with the manikin attached to the floor of the submerged LSM using the Velcro restraint (restrained). Two customized, full-torso manikins (Ambu International A/S, Kopenhagen, Denmark) were used; one was designed for the ETT, and the other were designed for the LMA and the ILM. The customized ETT manikin was used for the ETT tests and the customized LMA–ILM manikin was used for the COPA, LMA, and ILM tests. The LMA–ILM manikin was used for the COPA because previous testing showed that insertion was easier than with the ETT manikin. The manikins had a mass of 40 kg when submerged. All airway equipment and manikins were made neutrally buoyant by adding small weights or small plastic air sacks at locations that did not impede function or test performance. Diving equipment included a wet suit, 10-l air tank, buoyancy control device, flippers, and wide-vision face mask. Lighting was similar in all environments. Anesthesiologist–divers achieved neutral buoyancy by adjusting the buoyancy control devices.

Before commencement of the study, the investigators practiced insertion of all devices in all experimental conditions. Training for the poolside condition took approximately 20 min and included two attempts with each device. Training for the free-floating and restrained conditions took approximately 90 min each and included four to eight attempts with each device. Previous clinical experience of the investigators with these devices was as follows: ETT, more than 1,000 uses; COPA, 50–100 uses; LMA, more than 200 uses; and ILM, 0–200 uses. All investigators inserted each device on 10 occasions in each of the poolside, free-floating, and restrained conditions. Opening a sealed envelope randomized the order of devices for each investigator. The investigator was unaware of the type of device they were to use until they entered the LSM or walked toward the table. In addition to the randomized device, the sealed box contained a 20-ml syringe, a self-inflating bag, and a waterproofed size 3 Macintosh laryngoscope. The self-inflating bag was filled with water for the simulated microgravity conditions.

In the poolside condition, the investigator walked to the appropriate manikin, touched it, and then opened the sealed box and commenced airway management. All diving equipment, including the wide-vision face mask but with the exception of flippers, was worn for the poolside condition. In the free-floating and restrained conditions, the appropriate manikin was held by a second diver in the center of the LSM and was released when the investigator entered the hatch. In the free-floating condition, the investigator swam to the manikin, touched it, then opened the sealed box and commenced airway management. In the restrained condition, the investigator swam to the manikin, touched it, attached it to the Velcro restraints, opened the sealed box, and commenced airway management. All airway management was conducted from above the head of the manikin. The ETT was inserted using the laryngoscope; all other airway devices were inserted without a laryngoscope in accordance with the manufacturer's recommendations.[8–10] The insertion technique for the COPA included grasping the head, opening the mouth, placing

Table 1. Airway Management Data

	ETT			COPA			LMA			ILM		
	Poolside	Free-floating	Restraints	Poolside	Free-floating	Restraints	Poolside	Free-floating	Restraints	Poolside	Free-floating	Restraints
Insertion attempts; n												
1	40	0	22	40	38	40	39	36	39	40	37	40
2	0	2	10	0	2	0	1	4	1	0	3	0
3	0	5	7	0	0	0	0	0	0	0	0	0
Fail	0	33	1	0	0	0	0	0	0	0	0	0
Placement; n												
Adequate	40	6	37	36	34	34	40	39	40	38	38	36
Inadequate	0	1*	2*	4	6	6	0	1	0	2	2	4
Airway management failure; n	0	34	3	4	6	6	0	1	0	2	2	4
Time to successful insertion; s	19 ± 3	33 ± 21	36 ± 7	19 ± 3	31 ± 7	33 ± 6	19 ± 2	33 ± 8	34 ± 6	19 ± 2	31 ± 7	34 ± 5

Number of insertion attempts, adequacy of placement, airway management failure and time to successful insertion in normogravity by the poolside (Poolside), simulated microgravity with the manikin floating free (Free-floating) and simulated microgravity with the manikin attached to the floor with restraints (Restraints) for the endotracheal tube (ETT), cuffed oropharyngeal airway (COPA), standard laryngeal mask airway (LMA) and intubating laryngeal mask airway (ILM). Data are mean ± SD or numbers (%).

* Esophageal intubation.

the device in the mouth, and rotating it into position. The insertion technique for the LMA included grasping the head, opening the mouth, flattening the cuff against the hard palate, and pushing it along the posterior palatopharyngeal curve using the index finger. The insertion technique for the ILM included grasping the head, opening the mouth, flattening the cuff against the hard palate, and using a single-handed technique to rotate it into the pharynx. Once inserted, the device cuff was inflated to the maximum recommended volume using a syringe filled with air (poolside) or water (free-floating and restrained), and the proximal end of the airway device was attached to the self-inflating bag. The adequacy of placement was determined by noting the degree of artificial lung expansion during manual inflation of the bag at the poolside. Placement was considered inadequate if lung expansion was not detected. Care was taken to avoid displacement of the airway device during removal of the manikin from the pool. All fluid was allowed to drain from the manikin before adequacy of placement was assessed.

The second diver recorded the number of insertion attempts and the time to successful insertion (measured with a diving stopwatch). A maximum of three insertion attempts was allowed. A failed attempt was defined as removal of the device from the manikin. Insertion time was calculated from when the investigator touched the manikin to attachment of the self-inflating bag. Failed airway management was defined as failed insertion after three attempts or inadequate placement after successful insertion. Statistical analysis was performed using one-way analysis of variance, Friedman's two-way analysis of variance, and chi-square test. Unless otherwise stated, data are presented as mean ± SD. Significance was determined at $P < 0.05$.

Results

Data are presented in table 1. For the ETT, the number of insertion attempts was greater for the free-floating condition than the restrained condition ($P < 0.001$) and the poolside ($P < 0.001$) condition and was greater for the restrained condition than the poolside condition ($P < 0.001$). For the COPA, LMA, and ILM, the numbers of insertion attempts were similar among conditions. For all devices, the adequacy of placement was similar among conditions. For the ETT, airway management failed more frequently during the free-floating condition than during the restrained condition (85 *vs.* 8%, $P < 0.001$) and the poolside condition (85% *vs.* 0%, $P < 0.001$). For the COPA, LMA, and ILM, overall failure was similar among conditions. The time to successful insertion was longer for all airway devices in the free-floating and restrained conditions compared with the poolside condition (all, $P < 0.001$). The time to successful insertion was similar between the free-floating and restrained conditions for all devices. There was no evidence of skill

acquisition in any environment. There were no differences in performance among investigators.

Discussion

Our data suggest that conventional laryngoscope-guided intubation will have a high failure rate in microgravity unless restraints are applied. The anterior force exerted during laryngoscopy causes the head and neck to move out of the field of view. Intubation is difficult because the hand not holding the laryngoscope cannot synchronously stabilize the head–neck and direct the ETT toward the glottic inlet. The approximate force exerted by anesthesiologists during direct laryngoscopy is 40 N, and this force may be exerted for 10–20 s.[11–13] A 70-kg human in microgravity would move a distance of 0.3 m in 1 sec at this level of force, leaving only a brief opportunity for intubation. The application of a restraint allows the head and neck to be stabilized, leaving the hand not holding the laryngoscope free to direct the ETT toward the glottic inlet. It has been suggested that coaxial intubation with a self-retaining, bivalved laryngoscope might avoid the need for restraints by freeing the laryngoscope hand to stabilize the head and neck.[14] It may also be possible to stabilize the head and neck by gripping the head between the knees. These unconventional intubation techniques require assessment. In contrast, our data suggest that the COPA, LMA, and ILM will have a low failure rate in microgravity, with or without the use of restraints. Insertion of these devices does not require use of a laryngoscope; thus, one hand is free to stabilize the head and neck. In our analysis, we attempted no interdevice comparisons because of the potential differences in performance among specific airway devices and manikins. However, several studies in anesthetized patients have shown that laryngeal mask device insertion is easier than tracheal intubation for nonanesthesiologists[15–18]; this may also apply to astronauts in microgravity.

Our data suggest that airway management will take longer in microgravity. Specific delays were in achieving the correct investigator position, movement of the manikin, and drifting of equipment away from the investigator. These delays may be reduced in actual spaceflight with experienced crews who have optimized their manual manipulation and movement skills in this environment. Airway management was conducted from above the head of the manikin in all cases; however, this positioning is necessary only for ETT. It is possible that insertion times would have been shorter for some of the other airway devices if different investigator positions had been allowed. Insertion times were unaffected by the use of restraints. The time saved by improved manikin stability was counteracted by the extra time taken to apply the restraint (≈ 8 s).

Our study was conducted by anesthesiologists using manikins in a neutral buoyancy environment, and our findings should be extrapolated cautiously to astronauts managing patients in microgravity. Airway management will probably be more difficult for astronauts. The relative success rates for different airway devices may vary between anesthesiologists and astronauts, and between manikins and patients. The hydrodynamic resistance of water slows movements and makes objects less likely to drift away compared with low-gravity conditions in space. Water can also be used for propulsion; an unavoidable limitation of our methodology was that the anesthesiologist–divers swam rather than propelled themselves off the LSM walls. We did not test the performance of the face mask and Guedel airway because of lack of an appropriate manikin and difficulties in measuring endpoints. We did test the esophageal tracheal combitube and found a high failure rate for airway management (poolside, 25%; free-floating, 38%; restrained, 40%). However, we did not include these data because the anesthesiologist–divers had no prior experience with the device, and we were concerned about the validity of these observations. A potential criticism of our study is that prestudy training was restricted to four to eight attempts with each device. However, there was no evidence of skill acquisition during the study, suggesting that a more extensive period of training would not have influenced the outcome.

During the first 37 yr of manned spaceflight, airway management has never been necessary. However, in 1962, Scott Carpenter aspirated food crumbs while in orbit on the Mercury 7 flight, and in 1975, several astronauts developed a mild chemical pneumonitis after inhaling propellant fluid during reentry from the Apollo-Soyuz mission.[5] As flight times are extended, the chances increase that an emergency that necessitates airway management will occur. The International Space Station will accommodate six people in orbit. The airway devices currently carried aboard Space Shuttles include a face mask, a pressure-cycled ventilator, a single-bladed laryngoscope, tracheal tubes, an introducer, a capnograph, and a tracheostomy kit.[19] The design of appropriate restraints for cardiopulmonary resuscitation has been extensively tested in parabolic flight and during a Shuttle

mission in 1991, but airway management training is currently confined to manikins in normogravity. We consider that airway management training in anesthetized patients in normogravity and in manikins in simulated microgravity would be useful adjuncts to the current program.

Ideally, this study would have been conducted in microgravity; however, research time in space is limited, and parabolic flights are too brief (20–30 s) for the study methodology. However, studies conducted during parabolic flight would probably yield sufficient information to construct evidence-based algorithms for airway management in microgravity. Interestingly, it has been shown that the performance using laryngeal mask devices is similar with cadavers and paralyzed anesthetized patients.[20,21] This suggests that fresh cadavers may be a more realistic model than the manikin for airway management training and research.

We conclude that the current emphasis placed on the use of restraints for conventional tracheal intubation in microgravity is appropriate. Extratracheal airway devices may be useful when restraints cannot be applied or intubation is difficult.

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